Manufacturing Processes

S.No.	Board of Study	Course Code	Course Title	Scheme of Examination					
				Theory			Practical		Total Marks
				ESE	CT	TA	ESE	TA	
1	Mechanical Engineering	2037472(037)	Manufacturing Process	70	20	30	-	-	120
2.	Mechanical Engineering	2037462(037)	Manufacturing Process**(Lab)**	-	-	-	30	50	80

Unit Number	Unit Titles	Total Marks
I	Introduction to Manufacturing Processes	6
II	Metal Casting	18
III	Metal Forming and Press Working	18
IV	Metal Joining	16
V	Plastic Molding and Powder Metallurgy	12
Total		**70**

Unit-1.0 Introduction to Manufacturing Processes

Manufacturing is the creation or production of goods with the help of equipment, labor, machines, tools, and chemical or biological processing or formulation. It is the essence of secondary sector of the economy. The term may refer to a range of human activity, from handicraft to high-tech, but it is most commonly applied to industrial design, in which raw materials from the primary sector are transformed into finished goods on a large scale. Such goods may be sold to other manufacturers for the production of other more complex products (such as aircraft, household appliances, furniture, sports equipment or automobiles), or distributed via the tertiary industry to end users and consumers (usually through wholesalers, who in turn sell to retailers, who then sell them to individual customers).

Manufacturing engineering, or the manufacturing process, are the steps through which raw materials are transformed into a final product. The manufacturing process begins with the product design, and materials specification from which the product is made. These materials are then modified through manufacturing processes to become the desired part.

Modern manufacturing includes all intermediate processes involved in the production and integration of a product's components. Some industries, such as semiconductor and steel manufacturers, use the term fabrication instead.

The manufacturing sector is closely connected with the engineering and industrial design industries.

1.1 Classification of basic manufacturing process based on chip-less and chip-removal processes,

There are two types of machining

Chip removal process
Chipless process (or non-chip removal process)

Chip removal process

In chip removal process the layers of metal from the parent metal (workpiece) separated in the form of chips to obtain the required dimension and shape. In this process, a compressive force is applied to shear off the material in the small pieces known as chips. The various chip removal process are turning, shaping, drilling, boring, grinding, honing.

Chipless process

Required form and dimension obtained by without removing material from workpieces. Force is applied to change the shape of the material. Examples of the chipless process are forging, rolling, spinning, stamping, embossing.

Non-conventional machining process in which very small material removal takes place at the molecular level also considered as a chipless machining process. Example electrolysis.

Extra:

The mechanical finishing process burnishing considered as a chipless process.

Primary and Secondary manufacturing processes,

Primary, Secondary and Advanced Manufacturing Processes – Examples

Manufacturing refers to all the processes that are used to convert raw materials or scrap into useful products by adding substantial value. It must be noted that Manufacturing is not any single process; instead, it is the term that represents a number of processes that are used to convert raw material or scrap into desired product. There exists a large number of manufacturing processes in order to process a wide variety of materials in different ways to satisfy perpetually varying demand. Thus it is convenient to group them depending on their primary objective to use; and hence, three classes arise, as discussed below.

- Primary Manufacturing Processes
- Secondary Manufacturing Processes
- Advanced Manufacturing Processes

In general, primary processes convert raw material or scrap to a basic primary shaped and sized product. Secondary processes further improve the properties, surface quality, dimensional accuracy, tolerance, etc. Advanced processes usually (but not necessarily) manufacture desired products at one step. Advanced processes are beneficial to provide magnificent properties and qualities to the products.

Primary manufacturing processes

These processes are used to convert raw material or scrap to a basic primary shaped and sized product. Such processes cannot provide exactly same product that is desired (unless the required product has very ordinary & simple shape with broad allowance on dimensions). Close dimensional tolerance cannot be achieved by these processes. Achievable surface finish and surface integrity of the products are not very impressive. Appearance of the product is also poor. However, these processes are much useful to give a basic property, shape and size so that it can be further processed in the secondary manufacturing processes. Various primary manufacturing processes are:

- Casting
- Forming, such as Forging, Rolling, Extrusion, etc.

- Joining, such as Welding, Soldering, etc.

Secondary manufacturing processes

These processes are used to further modify the output of primary manufacturing processes in order to improve the material properties, surface quality, surface integrity, appearance and dimensional tolerance. The input material for these processes must have some specific shape and size; otherwise products may not be accommodated within the machine facility. Various secondary manufacturing processes are:

- Machining
- Surface working, such as Heat Treatment, Coating, etc.

Advanced manufacturing processes

(This classification is ambiguous, but widely accepted!) With the advancement of technology, a number of new methods and technical systems have been developed that can directly convert raw material or scrap into products having close tolerance and dimension, superb surface quality, desired properties and magnificent appearance. Thus these processes eliminate the need to pass a product through a number of primary and secondary processes; and therefore, production time and cost can be reduced. Some of these processes are unique and completely different from above two groups; however, others are the developed version of processes from above two groups. Most of these processes use efficient, costlier and precision machines inbuilt with computer control system. The concept of Additive and Subtractive Manufacturing is associated with advanced manufacturing system. Various advanced manufacturing processes are:

- Powder Metallurgy (PM)
- Rapid Prototyping (RP) or 3-D Printing
- CNC machines, machining centers, etc.
- Dye Casting, etc.

Various generating & forming processes,

Forming and Generating Method in Lathe Machine Operations

Raw materials of irregular size and shape has very little value. So to impart some function ability in the raw material we have to add some values to it. By production or manufacturing process an irregular shaped work piece is converted into a high utility product. This finished product has desired size, shape and meets our requirement.

In machining process extra material is removed from the preformed blank. In this process different types of chips are formed when the cutting tool moves over the workpiece. Machining can produce semi-finishing or finishing according to the need of the machinist.

Rotational and non-rotational Machined parts

Machine parts are generally of two types

- Rotational

- Non-rotational

Rotational Machined Parts Features

- Rotational work part is cylindrical or can have a disc-like shape.
- In this work piece the material is removed from rotating workpiece.
- This work-part involves lathe machine operations like turning and boring.
- Drilling slightly different operation. An internal cylindrical shape is formed in drilling. And in most of the cases the drilling tool rotates rather the work piece.

Non-Rotational Machined Parts Features

- These are block like or plate like jobs.
- Shapes are got by the linear motion of the w/p along with the rotating or linear tool movement.
- Operations involve milling, shaping , sawing and planning.

Forming and Generating Method in lathe machine

The different characteristic geometry of the machining operation is mainly due to two factors

- The relative motion of the tool and workpiece.
- The geometry of the cutting tool

These machining operations are classified as generating and forming.

Generating Method features

- Workpiece geometry is dependent on the feed trajectory or movement of the cutting tool.
- Generating method involves different turning operations such as straight turning, taper turning. Peripheral milling and profile milling are also a member of this group.

1.2 Factors which influence selection of manufacturing process for a particular application.

Factors affecting selection of manufacturing process

Manufacturing Process Selection Criteria

The following points need to be considered before the actual manufacturing of a product.

1. Material selection including and considering all the environmental and recycling aspects
2. Selection of processing methods such as metal casting, metal forming, sheet metal working, powder metallurgy, machining, joining, finishing etc.
3. Shape and appearance of the final product
4. Dimensional tolerance and surface finish aspects of the final product

5. Economics of tooling
6. Design requirements
7. Functional requirements of the product
8. Production quantity required
9. Safety and environmental concerns
10. Cost

Product design is the most important parameter amongst all the parameters of the manufacturing system. As quality is imbibed at each stage in the product, if the product has not been designed right at the first stage, no subsequent operation or steps can bring back the quality into the product. Hence, the material and manufacturing process selection and all associated concerns such as availability, environmental considerations, recycling etc must be taken care of right at the product design and development stage. As far as the manufacturing process is concerned, it must be economical and capable of producing the geometric surfaces and other features which are embodied in the design of the product.

manufacturing process selection

Manufacturing Process Selection

Factors affecting the selection of manufacturing processes:

- ✓ Product quality.
- ✓ Equipment & tooling cost.
- ✓ Material cost.
- ✓ Material vs. process.
- ✓ Processing time.
- ✓ Labor.
- ✓ Energy consumption.
- ✓ Surface finish.
- ✓ Process waste and material recycling..

Manufacturing Processes Classification

There are six basic / fundamental classifications of manufacturing processes.

1. Metal casting or Molding: expendable mold and permanent mold
2. Metal Forming and Shearing: rolling, forging, extrusion, drawing, sheet forming, powder metallurgy
3. Material Removal Processes / Machining Processes: turning, boring, drilling, milling, planing, shaping, broaching, grinding, ultrasonic machining, chemical machining, electrical discharge machining (EDM), Abrasive flow machining (AFM), abrasive jet machining (AJM), electrochemical machining, high-energy beam machining, laser beam machining (LBM) etc.
4. Joining: welding, brazing, soldering, diffusion bonding, adhesive bonding, mechanical joining, plasma arc, plasma MIG, projection welding, ultrasonic, electron beam welding, laser welding etc.
5. Finishing (painting, anti-corrosion coatings, etc.)
6. Rapid Manufacturing: stereo-lithography, selective laser sintering, fused deposition

modeling, three dimensional printing, laminated object manufacturing, laser engineered net shaping

1.3 Recall mechanical properties of metals.

The mechanical properties of metals determine the range of usefulness of the metal and establish the service that can be expected.

Said another way it refers to how metals will respond to external loads.

This includes how they deform (twist, compress, elongate) or break as a function of applied temperature, time, load and other conditions.

Mechanical properties are also used to help specify and identify the metals.

They are important in welding because the weld must provide the same mechanical properties as the base metals being joined.

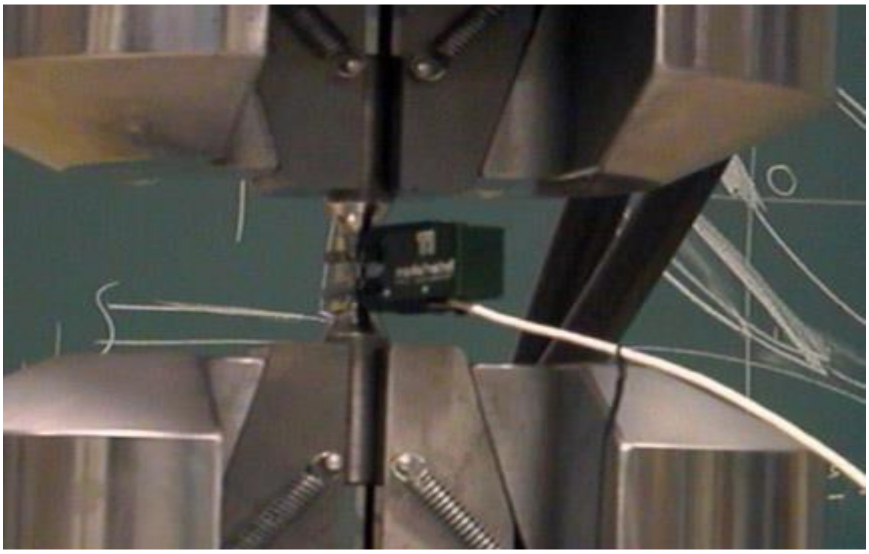
The adequacy of a weld depends on whether or not it provides properties equal to or exceeding those of the metals being joined.

Mechanical properties are characterized by stress and strain (tension, compression, shear, torsion), elastic deformation and plastic deformation (yield strength, tensile strength, ductility, toughness, hardness).

- **Hardness**: Resistance to abrasion and indentation.
- **Toughness and Resilience**: Measure of how metal absorbs energy
- **Ductility**: measure of the ability to deform plastically without fracture (fracture strain, area reduction, elongation)
- **Strength**: Offset yield, proof, fracture, yield, ultimate – measured as stress
- **Stiffness**: Young’s Modulus or Elastic Modulus
- **Loading**: Tensile (pulling on each end of a metal bar is tensile strength), compressive, shear, torsion)
- **Stress and Strain**: tension and compression, shear and torsion

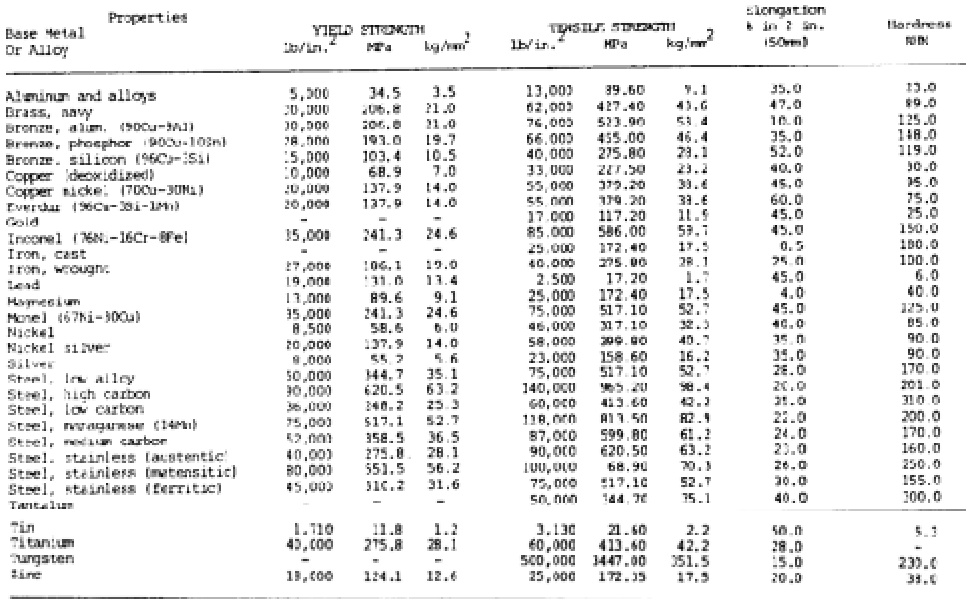
The mechanical properties of metals are almost always given in MPa or Ksi. (1000 psi = 1 ksi = 6.89 MPa).

For detail on each mechanical properties of metals concept continue reading below.



Modern Materials Testing System. Extensometer attached to metal specimen for testing mechanical properties of metal.

Table Of Mechanical Properties Of Metals



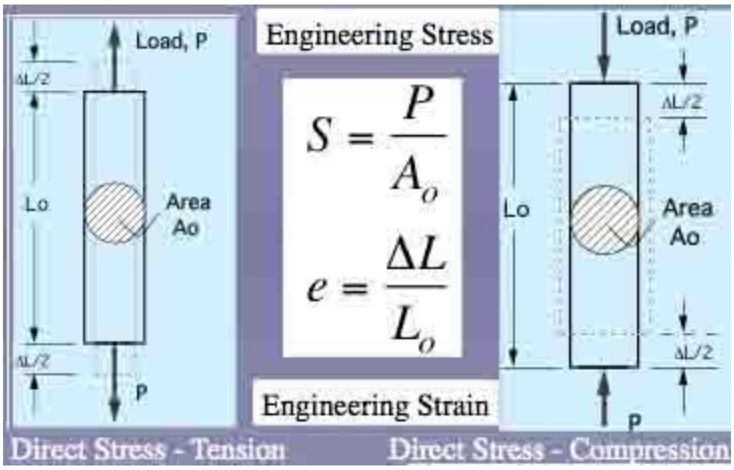
Properties Base Metal Or Alloy	YIELD STRENGTH lb/in.^{2}	 MPa	 kg/mm^2	TENSILE STRENGTH lb/in.^{2}	 MPa	 kg/mm^2	Elongation % in 2 in. (50mm)	Hardness BHN
Aluminum and alloys	5,000	34.5	3.5	13,000	89.60	9.1	35.0	23.0
Brass, navy	30,000	206.8	21.0	62,000	427.40	43.6	47.0	89.0
Bronze, alum. (90Cu-9Al)	30,000	206.8	21.0	76,000	523.90	53.4	10.0	125.0
Bronze, phosphor (90Cu-10Sn)	28,000	193.0	19.7	66,000	455.00	46.4	35.0	148.0
Bronze, silicon (96Cu-3Si)	15,000	103.4	10.5	40,000	275.80	28.1	52.0	119.0
Copper (deoxidized)	10,000	68.9	7.0	33,000	227.50	23.2	40.0	30.0
Copper nickel (70Cu-30Ni)	20,000	137.9	14.0	55,000	379.20	38.6	45.0	35.0
Everdur (96Cu-3Si-1Mn)	20,000	137.9	14.0	55,000	379.20	38.6	60.0	75.0
Gold	-	-	-	17,000	117.20	11.9	45.0	25.0
Inconel (76Ni-16Cr-8Fe)	35,000	241.3	24.6	85,000	586.00	59.7	45.0	150.0
Iron, cast	-	-	-	25,000	172.40	17.5	0.5	180.0
Iron, wrought	27,000	186.1	19.0	40,000	275.80	28.1	25.0	100.0
Lead	19,000	131.0	13.4	2,500	17.20	1.7	45.0	6.0
Magnesium	13,000	89.6	9.1	25,000	172.40	17.5	4.0	40.0
Monel (67Ni-30Cu)	35,000	241.3	24.6	75,000	517.10	52.7	45.0	125.0
Nickel	8,500	58.6	6.0	46,000	317.10	32.3	40.0	85.0
Nickel silver	20,000	137.9	14.0	58,000	399.80	40.7	35.0	90.0
Silver	8,000	55.2	5.6	23,000	158.60	16.2	35.0	90.0
Steel, low alloy	50,000	344.7	35.1	75,000	517.10	52.7	28.0	170.0
Steel, high carbon	90,000	620.5	63.2	140,000	965.20	98.4	20.0	201.0
Steel, low carbon	36,000	248.2	25.3	60,000	413.60	42.2	35.0	310.0
Steel, manganese (14Mn)	75,000	517.1	52.7	118,000	813.50	82.9	22.0	200.0
Steel, medium carbon	52,000	358.5	36.5	87,000	599.80	61.2	24.0	170.0
Steel, stainless (austenitic)	40,000	275.8	28.1	90,000	620.50	63.2	20.0	160.0
Steel, stainless (matensitic)	80,000	551.5	56.2	100,000	68.90	70.3	26.0	250.0
Steel, stainless (ferritic)	45,000	310.2	31.6	75,000	517.10	52.7	30.0	155.0
Tantalum	-	-	-	50,000	344.70	35.1	40.0	300.0
Tin	1,710	11.8	1.2	3,130	21.60	2.2	50.0	5.3
Titanium	40,000	275.8	28.1	60,000	413.60	42.2	28.0	-
Tungsten	-	-	-	500,000	3447.00	351.5	15.0	230.0
Zinc	18,000	124.1	12.6	25,000	172.35	17.5	20.0	38.0

Mechanical Properties of Metals. Values depend on Heat Treatment of Mechanical Condition or Mass of the Metal.

Stress And Strain

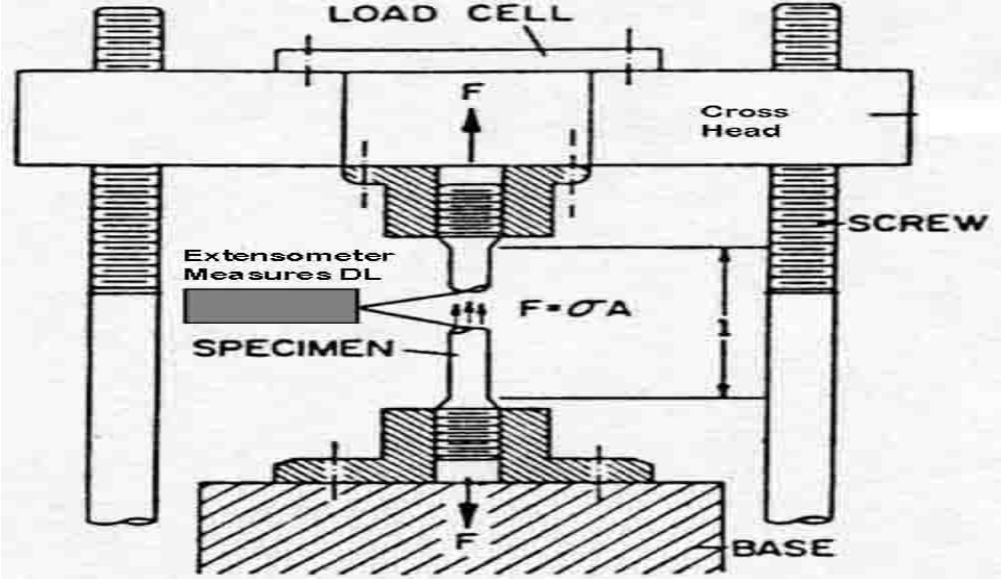
Metal stress and strain are one of the primary mechanical properties of metals. Another way to think about the concept is load/area. The deformation of metal can be measured directly, although stress cannot.

- Strain: deformation of the component/original length
- Stress: torsional, shear and direct



Examples of Direct Stress on Metal

Metal Tensile Strength



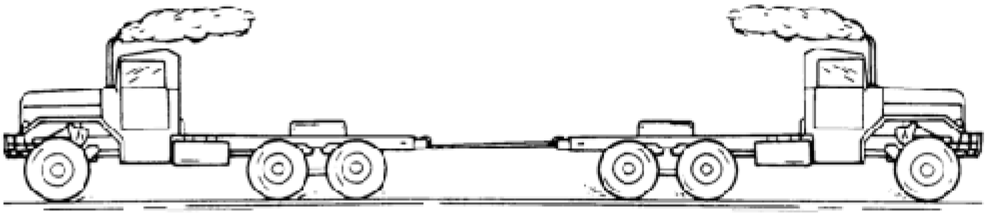
Typical Universal Testing Machine

Tensile strength is defined as the maximum load in tension a material will withstand before fracturing, or the ability of a material to resist being pulled apart by opposing forces.

Also known as ultimate strength, it is the maximum strength developed in a metal in a tension test. (The tension test is a method for determining the behavior of a metal under an actual stretch loading.

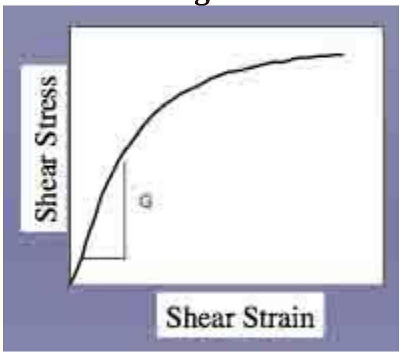
This test provides the elastic limit, elongation, yield point, yield strength, tensile strength, and the reduction in area.) The tensile strength is the value most commonly given for the strength of a material and is given in pounds per square inch (psi) (kiloPascals (kPa)).

The tensile strength is the number of pounds of force required to pull apart a bar of material 1.0 in. (25.4 mm) wide and 1.00 in. (25.4 mm) thick (see figure 7-1 below).



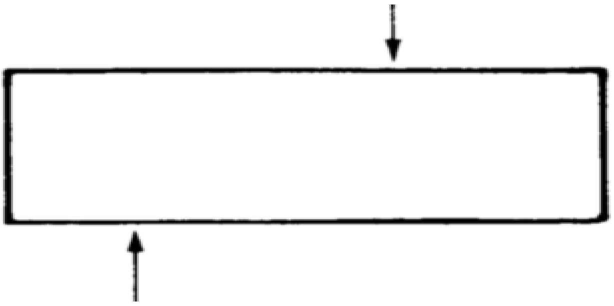
Metal Tensile Strength – Fig. 7-1

Shear Strength



Shear Stress and Strain

Shear strength is the ability of a material to resist being fractured by opposing forces acting of a straight line but not in the same plane, or the ability of a metal to resist being fractured by opposing forces not acting in a straight line (see figure 7-2 below).



Metal Shear Strength Diagram

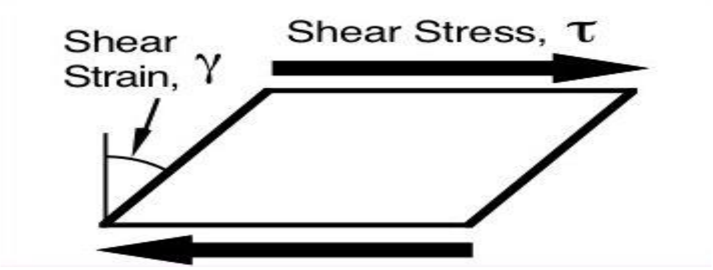


Fig. 7-2Shear Stress and Strain

Diagram:
shear stress, t = Shear Load / Area
shear strain, g = angle of deformation (radians)
shear modulus, G = t /g (elastic region)

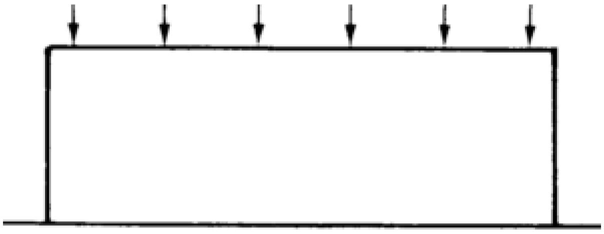
Fatigue Strength

Fatigue strength is the maximum load a material can withstand without failure during a large number of reversals of load. For example, a rotating shaft which supports a weight has tensile forces on the top portion of the shaft and compressive forces on the bottom. As the shaft is rotated, there is a repeated cyclic change in tensile and compressive strength. Fatigue strength values are used in the design of aircraft wings and other structures subject to rapidly fluctuating loads. Fatigue strength is influenced by micro-structure, surface condition, corrosive environment, and cold work.

Compressive Strength

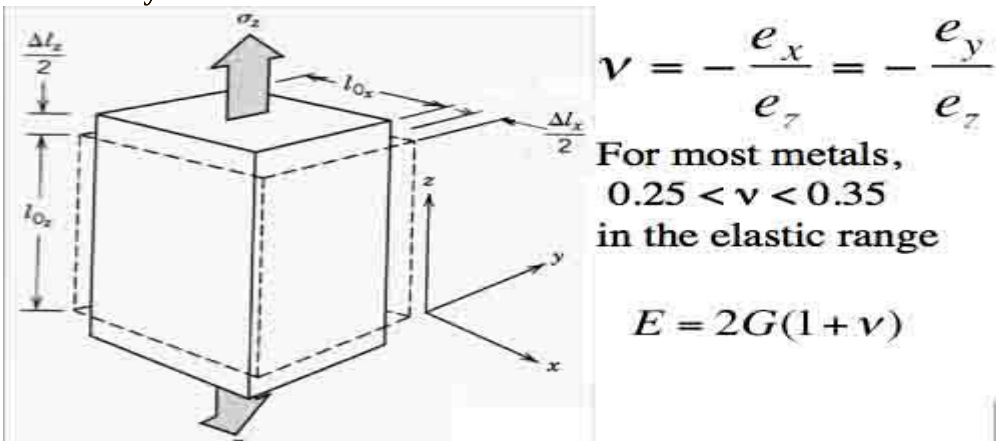
Compressive strength is the maximum load in compression a material will withstand before a predetermined amount of deformation, or the ability of a material to withstand pressures acting in a given plane (figure 7-3).

The compressive strength of both cast iron and concrete are greater than their tensile strength. For most materials, the reverse is true.



Compressive Strength of Metal – Figure 7-3)

Elasticity



$$\nu = -\frac{e_x}{e_z} = -\frac{e_y}{e_z}$$

For most metals,
$0.25 < \nu < 0.35$
in the elastic range

$$E = 2G(1+\nu)$$

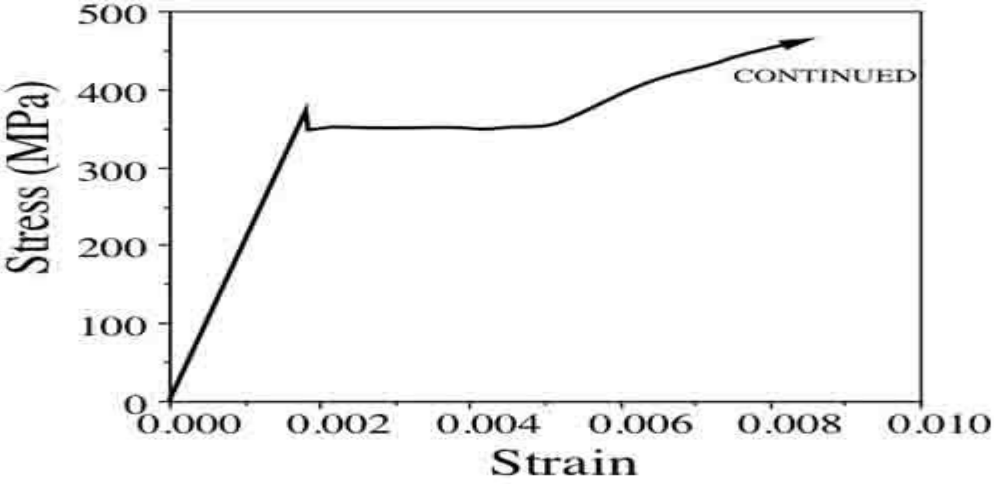
Poisson’s Ratio, v

Elasticity is the ability of metal to return to its original size, shape, and dimensions after being deformed, stretched, or pulled out of shape.

- **The elastic limit** is the point at which permanent damage starts.
- **The yield point** is the point at which definite damage occurs with little or no increase in load.
- **The yield strength** is the number of pounds per square inch (kiloPascals) it takes to produce damage or deformation to the yield point.

Measured using Poisson’s ratio (the ratio of lateral to axial strain), which states that when a metal is strained in one direction, there are corresponding strains in all other directions.

Modulus Of Elasticity



Modulus of Elasticity Stiffness, Stress and Strain Chart

The modulus of elasticity is the ratio of the internal stress to the strain produced.

Elastic Deformation

Hooke’s Law:

S = Ee

The concept of elastic deformation refers to deformation that is not permanent.

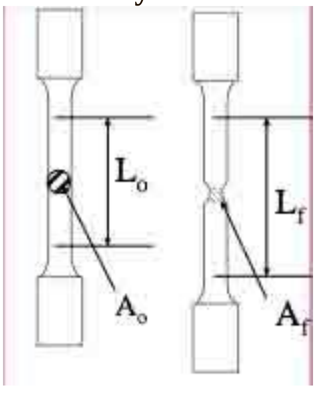
The load on the metal creates the deformation which returns to its original form and dimensions when the load is removed.

When it comes to the majority of metals, the region which is elastic is linear.

Non-linear metals include cast iron.

Hooke’s law is applied to linear elastic behavior where E is the modulus of elasticity.

Ductility



Metal Ductility – AR% and ER%

The ductility of a metal is that property which allows it to be stretched or otherwise changed in shape without breaking, and to retain the changed shape after the load has been removed.

It is the ability of a material, such as copper, to be drawn or stretched permanently without fracture.

The ductility of a metal can be determined by the tensile test by determining the percentage of elongation.

The lack of ductility is brittleness or the lack of showing any permanent damage before the metal cracks or breaks (such as with cast iron).

Elongation Equation

The strain at fracture in tension, expressed as a percentage:

((final gage length – initial gage length) / initial gage length) x 100
Percent elongation is a measure of ductility.

Area Reduction

The reduction in cross-sectional area of a tensile specimen at fracture:

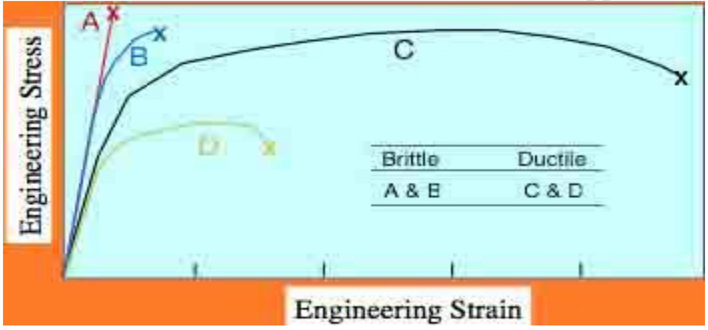
((initial area – final area) / initial area) x 100
Percent reduction in area is also a measure of ductility.

Brittleness

Brittleness is the property opposite of plasticity or ductility.

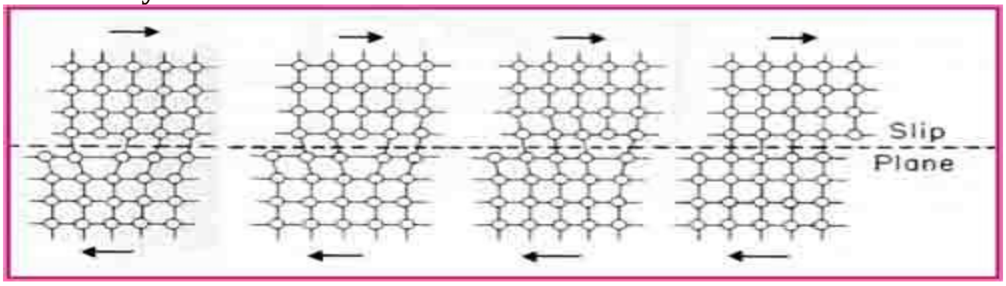
A brittle metal is one than cannot be visibly deformed permanently, or one that lacks plasticity.

- Metals are brittle is the EL% < 5% (approximate)
- Metals are ductile if the EL% > 8% (approximate)



Brittle vs. Ductile Materials

Plasticity



Microstructural Origins of Metal Plasticity

Plasticity is the ability of a metal to be deformed extensively without rupture. Plasticity is similar to ductility.

It measure the slide, climb and slip of atoms in the crystal structure.

The climb and slip occur at dislocations while slide occurs at the grain boundaries.

Malleability

Malleability is another form of plasticity, and is the ability of a material to deform permanently under compression without rupture. It is this property which allows the hammering and rolling of metals into thin sheets. Gold, silver, tin, and lead are examples of metals exhibiting high malleability. Gold has exceptional malleability and can be rolled into sheets thin enough to transmit light.

Reduction Of Area

This is a measure of ductility and is obtained from the tensile test by measuring the original cross-sectional area of a specimen to a cross-sectional area after failure.

Resilience And Toughness

Toughness is a combination of high strength and medium ductility.

It is the ability of a material or metal to resist fracture, plus the ability to resist failure after the damage has begun.

A tough metal, such as cold chisel, is one that can withstand considerable stress, slowly or suddenly applied, and which will deform before failure.

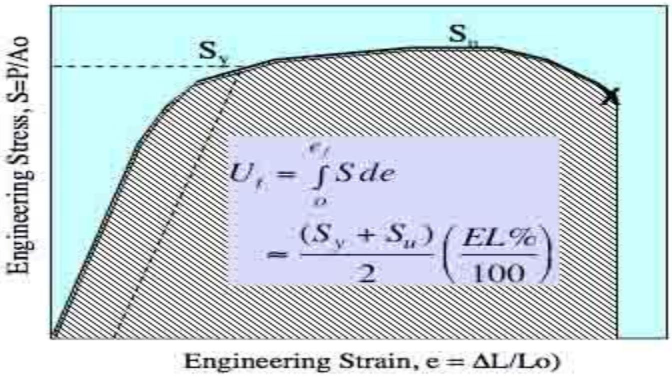
Toughness is the ability of a material to resist the start of permanent distortion plus the ability to resist shock or absorb energy.

Note that both the toughness and resilience equations are determined as:

energy/unit volume

Toughness Equation:

(J/m^3 or $N.mm/mm^3 = MPa$)

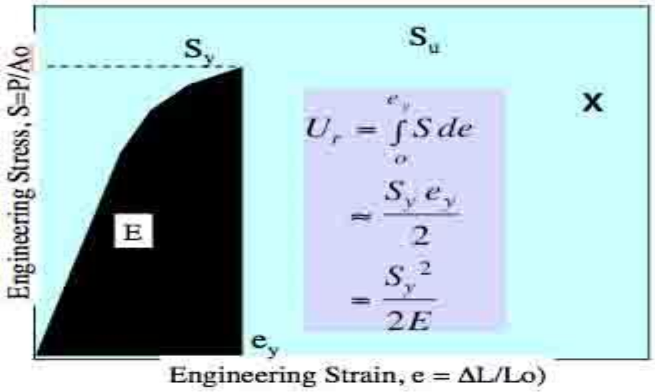


Toughness Chart, Ut

Resilience is the measure of the ability of a material to absorb energy without plastic or permanent deformation.

Resilience Equation:

(J/m^3 or $N.mm/mm^3 = MPa$)



Resilience Chart, Ur

Weldability And Machinability

The property of weldabiity and machinability is the difficulty or ease with which a material can be welded or machined.

Abrasion Resistance

Abrasion resistance is the resistance to wearing by friction.

Impact Resistance

Resistance of a metal to impacts is evaluated in terms of impact strength.

A metal may possess satisfactory ductility under static loads, but may fail under dynamic loads or impact.

The impact strength of a metal is determined by measuring the energy absorbed in the fracture.

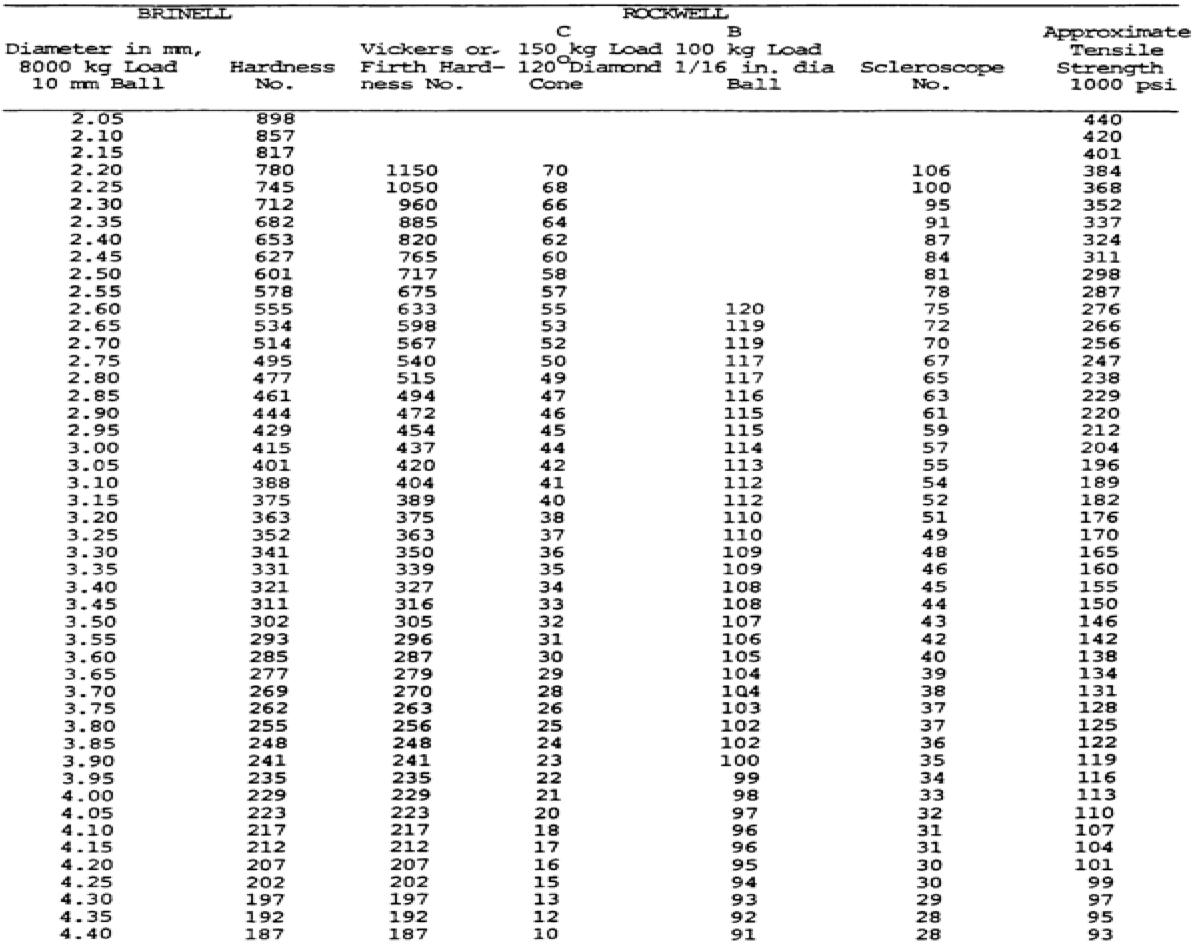
Hardness

Hardness is the ability of a metal to resist penetration and wear by another metal or material.

It takes a combination of hardness and toughness to withstand heavy pounding.

The hardness of a metal limits the ease with which it can be machined, since toughness decreases as hardness increases.

Table 7-3 below illustrates the hardness of various metals.



BRINELL			ROCKWELL			
Diameter in mm, 8000 kg Load 10 mm Ball	Hardness No.	Vickers or Firth Hardness No.	C 150 kg Load 120° Diamond Cone	B 100 kg Load 1/16 in. dia Ball	Scleroscope No.	Approximate Tensile Strength 1000 psi
2.05	898					440
2.10	857					420
2.15	817					401
2.20	780	1150	70		106	384
2.25	745	1050	68		100	368
2.30	712	960	66		95	352
2.35	682	885	64		91	337
2.40	653	820	62		87	324
2.45	627	765	60		84	311
2.50	601	717	58		81	298
2.55	578	675	57		78	287
2.60	555	633	55	120	75	276
2.65	534	598	53	119	72	266
2.70	514	567	52	119	70	256
2.75	495	540	50	117	67	247
2.80	477	515	49	117	65	238
2.85	461	494	47	116	63	229
2.90	444	472	46	115	61	220
2.95	429	454	45	115	59	212
3.00	415	437	44	114	57	204
3.05	401	420	42	113	55	196
3.10	388	404	41	112	54	189
3.15	375	389	40	112	52	182
3.20	363	375	38	110	51	176
3.25	352	363	37	110	49	170
3.30	341	350	36	109	48	165
3.35	331	339	35	109	46	160
3.40	321	327	34	108	45	155
3.45	311	316	33	108	44	150
3.50	302	305	32	107	43	146
3.55	293	296	31	106	42	142
3.60	285	287	30	105	40	138
3.65	277	279	29	104	39	134
3.70	269	270	28	104	38	131
3.75	262	263	26	103	37	128
3.80	255	256	25	102	37	125
3.85	248	248	24	102	36	122
3.90	241	241	23	100	35	119
3.95	235	235	22	99	34	116
4.00	229	229	21	98	33	113
4.05	223	223	20	97	32	110
4.10	217	217	18	96	31	107
4.15	212	212	17	96	31	104
4.20	207	207	16	95	30	101
4.25	202	202	15	94	30	99
4.30	197	197	13	93	29	97
4.35	192	192	12	92	28	95
4.40	187	187	10	91	28	93

Hardness Conversion Table – Table 7-3

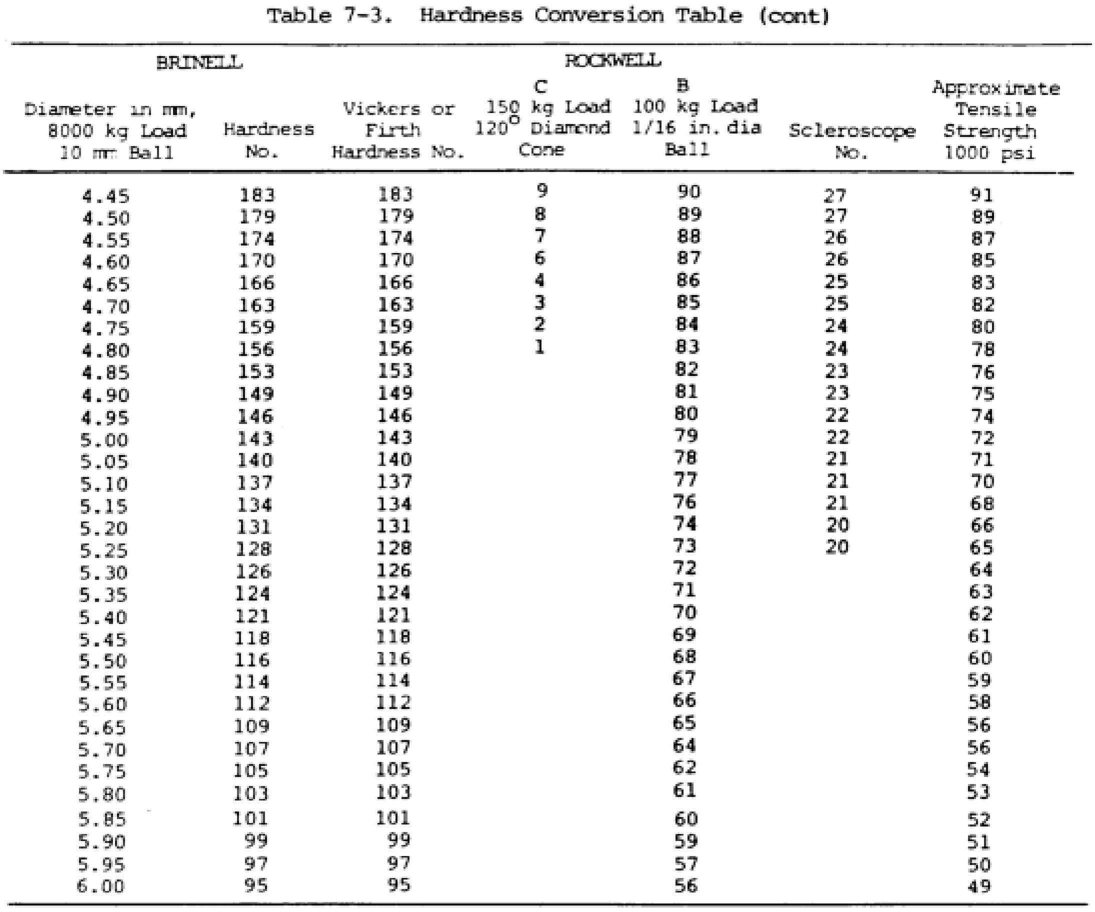


Table 7-3. Hardness Conversion Table (cont)

BRINELL			ROCKWELL			
Diameter in mm, 8000 kg Load 10 mm Ball	Hardness No.	Vickers or Firth Hardness No.	C 150 kg Load 120° Diamond Cone	B 100 kg Load 1/16 in. dia Ball	Scleroscope No.	Approximate Tensile Strength 1000 psi
4.45	183	183	9	90	27	91
4.50	179	179	8	89	27	89
4.55	174	174	7	88	26	87
4.60	170	170	6	87	26	85
4.65	166	166	4	86	25	83
4.70	163	163	3	85	25	82
4.75	159	159	2	84	24	80
4.80	156	156	1	83	24	78
4.85	153	153		82	23	76
4.90	149	149		81	23	75
4.95	146	146		80	22	74
5.00	143	143		79	22	72
5.05	140	140		78	21	71
5.10	137	137		77	21	70
5.15	134	134		76	21	68
5.20	131	131		74	20	66
5.25	128	128		73	20	65
5.30	126	126		72		64
5.35	124	124		71		63
5.40	121	121		70		62
5.45	118	118		69		61
5.50	116	116		68		60
5.55	114	114		67		59
5.60	112	112		66		58
5.65	109	109		65		56
5.70	107	107		64		56
5.75	105	105		62		54
5.80	103	103		61		53
5.85	101	101		60		52
5.90	99	99		59		51
5.95	97	97		57		50
6.00	95	95		56		49

Hardness Conversion Table – Table 7-3 cont.

Elastic Deformation

The concept of elastic deformation is determined by Hooke’s Law. The notion is that elastic deformation is not permanent.

If a load is removed, the part returns to its original dimensions and shape.

Metal Harness Tests

Brinell Harness Test
In this test, a hardened steel ball is pressed slowly by a known force against the surface of the metal to be tested.

The diameter of the dent in the surface is then measured, and the Brinell hardness number (bhn) is determined by from standard tables (see table 7-3)

Rockwell Harness Test
This test is based upon the difference between the depth to which a test point is driven into a metal by a light load and the depth to which it is driven in by a heavy load.

The light load is first applied and then, without moving the piece, the heavy load is applied.

The hardness number is automatically indicated on a dial.

The letter designations on the Rockwell scale, such as B and C, indicate the type of penetrator used and the amount of heavy load (table 7-3).

The same light load is always used.

Scleroscope Hardness Test
This test measures hardness by letting a diamond-tipped hammer fall by its own weight from a fixed height and rebound from the surface; the rebound is measured on a scale.

It is used on smooth surfaces where dents are not desired.

Unit-2.0 Metal Casting

What is metal casting?

Metal casting is the process of making objects by pouring molten metal into an empty shaped space. The metal then cools and hardens into the form given to it by this shaped mold. Casting is often a less expensive way to manufacture a piece compared with machining the part out of a piece of solid metal. There are many metal casting methods to choose from. What type of casting is most efficient depends on the metals used, the size of the run, and the complexity of the casting.

Before starting a production run, it is helpful to know some of the terms and methods from the foundry floor.

- Jump to Casting terminology

- Jump to Types of metal casting

Cope and drag, or ram and swing, are words for the moving and stationary parts of a green sand mold.

Casting terminology

Casting mold

A **mold** is a cavity in a material that receives liquid metal and produces a cooled object in the shape of that cavity. Molds can be simple. The forms used to create ingots of metal are like loaf pans, with the metal simply poured inside and left to cool. Most molds are for more complex shapes and are based on a pattern. The pattern imprinted into a split mold. Half of the pattern is imprinted on one side of the mold and half on the other, and then the halves are clamped together before the mold is filled. By making the mold in two parts, the pattern can be withdrawn before filling. These molds can be made with a horizontal split

Cope and drag

In horizontal molding, the top half of the mold is called the **cope**, and the bottom half is called the **drag**.

Swing and ram

In vertical molding, the leading half of the mold is called the **swing**, and the back half is called the **ram**.

Molding cores

If a mold is supposed to have internal spaces or holes, a **core** is often made. These cores are shaped like the internal space. The cores are usually held in place by extending past the casting and being held in place through **core prints**, which suspends the core like a bridge between two banks. The empty spaces around the core will fill with metal, and the core will be removed from the final casting, leaving a hole where it once was. If the core is very long, it might be supported by **chaplets** to prop it up. These are usually made of the same metal as the final casting as they sit in the space that will flood with material and become part of the final casting.

Dimensional tolerance

One of the important factors in choosing a casting method is **dimensional tolerance**. Dimensional tolerance is the variation acceptable in the size of the final product. Metal shrinks when cooling, and the type of casting influences by how much. If a product needs to be precise, a client may want a casting method that produces **near net casting**. This means that the product is very close to being the right size when it is shaken out of the mold.

Surface finishing

Another consideration is **surface finishing**. How granular, bumpy, or rough can the surface of the casting be? What is acceptable for a cast iron pan is not acceptable for a wedding ring. Very smooth metal surfaces are usually created with machining, which is an extra cost: if shiny and smooth is a desired outcome, choosing a casting method with a finer finish may reduce machining costs.

Surface finish refers to how fine or granular a casting's surface is before machining.

Metal casting methods

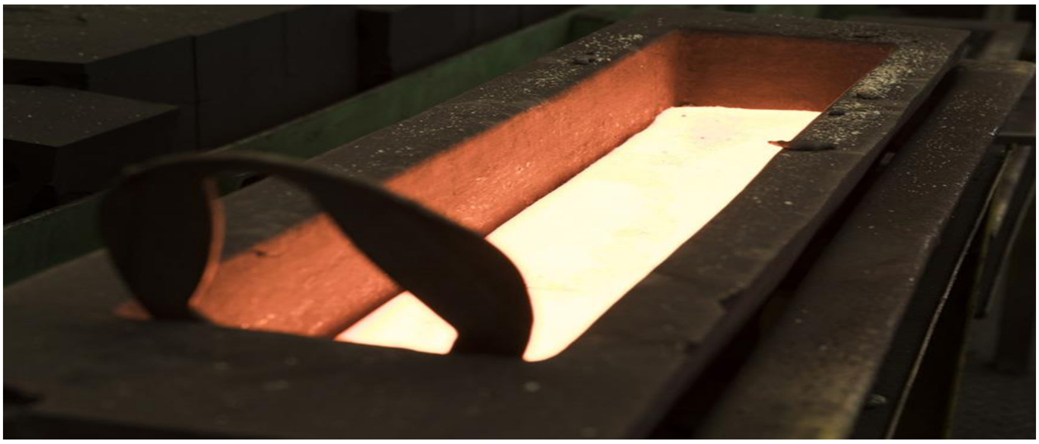
Metal casting comes in two main categories: processes with reusable molds and processes with expendable molds.

- Reusable molds:
    - Permanent molds
    - Semi-permanent molds
    - Slush casting
    - Centrifugal casting
    - Pressure casting
    - Die casting
- Expendable molds
    - Sand casting
    - Shell molding
    - Investment casting (lost-wax)
    - Full mold or foam

Reusable or permanent molds create many items, whereas expendable molds are destroyed by the casting process. Although it may seem from a layman's perspective that reusable molds must be more cost effective for a large production run, this is not always the case. Most iron and steel objects are made through expendable casting processes.

Low temperature molding substances (resins, chocolate, wax, etc.) almost always use reusable molds. What makes metallurgy different is the high temperatures involved. These put a lot of strain on the mold. It is therefore not a surprise that alloys with a lower melting point like zinc, aluminum, magnesium, tin, or copper are more often those that succeed in reusable molding processes.

However, in some circumstances, even ferrous metals are poured into reusable molds. The complexity of design, choice of metal, and requirements for dimensional tolerance and surface finishing all influence whether reusable molds are appropriate.



Permanent molds can be simple, like this form, or more complex and made in two parts.

Reusable molds

Permanent molds

Permanent molds are usually made of metal—one that has a higher melting point than the metal they are filled with. Fluid metal is poured without any type of external pressure. Permanent cores must be simple so they can be withdrawn for reuse from the finished casting.

These molds are sometimes used in iron casting, as well as with lower-temperature alloys. Turntables, rather than assembly lines, are the most common industrial workflow. Individual operations, such as coating the mold, placing the cores, closing the mold, pouring, opening the mold, and ejecting the casting, are performed as each mold passes through the next stations.

Molds are preheated before the first casting is poured so that it does not crack due to the difference in temperature.

The castings that come from this method cannot have walls as thin as those in other reusable methods, such as die casting. However, the castings are produced with “close tolerance,” which means that the size of the final casting can be more precisely predicted. Castings made this way are dense and fine grained. They have a smoother surface finish and avoid several types of defects.

This form of molding is durable enough to be used with iron, but it is not a preferred style for yellow brasses. Yellow brasses are high in zinc and foul the mold or die.

Semi-permanent molds

The only change in semi-permanent mold casting is that the cores used in the casting process might be expendable sand cores. More complex core shapes are possible with sand cores, because they do not need to be extracted intact from the final casting. If an opening in the casting is left to remove cores, they can be “shaken out” on a vibrating table, to drain like sand through an hourglass. The tolerance, density, and appearance advantages of permanent mold casting exist only in the section cast against the metal mold.

Slush casting

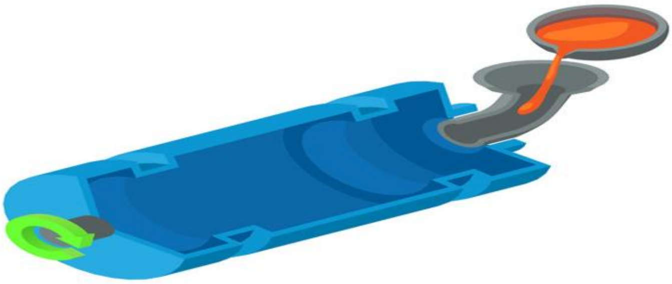
This colorfully named casting style creates hollow castings without needing cores by merely coating the inside of the mold with a small amount of metal, creating a metal “skin”. There are different ways to approach slush casting depending on how quickly the metal or other material sets. In one method, the founder can pour small amounts of the liquid into a mold and rotate to cover the inside with the metal. In another, the founder can fill the mold completely and then pour excess material out after a specified cooling time. Zinc, aluminum, and pewter are metals that are commonly slush cast.

Centrifugal casting

In true centrifugal casting, a water-cooled mold is rotated around its central axis at high speed while liquid metal is fed in. Centrifugal force pulls the liquid metal along the mold’s surface in an even layer. For this method to work, the final casting must have even geometries around the axis of spin. This form of casting is therefore best for those molds that are roughly cylindrical or circular, like tubes or rings.

Objects cast in this method usually have a very low defect rate. Impurities end up close to the bore, or inner surface, of the casting, and can be machined away. Most pipes or fittings that will be used under pressure are cast centrifugally, because of the strength of their seamless structure.

Some small metal castings, like jewelry, are made using a centrifuge that swings an entire mold around a central point, pulling metal from a crucible as it whirls. These castings are not true centrifugal castings, but a form of pressure casting.



Centrifugal castings have no seams and impurities can be machined from the bore.

Pressure casting

Pressure casting methods use forces other than gravity to control the flow of metal into a permanent mold. Air or gas, vacuums, mechanical, or centrifugal forces are all used in pressure casting. These methods allow foundries to precisely control the rate at which a mold fills: gravity always works with the same force, but man-made forces can be varied.

Vacuum casting pulls metal into a mold when the mold is depressurized, and the vacuum created pulls liquid metal up from a reservoir below. The vacuum must stay on while the metal cools, and so this method is mostly used for thin walled castings. It provides excellent surface finish. Low pressure castings invert this process by pressurizing the furnace where the liquid metal sits, rather than creating a vacuum in the mold. The metal is pushed through risers into the mold cavity.

All die casting machines (below) also use some form of pressure to help create castings.

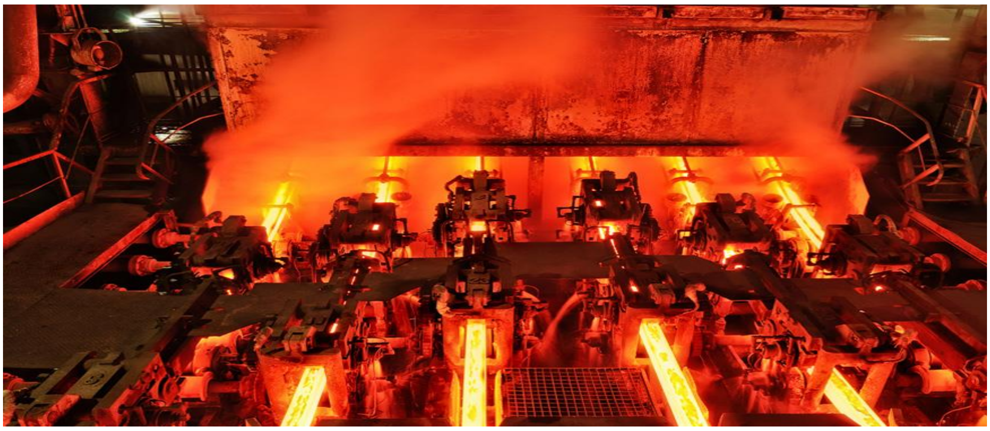
Die casting

Die casting machines consist of a basin holding molten metal, a metallic mold or die on two plates, and an injection system that draws the material and forces it under pressure into the die.

The process for die casting starts with an open mold. Nozzles spray the mold with a lubricant to help prevent the part from sticking. The two halves of the mold are then closed, and the closed mold is injected using a pressure nossle. The new casting is given a moment to cool before the die opens. Ejector pins push the new casting from the die, and then the process starts again.

There are two forms of metal injection in die casting. Cold-chamber die casting works like a syringe: before each die is cast, an injection chamber must be filled with molten metal, and then a piston pushes the injector's contents into the die. Hot-chamber or gooseneck die casting works by immersing the chamber of the injection system into the molten metal, where the shape of the system means the injector refills itself. Hot-chamber die casting pushes this material into the mold either with a piston or with air pressure.

Gooseneck systems are more prone to corrosion because they sit in a bath of melted metal. For this reason, they're usually used with aluminum or aluminum-zinc alloys that have a lower melting point. The piston or cold-chamber injection die caster can be used for the higher temperatures needed to melt brass and bronze, because the injector is not continuously exposed to the heat.



Continuous casting machines extrude unceasing metal shapes but cut them into manageable lengths.

Continuous Casting

Even metal parts we consider completely machined, rolled, or otherwise worked have often had their start on the foundry floor. Continuous casting creates blooms, billets, and slabs, which are different sizes of simple metal shapes, by extruding them through a permanent form. This casting process creates the raw material for worked steel.

The continuous casting process starts high above the factory floor. Molten metal is fed into a funnel that controls the rate of casting. The funnel fills a mold below it, which is a simple form, usually 20-80 inches long, and shaped on its width like a square, circle, or rectangle. The mold walls are cooled so that the exterior of the casting freezes as it passes through. As the metal leaves the form it is solidifying, but still pliable. This allows the continuous casting machine to bend it so that the finished produced comes out horizontally. A series of wheels guide the slab to a conveyer belt while cooling sprays solidify the surface. Gas jets on the horizontal surface cut the continuous metal piece into manageable lengths, so they can be lifted and stacked.

Expendable molds

Expendable mold methods are the clear winners when it comes to casting ferrous metals. They are cost effective because they do not have to be sturdy for the high temperatures involved.

Sand casting

Sand casting is the most common method used for metal casting. It is manufacturing process at least three thousand years old: the first evidence of clay casting comes out of China, during the Shang Dynasty (c. 1600 to 1046 BC).

It is no wonder this process is still so popular: sand is cheap, plentiful, pliable, and able to take the heat.

Cores created out of sand are easy to remove: they can be shaken out with a vibrating table. Runners and gates, used to direct the metal into the mold cavity, are either cut by hand by an experienced molder or are created as part of the pattern.

The surface finish on sand cast items is often rough, and the dimensional tolerance not precise, so sand casting is great for producing large, rugged pieces from decorative fences to cast iron pans to car engine parts.

Shell molding

Shell molding is a form of sand casting that provides closer dimensional tolerances. It’s very similar to sand molding, only the sand is mixed with a resin. A mixture of sand and resin are poured over each half of hot metal molding pattern. This mixture melts and cools into a shell. The “shells” of the mold are brought together, and usually supported by a flask full of sand. With the resin providing extra support to the interior surfaces, these shells form a very precise mold.

Often, shell molding is used to produce cores for traditional sand casting. The resin gives the sand cores strength to keep shape, even when positioned over the void that will become a casting. These shell cores may be hollow, created in a hot metal mold in a process like slush casting. The two halves of the core mold are clamped and heated, and then filled with resin coated sand. The mold bakes until the shell wall is thick enough to support the size of the core and then the excess, uncured resinous sand is poured back out. When the two halves of the mold are split they reveal the sturdy core, now ready to be placed in the sand-casting mold create space in the casting.

Investment casting these automotive parts provides excellent dimensional tolerance.

- ### *Investment casting (lost-wax casting)*

Sand casting is by far the most used form of metal casting, and yet there is one aspect of sand casting that makes it inappropriate for some projects. Sand casting patterns need to be removed from the mold they create, which can mean intricate pattern construction. Draft requirements, parting line placements, gates, risers, and cores require a pattern maker to carefully consider the pattern's needs at each stage in the casting process.

The lost-wax, investment, or precision-casting process is an alternative to sand casting that can work with most grades of metal, even high-melting point ferrous alloys, and yet avoids some of these challenges of patternmaking in sand casting.

A designer for an investment casting makes an accurate metal die into which the wax or plastic patterns are cast. These patterns are assembled on a sprue also made of this material: the foundry worker uses a torch to melt the sprue enough to attach each pattern to it.

This assembly is then used to create a shell that will be used as the mold. It is sprayed, brushed, or dipped in a slurry of a fine-grained, highly refractory aggregate, and a proprietary bonding agent composed chiefly of ethyl silicate. This mixture is then allowed to set. The pattern is coated repeatedly with coarser slurries until a shell of the aggregate is produced around the pattern. The molds stand until the coating has set, after which they are heated in an oven in an inverted position so that the wax will run out and be collected for reuse. After the wax is removed, the molds are baked in a preheated furnace. The molds may then be supported with loose sand and poured in any conventional manner.

Lost wax or investment castings have great surface finish and no parting lines.

When the castings have cooled, the shell around the investment casting is broken and shaken off using a vibrating table.

Investment casting provides superior surface finish, and high dimensional accuracy. There are no parting lines like there are in sand casting.

Full mold or foam casting process

The full mold or foam casting process is a combination of sand and investment cast processes. A foamed polystyrene pattern is used. Indeed, the foamed pattern may be made complete with a gating and runner system, and it can incorporate the elimination of draft allowance. Sometimes the pattern is removed prior to filling, but with some foams the pattern can be left in place in the mold to instantly vaporize when hot metal is poured in.

This process is ideal for casting runs of one or a few pieces, but sometimes foundries mass-produce foam patterns to create production quantities. There is extra expense for the equipment to make the destructible foam patterns, but often the economics of the total casting process can be favorable if the pattern is very complex.

Comparing casting processes

Consultation with manufacturers is helpful to find the most cost-effective way to cast a project. In general, ferrous metals will be cast using expendable molds, whereas non-ferrous metals have a wider range of possibilities, but there are exceptions even to this simple rule.

2.1 Definition and Need

What Is Metal Casting?

Metal casting is defined as the process in which molten metal is poured into a mould that contains a hollow cavity of a desired geometrical shape and allowed to cool down to form a solidified part. The term ‘casting’ is also used to describe the part made by the casting process which dates back 6000 years.

Historically it is used to make complex and/or large parts, which would have been difficult or expensive to manufacture using other manufacturing processes.

Metal casting is a modern process with ancient roots. In the metal casting process, metal shapes are formed by pouring molten metal into a mold cavity, where it is cooled and later extracted from the mold.

Metal casting is arguably the earliest and most influential industrial process in history. It’s used to make many of the metal objects used in our daily lives: automotive parts, train wheels, lamp posts, school bus pedals, and much more.

Plus, metal casting foundries rely on metal recycling as a cost-efficient source of raw material, significantly reducing wasted scrap metal that might end up in landfills.

The Metal Casting Process

1. Patternmaking

A pattern is a replica of the exterior of the casting. Patterns are typically made of wood, metal, plastic, or plaster. Patternmaking is incredibly important for industrial part-making, where precise calculations are needed to make pieces fit and work together.

2. Core Making

If casting is hollow, an additional piece of sand or metal (called a core) shapes the internal form to make it hollow. Cores are typically strong yet collapsible so they can be easily removed from the finished casting.

3. Molding

To visualize the metal casting process so far, imagine yourself walking on the beach toward the ocean. Look at a footprint you leave behind in the wet sand. Your foot would be the core, and the impression left in the sand is a mold of your foot.

Molding is a multistep process that will form a cast around the pattern using molding sand. In casting, a mold is contained in a frame called a flask. Greensand, or molding sand, is packed into the flask around the pattern.

This is known as metal sand casting. Once the sand is packed tight, the pattern can be removed and the cast will remain. Alternatively, a two-piece, non-destructible metal mold can be created so that the mold can be used repeatedly to cast identical parts for industrial applications.

4. Melting And Pouring Molten Metal

After the metal is melted, it is poured into the cavity of the mold and left to solidify. Once solidified, the shakeout process begins: the molds undergo vibration to remove sand from the casting.

In industrial applications, equipment like our Two-Mass Shakeouts keeps production output high because of its efficient and smooth performance. Removed sand is typically collected, cooled, and reclaimed to be used once more in future castings.

5. Cleaning

In this final step, the cast metal object is removed from the mold and then fettled. During the fettling, the object is cleaned of any molding material, and rough edges are removed.

Types Of Metal Casting

Metal casting can be divided into two groups by the basic nature of the mould design. i.e. expendable mould and permanent mould castings. It can be further subdivided into groups depending on their pattern material.

- Reusable molds:
  - Permanent molds
  - Semi-permanent molds
  - Slush casting
  - Centrifugal casting
  - Pressure casting
  - Die casting
- Expendable molds:
  - Sand casting
  - Shell molding
  - Investment casting (lost-wax)
  - Full mold or foam

Expendable Mould Casting

Expendable mould casting, as the name suggests uses a temporary non-reusable mould to produce the final casting as the mould will be broken to get the casting out. These moulds are typically made of materials such as sand, ceramics & plaster.

These are generally bonded using binders called bonding agent to improve its properties. Complex intricate geometries can be cast using expendable mould casting.

Permanent Mould Casting

Sometimes called non-expendable mould casting, permanent mould casting uses permanent moulds that are reused after each production cycle. Although permanent mould casting produces repeatable parts due to re-use of the same mould, it can only produce simple castings as the mould needs to be opened to remove the castings.

Composite Mould Casting

As the name suggests these uses both expendable and re-useable casting moulds to produce castings. These normally include materials such as sand, wood, graphite and metal.

Application of Metal Casting

A sector-wise casting consumption is given below which highlights the importance of casting in any industrial setup.

- Transport: Automobile, aerospace, railways and shipping
- Heavy Equipment: Construction, farming and mining
- Machine Tools: Machining, casting, plastics molding, forging, extrusion and forming
- Plant Machinery: Chemical, petroleum, paper, sugar, textile, steel and thermal plants
- Defense: Vehicles, artillery, munitions, storage and supporting equipment
- Electrical Equipment Machines: Motors, generators, pumps and compressors
- Hardware: Plumbing industry pipes, joints, valves and fittings
- Household: Appliances, kitchen and gardening equipment, furniture and fittings
- Art Objects: Sculptures, idols, furniture, lamp stands and decorative items

Advantages of Metal Casting

- Metal casting can produce complex shapes
- Features like internal cavities or hollow sections can be easily achieved
- Large components can be produced in one-piece cast
- Materials that are difficult or expensive to manufacture using other manufacturing processes can be cast
- Compared to other manufacturing processes, casting is cheaper for medium to large quantities
- Almost all the metals can be cast
- Near net shape often without or very minor post-processing

Disadvantages of Metal Casting

- Relatively coarse surface finish and hence wider tolerance has to be allowed and is not suitable for mating interfaces
- Metal casting such as shell molding has a limit in terms of size and the pattern
- Patterns are time-consuming and expensive to make although additive manufacturing processes such as binder jetting are being used lately to make a mold
- Die casting can be very expensive for smaller to medium quantities due to the high die cost
- Part size and material choices depend on the casting process chosen. For instance, only non-ferrous metal can be used for permanent mold castings.

2.2 Pattern: types, materials,pattern allowances, color code, applications

Types of Pattern Allowances in Casting Process & Their Uses

What is Pattern?

For making the casting product in the casting process, a pattern is used to make a mold cavity in the sand.

A pattern is similar to the casting product but not exactly the same size, given some allowance because of the shrinkage property of cast metal.

The pattern materials can be made of wood, metal, plastic, compound, or wax.

Usually, the patterns are made of wood only because they are cheap, and they are also easy to make.

Pattern Allowance

A pattern is a replica of casting which is used to make a mold cavity but it has slightly large dimensions.

This change in the pattern is due to when the cast solidifies, it shrinks at some limit due to metal shrinkage property at the time of cooling.

So to compensate for this, a pattern is made a little bigger.

These slight changes in the pattern are known as pattern allowance.

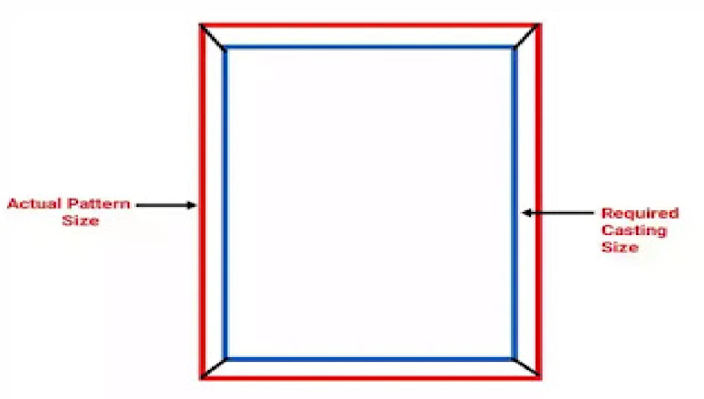
Types of Pattern Allowance

There are the following types of pattern allowances are used in the casting process.

- Shrinkage Allowance
- Draft Allowance
- Machining Allowance
- Deformation or Camber Allowance
- Shake or Rapping Allowance

Shrinkage Allowance

Shrinkage is defined as the reduction during the cooling or solidification process.
This is a common property of all materials.
The magnitude of shrinkage varies from material to material, but each and every material has to shrinks. For avoiding this, the pattern is made larger than the required size of the casting product with the help of the shrink rule.
Then the difference between actual pattern size and required casting size is known as shrinkage allowance.
Show in the figure.



Shrinkage Allowance

The shrinkage allowance is given in the pattern in mm/m (millimeter/meter).

Which is different for different materials.

Shrinkage Allowances For Different Materials

There are following some shrinkage allowance given inside the pattern for different materials are used in casting.

1. For grey cast iron shrinkage allowance is given from 6.95 to 10.5mm/m.
2. For white cast iron and steel, it is given up to 20.8 mm/m.
3. For Aluminium shrinkage allowance given 17 mm/m and for aluminum alloy given from 12.5 to 15 mm/m
4. For brass, it is given up to 15.3 mm/m.

Types of Shrinkage

There are following three types of shrinkage that happen during the casting process.

- Liquid Shrinkage
- Solidification Shrinkage.
- Solid Shrinkage

Liquid Shrinkage

The liquid contraction that occurs during cooling before solidification is called liquid shrinkage.

After pouring the molten metal into the mold cavity, the level of the molten metal decreases during cooling due to the liquid shrinkage.

Solidification Shrinkage

The contraction phase changes from liquid to solid, which is called solidification shrinkage.

The solidification shrinkage reduces the height of the casting metal.

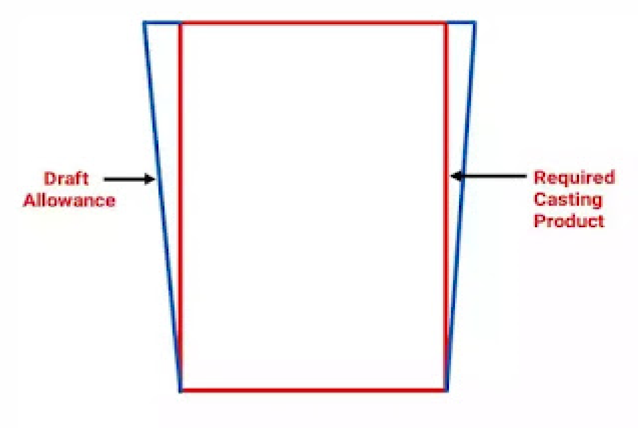
Solid Shrinkage

The shrinkage of solidified casting at room temperature due to thermal contraction is called solid shrinkage.

The solid shrinkage further reduces the height of the casting metal.

Draft Allowance

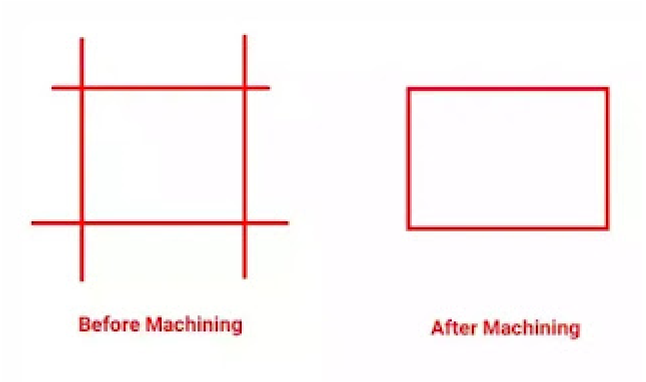
During removing the pattern from the mold cavity, the parallel surfaces in the direction in which the pattern is withdrawn are slightly damaged and also converted into slightly tapered surfaces.
To compensate for these changes, these parallel surfaces on the pattern are slightly tapered by about 1 to 2 degrees.
By which removal of the pattern from the mold cavity becomes easy and suitable and also does not affect the casting in any way.
These small changes in the surface of the pattern are called draft allowances to protect it from damage.
See in the figure.



Draft Allowance

Machining Allowance

As we know that the product of the casting process gives a very poor surface finish, so the surface of the final product of casting always is rough.
But we required a product that is polished and has a good surface finish.
So in order to have a good surface finish, the final product of the casting is machined with the help of a lathe machine, milling machine, shaper machine, slotting machine with these processes such as turning, grinding, shaping, drilling to obtain a surface finish.
This allowance is added to the basic size of the pattern.
It ranges from less than 2 mm to 15 mm depending on the size and material of the pattern.
Show in the figure casting product before machining with allowances and after machining.

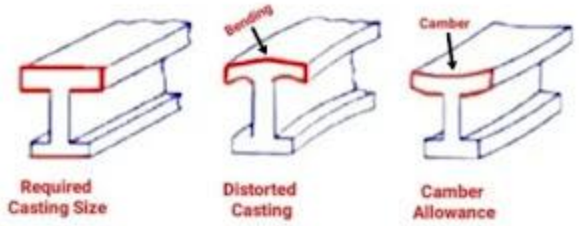


Machining Allowance

Deformation or Camber Allowance

When the metal is in the cooling process, stress is developed during the solidifying of this metal due to uneven metal thickness in the casting process.
This stress can cause deformation or bend in the casting.
To avoid this bending or deformation in castings, camber is provided in the opposite direction so that when bending occurs due to uneven thickness of metal, the casting product becomes straight.

These small changes in a pattern to avoid bending in the casting process are called bending or camber allowances.
Show in the figure camber provided in a pattern.



Deformation or Camber Allowance

Shake or Rapping Allowance

When the pattern is to be removed from the sand of the casting, a slight shake is required to remove the pattern from the sand and this will increase the dimension of the casting slightly.

To avoid this increase in the dimension of the casting, the pattern is made slightly smaller than the casting.

These small changes in the dimensions of the pattern in the casting process are called the shaking or rapping allowance.

Which pattern allowance is Negative allowance?

Shake or rapping pattern allowance is known as the negative allowance.

Why is pattern allowance required?

Due to shrinkage property of cast metal pattern allowances given to the pattern in casting process.

How many types of allowances are there in casting?

Pattern allowances are five types shrinkage, draft, machining, deformation and rapping allowances.

To have good surface finish and accuracy which of the allowance is given?

For good surface finish and accuracy machining allowance is given.

Which types of pattern allowances used to reduce the chances of damage due to withdrawing of a pattern from the mould cavity?

Draft allowances used to reduce the chances of damage during withdrawing of a pattern from the mould cavity.

Colour of Pattern:

There are several colors used in the pattern and those are like:

- Yellow used for Core Prints
- Red used for surfaces to be machined
- Black surfaces to be left unfinished
- Colour Less used for parting surface

Functions of Pattern:

These are some functions of a Pattern:

- It is used for preparing a mold cavity which is used for Casting any parts.
- Some accurate pattern can minimize the production cost of a product because of no further machining is required.
- It reduces casting defects.

Materials Used for Pattern:

Some key factors are in mind before choosing a material for the pattern:

- The materials used in the pattern should be cheap in cost and easily available in the market.
- The material should have a good surface finish.
- The material should have withstood high temperatures and does not change its shape at high temperatures.

Generally, we use 5 different types of material to make the patter and those are:

- Wood
- Metals
- Plaster of Paris
- Plastics
- Wax

Let me go a little in-depth,

Wood:

As we all know woods are easily available, and the price is quite low so it is satisfied us some basic criteria which I mentioned above.

Also, there are some advantages using wood in pattern and those are:

1. Wood is light in weight
2. Easily Available in the market
3. You can make any shape using wood
4. Woods gives good surface finish

However wood is attracted to moisture and sometimes it can change shape on high temperature or after dry out from moisture, this is an important con of using wood as a pattern.

Not only this reason woods are very week in strength, and it wears out quickly due to its low resistance to sand abrasion.

For these above reasons, it is not used for very big product casting.

Generally, pines deodar, walnut, teak's are used for making a pattern.

Metals:

In metals, cast iron, brass, aluminum are generally used in patterns. It gives smooth surface finish, this is the only reason that metals are used in large production casting workshops.

These are some advantages of using Metal Pattern:

1. Smooth surface finish can be obtained by metal patterns.
2. Deformation is less.
3. Closer dimensional tolerance.

Although there are some disadvantages of using this type of pattern like it is a little bit costlier, heavy, sometimes rusting effect occurred on the surfaces of the metals.

Plaster of Paris:

It is generally used if you need to set up the pattern quickly. The main advantage of this pattern is it can easily cast into intricate shapes.

However, it is not for repetitive usages as it is fragile.

Plastics:

Different types of plastics are nowadays used in pattern because of their lighter weight, strength, and dimensionally stable and also for cheap in cost.

Thermoplastics and polystyrene are commonly used for making patterns, and Thermosetting plastics such as phenolics and epoxies are also used in a pattern.

There are few advantages of using pattern and those are:

1. Light in weight.
2. Cheap in price.
3. It posses good compressive strength.
4. No tension of rusting or moisture absorbing.

However, they are a little weak in strength and not good abrasion-resistant.

Wax:

A wax pattern used in the investment casting process. By using this pattern we get a high degree of accuracy and have an excellent surface finish.

However it needs little care handling otherwise it can be broken, and it is used in small casting.

Types of pattern:

The pattern can be classified in different types as per their design, some of those are mentioned below:

- Single Piece Pattern
- Two-Piece or Split Pattern
- Multipiece Pattern
- Match Plate Pattern
- Gated Pattern
- Sweep Pattern
- Loose Piece Pattern
- Skeleton Pattern
- Shell Pattern
- Segmental Pattern

Let me explain this pattern briefly.

Single Piece Pattern:

As the name denotes a single piece that means it has only 1 section, and inside this, the shape of the pattern is made.

Split Pattern:

It has two sections and this two-section is connected by pin named dwell pin to attach the two-portion.

When we joined the two-block the joining surface is called parting surface.

Generally, it is used to make the hollow cylindrical casting.

2.3 Cores: Need, types, materials

Cores and Casting of Metals | Metallurgy

After reading this article you will learn about:- 1. Meaning of Cores 2. Types 3. Materials 4. Prints 5. Shifting 6. Chaplets 7. Chills.

Meaning of Cores:

Core is a pre-prepared shape of the mould. It is used to provide internal cavities, recesses, or projections in the casting. It is usually positioned into a mould after the removal of the pattern. A core is usually made of the best quality sand and is placed into desired position in the mould cavity. Core prints are added to both sides of the pattern to create impressions that allow the core to be supported and held at both ends.

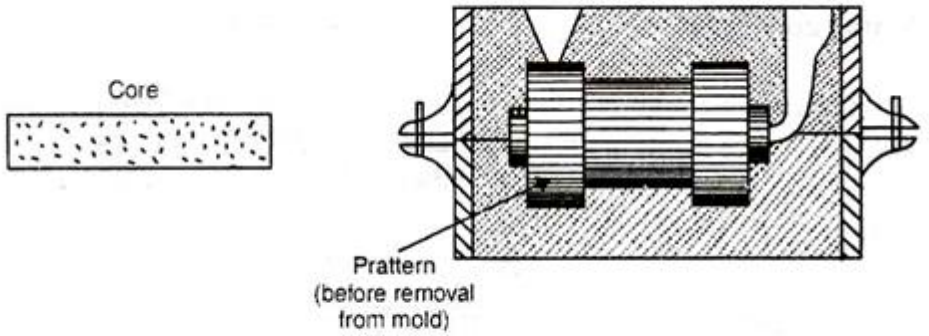


Fig. 3.10. The pattern, mold, and core used for producing a short pipe.

When the molten metal is poured, it flows around the core and fill the rest of the mould cavity. Cores are subjected to extremely severe conditions, and they must, therefore, possess very high resistance to erosion, exceptionally high strength, good permeability, good refractoriness, and adequate collapsibility.

Special vent holes are provided on the core to allow gasses to escape easily. Sometimes, cores are reinforced with low carbon steel wires or even cast-iron grids (in case of large cores) to ensure stability and resistance to shrinkage.

Types of Cores:

Generally, cores are of two types:

1. Green Sand Core:

A core formed by the pattern itself, in the same sand used for the mould is known as green sand core. The pattern is so designed that it provides the core of green sand. The hallow part in the pattern produces the green sand core. It is shown in Fig. 3.11 (a).

2. Dry Sand Core:

A core is prepared separately in core boxes and dried, is known as dry sand core. The dry sand cores are also known as process cores. They are available in different sizes, shapes and designs as per till requirement. Dry sand core is shown in Fig. 3.11. (b).

Some common types of dry-sand cores are:

(i) Horizontal Core:

The horizontal core is the most common type of core and is positioned horizontally at the parting surface of the mould. The ends of the core rest in the seats provided by the core prints on the pattern. This type of core can withstand the turbulence effect of the molten metal poured. A horizontal core for gear blank mould is shown in Fig. 3.11 (c).

(ii) Vertical Core:

The vertical core is placed vertically with some of their portion lies in the sand. Usually, top and bottom of the core is kept tapered but taper on the top id greater them at bottom. A vertical core is shown in Fig. 3.11 (d).

(iii) Balance Core:

The balance core extends only one side of the mould. Only one core print is available on the pattern for balance core. This is best suitable for the casting has only one side opening. This is used for producing blind holes or recesses in the casting. A balance core is shown in Fig. 3.12 (e).

(iv) Hanging Core:

The hanging core is suspended vertically in the mould. This is achieved either by hanging wires or the core collar rests in the collar cavity created in the upper part of the mould. This type of core does not have bottom support. A hanging core is shown in Fig. 3.11 (h).

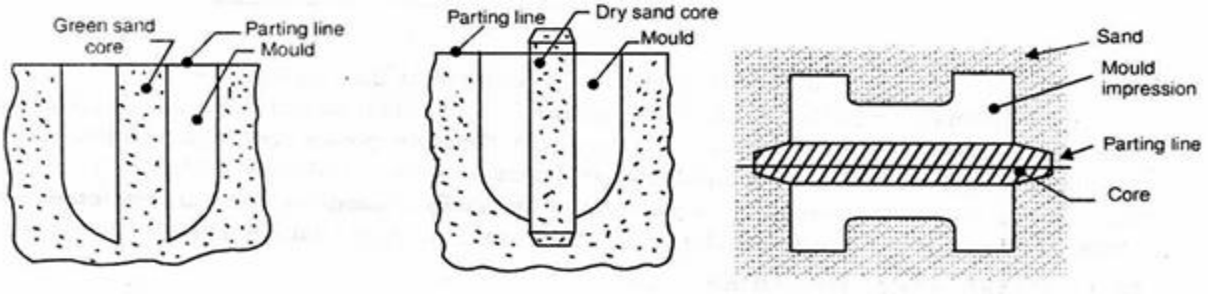
(v) Drop Core:

The drop core is used when the core has to be placed either above or below the parting line. A drop core is shown in Fig. 3.11 (J). This core is also known as wing core, tail core, chair core, etc.

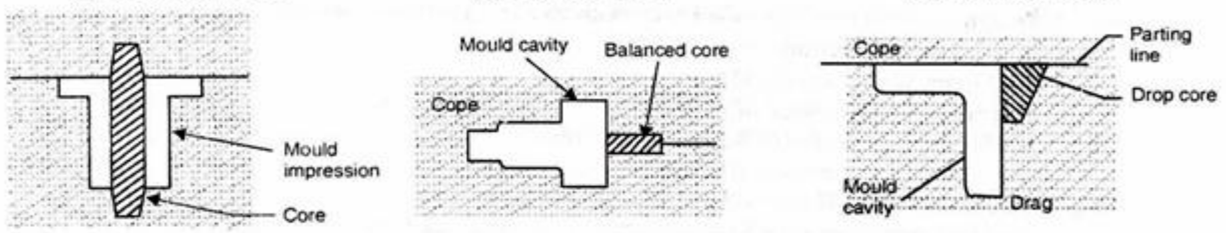
(vi) Kiss Core:

The kiss core is used when a number of holes of less dimensional accuracy is required. In this case, no core prints are provided and consequentially, no seat is available for the core. The core is held in position approximately between the cope and drag and hence referred as kiss core.

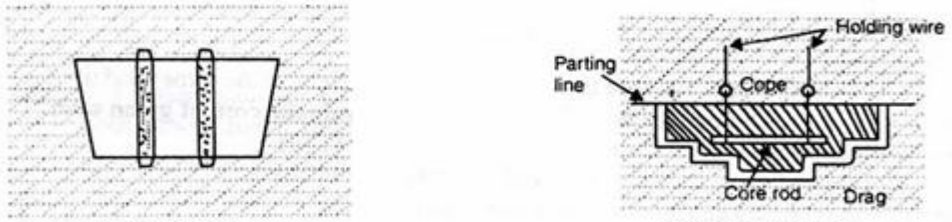
A kiss core is shown in Fig. 3.11 (g):



(*a*) Green Sand Core. (*b*) Dry Sand Core. (*c*) Horizontal core.



(*d*) Vertical core. (*e*) Balanced core. (*f*) Drop core.



(*g*) Kiss core. (*h*) Hanging core.

Fig. 3.11. Type of cores.

Core Materials:

The compositions of core material are the mixture of sand, binders and additives. Core sands are silica, zircon, Olivine etc. and core binders are core oils, resins, molasses, dextrin etc., are generally used for preparation of core materials.

Sand contains more than 5% clay reduces not only permeability but also collapsibility and hence not suitable for core making.

The commonly used core sand is a mixture of following items:

(i) Core Sand:

The sand may be green sand for smaller castings and mixture of fire clay, green sand and betonies for heavier casting. The cores are oven backed to dry away its moisture. The dry sand cores are strong than green and cores. Also, the sand with rounded grains is best suitable for core making as they have better permeability than the angular grains sand.

(ii) Oil Sand:

Oil sand can be used for almost any sand casting application.

A typical composition of oil sand is:

Sand 95 — 96%
Cereal flour 1 — 1.05%
Core oil 1 — 1.5%
Water 1 — 2%
Bentonite 0.1—0.3%

Oil sand is very popular in core making because:

(a) They get good strength.
(b) They provide excellent surface finish.
(c) They have better collapsibility after baking.
(c) The backed oil sand cores are very hard and not easily damaged in handling of mould.

(iii) Resin Sand:

These are thermosetting or thermoplastic binders such as rosin, phenol, urea, furan, formaldehyde etc. are used to obtain good bonds to sand. They are becoming common in use due to their high strength, low gas formation, excellent collapsibility, resistance to moisture absorption, better dimensional accuracy to casting, etc.

(iv) CO_2 – Sodium Silicate Sand:

Silica sand and sodium silicate (3-4%) is rammed in the core and then CO_2 gas is passed through sand to make the core hard. Such types of cores are used for very large castings. They do not need to drying and hence is very fast method of core making,

(v) Core Binders:

Natural sand has not sufficient binding properties and hence some binders are used to improve the binding strength of core sand. The functions of binders are to hold the sand grains together and to provide better strength to the core.

There are two types of binders used are:

a. Inorganic Binders:

They include fire clay, bentonite, limonite, silica powder, iron oxide, aluminum oxide, etc. They are very fine powder and popularly used.

b. Organic Binders:

They include core oils like petroleum oil, vegetable oil, linseed oil, corn oil, malasses and dextrin. Organic binders get harder rapidly and provide good strength.

(vi) Core Additives:

In addition to core sand and core binder, some additives are used to improve the special properties of the core.

The additives are:

(a) Kaolin or fire clay to improve stability.
(b) Iron oxide (Fe_2O_3) and aluminum oxide (Al_2O_3) to improve hot strength.
(c) Zircon flour and pitch flour to improve refractoriness.
(d) Molasses to improve binding properties.

(e) Organic additives to improve collapsibility like raw dust.

(f) Silica powder, paints and graphite bonded with resin are used to improve the surface finish.

Properties of Good Core Materials:

A good dry sand core must have the following properties in order to successfully use in casting process:

1. Strong:

It should be strong enough to withstand the turbulence force of molten metal. It should be erosion resistant.

2. Hardness:

It should be capable, of being baked to obtain good hardness strength.

3. Permeability:

It must be permeable to allow the easy escape of the gases formed.

4. Refractoriness:

It must be highly refractory in nature to withstand high temperature of the molten metal.

5. Dimensional Stability:

It should be stable in dimensional accuracy, shape and size during pouring and solidification.

6. Minimum Gas-Formation:

Core material should generate minimum gases, while subjecting to molten metal in casting process.

7. Good Surface Finish:

Core surface should be smooth enough to provide good surface finish of the casting.

8. Sufficiently Collapsible:

Cores must be sufficiently collapsible i.e., easy removal of the core from the casting after solidification.

Core Prints:

The core prints are extra projections provided on the pattern that form a recesses in the mould to hold and position the core in their right position. There are several types of core prints, e.g., vertical, horizontal, balancing, hanging and drop core prints.

Core Shifting:

The cores, while containing a metal, shift their position due to the turbulent action of the molten metal. Also, due to upward thrust of the molten metal, thin cores tend to float easily and shifted from their right position.

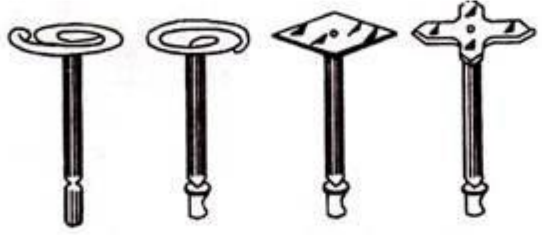
To avoid shifting, the weight of the core is increased by embedding steel rods, steel wires, thin pipes, etc., during core making. This is known as reinforcing of core.

Core Chaplets:

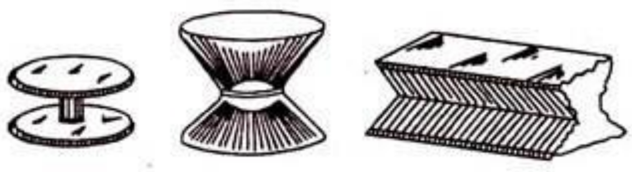
If the core length is long and the end supports are at higher distances to each other, the core will sagging during pouring of hot molten metal.

In such cases, chaplets are used to overcome these defects. Chaplets are so designed to provide the support to the core and restrict them from sagging.

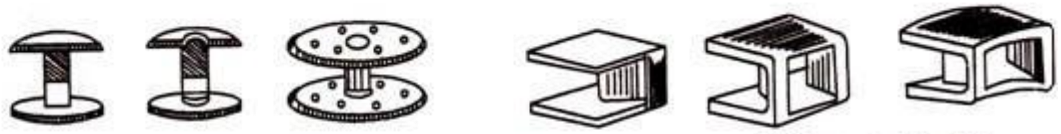
The chaplets are made of the same material as the casting metal so as to become an integral part of the casting. Some commonly used chaplets are shown n Fig. 3.14.



(*a*) Radial chaplets.



(*b*) Double headed chaplets.



(c) Cast chaplets. (d) Sheet metal chaplets.

Fig. 3.14. Various types of chaplets.

Core Chills:

The core chills are the metal pieces, either inserted or placed to touch the surface of the casting for speeding up the solidification process at that particular portion where it is slow. The thinner area solidifies faster, creating stresses and distortion of the casting.

Therefore, it is necessary to provide a means that will uniform the solidification (chilling) rate at all sections of the casting.

The chills are of following two types:

(i) Internal Chill:

An internal chill is placed in a mould in place where the area is comparatively large to help uniform solidification throughout the casting.

This is shown in Fig. 3.15:

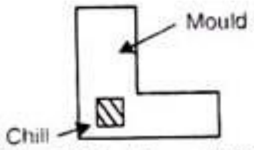


Fig. 3.15. Internal chill.

(ii) External Chill:

An external chill is placed around the mould just touching the surface of it.

This is shown in Fig. 3.16:

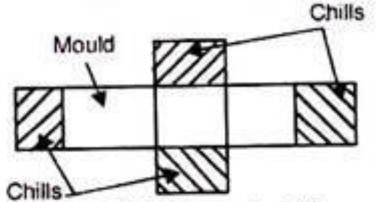


Fig. 3.16. External chill.

2.4 Moulds:

Types of Casting Molds

All sorts of things are cast out of molds.

Casting is a process in which a liquid is poured into a mold in order to produce a product. There are several types of molds that are used in the casting process. Some are temporary and are destroyed during the casting process. Others are permanent and are reused again and again. The type of mold chosen is usually based on the requirements of the final product.

Sand Mold

Sand molds are one of the oldest and most basic types of molds. Dry sand is pressed into a box (called a flask). A pattern made of wood or metal is pressed into the sand, creating a mold. Liquid metal or another material can then be poured into the mold, and the excess sand is brushed away when the part has cooled.

Vacuum Form

Vacuum forming can create many thin, weak molds in a short period of time. A sheet of plastic is suspended over a form, or "buck." The plastic is heated until it is soft, then pressed down on the buck. A vacuum is then turned on beneath the plastic to form it to the shape of the buck. These molds are strong enough to be reused, but thin enough to be cut from the final casting if needed.

Ceramic Molds

Ceramic molds are typically employed with the "lost wax" process of casting. A wax model is created of the desired item. It is then encased in ceramic, leaving a small channel open. When the ceramic is fired the wax melts away, leaving a ceramic mold. The casting material can now be poured in, creating an exact replica of the wax model. When the casting material has hardened, the mold is shattered, freeing the cast.

Permanent Mold

Permanent molds are often made of steel, iron, silicone or urethane. The casting material is either poured in or injected. Once the cast has hardened, it is removed from the mold. Permanent molds can only be made of hard materials if there are no undercuts in the cast (areas where the cast and the mold lock together). Soft mold materials do not have this issue.

Multi-Piece Mold

This toy was cast from a two-part mold. A seam can be seen running down the back.

For especially complex castings, multi-piece molds must be used. Often these are two halves that are locked together while the casting is taking place, but molds comprised of many more pieces are used as the casting gets more intricate.

Die Casting

Die casting is the preferred method for creating many small castings. Liquid metal is forced under pressure into a steel mold, or "die." Often many identical castings are built into the same die, allowing rapid manufacture of parts.

Molding sand: Types, properties, binders, additives, mixing, Molding equipments & tools

The general sources of receiving molding sands are the sea shores, rivers, lakes, deserts and granular elements of rocks.
Molding sands can be classified mainly into **two types namely natural or synthetic**. Natural molding sands contains sufficient amount of binder material. Whereas synthetic molding sands are prepared artificially using basic sand molding constituents (silica sand in 85-91%, binder 6-11%, water or moisture content 2-8%) and other additives in proper proportion by weight with perfect mixing and mulling in suitable equipment's.

1. Constituents of Molding Sand

The main constituents of molding sand involve **silica sand, binder, moisture content and additives**.

1.1 Silica sand

Silica sand in form of granular quarts is the main constituent of molding sand having enough refractoriness which can impart strength, stability and permeability to molding and core sand. But along with silica small amounts of iron oxide, alumina, lime stone ($CaCO_3$), magnesia, soda and potash are present as impurities. The chemical composition of silica sand gives an idea of the impurities like lime, magnesia, alkalis etc. present. The presence of excessive amounts of iron oxide, alkali oxides and lime can lower the fusion point to a considerable extent which is undesirable. The silica sand can be specified according to the sand grain size and the shape (angular, sub-angular and rounded) of the sand.

1.2 Binder

Binders can be either inorganic or organic substance. Binders included in the inorganic group are clay sodium silicate and port land cement etc. In foundry shop, the clay acts as binder which may be Kaolinite, Ball Clay, Fire Clay, Limonite, Fuller's earth and Bentonite. Binders included in the organic group are dextrin, molasses, cereal binders, linseed oil and resins like phenol formaldehyde, urea formaldehyde etc. Binders of organic group are mostly used for core making. Among all the above binders, the bentonite variety of clay is the most commonly used. However, this clay alone can't develop bonds among sand grins without the presence of moisture content in molding sand and core sand.

1.3 Moisture

The amount of **moisture content** in the molding sand varies from 2 to 8%. This amount is added to the mixture of clay and silica sand for developing bonds. This is the amount of water required to fill the pores between the particles of clay without separating them. This amount of water is held rigidly by the clay and is mainly responsible for developing the strength in the sand. The effect of clay and water decreases permeability with increasing clay and moisture content. The green compressive strength first increases with the increase in clay content, but after a certain value, it starts decreasing. For increasing the molding sand characteristics some other additional materials besides basic constituents are added which are known as additives.

1.4 Additives

Additives are the materials generally added to the molding and core sand mixture to develop some special property in the sand. Some commonly used additives for enhancing the properties of molding and core sands are coal dust, corn flour, dextrin, sea coal, pitch, wood flour, silica flour.

1.4.1 Coal dust

Coal dust is added mainly for producing a reducing atmosphere during casting process. This reducing atmosphere results in any oxygen in the poles becoming chemically bound so that it cannot oxidize the metal. It is usually added in the molding sands for making molds for production of grey iron and malleable cast iron castings.

1.4.2 Corn flour

Corn flour belongs to the starch family of carbohydrates and is used to increase the collapsibility of the molding and core sand. It is completely volatilized by heat in the sand mould, thereby leaving space between the sand grains. This allows free movement of sand grains, which finally gives rise to mould wall movement and decreases the mold expansion and hence defects in castings. Corn sand if added to molding sand and core sand improves significantly strength of the mold and core.

1.4.3 Dextrin

Dextrin also belongs to starch family of carbohydrates that behaves also in a manner similar to that of the corn flour. Dextrin increases dry strength of the molds.

1.4.4 Sea coal

Sea coal is the fine powdered bituminous coal which positions its place among the pores of the silica sand grains in molding sand and core sand. When heated, sea coal changes to coke which fills the pores and is unaffected by water. Because to this, the sand grains become restricted and cannot move into a dense packing pattern. Thus, sea coal reduces the mould wall movement and the permeability in mold and core sand and hence makes the mold and core surface clean and smooth.

1.4.5 Pitch

Pitch is distilled form of soft coal. It can be added from 0.02 % to 2% in mold and core sand. Pitch enhances hot strengths, surface finish on mold surfaces and behaves exactly in a manner similar to that of sea coal.

1.4.6 Wood flour

Wood flour is a fibrous material mixed with a granular material like sand. Wood flour is relatively long thin fibers prevent the sand grains from making contact with one another. wood flour can be added in between 0.05 % to 2% in mold and core sand. Wood flour volatilizes when heated, thus allowing the sand grains room to expand. Wood flour will increase mould wall movement and decrease expansion defects. Wood flour also increases collapsibility of both mold and core.

1.4.7 Pulverized Silica or Silica flour

Silica flour is called as **pulverized silica.** Pulverized silica can be easily added up to 3% which increases the hot strength and finish on the surfaces of the molds and cores. It also reduces metal penetration in the walls of the molds and cores.

2. Different types of Molding Sand:

Molding sands can also be classified into **various types according to their use** are backing sand, core sand, dry sand, facing sand, green sand, loam sand, parting sand, system sand.

2.1 Backing sand or floor sand

Backing sand or floor sand is used to back up the facing sand and is used to fill the whole volume of the molding flask. Backing sand is sometimes called black sand because of old, repeatedly used molding sand is black in color due to addition of coal dust and burning on coming in contact with the molten metal.

2.2 Core sand

Core sand is used for making cores and it is sometimes also known as oil sand. Core sand is highly rich silica sand mixed with oil binders such as core oil which composed of linseed oil, resin, light mineral oil and other bind materials. Pitch or flours and water may also be used in large cores for the sake of economy.

2.3 Dry sand

Green sand that has been dried or baked in suitable oven after the making mold and cores is called **dry sand**. It possesses more strength, rigidity and thermal stability. Dry sand is mainly used for larger castings. Mold prepared in this sand are known as dry sand molds.

2.4 Facing sand

Facing sand forms the face of the mould. It is next to the surface of the pattern and it comes into contact with molten metal when the mould is poured. Initial coating around the pattern and hence for mold surface is given by facing sand. Facing sand have high strength refractoriness. Facing sand is made of silica sand and clay, without the use of already used sand. Different forms of carbon are used in facing sand to prevent the metal burning into the sand. A facing sand mixture for green sand of cast iron may consist of 25% fresh and specially prepared and 5% sea coal. They are sometimes mixed with 6-15 times as much fine molding sand to make facings. The layer of facing sand in a mold usually ranges between 20-30 mm. From 10 to 15% of the whole amount of molding sand is the facing sand.

2.5 Green sand

Green sand is also known as **tempered or natural sand** which is a just prepared mixture of silica sand with 18 to 30% clay, having moisture content from 6 to 8%. The clay and water furnish the bond for green sand. It is fine, soft, light, and porous. Green sand is damp, when squeezed in the hand and it retains the shape and the impression to give to it under pressure. Molds prepared by this sand are not requiring backing and hence are known as green sand molds. Green sand is easily available and it possesses low cost. Green sand is commonly employed for production of ferrous and non-ferrous castings.

2.6 Loam sand

Loam sand is mixture of sand and clay with water to a thin plastic paste. Loam sand possesses high clay as much as 30-50% and 18% of water. Patterns are not used for loam molding and shape is given to mold by sweeps. Loam sand is particularly employed for loam molding used for large grey iron castings.

2.7 Parting sand

Parting sand without binder and moisture is used to keep the green sand not to stick to the pattern and also to allow the sand to the parting surface the cope and drag to separate without clinging. Parting sand is clean clay-free silica sand which serves the same purpose as parting dust.

2.8 System sand

In mechanized foundries where machine molding is employed. System sand is used to fill the whole molding flask. In mechanical sand preparation and handling units, facing sand is not used. The used sand is cleaned and re-activated by the addition of water and special additives. This is known as system sand. Since the whole mold is made of this system sand, the properties such as strength, permeability and refractoriness of the molding sand must be higher than those of backing sand.

3. Properties of Molding sand

The **basic properties required in molding sand and core sand** are adhesiveness, cohesiveness, collapsibility, flowability, dry strength, green strength, permeability, refractoriness described as under.

3.1 Adhesiveness

Adhesiveness is a property of molding sand to get the stick or adhere to foreign material such sticking of molding sand with the inner wall of molding box.

3.2 Cohesiveness

Cohesiveness is property of molding sand by virtue which the sand grain particles interact and attract each other within the molding sand. Thus, the binding capability of the molding sand gets enhanced to increase the green, dry and hot strength property of molding and core sand.

3.3 Collapsibility

After the molten metal in the mould gets solidified, the sand mould must be collapsible so that free contraction of the metal occurs and this would naturally avoid the tearing or cracking of the contracting metal. In absence of collapsibility property the contraction of the metal is hindered by the mold and thus results in tears and cracks in the casting. This property is highly required in cores.

3.4 Dry strength

As soon as the molten metal is poured into the mould, the moisture in the sand layer adjacent to the hot metal gets evaporated and this dry sand layer must have sufficient strength to its shape in order to avoid erosion of mould wall during the flow of molten metal. The dry strength also prevents the enlargement of mould cavity cause by the metallostatic pressure of the liquid metal.

3.5 Flowability or plasticity

Flowability or plasticity is the ability of the sand to get compacted and behave like a fluid. It will flow uniformly to all portions of pattern when rammed and distribute the ramming pressure evenly all around in all directions. Generally sand particles resist moving around corners or projections. In general, flowability increases with decrease in green strength and vice versa. Flowability increases with decrease in grain size of sand. The flowability also varies with moisture and clay content in sand.

3.6 Green strength

The green sand after water has been mixed into it, must have sufficient strength and toughness to permit the making and handling of the mould. For this, the sand grains must be adhesive, i.e. they must be capable of attaching themselves to another body and. therefore, and sand grains having high adhesiveness will cling to the sides of the molding box. Also, the sand grains must have the property known as cohesiveness i.e. ability of the sand grains to stick to one another. By virtue of this property, the pattern can be taken out from the mould without breaking the mould and also erosion of mould wall surfaces does not occur during the flow of molten metal. The green strength also depends upon the grain shape and size, amount and type of clay and the moisture content.

3.7 Permeability

Permeability is also termed as porosity of the molding sand in order to allow the escape of any air, gases or moisture present or generated in the mould when the molten metal is poured into it. All these gaseous generated during pouring and solidification process must escape otherwise the casting becomes defective. Permeability is a function of grain size, grain shape, and moisture and clay contents in the molding sand. The extent of ramming of the sand directly affects the permeability of the mould. Permeability of mold can be further increased by venting using vent rods.

3.8 Refractoriness

Refractoriness is defined as the ability of molding sand to withstand high temperatures without breaking down or fusing thus facilitating to get sound casting. It is a highly important characteristic of molding sands. Refractoriness can only be increased to a limited extent. Molding sand with poor refractoriness may burn on to the casting surface and no smooth casting surface can be obtained. The degree of refractoriness depends on the SiO_2 i.e. quartz content, and the shape and grain size of the particle. The higher the SiO_2 content and the rougher the grain volumetric composition the higher is the refractoriness of the molding sand and core sand. Refractoriness is measured by the sinter point of the sand rather than its melting point.

3.9 Miscellaneous properties of molding sand

In addition to above requirements, the molding sand should not stick to the casting and should not chemically react with the metal. Molding sand need be economically cheap and easily available in nature. It need be reusable for economic reasons. Its coefficients of thermal expansion need be sufficiently low.

Type of moulds, mouldmaking, applications

Parts of Sand Mold- Features

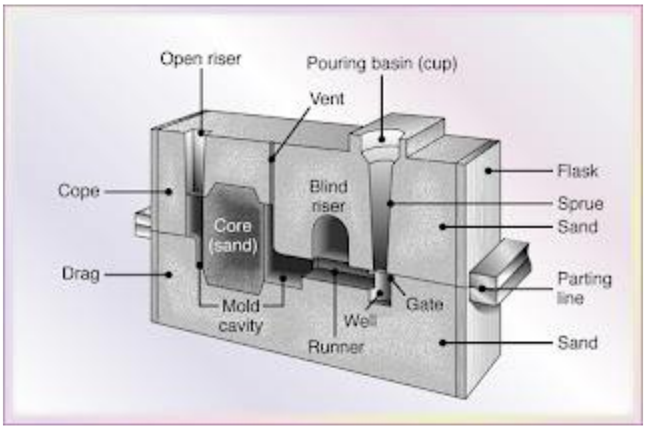
Cope and drag in Sand Mold :

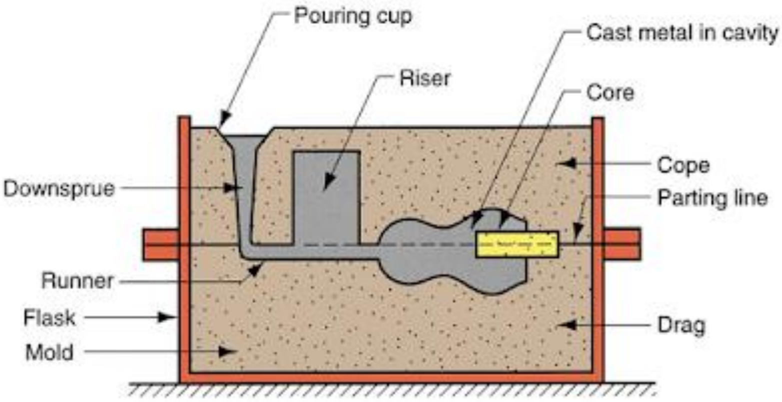
Cope and Drag are the two parts of the casting flask. Cope is the upper part and drag is the lower part. Even if the casting process is flaskless , the same terms are used for the upper ans lower parts. Generally the flask is made of wood or metal. It contains molding sand. When metal is poured into the mold cavity the flask supports the mold.

Gating system:

If the molten metal is poured directly from the ladle , it will erode the bottom of the mould cavity. So molten metal is poured from the ladle to the cavity through a gating system. The gating system in casting creates a series of channels through which molten metal reaches the cavity. Gating system has -

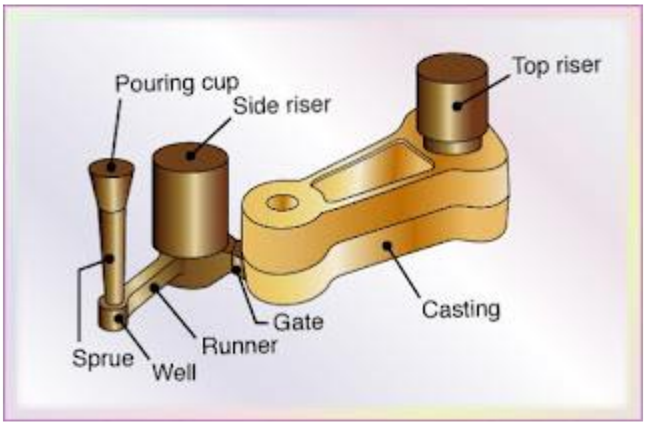
- Pouring Basin : It receives the molten metal from the liquid metal container.
- Sprue : Pouring cup is attached to the sprue. It is vertical in shape . On the other part of the sprue there is part called runner.
- Sprue Base : Its the base of the sprue
- Runner : It is the horizontal part of the gating system. It connects the spues with the gates.
- The next part is the choke.
- Then comes the skim bob
- Gates and ingates : It controls the movement of the metal from the runners into the cavity.
- Riser

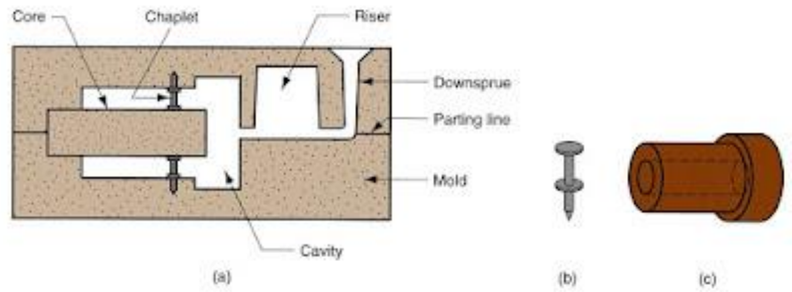




Riser:

The risers are also known as feed heads. When the metal solidifies it starts to shrink. And then risers comes into play. These feeder supply metals to the cavity when shrinking of the metal starts.





Core:

Cores are required to create the castings with holes. It can be made of refractory materials. Most often core sand is used to make it. Metal cores are also available but less frequently used.

Chaplets:

Chaplets are the supports for the cores. These are needed particularly when the cores are very big. Usually metal pieces are used to support the core. Without chaplets the core can be displaced and the casting can be spoiled. These chaplets are set-up between the core and mold surface. Caution should be taken while placing chaplets. Clean, oil and moisture free pieces should be used as chaplets.

Chills:

These are huge metal pieces used to reduce the effect of shrinkage. These increases the thermal conductivity and heat capacity. It helps in speeding up the cooling process. So thick metal parts are cooled quickly. They can be used along with the risers.

2.5 Melting of metal: Pitfurnace, Cupola, Induction furnace

Melting Point of Metals

Knowing the melting points of different metals is important for fabricators and welders. Metals melt gradually, as the metal absorbs heat. Well before a piece of metal reaches its complete melting point, it may begin to soften and warp. To keep things simple, we generally classify the melting point of a metal as that point where it has become fully liquid (called liquidus).

When joining metals with very different melting points, such as copper and steel, brazing might be a better choice than welding. In brazing, an oxy-acetylene torch is used to heat a filler metal, typically a brass alloy, which has a lower melting point than the two metal parts. As the filler melts, it's drawn into the joint, and then solidifies when cooled. The two parts being joined never reach their melting point, which means that the joint is not permanent.

Welding and Brazing

Welding is the process of joining two sections of metal by heating both parts to their melting point, creating a liquid melt pool in which their molecules mix completely. A third metal filler is often added to the melt pool. When the molten metal cools and solidifies, the two parts are fused completely with an unbreakable bond.

Knowing which metals can be welded, and choosing the best metals for welding, may depend partly on their melting points – if they differ by a large amount, one of the sections will melt faster than the other. This could cause a blowout or other mechanical weaknesses.

When joining metals with very different melting points, such as copper and steel, brazing might be a better choice than welding. In brazing, an oxy-acetylene torch is used to heat a filler metal, typically a brass alloy, which has a lower melting point than the two metal parts. As the filler melts, its drawn into the joint, and then solidifies when cooled. The two parts being joined never reach their melting point, which means that the joint is not permanent.

The following list of melting points of common metals and their alloys ranges from lowest to highest (note that the melting point will vary depending on the exact alloy composition):

Lead has one of the lowest melting points of any metal at 621 F (327 C).

Aluminum has a relatively low melting point of 1218 F (659 C). When alloying metals are added to aluminum, its melting point can range widely from around 848 F to 1230 F (453 C to 666 C). Adding aluminum to other metals also tends to lower their melting points.

Bronze: 1675 F (913 C). Bearing bronze contains mostly copper, plus lead and zinc, bringing down its melting point to 1790 F (977 C). Silicon bronze is a low-lead brass alloy that is generally composed of 96% copper plus a small percentage of silicon. Its melting point is 1880 F (1025 C).

Brass: 1700 F (927 C) Brass is an alloy of copper.

Copper: 1981 F (1083 C)

Cast iron: 2200 F (1204 C)

Steel: 2500 F (1371 C)

Stainless steel: 2750 F (1510 C)

Nickel: 2646 F (1452 C)

Wrought iron: 2700 F (1482 C)

Iron:2800 F (1538 C)

Tungsten has an extremely high melting point of 6150 F (3399 C) which is why it's used for TIG welding electrodes.

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Our pit furnaces are designed and manufactured for very small to very large workpieces. Pit furnace is available with or without retorts in customized dimensions and variations to carry out the complete heat-treatment process.

Pit furnaces are used in various applications like gears of wind power generation and bearings in the railway industry for gas carburizing and nitriding.

Induction furnace

An induction furnace is an electrical furnace in which the heat is applied by induction heating of metal. Induction furnace capacities range from less than one kilogram to one hundred tons, and are used to melt iron and steel, copper, aluminum, and precious metals.

The advantage of the induction furnace is a clean, energy-efficient and well-controlled melting process, compared to most other means of metal melting.

Most modern foundries use this type of furnace, and many iron foundries are replacing cupola furnaces with induction furnaces to melt cast iron, as the former emit much dust and other pollutants.

Induction furnaces do not require an arc, as in an electric arc furnace, or combustion, as in a blast furnace. As a result, the temperature of the charge (the material entered into the furnace for heating, not to be confused with electric charge) is no higher than required to melt it; this can prevent loss of valuable alloying elements.

The one major drawback to induction furnace usage in a foundry is the lack of refining capacity: charge materials must be free of oxides and be of a known composition, and some alloying elements may be lost due to oxidation, so they must be re-added to the melt.

Cupola furnace

A cupola or cupola furnace is a melting device used in foundries that can be used to melt cast iron, Ni-resist iron and some bronzes. The cupola can be made almost any practical size. The size of a cupola is expressed in diameters and can range from 1.5 to 13 feet (0.5 to 4.0 m). The overall shape is cylindrical and the equipment is arranged vertically, usually supported by four legs. The overall look is similar to a large smokestack.

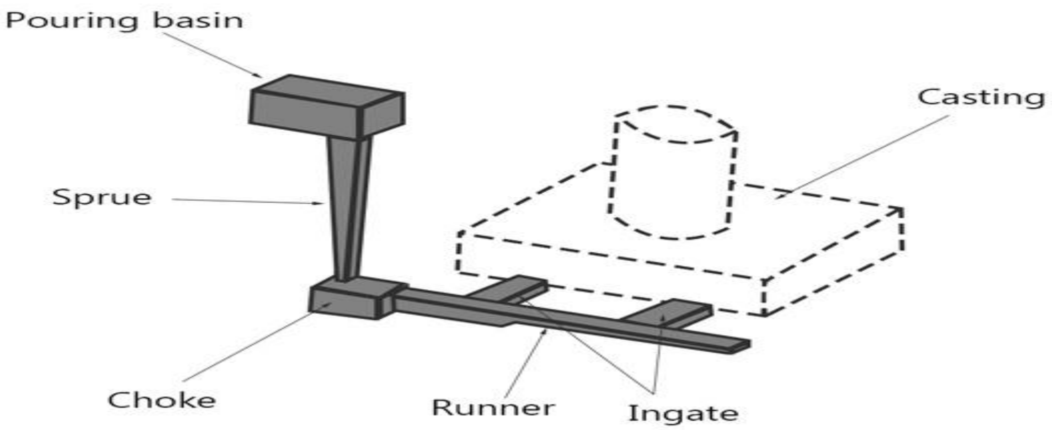
The bottom of the cylinder is fitted with doors which swing down and out to 'drop bottom'. The top where gases escape can be open or fitted with a cap to prevent rain from entering the cupola. To control emissions a cupola may be fitted with a cap that is designed to pull the gases into a device to cool the gases and remove particulate matter.

The shell of the cupola, being usually made of steel, has refractory brick and plastic refractory patching material lining it. The bottom is lined in a similar manner but often a clay and sand mixture ("bod") may be used, as this lining is temporary. Finely divided coal ("sea coal") can be mixed with the clay lining so when heated the coal decomposes and the bod becomes slightly friable, easing the opening up of the tap holes. The bottom lining is compressed or 'rammed' against the bottom doors. Some cupolas are fitted with cooling jackets to keep the sides cool and with oxygen injection to make the coke fire burn hotter.

2.6 Metal pouring: Gates and Risers.

What is the gating system in casting?

In the metal foundry, the gating system in casting is a metal pouring system that conducts molten metal into the mold cavity. Metal flows down from the pouring basin into the sprue and passes through the runner and gates before entering the mold cavity.



Gating system in casting

Designing a gating system requires careful consideration according to the technology, materials, and castings.

This system determines the flow rate of metal to the mold cavity.

If the flow rate is too fast, there is a risk of corrosion while if the speed is too slow it can cause the metal to be cool before filling the chamber, which directly affects the quality of the casting.

The shape and size of the gating system in casting are properly arranged when making the mold. If the gating system is not designed properly, it can cause severe casting defects.

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Functions of gating system in sand casting

The gating system in casting is designed to serve the following **4 main goals**:

- Fill the mold cavity with enough metal in the shortest time without having to increase the metal temperature.
- The metal flows smoothly, minimizing turbulence that causes air trapping during casting.
- The gating system sets the appropriate temperature range so that during the metal cooling process, shrinkage will occur in the gating system, not in the casting parts.
- Combined with metal impurities removal system.

Design requirements of the gating system

A well-designed gating system in casting should satisfy the following requirements:

- Good control of metal flow. No impact, no splashes, smooth and steady continuity.
- Do not carry slag, impurities and gases into the mold cavity.
- Fills the mold cavity quickly, does not reduce the dilution of metal.
- Controlling the temperature in the mold cavity to cool the metal stably.
- Capable of adding metal and not wasting much metal.
- Easy to disassemble after the casting has solidified.
- Economic and maximizing casting yield.

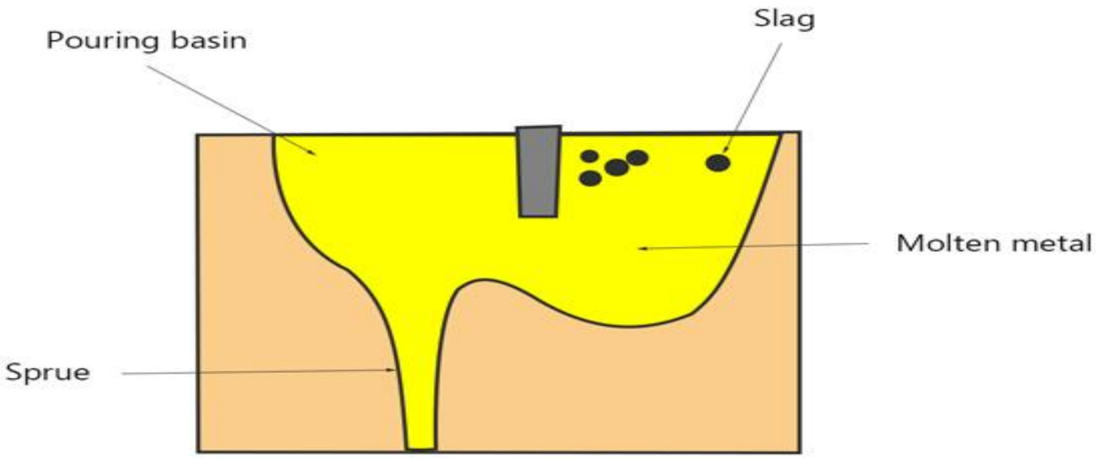
If the gating system is designed incorrectly, ***the following errors can occur****:*

- Oxidizing metals.
- Corrosive to mold.
- Causing shrinkage of objects in the mold.
- Make metal penetrate the mold wall.
- Cool uneven casting.

Gating system diagram

The gating system in sand casting includes:

1. Pouring basin or pouring cup

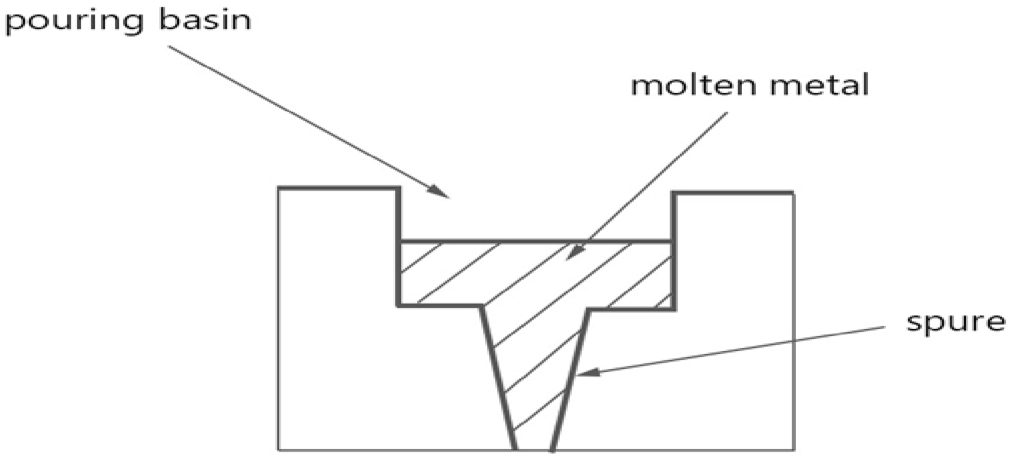


Pouring basin

The Pouring basin is the funnel-shaped inlet, located on top of the system, **where metal is poured from the ladles into the mold**.

Pouring basin helps to regulate the flow rate of liquid metal and reduces turbulence at the sprue entrance, and helps to separate sediment and slag before entering the sprue.

2. Sprue



Sprue in gating system

Sprue casting is a vertical passageway from pouring basin down runner and gates. Liquid metal going down the vertical sprue loses pressure but increases speed due to the effect of gravity.

The sprue cross section can be circular, square or rectangular (**preferably circular**). Sprue is designed to taper down **to avoid air aspiration**. Bigger end above for metal pick-up, while smaller end connects to runner.

The foot of the sprue is rotated at a right angle to the runner to prevent free fall of liquid metal, known as the sprue well.

3. Cross gate or runner

Runner in casting is a horizontal channel connecting the sprue well to the gates. Liquid metal will flow from the sprue to the runner and fill the mold cavity appropriately. Runner has the effect of **slowing down the speed of liquid metal** when it is free falling in a high speed sprue.

Runner must be filled with molten metal to **prevent slag** from entering the cavity and ensure steady flow.

4. Ingate (or gate)

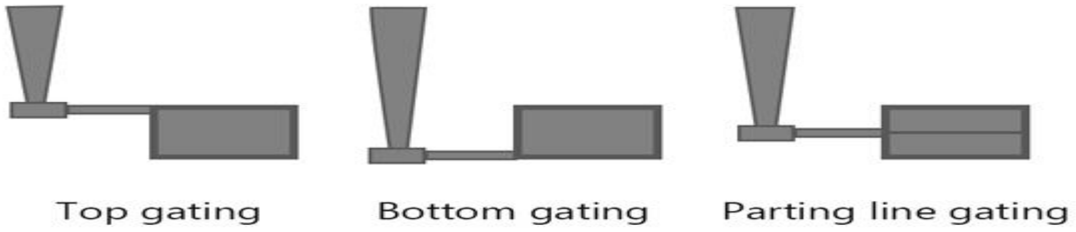
Ingate is the end of the path and where the mold cavity begins. It **leads the liquid metal** that flows from the runner into the mold cavity. Depending on the characteristics of the casting, there are different number of ingates.

There are two types of gates: big gate and small gate. The small gate is used for slowing solid casting, while the large gate is for fasting solid casting.

The gate should not have sharp edges as they can crack during pouring so that the sand can be caught in the molten metal into the mold cavity.

Types of gates in casting:

Gate is divided into 3 categories:



Types of gate in casting

- **Top gate**: the gate is in the cope mold part.

The disadvantages of top gate are high metal flow turbulence, poor casting surface.

- **Bottom gate**: the gate is in the drag mold part. In the bottom gate, liquid metal fills the lower part of the mold cavity and gradually increases into the mold wall.

The bottom gate has the advantage of less chaos and sand erosion than the top gate.

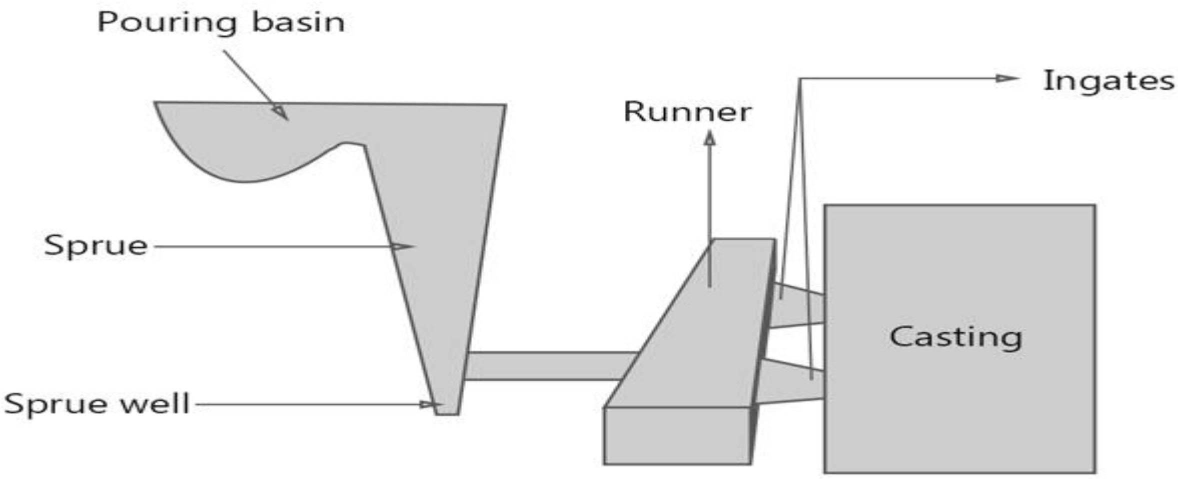
The downside of the bottom gate is that the metal flow **can be clogged due to solidification** before the mold is full. The temperature range generated by the bottom gate is **difficult to reach the standard** causing uneven solidification.

- **Parting line side gate**: is the gate located along the parting line. The compartment below the parting line is filled with liquid metal through top gating, while the compartment above the parting line is filled with the bottom gating. This gate type solves the disadvantages of the two types above.

Types of gating system

There are two types of gating systems: **Pressurized Gating System** and **Unpressurized Gating System**. Choosing the right casting system with the correct area ratio will define the quality of the casting.

1. Pressurized Gating System



Pressurized gating system

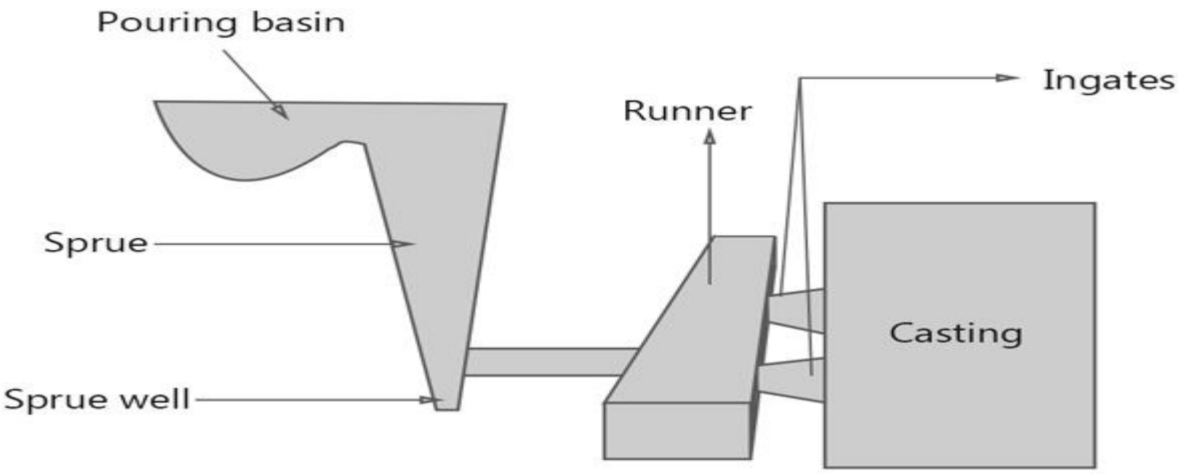
The Pressurized gating system is a gating system whose cross-sectional surface area decreases gradually towards the mold cavity (smaller than the narrowest downsprue-runner area). The in-gate area is minimized to put pressure on the system. At the gates, the flow rate of liquid metal is almost equal.

Sprue is always full of metal creating back pressure, which reduces air aspiration.

Here metal that is always running at high speeds becomes more chaotic and it is easy to create eddy currents in gates leading to erosion.

This system gives special priority to injection molding with cast iron materials.

2. Un-Pressurized Gating System



Unpressurized gating system

The Un-Pressurized Gating System is a gating system whose total surface area of the doors increases gradually towards the mold cavity (larger than the narrowest downsprue area). Liquid metal flow at gates are different.

Gating ratio

Gating ratio is the ratio between the cross-sectional area of the sprue to the total cross-sectional area of the runners to the total cross-sectional area of the ingates.

The formula for the gating ratio is As: Ar: Ag.

With the Pressurized Gating System, the gating ratio is usually 1: 2: 1 or 1: 0.75: 0.5. This system is called a "*Gate control system*" because **ingates control the flow of the metal**.

With the Unpressurized Gating System, the gating ratio is usually 1: 2: 2 or 1: 3: 3 or 1: 1: 3. This system is called a "*Choke control system*" because the **choke controls the flow of the metal**.

Table of gating ratio for various of materials:

Materials	Gating ratio
Aluminum	1:2:1 1:1.2:2 1:2:4 1:3:3 1:4:4 1:6:6
Aluminum bronze	1:2.88:4.8
Brass	1:1:1 1:2:3 1.6:1.3:1
Copper	2:8:1 3:9:1

Ductile iron	1.15:1.1:1 1.25:1.13:1 1.33:2.67:1

Gating ratio of materials

The hydraulic principle used in gating systems

Reynolds number

This is the number that helps to predict flow types with different liquid flows. The nature of the flow in the gating system can be established by calculating the Reynolds number:

$$Re = \rho uL/\mu = uL/v$$

Re: Reynold's number

ρ: fluid density (kg/m3)

u: velocity of flow (m/s)

L: characteristic linear dimension (m)

μ: fluid dynamic viscority (Pa.s)

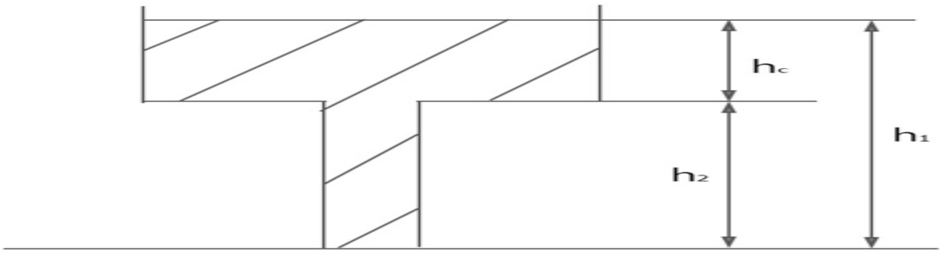
v: fluid kinematics viscosity (m2/s)

- If $Re > 2000$, the flow is stable.
- If $Re < 2000$, the flow is chaotic.

If the flow is turbulent, the grains of sand in the mold will **be shot out of the mold and the gating system entering the mold cavity** causes problems such as contamination of the casting, air aspiration in the mold, and erosion of the mold wall.

Bernoulli's Equation

Liquid metals run through different channels in the mold according to Bernoulli's theorem that the total head remains constant at any section.



Bernoulli's Equation in gating system

$$h_1 + \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = h_2 + \frac{p_2}{\rho g} + \frac{v_2^2}{2g}$$

h: potential head (m)

p: pressure (Pa)

V: molten metal velocity (m/s)

w: specific weight of liquid (N/m2)

g = 9.8 (m/s)

ρ: fluid density (kg/m3)

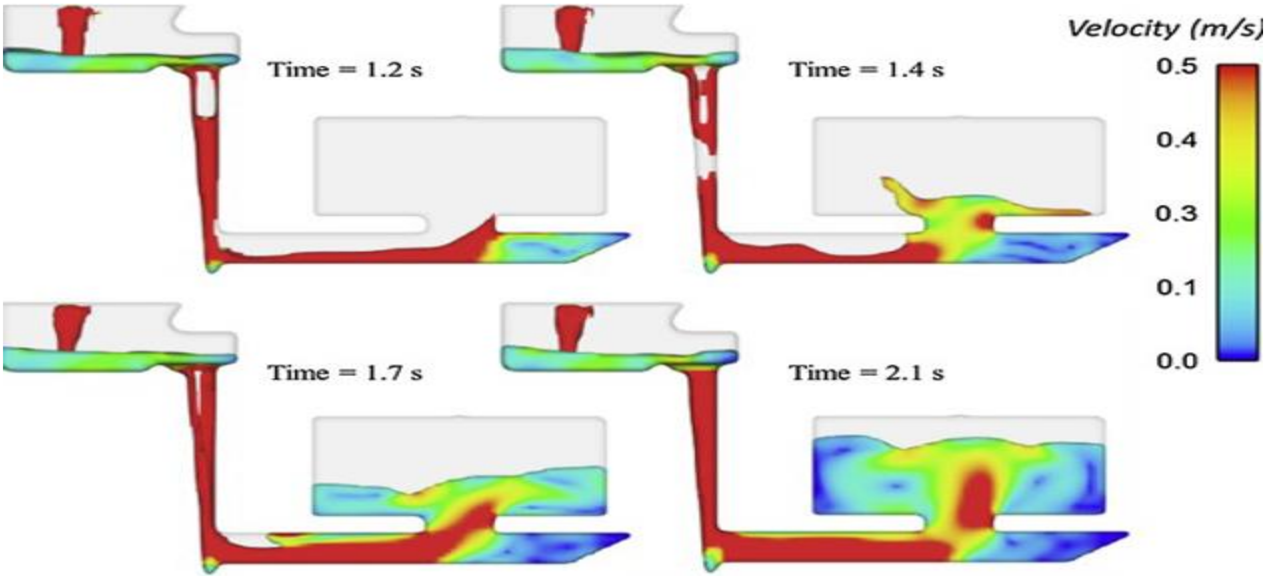
The gating system must be designed so that the liquid metal is always full. All cross-sections and changes in direction should **avoid sharp corners** and **take advantage of rounded corners**.

How to design gating system

To design the pouring system, the designer must adhere to the **design requirements** as outlined above. Here are the formulas to calculate to design a suitable gating system.

Click here for the detail.

1. Calculate pouring time



Pouring time

Pouring time is the time when metal fills the mold cavity. The longer the Pouring time, the higher the pouring temperature, and the filling of the mold is not guaranteed. The shorter the pouring time, the more chaotic metal flow in the mold leads to die erosion, and excessive shrinkage.

The pouring time should be optimized based on these factors:

- Casting materials
- The complexity of the casting
- Size of the casting
- Section thickness

The formula for calculating optimal pouring time:

- With Gray cast iron material with the weight less than 450kg:

$t=K(1.41+T/14.59)\sqrt{W}$

K = fluidity of iron (inches) / 40

K: fluidity factor

T: average section thickness (mm)

W: mass of casting (kg)

- With Gray cast iron material with the weight greater than 450kg:

$t=K(1.236+T/16.65)\sqrt[3]{W}$

- With steel casting:

$t=(2.4335-0.3953\log W)\sqrt{W}$

- With Ductile iron:

$t=K_1\sqrt{W}$

K_1= 2.08 for thinner sections.

K_1= 2.67 for sections of 10 to 25mm thick.

K_1= 2.97 for heavy sections.

- With Copper alloy castings:

$t=K_2\sqrt[3]{W}$

- Castings with thin walls and complex shapes weigh up to 450kg:

$t=K_3\sqrt[3]{W'}$

W’: mass of the casting with gates and risers (kg)

Thickness (mm)	**K_3**

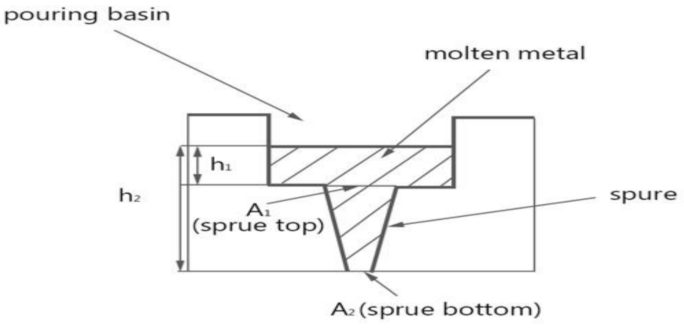
1.5 – 2.5	1.62
2.5 – 3.5	1.68
3.5 – 8.0	1.85
8.0 – 15.0	2.20

- Casting weight ranges from 450kg – 1000kg:

$t=K_4\sqrt[3]{(W'T)}$

Thickness (mm)	**K_4**
< 10	1.00
10 – 20	1.35
20 – 40	1.50
> 40	1.70

2. Design Sprue



Sprue design

The ideal design of the sprue is that the large top ends and tapers downwards like a parabola. However, for easier production, **it is recommended to use a cone cylinder**. The minimum gradation level is 5%.

The sprue output circular cross-section is designed based on the area of the choke area and the gating ratio. This helps to r**educe disturbances and heat loss**.

The sprue calculation formula:

$A_1/A_2=\sqrt{h_2}/\sqrt{h_1}$

h1 and h2: metal static pressure head on top sprue and bottom sprue.

A1 and A2: the respective cross-sectional area.

Design of the sprue well: A reasonable sprue well design is to make a cylinder twice the diameter of the sprue exit and twice the depth of the runner. A fillet placed between the well and the runner will **help the metal to steer perpendicular smoothly**.

3. Design Choke

The choke is a control area placed in the sprue well to **control the flow of liquid metal flowing into the mold cavity** so that the mold is filled in calculated pouring time.

The choke area plays an important role in gating systems because the area allows metal to pass through at a consistent and constant flow. The choke has the **smallest ratio in the gating system** compared to the other parts and cross-sectional area is smallest in the control area.

Formula to calculate choke area:

$A=W/(dtC\sqrt{(2gH)})$

A: choke area (mm)

t: pouring time (s)

d: mass density of molten metal (kg/mm3)

Al: d = 2500

Cu, Fe, Ni, Co: d = 7000

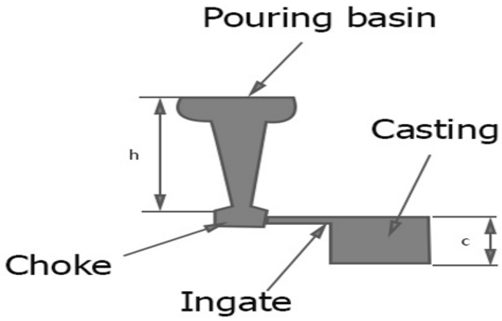
C: efficiency of the used gating system (= 0.8)

W: casting weight including feeders and gating channels (kg)

g = 9.8 m/s2

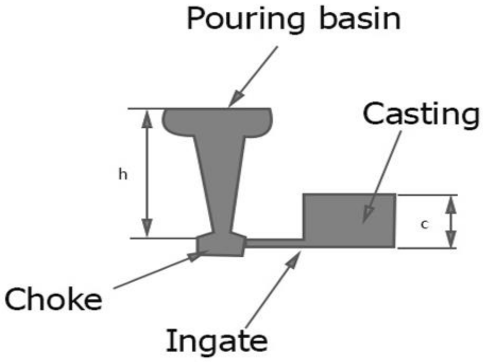
H: sprue height (mm), calculate H by:

- With top gate: H = h



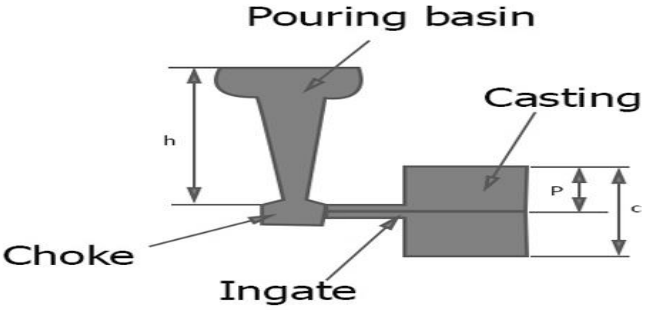
Sprue height top gate

- With bottom gate: H = h – c/2



Sprue height bottom gate

- With parting line gate: $H = h - P^2/2c$



Sprue height parting line gate

4. Design runner

The total cross-sectional area of the runner must be greater than the sprue exit to **reduce the speed of the metal flow** from the sprue to the ingates.

Priority ratio of the sprue exit to runner cross section is 1: 2. Greater proportions may result in flow separation and air aspiration.

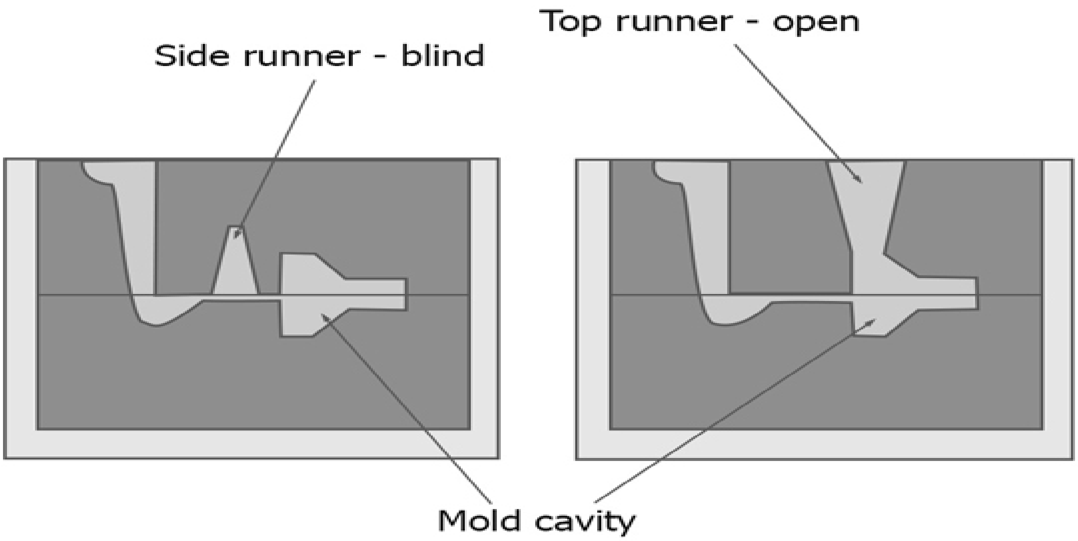
If there are multiple ingates, the cross-sectional area of the runner after each passing through the ingate must **gradually decrease** by an area equal to that of the ingate to ensure a steady flow.

5. Design Ingate

Ingate must be made larger than the sprue exit to speed the metal below the limit.

- Ingate must have a smaller cross-section for easy to fettle.
- Ratio volume on cooling surface area must be less than ratio of connected part to avoid local hot spot.
- The area of the cross-sectional surface of the ingate must be proportional to the size of the connected casting area. The larger the casting area, the greater the flow required resulting in a larger ingate.

6. Design Riser (or feeder, header)



Riser design in gating system

The Riser is a molten metal cavity in a mold, ready to supply metal to the mold cavity to compensate for shrinkage as the metal cools. It is placed in the final solidification position of the casting, and it is in the liquid state for the longest time. The Riser is also where the gases generated inside the mold are released during the casting process.

Optimal riser design:

- **Riser size**: The ratio of volume / surface area of the riser must be larger than that of the casting to maintain a liquid state. If this condition cannot be met, the metal shall be kept liquid by heating externally or by using an exothermic material in the riser.
- **Position of the riser**: the distance of the risers must be properly calculated based on the metal feeding distance of the risers.
- **Riser shape**: the recommended shape for the riser is cylindrical because globular is supposed to be the best but is difficult to cast. The bottom of the riser should be hemispherical to increase the volume / surface area ratio.

How to check the effectiveness of gating design?

The design of the gating system is tested through the following techniques:

- **Water in transparent mold**: the filling of the mold is recorded by the high speed X-ray camera and defect can be observed.

- **High speed radiography**: the filling of the mold is recorded by the high speed X-ray camera and defect can be observed.
- **Open mold**: part of the cope mold on the mold cavity is cut and the liquid metal flow that fills the mold cavity is rotated back by the camera.
- **Contact wire sensor**: the wires are placed in different parts of the mold, when the metal line touches the wire will be recorded with miltichannel recorder.
- **Water in transparent mold**: The addition of oil droplets or color makers will make it easier to record the speeds in different areas.

2.7 Casting Processes: Dry sand mould casting, Shell mould casting, Investment casting, Die casting, Centrifugal casting.

Types of Casting Processes

Where did casting begin?

The casting process is an ancient art that goes back several thousand years to the beginning of written history. The archeological record has finds that document the use of the casting process over 6000 years ago around 3000 BC or BCE. The supposition is that the molds of that time were two pieces of pottery that were tied together with a rope and had a hole in them to be able to pour in the molten metal. Early weapons and hunting tools are presumed to have been formed in this way.

The ancient techniques were used by the Egyptians to plaster the heads of mummies, which was part of the spiritual beliefs of the Egyptian culture. Included in this ceremonial process was the molding of jewelry and other items. At the same time the Egyptians were perfecting the art of casting, eastern cultures were using the method.

By the time molding reached the Greeks and Romans, it had become an artform used to cast bronze statues using a hollow wax casting. Each part of a piece was cast separately. The core of the mold was made of clay and covered with wax followed by a layer of clay that was heated to melt the internal wax, which was heated a second time to burn out the remaining wax. Once the mold was stable and prepared, the molten metal was poured into the area where the wax had been removed, a method that is similar to modern day investment casting.
Artisans of the Renaissance period were fascinated by the works of the Greeks and Romans. They continued and perfected the casting process with improved molds made from wood, terracotta, or plaster. The most difficult part of the process was the creation of the mold to produce a correctly proportioned form.

The present use of casting to produce tools, bowls, and other practical items was begun in China around 1000 BCE. Using iron, the Chinese mass produced farm tools and weapons. The technique did not reach European cultures until several centuries later and was used to make cannon, cannon balls, and bullets.
With the advent of the industrial revolution in America and Europe, casting became a standard manufacturing process much like it is today. As new metals were discovered and techniques improved, the products produced were of higher quality and endurance. Today, a variety of casting methods are used to make everyday items for commercial and industrial use.

Different Types of Casting and the Casting Process

Although casting is one of the oldest known manufacturing techniques, modern advances in casting technology have led to a broad array of specialized casting methods. Hot forming processes, such as die-casting, investment casting, plaster casting, and sand casting, each provide their own unique manufacturing benefits. Comparing both the advantages and disadvantages of the common types of casting processes can help in selecting the method best suited for a given production run.

Sand Casting

Sand casting typically relies on silica-based materials, such as synthetic or naturally-bonded sand. Casting sand generally consists of finely ground, spherical grains that can be tightly packed together into a smooth molding surface. The casting is designed to reduce the potential for tearing, cracking, or other flaws by allowing a moderate degree of flexibility and shrinkage during the cooling phase of the process. The sand can also be strengthened with the addition of clay, which helps the particles bond more closely. Automotive products such as engine blocks are manufactured through sand casting.

Sand casting involves several steps, including patternmaking, molding, melting and pouring, and cleaning. The pattern is the form around which the sand is packed, usually in two parts, the cope and the drag. After the sand is compacted enough to replicate the pattern, the cope is removed and the pattern extracted. Then, any additional inserts called core boxes are installed and the cope is replaced. After the metal has been poured and solidified, the casting is removed, trimmed of the risers and gates that were used in the pouring process, and cleaned of any adhered sand and scale.

Sand casting's main advantages as a casting process include:

- Relatively inexpensive production costs, especially in low-volume runs.
- The ability to fabricate large components.
- A capacity for casting both ferrous and non-ferrous materials.
- A low cost for post-casting tooling.

Despite its benefits, sand casting yields a lower degree of accuracy than do alternate methods and it can be difficult to sand cast components with a predetermined size and weight specifications. Furthermore, this process has a tendency to yield products with a comparatively rough surface finish.

You can use the Thomas Supplier Discovery Platform to find Sand Casting Companies for your needs.

Investment Casting

Investment, or lost-wax, casting uses a disposable wax pattern for each cast part. The wax is injected directly into a mold, removed, then coated with refractory material and a binding agent, usually in several stages to build up a thick shell. Multiple patterns are assembled onto common sprues. Once the shells have hardened the patterns are inverted and heated in ovens to remove the wax. Molten metal is then poured into the remaining shells where it hardens into the shape of the wax patterns. The refractory shell is broken away to reveal the completed casting. Investment casting is often used to manufacture parts for the automotive, power generation, and aerospace industries, such as turbine blades. Some of the central advantages and disadvantages of investment casting include:

- A high degree of accuracy and precise dimensional results.
- The ability to create thin-walled parts with complex geometries.
- The capacity for casting both ferrous and non-ferrous materials.
- Relatively high-quality surface finish and detail in final components.

Although it is highly precise, investment casting is usually more expensive than other comparable casting techniques and is typically only cost-efficient when sand or plaster castings cannot be used. However, the expense can sometimes be compensated for with reduced machining and tooling costs due to investment castings' quality surface results.

You can use the Thomas Supplier Discovery Platform to find Investment Casting Companies for your needs.

Plaster Casting

Plaster casting is similar to the sand casting process, using a mixture of gypsum, strengthening compound, and water in place of the sand. The plaster pattern is typically coated with an anti-adhesive compound to prevent it from becoming stuck against the mold, and the plaster is capable of filling in any gaps around the mold. Once the plaster material has been used to cast the part, it usually cracks or forms defects, requiring it to be replaced with fresh material. The advantages offered by plaster casting include:

- A very smooth surface finish.
- The ability to cast complex shapes with thin walls.
- The capacity for forming large parts with less expense than other processes, such as investment casting.
- A higher degree of dimensional accuracy than that of sand casting.

This process tends to be more expensive than most sand casting operations and may require frequent replacements of the plaster molding material. It is usually more effective and cost-efficient when the quality of the surface finish is an important requirement. Its application is generally limited to casting aluminum and copper-based alloys.

You can use the Thomas Supplier Discovery Platform to find Plaster Casting Companies for your needs.

Die Casting (Metal Casting Process)

Die casting is a method of molding materials under high pressure and usually involves non-ferrous metals and alloys, such as zinc, tin, copper, and aluminum. The reusable mold is coated with a lubricant to help regulate the die's temperature and to assist with component ejection. Molten metal is then injected into the die under high pressure, which remains continuous until the workpiece solidifies. This pressurized insertion is rapid, preventing any segment of the material from hardening before being cast. After the process is completed, the component is taken out of the die and any scrap material is removed. A few of the major advantages provided by die casting include:

- Close size and shape tolerances.
- High component dimensional consistency and uniform design.
- A reduced need for post-casting machining.

Despite its advantages, die casting as a metal casting process has relatively high tool costs, making it more cost-efficient in high-volume product runs. It can also be difficult to ensure the mechanical properties of a die-cast component, meaning these products usually do not function as structural parts. As the molds are typically two-piece, die casting is limited to products that can be removed from the mold without destroying the mold, as is done in other casting processes.

For more information on Die Casting, you can review our Types of Die Casting guide, which goes into depth on the various types, alloys, and considerations for choosing a specific process/alloy combination.

Centrifugal Casting

Centrifugal casting is used to produce long, cylindrical parts such as cast iron pipe by relying on the g-forces developed in a spinning mold. Molten metal introduced into the mold is flung against the interior surface of the mold, producing a casting that can be free of voids. Originally invented as the de Lavaud process using water-cooled molds, the method is applied to symmetrical parts such as soil pipe and large gun barrels and has the advantage of producing parts using a minimal number of risers. For asymmetric parts that cannot be spun around their own axes, a variant of centrifugal casting, called pressure casting, arranges several parts around a common sprue and spins the molds around this axis. A similar idea is applied to the casting of very large gear rings, etc. Depending on the material being cast, metal or sand molds may be used.

Permanent Mold Casting

Permanent mold casting shares similarities with die casting and centrifugal casting, notably the use of reusable molds. These can be made of steel, graphite, etc. and are generally used to cast materials such as lead, zinc, aluminum and magnesium alloys, certain bronzes, and cast iron. It is a low-pressure process with pouring usually done by hand using multiple molds on a turntable. As the molds rotate through the various stations they are successively coated, closed, filled, opened, and emptied. One such method is known as slush casting, where the mold is filled but emptied before the metal fully hardens. Molten metal is dumped from the casting to produce a hollow, cast shell. A similar idea is used in the molding of hollow chocolate products such as Easter bunnies. The use of metal molds induces faster heat transfer through the mold, allowing the shell to harden while the core remains liquid.

2.8 Casting defects: Blow, scar, blister, gas holes, pin holes, porosity, drop,inclusion, dross, dirt, wash, buckle, scab, rat tail, penetration, swell, misrun, cold shut, hot tear, shrinkage cavity, mould shift, core shift and

GAS POROSITY CASTING DEFECTS AND CAUSES

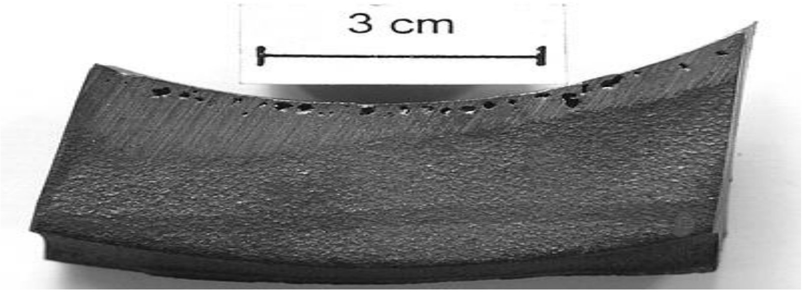
Gas porosity occurs when the metal traps gas (most often nitrogen, oxygen or hydrogen) during casting.

When the casting cools and solidifies, bubbles form because the solid form of the metal cannot hold as much gas as the liquid form. These bubbles appear on a casting as rounded, circular cavities or holes.

There are three types of casting defects related to gas porosity:

1. Pinholes

Pinholes, also sometimes referred to as ***porosities***, are very tiny holes (about 2 mm) usually found in the cope (upper) part of the mold, in poorly vented pockets.



They usually appear in large numbers together, either at the surface or just below the surface of the casting. They are always visible to the naked eye and don’t require equipment to identify.

2. Subsurface blowhole

Blowholes, or simply blows, are larger cavities than pinholes.

A subsurface blowhole appears on the inside of a cast and usually isn’t visible until after machining.

Subsurface blowholes can be difficult to detect before machining, requiring harmonic, ultrasonic, magnetic or x-ray analysis.

3. Open holes

These blowholes appear on the surface of the cast and are easier to detect than subsurface blowholes.

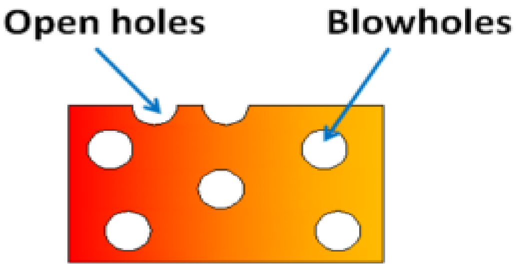
Causes and prevention of gas porosity

There are several causes of cavity defects.

- Poor venting of mold and cores
- Insufficient drying of mold and cores

How can you prevent gas porosity?

Scars are shallow blows that appear on a flat surface, while ***blisters*** are scars covered with a thin layer of metal.



- Excessive moisture content of molding sand
- Inadequate gas permeability of molding sand

Potential solutions include:

- Incorporate good fluxing and melting practices: melt metal in a vacuum, in an environment of low-solubility gases or under a flux that prevents contact with the air
- Increase gas permeability of sand: coarser sands have a higher permeability
- Increase permeability of mold and cores. Allow air and gas to escape from the mold cavity
- Dry out molds and cores before use and store dry
- Increase rate of solidification by reducing metal temperature during casting

SHRINKAGE CASTING DEFECTS AND CAUSES

Shrinkage occurs because metals are less dense as a liquid than a solid.

A shrinkage cavity is a depression in a casting which occurs during the solidification process. Shrinkage porosity appears with angular edges, compared to the round surfaces of gas porosity. Cavities might also be paired with dendritic fractures or cracks.

Large shrinkage cavities can undermine the integrity of the casting and may cause it to eventually break under stress.

Shrinkage can result in two types of casting defects.

4. Open shrinkage defects

These are open to the atmosphere. Air compensated as the shrinkage cavity forms.

Pipes are open shrinkage defects that form at the surface and burrow into the casting. ***Caved surfaces*** are shallow, open shrinkage defects that form across the surface of the casting.

5. Closed shrinkage defects

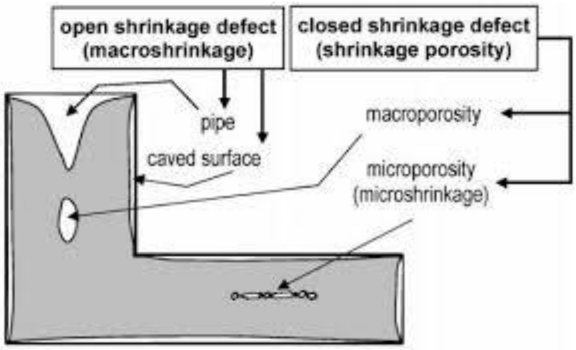
Also known as ***shrinkage porosity***, closed shrinkage defects form within the casting. Macro shrinkage can be viewed with the naked eye, but micro shrinkage cannot.

Closed shrinkage defects usually appear at the top of hot spots, or isolated pools of hot liquid.

Prevent shrinkage cavities by improving casting structure

Alloys always shrink when changing from molten to solid. This is because the density of a casting alloy in the molten state is lower than that in the solid state.

You should expect some shrinkage during solidification. Factor a shrinkage allowance into the pattern design before casting.



You can prevent shrinkage casting defects by improving the overall casting structure:

- Design a running (gate) system with risers that ensure a continuous flow of molten metal
- Increase local heat dissipation by inserting internal chills, cooling ribs or cooling coils
- Reduce casting temperature to limit the total volume deficit

MOLD MATERIAL CASTING DEFECTS AND CAUSES

Mold material casting defects are related to the mold material, which is most commonly sand. You and your supplier can typically address these casting defects and causes by modifying the mold.

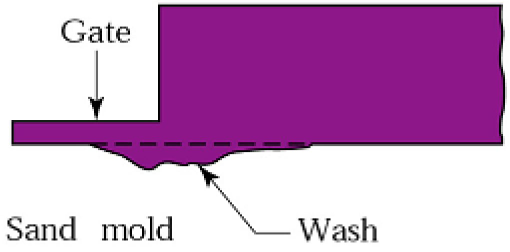
6. Cuts and washes

Cuts and washes are areas of excess metal. These appear when the molten metal erodes the molding sand.

A cut appears as a low projection along the surface of the drag face, decreasing in height as it extends from one side of the casting to the other.

Causes and prevention of cuts and washes

Cuts and washes can be caused by molten metal flowing at a high velocity, causing too much metal to flow through the gate.



You can prevent cuts and washes easiest by:

- Designing the gating system properly
- Improving mold and core strength
- Adding more binders to the facing and core sand

7. Fusion

Fusion occurs when sand grains fuse with molten metal. It appears as a thin crust with a brittle, glassy appearance firmly adhered to the casting.

Causes and prevention of fusion

Two main factors can cause fusion:

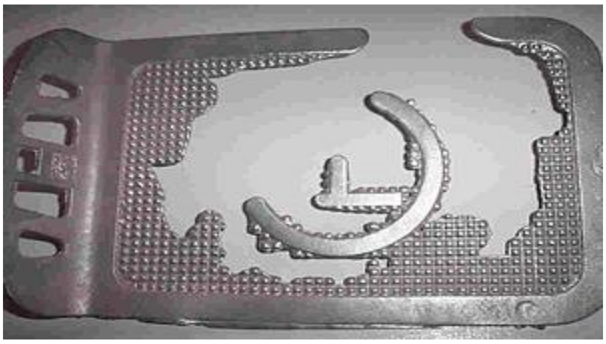
- Low refractoriness of clay or sand
- Too high pouring temperature of molten metal

Refractoriness is the ability of the molding material to resist the temperature of the liquid so it doesn’t fuse with the metal. Silica sand has the highest refractoriness.

Improving the refractoriness of the molding material and/or reducing the pouring temperature of the molten metal will help prevent fusion.

8. Run out

Run out is when liquid metal leaks out of the mold, leading to an incomplete or missing casting.



A faulty mold or flask is responsible for run out.

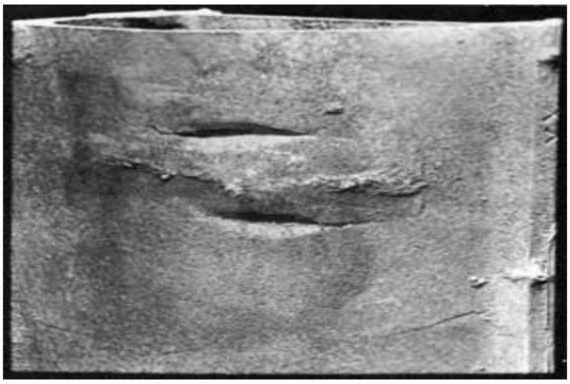
Prevention of run out and incomplete castings

To prevent this casting defect, design the casting mold with precision. Inspect and replace any defective molds before casting.

High temperatures can lead to excess wear and tear of the mold. Use quality raw materials for your mold that can resist high temperatures.

9. Swells

Swells are an enlargement of the casting. Swells typically take on the shape of a slight, smooth bulge on the vertical face of castings.



Causes and prevention of swells

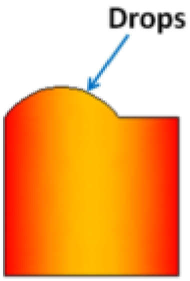
Swell is usually caused by improper or soft ramming of the mold or a low strength mold.

Molds should be built to withstand liquid metal pressure. Otherwise, the mold wall may give way or move back, causing swelling.

Using a strong, properly rammed mold prevents swells.

10. Drops

Drops occur when pieces of sand fall into metal casting when it’s still liquid. Drops appear as an irregularly shaped projection on the cope (top) surface of a casting.



Causes and prevention of drops

Four potential causes for drops and their preventions include:

- **Low sand strength:** Use sand of a higher strength if this your culprit
- **Soft ramming:** Provide harder ramming
- **Insufficient fluxing of molten metal**: Properly fluxing molten metal removes impurities
- **Insufficient reinforcement of sand projections in the cope**: Reinforce sand projections using nails or gaggers to fix this issue

11. Rat tails, veins and buckles

Rat tails, or veins, appear as an irregular line or crack on the casting, when the surface of the molding sand buckles up. Rat tails usually occur on the surface of the mold bottom, an area covered with molten material.

Buckles are a more severe form of rat tails.

Causes and prevention of rat tails and buckles

Rat tails and buckles occur when excessive heat of the metal causes the sand to expand. This may be caused by:

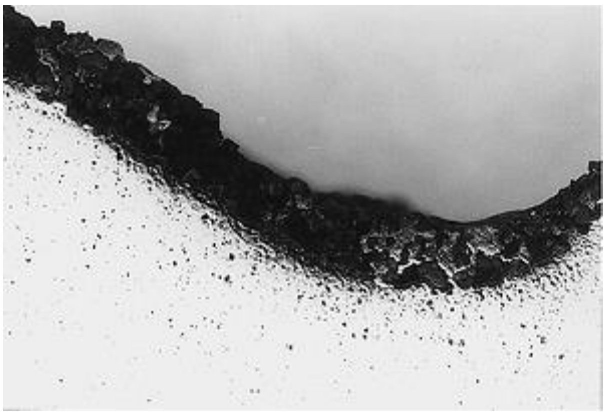
- **Poor expansion properties of the sand**: Add combustible additives to sand.
- **A hot pouring temperature**: Reduce pouring temperature of metal.
- **Poor mold design**: Large and flat sections are more prone to rat tails. The mold also should not be too hard, as it must allow for proper expansion.

12. Metal penetration

Metal penetration occurs when liquid metal penetrates gaps in the molding sand. The penetration is visible to the naked eye as a rough and uneven surface finish of the casting.

Causes and prevention of metal penetration

Metal penetration is due to:

- 
- Use of sand with low strength and high permeability
- Use of large or coarse sand grain: the coarser the sand grains, the more severe the metal penetration
- Lack of mold wash
- Soft ramming of sand

Prevent metal penetration by fixing these areas. Use high strength, small grain size, low permeability and hard ramming of sand. Ensure a protective barrier against metal penetration by coating the surface of molds with a mold wash.

You can typically remove metal penetration by grinding down the rough surface of the casting.

METALLURGICAL CASTING DEFECTS AND CAUSES

There are two types of metallurgical defects to watch out for.

13. Hot tear/crack

Cracks appear in the form of irregular crevices in a branched pattern.

Some cracks are obvious and easily seen, while others can require magnification.

Cracks occur as the casting cools, towards the end of solidification.

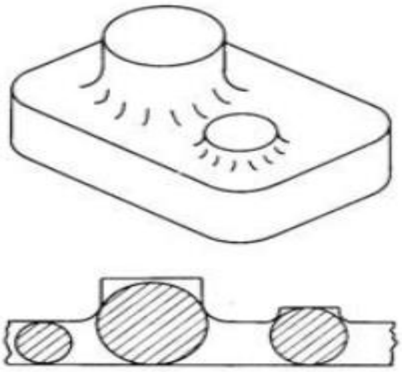
Causes and prevention of hot tears and cracks

If the solidifying metal does not have sufficient strength to resist tensile forces during solidification, hot tears will appear.

Hot tears are mostly caused by poor mold design. Modifying the mold to improve collapsibility can easily resolve these issues.

14. Hot/hard spots

Hot spots are spots that are harder than the surrounding area. This is because they cooled more quickly than the surrounding material.



Hard spots can interfere with machining and increase tool wear.

Causes and prevention of hot spots

Hot spots are a direct result of improper cooling practices. There are two potential solutions if hot spots are your problem:

- Start by correcting cooling practice
- Also consider changing the metal's chemical composition

POURING CASTING DEFECTS AND CAUSES

Pouring metal defects arise during the process of pouring metal into the mold. If you have a pouring metal defect, it will fall into one of these categories:

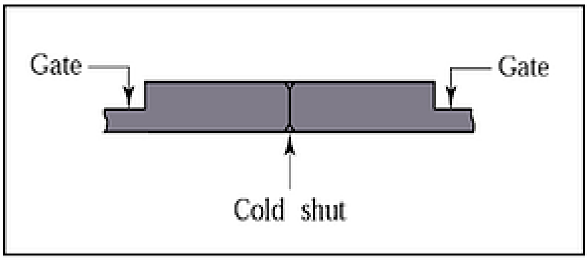
15. Cold shut/lap

Cold shut is a type of surface defect. You'll see a line or crack with a round edge on the casting surface.

This defect is visible to the naked eye and often results in rejecting the cast, as it creates a weak spot.

Causes and prevention of cold shut

When molten metal enters the mold from two gates, the streams will meet at a junction. Low temperatures can prevent fusion at the junction, causing the streams to solidify before fusion, creating a cold shut.



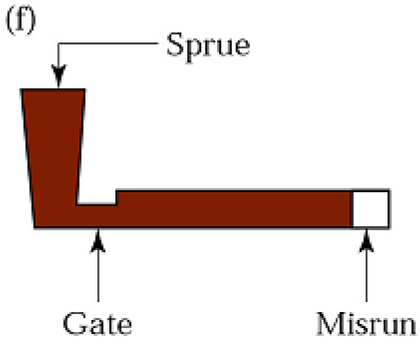
Cold shut is usually a result of a lack of fluidity of the molten metal, or a poor design of the gating system.

The best way to prevent cold shuts is to increase fluidity of the molten metal. This can be done in a few ways:

- **Optimize gating system** to minimize narrow cross-paths and ensure short flow paths
- **Increase the pouring temperature** to prevent premature solidification
- **Improve gas permeability of the mold** (through coarser grain size, etc.)

16. Misruns are closely related to cold shuts

Misruns occur when the liquid metal is too cold to flow to the extremities of the mold cavity before freezing and solidifying.



The liquid metal does not completely fill the mold cavity. The misrun is the unfilled portion or space in the mold.

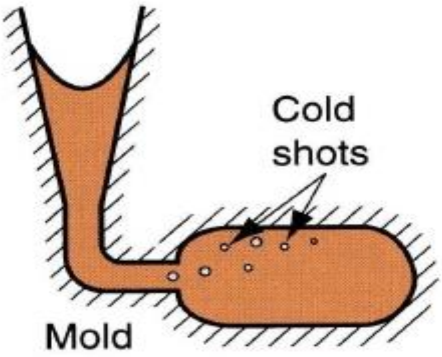
Causes and prevention of misruns

The reasons for premature solidification are similar to those for cold shut. If you have a misrun, check:

- Mold design
- Gating system design and
- Molten metal fluidity

17. Cold shots

Splattering during pouring of a liquid can cause solid globules to form.



As these globules freeze, they become entrapped in the casting.

Cold shots are typically ball, drop or pearl shaped and loosely attached to the metal.

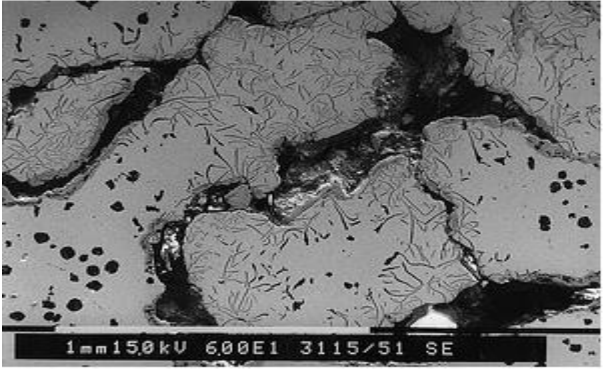
Causes and prevention of cold shots

To prevent splattering and cold shots, consider

- **Modifying pouring procedures** to minimize turbulence
- **Adjusting gating system designs** to reduce gate speed

18. Slag inclusion (scab)

These irregular metallic crusts are found on the casting surface. Scabs are typically only a few millimeters thick but can be seen by the naked eye. They usually have sharp edges, irregular shapes and are firmly bonded to the casting.



Scabs are closely related to rat tails and they usually appear together. Removal of scabs will typically reveal a rat tail underneath.

Causes and prevention of slag inclusion

Slag inclusion is caused when molten metal containing slag particles is poured into the mold cavities and solidifies.

Preventing slag inclusion is a simple fix. Remove slag particles from the molten metal before pouring it into the mold cavity.

You can remove slag by:

- Melting the metal with a flux, in a vacuum or in an inert atmosphere
- Adding ingredients to the mixture to cause slag to float to the top where you can easily see and remove it before pouring. Or use a special ladle that pours metal from the bottom.
- Adding a ceramic filter into the gating system

CASTING SHAPE DEFECTS AND CAUSES

These types of casting defects are related to the overall shape of the final casting.

19. Shift/mismatch

Mold shift is due to misalignment of upper (cope) and lower (drag) part of the mold. Mold shift is usually reflected as a horizontal displacement.

Core shift is similar to mold shift, but it’s the core that is misaligned, not the mold. Core shift is usually reflected as a vertical displacement.

Causes and prevention of shift

Some causes of shift can include:

- Loose box pins
- Inaccurate pattern dowel pins or
- Carelessness in placing the cope on the drag, causing misalignment

If you're experiencing shift, try checking the match plate pattern mounting and alignment. Make sure to use proper molding box and closing pins.

20. Flash, fin and burrs

Flash is one of the most frequently occurring casting defects and also a common injection molding defect.

Flash, also known as casting fin or burrs, is any unwanted and excess material attached to a cast. It's typically a thin sheet of metal that forms at the parting faces. Flash is a waste material that turns into dross after being re-melted.

Causes and prevention of flash, fin and burrs

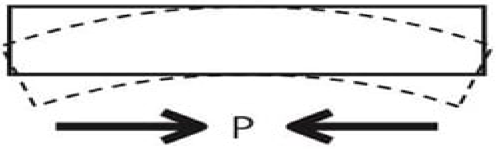
Flash on the casting surface is due to a crack or gap on the core surface. Insufficient weight on the mold or improper clamping of the flask can lead to a gap.

Remedy this issue by reassembling the mold and cores. There should be enough weight on the top part of the mold so that the two parts fit together tightly.

Flash can vary from minor to very serious. If it's not too serious, manufacturers can remove flash by breaking it off with a hammer or pliers and filing it down to the parting line. However, this can be a costly process.

21. Warping

Warping is an unwanted casting deformity that can occur over time, which results in a change in the dimensions of the final product.It can happen during or after solidification.



Causes and prevention of warping

Warping is typically a result of different rates of solidifications of different sections, which causes stress in adjoining walls. Large and flat sections are more prone to warping.

Normalizing heat treatment can remove residual stress in iron casting. A straightening between quench and aging processes might also be required for aluminum casting.

CONCLUSION

Knowledge of casting defects and causes is essential to managing casting quality.

You should set clear defect tolerances and quality expectations with your suppliers before production to help them understand your quality standards.

Defect tolerance can vary between products and types of casting defects. Determining your tolerance for these casting defects can help your supplier better understand your standards and prevent future misunderstandings and quality issues.

Ultimately, the manufacturer must strictly control quality of each casting process. Experienced importers rely on quality control inspections to limit casting defects in their products before they leave the factory.

What is Casting Defects?

It is an unwanted irregularities that appear in the casting during metal casting process. There is various reason or sources which is responsible for the defects in the cast metal. Here in this section we will discuss all the major types of casting defects. Some of the defects produced may be neglected or tolerated and some are not acceptable, it must be eliminated for better functioning of the parts.

Types

Casting defects can be categorized into 5 types

1. **Gas Porosity:** Blowholes, open holes, pinholes
2. **Shrinkage defects:** shrinkage cavity
3. **Mold material defects:** Cut and washes, swell, drops, metal penetration, rat tail
4. **Pouring metal defects:** Cold shut, misrun, slag inclusion
5. **Metallurgical defects:** Hot tears, hot spot.

The various casting defects that appear in the casting process are

1. Shift or Mismatch

The defect caused due to misalignment of upper and lower part of the casting and misplacement of the core at parting line.

Cause:

(i) Improper alignment of upper and lower part during mold preparation.
(ii) Misalignment of flask (a flask is type of tool which is used to contain a mold in metal casting. it may be square, round, rectangular or of any convenient shape.)

Remedies

(i) Proper alignment of the pattern or die part, molding boxes.
(ii) Correct mountings of pattern on pattern plates.
(iii) Check the alignment of flask.

2. Swell

It is the enlargement of the mold cavity because of the molten metal pressure, which results in localised or overall enlargement of the casting.

Causes

(i) Defective or improper ramming of the mold.

Remedies

(i) The sand should be rammed properly and evenly.

Also Read:

- Types of Patterns in Casting Process
- Types of Moulding Sand
- Difference Between Forging and Casting

3. Blowholes:

When gases entrapped on the surface of the casting due to solidifying metal, a rounded or oval cavity is formed called as blowholes. These defects are always present in the cope part of the mold.

Causes

(i) Excessive moisture in the sand.
(ii) Low Permeability of the sand.
(iii) Sand grains are too fine.
(iv) Too hard rammed sand.
(v) Insufficient venting is provided.

Remedies

(i) The moisture content in the sand must be controlled and kept at desired level.
(ii) High permeability sand should be used.
(iii) Sand of appropriate grain size should be used.
(iv) Sufficient ramming should be done.
(v) Adequate venting facility should be provided.

4. Drop

Drop defect occurs when there is cracking on the upper surface of the sand and sand pieces fall into the molten metal.

Causes

(i) Soft ramming and low strength of sand.
(ii) Insufficient fluxing of molten metal. Fluxing means addition of a substance in molten metal to remove impurities. After fluxing the impurities from the molten metal can be easily removed.
(iii) Insufficient reinforcement of sand projections in the cope.

Remedies

(i) Sand of high strength should be used with proper ramming (neither too hard nor soft).
(ii) There should be proper fluxing of molten metal, so the impurities present in molten metal is removed easily before pouring it into the mold.
(iii) Sufficient reinforcement of the sand projections in the cope.

5. Metal Penetration

These casting defects appear as an uneven and rough surface of the casting. When the size of sand grains is larges, the molten fuses into the sand and solidifies giving us metal penetration defect.

Causes

(i) It is caused due to low strength, large grain size, high permeability and soft ramming of sand. Because of this the molten metal penetrates in the molding sand and we get rough or uneven casting surface.

Remedies

(ii) This defect can be eliminated by using high strength, small grain size, low permeability and soft ramming of sand.

6. Pinholes

They are very small holes of about 2 mm in size which appears on the surface of the casting. This defect happens because of the dissolution of the hydrogen gases in the molten metal. When the molten metal is poured in the mold cavity and as it starts to solidify, the solubility of the hydrogen gas decreases and it starts escaping out the molten metal leaves behind small number of holes called as pinholes.

Causes

(i) Use of high moisture content sand.
(ii) Absorption of hydrogen or carbon monoxide gas by molten metal.
(iii) Pouring of steel from wet ladles or not sufficiently gasified.

Remedies

(i) By reducing the moisture content of the molding sand.
(ii) Good fluxing and melting practices should be used.
(iii) Increasing permeability of the sand.
(iv) By doing rapid rate of solidification.

7. Shrinkage Cavity

The formation of cavity in the casting due to volumetric contraction is called as shrinkage cavity.

Causes

(i) Uneven or uncontrolled solidification of molten metal.
(ii) Pouring temperature is too high.

Remedies

(i) This defect can be removed by applying principle of directional solidification in mold design.
(ii) Wise use of chills (a chill is an object which is used to promote solidification in a specific portion of a metal casting) and padding.

Also Read:

- Types of Chips in Metal Cutting
- Mechanical Properties of Materials
- Blast Furnace: Introduction, Definition, Construction, Working Principle, Applications & Advantages

8. Cold Shut

It is a type of surface defects and a line on the surface can be seen. When the molten metal enters into the mold from two gates and when these two streams of molten metal meet at a junction with low temperatures than they do not fuse with each other and solidifies creating a cold shut (appear as line on the casting). It looks like a crack with round edge.

Causes

(i) Poor gating system
(ii) Low melting temperature
(iii) Lack of fluidity

Remedies

(i) Improved gating system.
(ii) Proper pouring temperature.

9. Misrun

When the molten metal solidifies before completely filling the mold cavity and leaves a space in the mold called as misrun.

Causes

(i) Low fluidity of the molten metal.
(ii) Low temperature of the molten metal which decreases its fluidity.
(iii) Too thin section and improper gating system.

Remedies

(i) Increasing the pouring temperature of the molten metal increases the fluidity.
(ii) Proper gating system
(iii) Too thin section is avoided.

10. Slag Inclusion

This defect is caused when the molten metal containing slag particles is poured in the mold cavity and it gets solidifies.

Causes

(i) The presence of slag in the molten metal

Remedies

(i) Remove slag particles form the molten metal before pouring it into the mold cavity.

11. Hot Tears or Hot Cracks

when the metal is hot it is weak and the residual stress (tensile) in the material cause the casting fails as the molten metal cools down. The failure of casting in this case is looks like cracks and called as hot tears or hot cracking.

Causes

(i) Improper mold design.

Remedies

(i) Proper mold design can easily eliminate these types of casting defects.
(ii) Elimination of residual stress from the material of the casting.

12. Hot Spot or Hard Spot:

Hot spot defects occur when an area on the casting cools more rapidly than the surrounding materials. Hot spot are areas on the casting which is harder than the surrounding area. It is also called as hard spot.

Causes

(i) The rapid cooling an area of the casting than the surrounding materials causes this defect.

Remedies

(i) This defect can be avoided by using proper cooling practice.
(ii) By changing the chemical composition of the metal.

13. Sand Holes

It is the holes created on the external surface or inside the casting. It occurs when loose sand washes into the mold cavity and fuses into the interior of the casting or rapid pouring of the molten metal.

Causes:

(i) Loose ramming of the sand.
(ii) Rapid pouring of the molten metal into the mold results in wash away of sand from the mold and a hole is created.
(iii) Improper cleaning of the mold cavity.

Remedies

(i) Proper ramming of the sand.
(ii) Molten metal should be poured carefully in the mold.
(iii) Proper cleaning of the molten cavity eliminates sand holes.

14. Dirt

The embedding of particles of dust and sand in the casting surface, results in dirt defect.

Causes:

(i) Cursing of mold due to improper handling and Sand wash (A sloping surface of sand that spread out by stream of molten metal).
(ii) Presence of slag particles in the molten metal.

Remedies:

(i) Proper handling of the mold to avoid crushing.
(ii) Sufficient fluxing should be done to remove slag impurities from molten metal.

15. Honeycombing or Sponginess

It is an external defect in which there is a number of small cavities in close proximity present in the metal casting.

Causes:

(i) It is caused due to dirt and scurf held mechanically in the suspension of the molten metal.
(ii) Due to imperfect skimming in the ladle.

Remedies

(i) Prevent the entry of dirt and scurf in the molten metal.
(ii) Prevent sand wash.
(iii) Remove slag materials from the molten metal by proper skimming in the ladle.

16. Warpage:

It is an accidental and unwanted deformation in the casting that happens during or after solidification. Due to this defect, the dimension of the final product changes.

Causes:

(i) Due to different rates of solidification of different sections. This induces stresses in adjoining walls and result in warpage.
(ii) Large and flat sections or intersecting section such as ribs are more prone to these casting defects.

Remedies

(i) It can be prevented by producing large areas with wavy, corrugated construction, or add sufficient rib-like shape, to provide equal cooling rates in all areas.
(ii) Proper casting designs can reduce these defects more efficiently.

17. Fins

A thin projection of metal, not considered as a part of casting is called as fins or fin. It is usually occurs at the parting of the mold or core section.

Causes:

(i) Incorrect assembling of mold and cores.
(ii) Insufficient weight of the mold or improper clamping of the flask may produce the fins.

Remedies

(i) Correct assembly of the mold and cores.
(ii) There should be sufficient weight on the top part of the mold so that the two parts fit together tightly.

2.9 Inspection of castings: Visual inspection, pressure test, magnetic particle inspection, dye penetration inspection, Radiographic inspection, ultrasonic inspection.

There are five basic NDT methods used to detect weld defects;

1. Visual Inspection (VT)
2. Magnetic Particle Testing (MPT)
3. Dye Penetrant Liquid Testing (DPI)
4. Radiographic Testing (RT)
5. Ultrasonic Testing (UT).

UT and RT can detect both external and internal discontinuities while MPI, DPI and VT can only detect external defects. Also, defects classified as volumetric such as Porosity Inclusions (slag, metal and non-metal) are better revealed by RT. Planar defects such as cracks, lack of fusion and incomplete penetration are better revealed by UT.

Flaws in some materials such as nickel-based alloys and austenitic stainless steels can only be detected with RT and DPI. As discussed previously, MPI is only used on ferromagnetic materials. Joint configuration and accessibility of the welded joint are two other factors that determine the NDT method used. While UT is good for joints with limited access to both sides.

VISUAL INSPECTION (VT)

The visual inspection of welds is a method of non-destructive examination. It is the most commonly used of any non-destructive examination. Additionally, it is a first step in locating defects before any further NDT is undertaken.

This is because the weld integrity is verified visually. The limitation of this method is that it can only detect external surface-breaking defects. For example, external cracks, undercut, under-fill and surface porosity.

MAGNETIC PARTICLE TESTING/INSPECTION (MPT/MPI)

Magnetic Particle Inspection is used for locating surface or near-surface flaws in ferromagnetic materials. This is a simple-to-use inspection method but, as the name suggests, is limited in use to magnetic materials. In other words ferritic (not austenitic) steels.

The basic principle is that the component is magnetised by the use of a magnetic yoke or prods. This creates magnetic lines of force which form a closed loop or circuit. All of these lines of force create the magnetic field.

The force that attracts other magnetisable material is known as magnetic flux. It is made up of all the lines of force.

A discontinuity will disrupt the flow of the lines of force, therefore cutting the lines of flux. This produces a flux leakage around the discontinuity. A flux leakage or leakage field are lines of force leaving the material. This occurs due to the passing of air between the two poles of opposite polarity.

You can detect a flux leakage with magnetic powder. Iron particles sprayed or dusted onto the surface will be attracted to the area forming a line of powder. Thus, indicating the location, size and shape of the discontinuity.

This method can either use AC or DC electric current to generate the magnetic field. The magnetic field produced by DC has more penetrating power than those produced by AC.

MPT/MPI has an advantage over liquid penetrant inspection because it can be used to detect some discontinuities that are not surface breaking. For example, cracks filled with carbon, slag and other contaminants (as long as the flux leakage is strong enough).

The limitation of this method is that it cannot be used for inspection of non-ferromagnetic materials. For example, copper, aluminium, magnesium or austenitic steels. The strength of the magnetising current should be specified in a written examination procedure.

The adequacy of the magnetic field should be verified by the equipment is capable of lifting a specified weight. DC yokes are capable of lifting no less than 18kg of mild steel at a pole spacing of between 75-300mm. AC yokes are capable of lifting 4.5kg of mild steel at a pole spacing between 75-300mm.

LIQUID PENETRANT INSPECTION (DPT/DPI)

Dye penetrant testing is a simple, cheap and easily portable inspection method. It involves detecting and locating discontinuities. For example, cracks and pores in nonporous materials provided the flaws are clean and open to the surface.

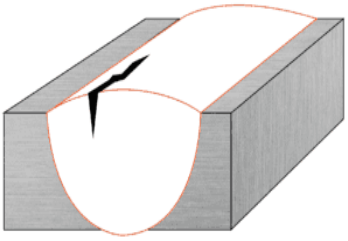
DPI can detect surface breaking discontinuities only and relies on a coloured or fluorescent dye, sprayed or brushed onto the surface. This penetrates any discontinuities by capillary action. The penetrant is left on for a short amount of time to enable the dye to penetrate any very fine discontinuities.

After cleaning any excess penetrant, the dye is drawn to the surface by spraying on a developer. The developer is usually a fine, fluffy powder in the case of the colour contrast dye. The discontinuity is revealed by the dye staining the developer or fluorescing with the use of a black light.

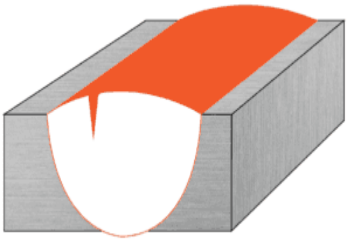
The fluorescent dye gives greater sensitivity than the colour contrast dye and does not require the use of a developer. However, it requires the use of an ultra-violet light source and a darkened room. This makes it a much less portable inspection method.

The dye used as a penetrant must be able to penetrate tight cracks. It also mustn't be able to be removed from more open discontinuities during the cleaning operation. Cleaning is carried out prior to applying the developer.

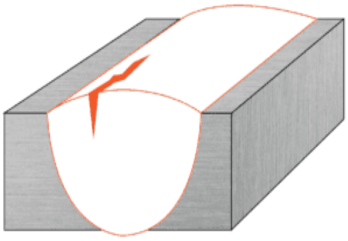
Careful surface preparation and thorough cleaning of the item before applying the penetrant is important. This method can be used for both non-magnetic and magnetic materials. It is particularly useful for non-magnetic materials where Magnetic Particle Inspection cannot be used.



Surface breaking crack



Application of penetration



Residual penetration in discontinuity after cleaning

RADIOGRAPHY INSPECTION (RT)

The previous two paragraphs deal with the defect detection techniques of MPI, DPI. These methods are capable of detecting surface or very near surface discontinuities. Therefore there is a need to enable internal discontinuities to be reliably detected – a so-called volumetric detection method.

Radiographic Testing (RT) is a non-destructive examination (NDE) technique that involves. The use of either x-rays or gamma rays to view the internal structure of a component. In the petrochemical and metal fabrication industry, RT is used to inspect welds and machinery to detect flaws. RT is also used to inspect weld repairs.

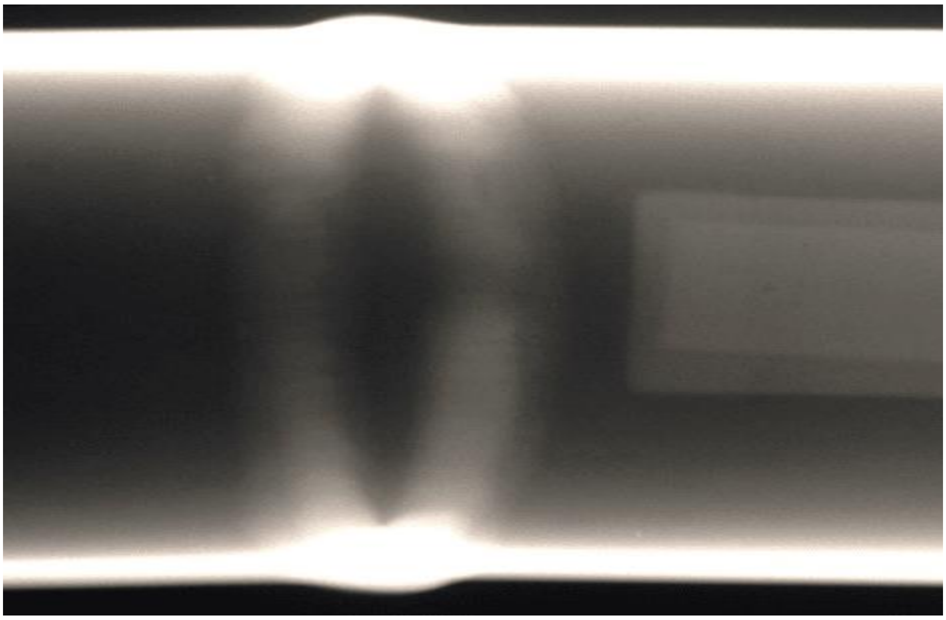
Compared to other NDE techniques, radiography has several advantages. It is highly reproducible and can be used on a variety of materials. The data gathered can be stored for later analysis.

RT can detect surface discontinuities, such as undercut, and inadequate joint penetration. Conversely, it can detect excessive reinforcement that may be detected by other methods such as VT, DPI or MPI.

Additionally, it can detect subsurface discontinuities that cannot be detected by other methods. However, radiography is most sensitive to discontinuities aligned with the radiation beam. On the other hand, ultrasonic inspection is most sensitive to discontinuities that are at a right angle to the sound beam.

RT is very good at detecting volumetric defects. Volumetric defects which are seen with complete clarity on RT, are often too small to detect by UT.

Radiography is an effective tool that requires very little surface preparation. Moreover, many radiographic systems are portable, which allows for use in the field and at elevated positions. There are conventional radiography and digital radiography techniques.



ULTRASONIC INSPECTION (UT)

UT is one of the most common methods because it ensures accurate detection of hidden flaws located inside the weld. It uses ultrasonic waves that propagate through a layer of metal and are reflected from its boundary. Thus, also reflecting from the boundaries of internal discontinuities.

It is possible to evaluate the metal thickness and defects by measuring the time difference between the sent and reflected signals. UT can also detect flaws by measuring the shape and amplitude of the reflected signals.

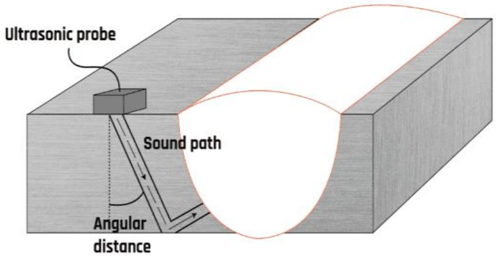
An instrument that is used for ultrasonic testing is called ‘flaw detector.’ The flaw detector utilizes special-purpose transducers and transmission techniques. This allows for the implementation of the echo pulse and pitch-catch.

With the pulse-echo technique, the transducer sends a probing signal to a test object. It then receives echo signals reflected from defects and from design features of the product. Based on the time of the signal arrival, it is possible to spot the location of the defects.

Based on the signal amplitude you can deduce the size of the defects. The disadvantage of this technique is the need for the defect to have a reflecting surface perpendicular to the ultrasonic beam. Planar defects also need to be located near the surface of the product to be detected.

UT is applicable to almost all materials. The principal limitations are the geometry of and access to the weld joint and penetration capability of the sound beam. Other factors which are considered include the angle of the sound beam, test surface and scan pattern.

Welds in some materials are difficult to inspect ultrasonically. For example, welds involving nickel-base alloys and austenitic stainless steels tend to scatter and disperse the sound beam.



2.10 Safety precautions in metal casting.

Safety Tips

Followings are few safety tips that one should know if he/she is dealing with casting process or alloys:

1. Wear eye protection, gloves, spats (covering top of feet), and thick clothing protecting all exposed skin on arms and legs. NO polyester or synthetic clothing.
2. Sand Floor in pouring area shall be clear of all objects not involved in pouring.
3. Clamp or weight up molds that require it.
4. Metal added to heat must be free of moisture and impurities.
5. Metal added to heat during melt must be preheated.
6. Skimmers and other melting tools must be preheated before use.
7. Move Slowly while removing crucible from furnace and moving to mold.
8. Do not look into exhaust during operation.
9. Inspect crucibles before use.
10. Inspect propane lines.
11. Use outdoors only.
12. No alcohol or drug use.
13. Wear respiratory protection while melting copper-base alloys (brass, bronze).

Unit-3.0 Metal Forming and Press working

What is a metal forming press?

A metal forming press, also known as a stamping press, is a machine tool used to precisely shape and cut metal typically using upward and downward movements. Metal, supplied in sheet, coil, or tube form, is pressed between two halves of a press tool. The top half of the tool, a punch, is attached to the ram, and the bottom half of the tool, a die, is attached to the bolster plate secured to the bed of the press. Posts and bushings are often used to guide the pressing motion.

In general, metal forming is a manufacturing process that reshapes metal by plastic deformation. Metal can be permanently bent, stretched, and compressed into complex geometric shapes with a press. The ability to reshape the metal is proportional to the type and amount of stress applied to the part.

Metal forming presses can be cam driven mechanically, powered via a flywheel and motor, or hydraulically, which uses fluid pressure to exert force during the forming process. Mechanical presses are able to reach high production speeds and are used regularly in assembly plants, however hydraulically powered metal forming presses offer much more versatility. A wide range of press tonnage, forming capabilities, and overall complexity of finished parts can be achieved with the use of hydraulically powered forming presses. Hydraulic presses can be used in a wide variety of applications as a standalone press, in an automated press line, or as a transfer press. For these reasons and more, hydraulic metal forming presses are often found in manufacturing plants around the globe.

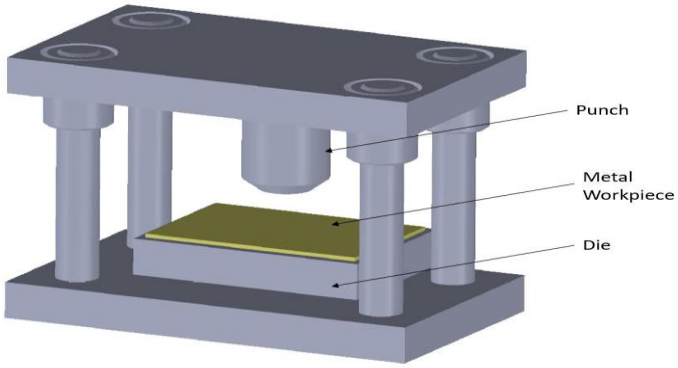


Fig.1: A simple representation of a metal forming tool set.

How does a Metal Press work? A press is simply a flat bed, and a pressing ram or rod, that is actuated either hydraulically/pneumatically or mechanically. To make a metal pressed part, you insert 2 halves of a metal press tool into the press. You then bolt the bottom of the tool to the work bed, and the top of the tool to the ram or rod. Once that is done, you can feed sheet metal material into the machine and the metal will be pressed between the two halves of the tool and it will be pressed into the desired shape.

Complex metal pressed parts are made in progressive metal press tools. In this process material is fed in one direction and progresses through several stages in the tool. Each stage of the tool adds more complexity to the part, by adding a bend or shearing a cut or punching a hole. The material is fed through periodically, so each time the tool opens, more material is fed in one end and finished pressed parts come out the other.

Hydraulic and Pneumatic Presses use a cylinder and fills this a liquid (including air) through a hydraulic pump. By adding liquid to the cylinder, the pressure builds. The pressure of the liquid is constant throughout the cylinder. This pressure then is exerted onto the pressing rod or ram which forms that pressure down onto the tool and work piece. Usually slower than mechanical presses, hydraulic presses are good for applying a constant amount of pressure over the entire length of the punch. This means they are generally better suited for parts that need to be pressed deeply or over an extended period.

Mechanical presses use an electric motor which spins a belt connected to a flywheel. This is transferred through a series of gears. These gears drive the ram up and down. To start the press, the flywheel is connected to a clutch and brake system which allows the flywheel to spin without actuating the ram at all. These mechanical systems usually run a lot faster than others, with most presses able to stamp the par 40-80 times in a minute. This rate is called Strokes Per Minute (also known as SPM) and it’s a critical factor in progressive tool design as it dictates how quickly you can make your product.

3.1 Cold and Hot working of metals, effect on metal properties, advantages & limitations.

What is Hot Working?

If the metalworking process is carried out above its re-crystallization temperature, it is called as **hot working**.
Re-crystallization temperature is the temperature at which atomic mobility can be repaired when any defect was present in the metal caused by the working process.

In this process, the metal is heated to the plastic state, and then the pressure is applied to get various size and shapes. When the pressure is applied, the metal grain size will be varied, and the metal’s mechanical properties are improved.

If the pressure is applied by hand hammer, then it is called as hand or **smith forging**. If hand hammering is replaced by power hammers, then it is called **hammer forging**.
Such type hot working of metals is called as **hot forging**. Hot-working can be used for forging, extrusion, and drawing, etc.
When metals are worked above the re-crystallization temperature, then it becomes plastic and causes the growth of grains.

During the hot working, the grains become loosened in their structure, and they realign in a proper manner. Only small pressure is required to shape the metal.

Advantages of Hot Working.

1. It is applicable for mass production work.
2. The metal size and shape can be easily changed.
3. Metalworking is done under high temperature; therefore, larger deformation is possible.
4. Metal grain structure will be refined.
5. Stresses and other defects can be minimized.
6. Hot-working leads to homogeneous structure of metal without defects and blowholes.
7. Mechanical, physical, and chemical properties of metals can be improved.
8. Hot working removes all types of imperfections caused by the Gas pores and composition differences.
9. Metal reaches to anisotropic behavior.
10. Metal regains softness and ductility after the process.
11. Hot working is a fast, reliable, and economical process.

Read Also: What is Bearing? 15 Types of Bearing [A Comprehensive Guide]

Disadvantages of Hot working.

1. It is a costlier process.
2. Hot working leads to poor surface finish due to oxidation, because the material will be worked under high temperature.
3. Sometimes it leads to lower strength due to loss of carbon due to oxidation.
4. On account of the loss of carbon from the surface of the steel piece being worked, the surface layer loses its strength, which is a disadvantage when the part is put to service.
5. It is difficult to attain dimensional accuracy due to uneven shrinkage of metal.

What is Cold Working?

If the metalworking process is carried out at a temperature below the re-crystallization temperature, it is called a **cold working process**.
This process needs comparatively higher pressure than hot working.

Soft, ductile, and malleable metals can be easily worked with cold working. But this process leads to hardness and distorted grain structure.

The cold working process is used in rolling, bending, spinning process, etc.

The cold working process also affects the following mechanical properties of metals significantly.

1. Hardness.
2. Yield Strength.
3. Ductility.
4. Tensile Strength.

Watch the video below for better understanding.

Advantages of Cold Working.
1. Dimensional accuracy can be maintained.
2. No heating of metals.
3. Better surface finish can be achieved since there is no oxidation during the cold working of metals.
4. Strength and hardness of the metal are increased.
5. Due to cold working, metal gains strength and hardness.
6. Better strength and wear properties of the material can be achieved.

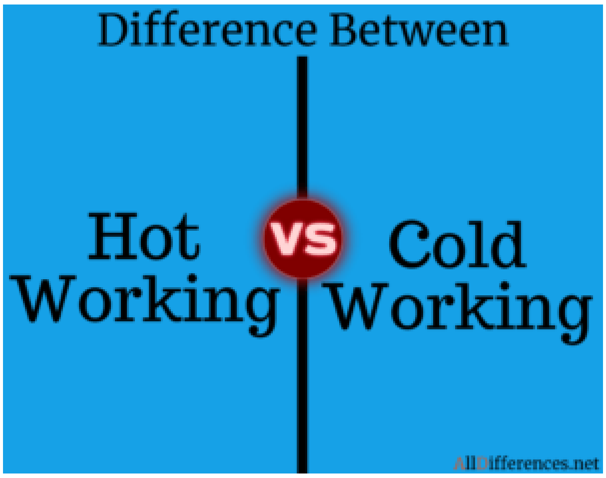
Disadvantages of Cold Working.
1. It leads to brittleness if the metals are worked under cold working.
2. Metals hardness is increased.
3. Cold worked components require a heat-treatment process.
4. Only ductile and malleable materials are suitable for cold working.
5. Greater force is essential for deformation. Therefore powerful machines are required.

Comparison Between Hot Working and Cold Working

Summary:

The Major **Difference Between Hot Working and Cold Working** is that both are the **metal forming** **processes. Forming** is the metalworking process of fashioning metal parts and objects through mechanical deformation.

Hot Working is done at temperatures **above** the recrystallization temperature of the metal, and **Cold Working** is done at temperatures **below** the recrystallization temperature of the metal.



Comparison Between Hot Working and Cold Working

Comparison Chart

Hot working	**Cold working**
Hot working is carried out above the recrystallization temperature but below the melting point, hence deformation of metal and recovery takes place simultaneously	Cold working is carried out below the recrystallization temperature and as such, there is not the appreciable recovery of metal

Hot working	**Cold working**
During the process, residual stresses are not developed in the metal	During the process, residual stresses are developed in the metal
Because of higher deformation the temperature used, the stress required for deformation is less	The stress required to cause deformation is much higher
Hot working refines metal grains, resulting properties.	Cold working leads to distortion of grains
No hardening of metal takes place.	Metal gets work hardened.
If the process is properly performed, it does not affect ultimate tensile strength, hardness, corrosion and fatigue resistance of the metal	It improves ultimate tensile strength, yield and fatigue strength but reduces the corrosion resistance of the metal
It also improves some mechanical properties like impact strength and elongation	During the process, impact strength and elongation are reduced
Due to oxidation and scaling, poor surface finish is obtained	Cold worked parts carry better surface finish.
Close dimensional tolerances cannot be maintained	Superior dimensional accuracy can be obtained
Hot working is most preferred where heavy deformation is required	Cold working is preferred where work hardening is required

Hot Working

- Hot working is accomplished at a temperature above the recrystallization temperature but below the melting or the burning point of the metal, because above the melting or the burning point, the metal will burn and become unsuitable for use.
- Every metal has a characteristic hot working temperature range over which hot working may be performed.
- The upper limit of working temperature depends on the composition of the metal, prior deformation, and impurities within the metal.
- The changes in structure from hot working improves mechanical properties such as ductility, toughness, resistance to shock and **vibration, % elongation, % reduction** in area, etc.

Hot Working Advantages

- Due to hot working, no residual stresses are introduced in the metal.

- Hot working refines the grain structure and improves the physical properties of the metal.
- Any impurities in the metal are disintegrated and distributed throughout the metal.
- The porosity of the metal is minimized by the hot working.
- During hot working, as the metal is in a plastic state, larger deformation can be accomplished and more rapidly.
- Hot working produces raw material which is to be used for subsequent cold working operations.

Hot Working Disadvantages

- Due to the loss of carbon from the surface of the steel piece being worked, the surface layer loses its strength.
- This weakening of the surface layer may give rise to fatigue crack which results in failure of the part.
- Close tolerances cannot be obtained.
- Hot working involves excessive expenditure on account of high tooling costs.

Cold Working

- The working of metals at temperatures below their recrystallization temperature is called as cold working.
- Most of the cold working processes are performed at room temperature.
- Unlike hot working, it distorts the grain structure and does not provide an appreciable reduction in size.
- Cold working requires much higher pressure than hot working.
- If the material is more ductile, it can be more cold worked.
- Cold Working results in Strain Hardening, distortion of grains and the crystallographic structure.

Cold Working Advantages

- Better dimensional control is possible because there is not much reduction in size.
- The surface finish of the component is better because no oxidation takes place during the process.
- Strength and hardness of metal are increased.
- It is an ideal method for increasing the hardness of those metals which do not respond to heat treatment.

Cold Working Disadvantages

- The ductility of the metal is decreased during the process.
- Only ductile metals can be shaped through cold working.
- Over-working of metal results in brittleness and it has to be annealed to remove this brittleness.
- To remove the residual stresses set up during the process, subsequent heat treatment is mostly required.

3.2 Forming processes, types, working principle, tools and equipment, applications of: Rolling, Forging, Drawing, Deep drawing, Extrusion.

What is Forming Process?

Forming Process also known as Metal Forming is a large set of manufacturing process by which a raw material converted into a product. In this process, we apply stresses like tension, compression, shear, etc. to deformed the raw material. The example of forming processes are sheet metal manufacturing, forging, rolling, extrusion, wire drawing, thread rolling, rotary swinging, and so on.

Classification or Types of Forming Process in Detail:

Forming Process can broadly be categorized into there types, and those are:

1. **Bulk Forming**
    - Rolling Process
    - Extrusion Process
    - Forging Process
    - Wire Drawing
    - Squeezing
2. **Sheet metal Forming**
    - Bending
    - Deep Drawing
    - Shearing
3. **Powder Metal Forming**
    - Powder Forging
    - Powder Injection
    - Powder Extrusion Moulding

#1 Bulk Forming:

One of the most important forming processes is the Bulk Forming process. This process can be used when the volume ratio of the metal is higher than the surface area. Along with that, the bulk-forming process works due to different types of forces. They are the shear force, the combination of tensile, and the compressive force. The examples of Bulk Forming processes are mentioned below.

a. Rolling:

Rolling is one of the most useful processes of forming. It falls under the bulk-forming process. The rolling process consists of two or more two rollers in a combination with the metal plate. In regards to the rolling process, the metal plates are passed between the combination of two or more than two rollers to make the metal plates thin and smooth surface finish.

Apart from that, the rollers that can be used in the rolling process rotate either in the same direction or in the opposite direction with respect to the other roller.

The main purpose of this rolling process is to reduce the thickness of the metal plates. In the forming processes, metal is not removed. Hence, before the rolling process starts, less width metal is taken with respect to the necessity, as after the rolling process this width is increased due to pressing and decreasing the thickness.

Rolling Process Diagram, *Learn Mechanical*

b. Extrusion:

The extrusion process is much different from other processes. In this process, the metal is heated at high temperatures. Then the metal is pressed by the comprehensive force of the die.

The die has an opening, through which the heated metal flows at the time of pressing by RAM. Hence, the proper shape can be made. Apart from that, in the extrusion process, the metal is heated so much that it becomes like a fluid as it can flow.

Extrusion Process Diagram, *Learn Mechanical*

c. Forging:

Forging is the process by which the metal can be heated at a very high temperature. This Forging process can be used to give a particular shape to the metal. It usually works due to the compressive force.

At first, the metal is heated at a very high temperature. Then this metal is placed in a die. After that, the compressive force is given to the heated metal as the metal can get the shape of the die by deformation with the help of the force that is given by the hammer or the other piece of the devices to the metal. Hence, the metal takes its shape by deformation.

Forging Operation Diagram, *Learn Mechanical*

d. Wire Drawing:

It is a kind of extrusion process, but not exactly. Here a wire-shaped die is used. The work-piece is passed through the die and takes the cross-section of the die opening. It is a pull process.

Wire Drawing Diagram, *Learn Mechanical*

e. Squeezing:

Squeezing is one of the most useful forming processes. In this process, die is used. The die should be closed type die. At first, the die has to be heated. Then the molten metal is placed to one part of the die. After that when the metal is going to be solid then the other die part is placed on the first die part and a compressive force is given to it. After solidifying the metal, it takes out as the prepared shape.

Squeezing Operation Diagram, *Learn Mechanical*

#2 Sheet Metal Forming:

Another important forming process is the Sheet Forming process. This sheet forming process works due to either the tensile force or the shear force. Usually, this force can be used in Hydraulic presses in order to produce the product from the sheets however some more steps like squeezing, bending and so on are also included in this process. In this process, no material is added or removes. Example of this type of forging is bending, deep drawing, shearing, etc.

a. Bending:

Bending is the process of forming where an angle is used in order to pressed by the compressive force of the metal plate that helps the material to bend in a particular angle so that, the plate can get its necessary shape. The shape of the angle usually looked like either the English letter "V" or "U".

Bending Operation Diagram, *Learn Mechanical*

b. Deep Drawing:

In this operation, a hollow cup shape die is used. The die is clamped using the blank-holder. In this process, the workpiece (sheet metal) placed over the die and a punch exerted the force on the workpiece, by this force sheet metal extend and filled the cavity and takes the shape of the die.

Deep Drawing Operation Diagram, *Learn Mechanical*

c. Shearing:

In this operation, the metal sheet is in cantilever position, and a punch coming from the top exerted the force on the cantilever position of the sheet. Shearing is just a cutting operation of the metal sheet.

Shearing operation Diagram, *Learn Mechanical*

#3 Powder Metal Forming:

Nowadays, the most innovative forming process is the Power Metal forming process. In this process, metal powders are used to form products. It is a computer-controlled process. In regards to that, in this process, the metal powders are heated under the melting point of the material.

By this process, the product of any complex shape which cannot be produced by any other forming processes can be done. Generally, this process is used to minimize the machining stages like grinding, polishing etc. and also minimize the production cost. The examples of Powder Metal Forming Processes are the following:

a. Powder Forging:

As the name denotes Powder Forging, that means here we use Powder Metals to get finish product. In this process, a mixture of blended powder poured into the die through the hopper, and the pressing is done by using a preform. Generally to get solid bonding we need to heat the Preform.

This process is completed into three steps:

1. Perform is heated, so that binding can be easily done.
2. Pre-Alloy powder (180–325 µm, source Open Learn) put into the die and pressed by the Preform. In this process, we get 80–85% solid density.
3. After pressing done by preform, it again goes for Mechanical Pressing, so that we can increase the density up to 98–99.5%.

Powder Forging Diagram, *Learn Mechanical*

b. Powder Injection:

The powder Injection process is also called metal injection moulding. In this process, the metal powders (<10µm) are blended with wax or polymer-based binder. The blended mixture undergoes compaction due to pressure exerted by the screw, and comes out through the die, and takes shape of it.

Powder Injection Diagram, *Learn Mechanical*

c. Powder Extrusion Moulding:

In this process, a hydrostatic compressive force is act on the powder metal. A die is fixed at the opposite side of the force applies, so when a force is act on the powder, it comes out through the die and takes the shape of the die.

Powder Extrusion Moulding, *Learn Mechanical*

Temperature in Forming Processes:

Temperature plays vital role in Forming Processes, by applying heat we can change the property of the forged material. So if we consider the temparature then there are three types of Forming Process.

1. Hot Forming
2. Warm Forming
3. Cold Forming

#2 Hot Forming Process:

The hot forming process mainly depends on the recrystallization temperature. In the Hot Forming Process, the metal is heated under its melting point along with above the recrystallization temperature. As it is heated above the recrystallization temperature so that, it is known as Hot Working Forming Process.

#2 Warm Forming Process:

It stands between Hot and Cold Forming process, here the temperature is maintained above the room temperature but below the recrystallization temperature. By doing so we can achieve intricate work geometry, and also required less power and forces.

#3 Cold Forming Process:

Cold Forming Process also depends on the recrystallization temperature. In the Cold Working Forming Process the metal is heated under the crystallization temperature of the metal. Hence, it is known as Cold Forming Process.

Advantages and Disadvantages of Metal Forming Process:

According to the above discussion, you already have an idea that we can categorized forming process broadly in two types Hot Forming, and Cold Forming, so each one has their own advantages and disadvantages, so let's discuss them.

Advantages of Hot Forming Process:

- The amount of hardening strain in the case of the hot forming process is low as compared to the cold forming process.
- Due to the temperature of the material, the amount of force required to deform the material is very low in amount.
- The amount of the ductility, as well as other mechanical properties that are present within a material, which is produced through the hot forming process, is quite high.
- Apart from the above advantages, less amount of residual stress can be generated in the hot forming process.

Disadvantages Hot Forming Process:

- The amount of heat required is high.
- Oftentimes, the major flaw present within the hot-formed process is the poor surface finish.

- Accuracy or precision is quite low as compared to the cold forming process.
- Apart from that, poor interchangeability is another issue that is incorporated with the hot forming process.
- Poor life cycle and handling issue.

In the above section, the advantages and disadvantages of Hot forming process are discussed. Now, the following portion includes the advantages and disadvantages of the cold forming process.

Advantages of Cold Forming Process:

- Heating is not required at all in this process.
- The surface that can be obtained at the end of this process is of very premium quality.
- The existence of directional properties.
- Wear and tear properties are very high.
- The strength is good in the case of the cold forming process.
- The major benefit of this process is the negligibility of contamination.

Disadvantages of Cold Forming Process:

- For the deformation of a material, a high amount of force is required.
- Powerful and high-quality power is required to deform a material.
- As compared to the hot forming process, the ductility level is bad.
- Hardening stress is more in the case of the cold forming process.
- Existence of residual stresses.

Now also look at the application of forming process.

Applications of Metal Forming Process:

Some major applications of the forming process are as follows:

- Seamless tubes, rods can be made with the help of the aforementioned process.
- Turbine rings can be produced by this method.
- Cement kilns can also be made with the help of this process.
- Bearings, plates, steel sheets, and various components of an automotive car can be developed with the help of this forming process.
- The missile, aircraft components are also manufactured through this process.
- Along with that, hinge, bolt, nails can also be formed by this process.
- Moreover, agricultural tools, military products are also produced with the help of this process.
- Furniture, hook, pin, screws can also be made from this process.
- Windows, doors, and other components of a car can be developed with the help of the forming process.
- Furthermore, the forming process can also be used in order to develop plastic products.

3.3 Safety precautions.

Safety Guidelines by The Ministry of Labour & Employment

The Ministry of Labour and Employment, Government of India enacted the Factories Act 1948 to consolidate and amend the laws regulating workers that work in the factories. It is applied to every factory that has 20 or more workers.

To safeguard workers, the government of India has prescribed certain standards related to safety, welfare and working hours that are mandatory to be followed by every employer. Here, we have listed those safety and welfare measures that every employer and owner of the factory needs to enforce.

Employee Health

CLEANLINESS: It is required to keep the factory clean and free from effluvia arising from a drain, privy and any other sources that can create annoyance and irritation.

DISCARDING WASTE AND EFFLUENTS: Every factory deals with waste and sewage due to heavy manufacturing processes. Hence, there should be effective arrangements in the factories for the treatment of effluents.

TEMPERATURE MAINTENANCE AND PROPER VENTILATION: For securing and maintaining the working environment, every factory must have an adequate ventilation system that circulates fresh air. It is also required to maintain the temperature within the factory to prevent injuries and provide comfortable conditions to work.

DUST AND FUME: Factories produce various toxic gases and fumes. So, it is necessary to keep the workers safe from these dangerous gases. In order to do so, employers must provide respiratory masks and other safety equipment that prevent workers from inhaling dust and fumes.

LIGHTING: Workers can face various health hazards in factories due to poor lighting. To secure workers from being injured, there should be proper lighting so that they can work efficiently.

Employee Safety

To prevent workers from various hazards, there are some points that should be implemented in factories:

- Machinery in factories should be properly fenced.
- Only trained adult workers should be allowed to work near machinery in motion and they must be provided with proper safety wear to prevent injuries.

- To avoid accidents, proper precautions should be taken while working with self-acting machines.
- In the case of emergencies where power cut is required, suitable arrangements should be made.
- All machinery run by power should be encased and effectively guarded.
- There should be a competent person to frequently inspect hoists and lifts.
- A proper inspection of lifting machines, chains, ropes, and lifting tackles must be done before using them and at regular intervals.
- Floors, stairs, and means of access should be properly maintained.
- Personal protective equipment must be provided to the workers for better safety.

Employee Welfare

There are also some measures that should be applied for employee welfare:

- Every factory should have adequate and suitable washing facilities.
- The first aid box should be available in the factories with prescribed contents.
- Factories with than 500 workers should have an ambulance.
- Every factory that has more than 150 workers must have adequate and suitable shelters or restrooms.

Working Hours

Generally, the workers should not be allowed to work in a factory for more than 48 hours a week. Workers should be given one full day holiday within a week. If a worker is asked to work on a scheduled weekly holiday, he should be provided compensatory off within three days of his scheduled weekly holiday.

3.4 Press working: Emphasis that press working is not formingprocess, Punching, Blanking, Notching, Lancing, Slitting,

Sheet metal fabrication is one of the popular metal forming processes used across various industries. This process enables forming, shaping, and joining the metal sheets to create the desired parts or components. There are different types of tools and techniques used to cut, join, and shape the metal. Press tools are centuries old; however, they have been adopted and evolved effectively with time. Equipped with pneumatic, mechanical, and hydraulic presses, press tools can produce pre-designed sheet metal parts in massive volumes. Today, a wide variety of press tools are available. They all are differentiated in terms of their unique features, perks, and constructions. Different constructions of a press tool lead to different working operations. Would you like to know what they are? This post introduces you to some important press working operations. So, stay tuned.

What Are the Common Press Working Methods?

Press working operations are also called sheet metal presses operations. This is because different operations are performed on sheets through various press tools to get the required shape. These press working operations are mainly divided into two categories – cutting and forming. There are various sub operations that fall under each of these two categories. Which working methods of sheet metal presses to choose will vary depending on specific application requirements. So, let's have a look at them.

1. **Sheet Metal Cutting Operations:** In this press work process, the sheet metal is subjected to tensile and compressive stresses to break its structure and separate it into different parts. Hence, it is considered an efficient material utilization operation. Sheet metal cutting operations include:

- **Punching:** It is a metal fabrication process where enough shearing force is applied on the sheet metal to produce holes and cutouts of different sizes and shapes. Punching is performed by placing the sheet metal between the punch and die. The punch presses drive downward at high speed through the sheet metal to create holes.
- **Blanking:** This press working process removes a pre-defined part from the sheet metal. The part is punched out with a single stroke, using one die and punch. This method usually produces a flat shape from a metal sheet.
- **Perforating:** It is the method of punching or stamping slots or holes in a pattern, not specifically in a round shape. The wastage of material here is minimal.
- **Shearing:** The sheet metal is separated into two or more pieces by simply cutting a long line. Shearing creates clean cuts with smooth edges. It doesn't produce wastage in the form of chips or debris.
- **Trimming:** As the name implies, this process removes the excess metal portions surrounding the formed pre-designed parts.
- **Notching:** This process produces desired parts by removing the edges of the metal workpiece. Notching is a manually operated and low-production process.
- **Lancing** is the operation of Cutting a sheet of metal through part of its length and then bending the cut portion
- **Slitting:** Slitting is similar to the shearing process. However, this process cuts a wide coil of sheet metal into various narrow coils using circular knives.

2. **Sheet Metal Forming Operations:** It is one of the most widely used processes that cause stress below the ultimate strength of the metal, which results in distortion. Sheet metal forming operations include:

- **Bending:** In this process, the sheet metal is bent into a curved form by applying enough force. During bending, the metal's shape is changed, but its volume is retained as it is. Sheet metal bending can be performed in various ways. Channel bending, offset bending, edge bending, v-bending are some popular types.
- **Drawing:** This method produces vessel-shaped or thin-walled hollow parts from a workpiece. Drawing is categorized into two types – deep drawing and shallow drawing.
- **Squeezing:** It is the most popular and widely used process of forming ductile metals. Squeezing has several operations, including coining, sizing, and riveting. These operations are performed to reduce the overall thickness of the metal.

Nibbling, Trimming.

Trimming:

When parts are produced by die casting or drop forging, a small amount of extra metal gets spread out at the parting plane. This extra metal, called flash, is cut – off before the part is used, by an operation called trimming. The operation is very similar to blanking and the dies used are also similar to blanking dies. The presses used for trimming have, however, relatively larger table.

Nibbling:

Nibbling is variation of notching, with overlapping notches being cut into the metal. The operation may be resorted to produce any desired shape, for example flanges, collars, etc.

Perforating:

Perforating is an operation is which a number of uniformly spaced holes are punched in a sheet of metal. The holes may be of any size or shape. They usually cover the entire sheet of metal.

Unit 4.0 Metal Joining

1. Introduction

Joining is an important process in a number of industries, such as aerospace, automotive, oil, and gas. Many products cannot be fabricated as a single piece, so components are fabricated first and assembled later. Joining technology can be classified as a liquid-solid-state process and mechanical means. Liquid-solid-state joining includes welding, brazing, soldering, and adhesive bonding. Mechanical joining includes fasteners, bolts, nuts, and screws.

Metal joining is a process that uses heat to melt or heat metal just below the melting temperature. Joining metal by fusion is known as fusion welding. Without fusion, the process is known as solid-state welding. Fusion welding includes arc welding and laser welding, Whereas solid-state welding such as friction stir welding (FSW) where process occurred below the melting temperature.

4.1 Classification, recall gas and arc welding processes.

Definition of Gas Welding:

Gas Welding is a welding process that melts and joins the metals by heating them with a flame caused by a reaction of fuel gas and oxygen. The flux may be used to deoxidize and cleanse the weld metal. The flux melts, solidify and forms a slag on the resultant weld bead.

Types of Gas Welding Process:

There are 3 types of Gas welding process which are presented below.

- Oxy-Acetylene (C2H2) Gas Welding
- Oxy-Gasoline welding
- Oxy-Hydrogen Gas Welding

From the above types, Oxy-Acetylene Gas Welding was presented below in a detailed way.

Oxy-Acetylene Gas Welding:

The most commonly used Gas Welding is ***Oxyacetylene gas welding*** because of its high flame temperature.

Properties of Oxygen and Acetylene:

Oxygen:

- Colorless, odorless and tasteless gas
- Supports combustions & increase heat

Acetylene:

- Colorless and has a very distinctive odor
- Highly flammable

Equipment of Gas Welding Process:

By Cierrex

The Gas Welding Equipment consists of the following parts which are mentioned below.

- Oxygen pressure regulator
- Acetylene pressure regulator
- Oxygen gas cylinder (Black)
- Acetylene gas cylinder (maroon/red)
- Oxygen gas hose(Blue)
- Acetylene gas hose(Red)
- Welding torch or blowpipe with a set of nozzles and gas lighter
- Filler rods and fluxes
- Protective clothing for the welder (e.g., asbestos apron, gloves, goggles, etc.)

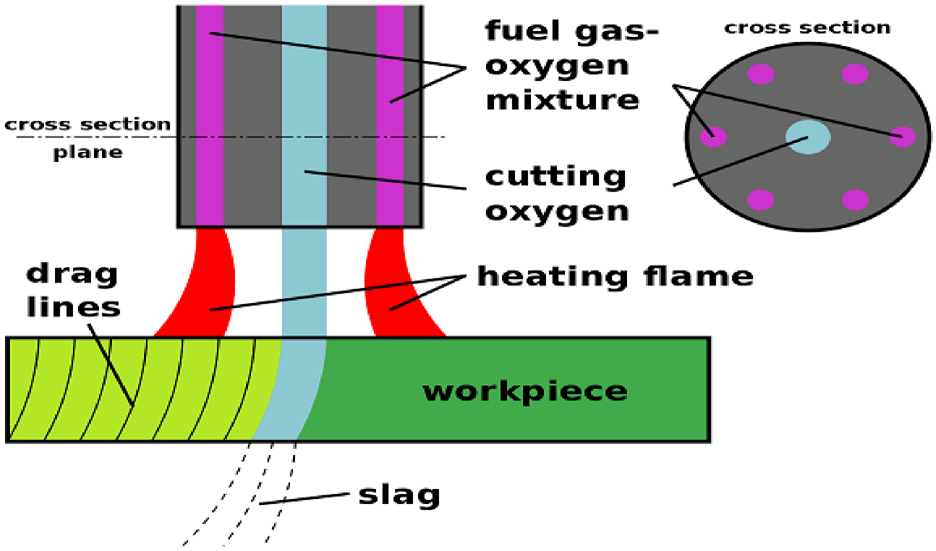
Working Principle of the Oxy-C2H2 Gas Welding Process:

The working principle of the Gas Welding process is as follows.

Oxygen and acetylene gases will be drawn from their respective cylinders mixed in the torch body so that the mixture is processing certain high pressure.

When these high-pressure mixture is passing through the convergent nozzle, the pressure energy is converted into velocity energy and coming out from the nozzle at high velocity.

When the initiation for the burning of this mixture is given, the continuous flame is produced and the heat available in the flame will be used for melting and joining of the plates.



Chemical Reactions Involved in Gas Welding:

$C_2H_2 + O_2 \rightarrow 2CO + H_2$ + heat

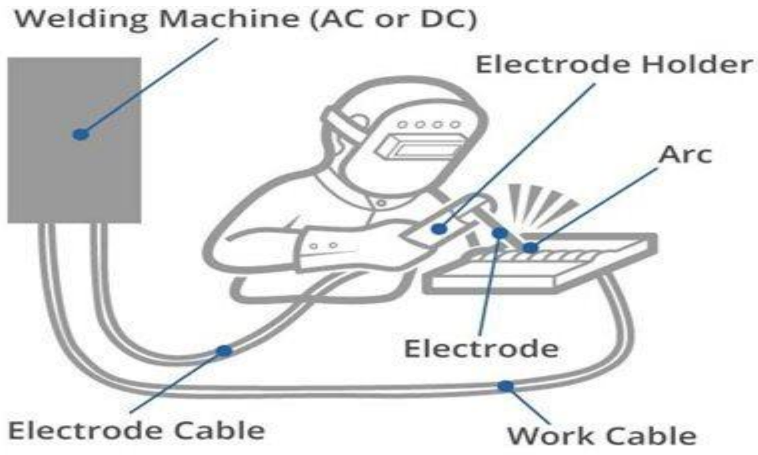
$2CO + O_2 \rightarrow 2CO_2$ + heat

$H_2 + 1/2\ O_2 \rightarrow H_2O$ + heat

For complete combustion of one unit Volume of acetylene, 2.5 units of volumes of oxygen are required.

How Does it Work?

Arc welding is a fusion welding process used to join metals. An electric arc from an AC or DC power supply creates an intense heat of around 6500°F which melts the metal at the join between two work pieces.



The arc can be either manually or mechanically guided along the line of the join, while the electrode either simply carries the current or conducts the current and melts into the weld pool at the same time to supply filler metal to the join.

Because the metals react chemically to oxygen and nitrogen in the air when heated to high temperatures by the arc, a protective shielding gas or slag is used to minimise the contact of the molten metal with the air. Once cooled, the molten metals solidify to form a metallurgical bond.

What are the Different Types of Arc Welding?

This process can be categorised into two different types; consumable and non-consumable electrode methods.

Consumable Electrode Methods

Metal Inert Gas Welding (MIG) and Metal Active Gas Welding (MAG)

Also known as **Gas Metal Arc Welding (GMAW)**, uses a shielding gas to protect the base metals from contamination.

Shielded Metal Arc Welding (SMAW)

Also known as **manual metal arc welding (MMA or MMAW)**, **flux shielded arc welding** or **stick welding** is a process where the arc is struck between the metal rod (electrode flux coated) and the work piece, both the rod and work piece surface melt to form a weld pool. Simultaneous melting of the flux coating on the rod will form gas, and slag, which protects the weld pool from the surrounding atmosphere. This is a versatile process ideal for joining ferrous and non-ferrous materials with a range of material thicknesses in all positions.

Flux Cored Arc Welding (FCAW)

Created as an alternative to SMAW, **FCAW** uses a continuously fed consumable flux cored electrode and a constant voltage power supply, which provides a constant arc length. This process either uses a shielding gas or just the gas created by the flux to provide protection from contamination.

Submerged Arc Welding (SAW)

A frequently-used process with a continuously-fed consumable electrode and a blanket of fusible flux which becomes conductive when molten, providing a current path between the part and the electrode. The flux also helps prevent spatter and sparks while suppressing fumes and ultraviolet radiation.

Electro-Slag Welding (ESW)

A vertical process used to weld thick plates (above 25mm) in a single pass. ESW relies on an electric arc to start before a flux addition extinguishes the arc. The flux melts as the wire consumable is fed into the molten pool, which creates a molten slag on top of the pool. Heat for melting the wire and plate edges is generated through the molten slag's resistance to the passage of the electric current. Two water-cooled copper shoes follow the process progression and prevent any molten slag from running off.

Arc Stud Welding (SW)

Similar to flash welding, **SW** joins a nut or fastener, usually with a flange with nubs that melt to create the join, to another metal piece.

Non-consumable Electrode Methods

Tungsten Inert Gas Welding (TIG)

Also known as **Gas Tungsten Arc Welding (GTAW)**, uses a non-consumable tungsten electrode to create the arc and an inert shielding gas to protect the weld and molten pool against atmospheric contamination.

Plasma Arc Welding (PAW)

Similar to TIG, **PAW** uses an electric arc between a non-consumable electrode and an anode, which are placed within the body of the torch. The electric arc is used to ionise the gas in the torch and create the plasma, which is then pushed through a fine bore hole in the anode to reach the base plate. In this way, the plasma is separated from the shielding gas.

Services

TWI has been at the forefront of developing arc welding processes and, as such, offers a number of associated services. Achievements include the invention of the twin wire MIG welding process (used to increase weld speed and metal deposition rate or to shape the weld bead) and transistor control technology, which paved the way for TWI to develop pulsed TIG, short-circuiting MIG and pulsed MIG processes.

4.2 Working principle, equipment, sketch, process parameters, applications of:

(i) MIG, TIG, Flux coated arc and submerged arc

Equipment Used in Arc Welding

A variety of equipment is used in the process of arc welding, including:

- **Welding machine:** Provides the power supply used for generating the heat necessary to the welding process.
- **Electrode holders:** They ensure electrodes are kept at a desired angle.
- **Cables or leads:** They carry current from the machine to the work.
- **Cable connectors:** Make a connection between machine switches and the electrode holder.
- **Chipping hammer and wire brushes:** Both are used to remove remaining particles or materials produced as a byproduct of the welding process.
- **Protective clothing and face shield:** Ultraviolet and infrared radiation is produced when welding, as well as sparks and heat. Protective clothing is worn, as well as a screen or shield to protect the eyes and face.

Welding is the practice of joining separate metal pieces by melting, then fusing them.
There are quite a few welding processes, including many you may never have heard of.

Some high-tech methods use lasers, microwaves, or electromagnets.
There are also low-tech methods like melting with a torch or forge, then hammering two pieces into one.

Here’s a look at the four most commonly used welding processes.

Four Common Types Of Welding Processes

There are many types of welding processes, but the four most common welding processes are:

1. MIG Welding (GMAW)
2. TIG Welding (GTAW)
3. Stick Welding (SMAW)
4. Flux Cored Arc Welding (FCAW)

Some of the reasons they’re so dominant:

- Industrial demands
- Affordability for DIY craftsmen
- With TIG welding, very high quality is key.
- Easy to learn (except TIG)

They’re all arc welding processes, meaning the workpiece, the grounding clamp, and the electrode complete an electrical circuit when the electrode makes contact. Lifting creates an arc.
This arc of electricity reaches thousands of degrees, melting the metal and causing separate pieces to flow together. The electrode uses a filler metal that melts and fills the gap, becoming part of the single piece of metal.

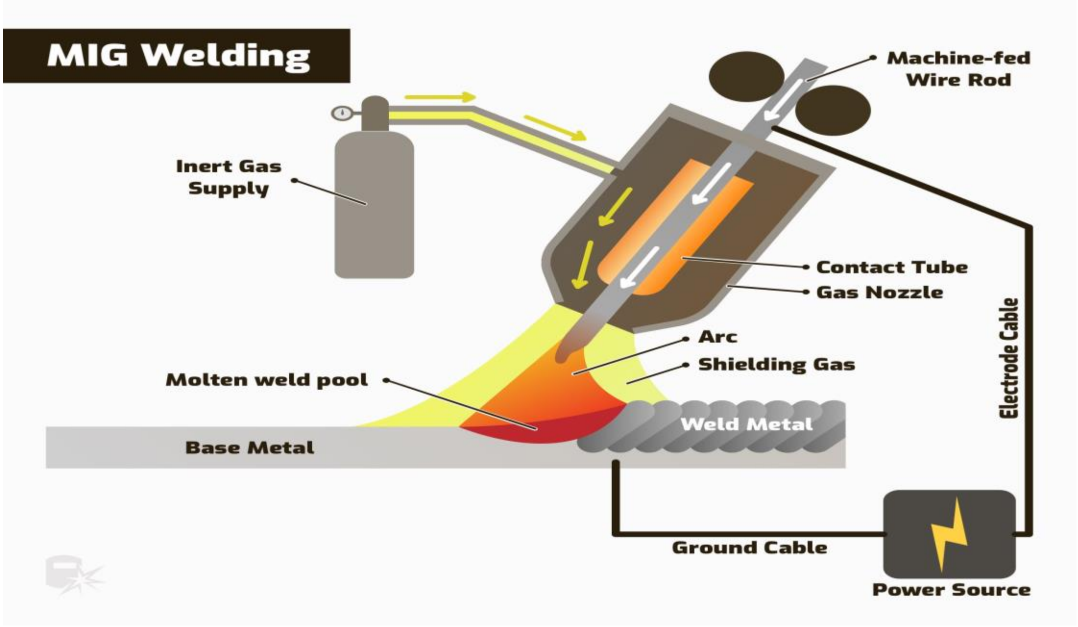
Thousands of degrees of surface heat generate chemical reactions with air and substances like oil or rust. Oxygen and nitrogen cause brittleness, rusting, porosity, and possible failure.

Each process shields the molten weld puddle from air and surface contaminants by flooding the arc region with inert gases, which don't react to other chemicals. Finished welds are much stronger, more consistent, and much cleaner without contacting the air while reaching fusion.

1. GMAW: Gas Metal Arc Welding (MIG Welding)

With MIG welding, the shielding gas comes from a pressurized bottle of inert gas. The arc is produced by a wire that also melts, filling the joint.

How It Works



GMAW welding is usually called MIG. In this process, the electrode is an electrically charged wire, continually feeding from a motorized spool into the weld while also flooding the shielding gas over the weld.
The welding lead to the MIG gun connects the power, has a sleeve inside to slide the electrode wire, and includes a gas hose as part of the MIG torch connection.

The shielding gas for MIG is usually carbon dioxide.

When It's Used

If speed is an issue, you're a beginner, or you need to keep the heat down, MIG welding is your best process. The shielding gas adds a layer of complexity but also provides good heat control and a clean weld.

Pros

- Good for production welding
- Continuous wire feed means easy to learn

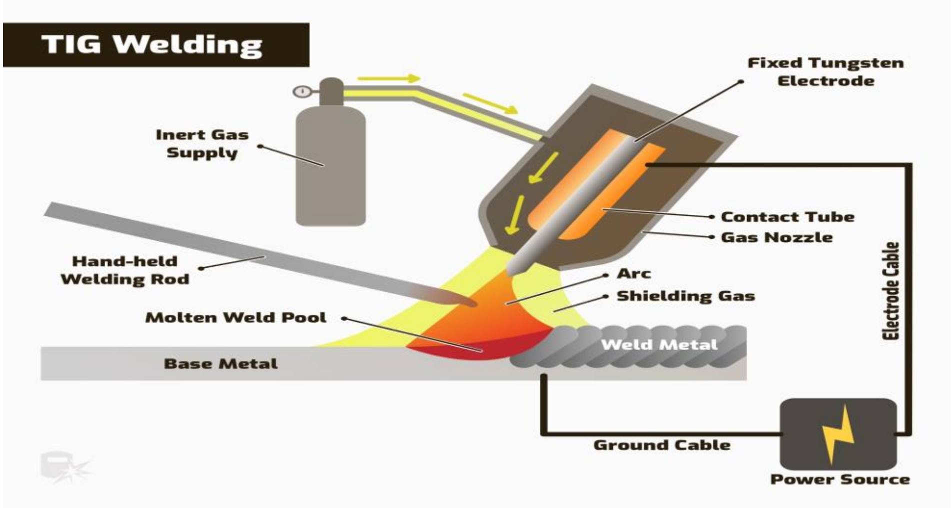
- Good heat control
- Clean welds
- Easy to learn

Cons

- Wind can blow away the shielding gas
- All paint and rust must be removed

2. GTAW: Gas Tungsten Arc Welding (TIG Welding)
TIG is a difficult process to master. It takes more knowledge, dexterity, time, and experience than other processes but pays off with better, more beautiful, and stronger welds.

How It Works



The main way TIG differs from other processes is its electrode. The electrode in the torch is a short tungsten rod, sharpened to a point.
The difference is that the electrode isn't consumed. Instead, while working the torch with one hand, the operator feeds a long rod made of filler metal into the weld puddle. This metal rod is consumed by the weld puddle. The electrode only strikes and maintains the arc to melt the metal as a flame torch would.
Favorable results depend greatly on the operator to handle the torch well, control the heat level and feed the filler rod at just the right speed. Like a MIG setup but with no wire feeding mechanism, the TIG torch connection carries pressurized inert gas to flood the arc region. The usual shielding gas for TIG welding is argon.

When It's Used

TIG welding is used in places where strong and clean welds are needed. Some structures made by TIG welding are covered once built and can't be maintained easily. Aircraft frames, electric devices, high-end electronics cabinetry, and race car roll cages are some examples.

Another case for TIG is the opposite situation, where the weld is always visible and requires a certain level of eye appeal or high-tech validation. Exposed hot rod frames, custom bodywork, or designer lawn furniture are some instances.

Pros

- AC TIG welds aluminum and magnesium alloys
- DC TIG welds brass, copper, steel, stainless steel, and titanium
- Best quality, highest precision
- Able to weld very thin materials
- No slag

Cons

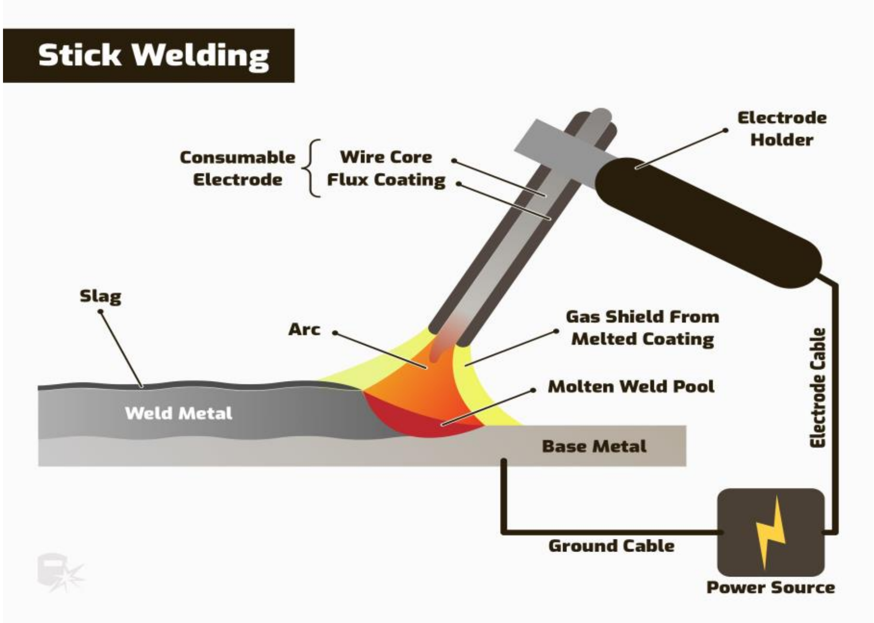
- It takes more skill and experience to master
- TIG machines are more costly

Related read: Differences Between MIG & TIG

3. SMAW: Shielded Metal Arc Welding (Stick Welding)

Stick welding came first, and it’s the simplest concept. People have been stick welding since the late 1800s. It has the oldest, simplest, and most proven technology.

How It Works



A stick welder has a power source and big cable leads with an electrode holder on one lead and a heavy clamp for the workpiece on the other. The electrode is a metal rod, like a piece of thick wire. They come in different metals and alloys.

The diameter of the welding rod varies. It’s selected according to the thickness of the metal. Welding rods are covered with a thick coating of a material called flux that burns in the arc, generating a gas to shield the welding puddle.

As the metal cools, the flux forms a thin, brittle crust called slag that must be chipped off and brushed away.

When It's Used

If it can be welded at all, it's welded by stick. Stick arc is preferred when it's hard to reach the weld, or there's rust, oil, and other contaminants at the weld joint. It works well on steel, cast iron, aluminum, stainless, and hard surfacing on farm equipment.

Pros

- Easy to learn
- Affordable
- Not contaminant sensitive
- You can weld almost any metal

Cons

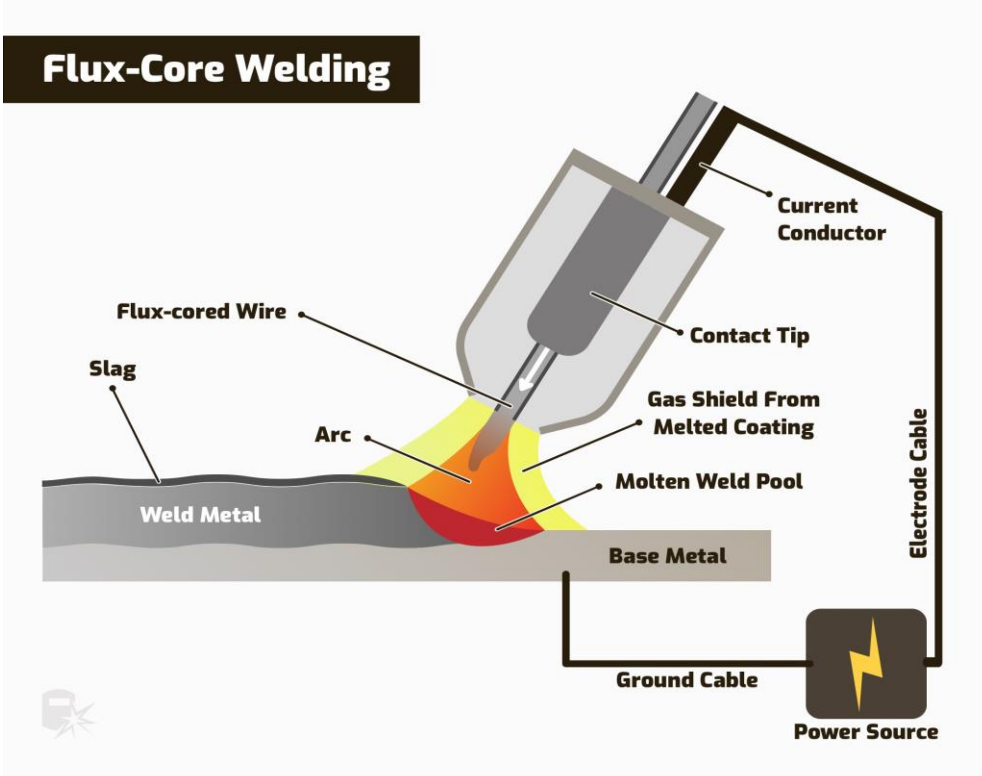
- Thin metal can be hard to work
- Generates a lot of heat.
- It takes a lot of time

Also read: Differences between MIG and Stick

4. FCAW: Flux Cored Arc Welding

Flux core welding. also known as gasless MIG welding, is a highly versatile process known for low cost, easy learning, and strong results. It's also used in manufacturing, but with shielding changes and bigger machines.

How It Works



Like how the stick process has an electrode coated in flux, the FCAW process uses a hollow wire filled with flux.

FCAW feeds a spool of wire through the welding lead as MIG does. You can weld faster than stick welders because the only time you change the electrode is when the wire spool runs out.

FCAW-S and FCAW-G

There are two flavors of flux core welding in main use.

FCAW-S

The "S" means "self-shielded," and it's the most common flux core technique because it's inexpensive, simple, and effective in a breeze.

FCAW-G

Also known as dual-shielded wire welding, the "G" means that an external shielding gas is used in addition to the standard flux core wire. This approach provides a smoother, more controllable arc than FCAW-S and MIG processes.

When It's Used

Most commonly, flux core welding is seen among hobbyists, small businesses, and fabrication shops because it provides great penetration, heat control, and ease of use at an inexpensive cost compared to MIG welding.

Pros

- Probably the easiest process to learn
- Works well on dirt, paint, and rusty material
- Can be used in windy conditions
- Handles thick steel well

Cons

- Slag needs to be removed
- Produces a lot of spatter

(ii) Resistance welding –Butt, Seam, Spot, Projection and Percussion.

RESISTANCE WELDING

In resistance welding the metal parts to be joined are heated by their resistance to the flow of an electrical current. Usually this is the only source of heat, but a few of the welding operations combine resistance heating with arc heating, and possibly with combustion of metal in the arc. The process applies to practically all metals and most combinations of pure metals and those alloys, which have only a limited plastic range, are welded by heating the parts to fusion (melting). Some alloys, however, may welded without fusion; instead, the parts are heated to a plastic state at which the applied pressure causes their crystalline structures to grow together. The welding of dissimilar metals may be accomplished by melting both metals frequently only the metal with the lower melting point is melted, and an alloy bond is formed at the surface of the unmelted metal.

In resistance welding processes no fluxes are employed, the filler metal is rarely used and the joints are usually of the lap type. The amount of heat generated in the workpiece depend on the following factors:
(1) Magnitude of the current,
(2) Resistance of the current conducting path, and Mathematically, H = IVt= I(IR)t= I2Rt

Where, H = heat generated in joules, I = current in Amp.,

R = resistance in ohms, t = time of current flow in seconds.

Types of Resistance welding

The major types of resistance welding are given as under:
(1) Spot Welding
(2) Seam Welding
(3) Projection Welding
(4) Resistance Butt Welding
(5) Flash Butt Welding
(6) Percussion Welding
(7) High Frequency Resistance Welding
(8) High Frequency Induction Welding

Some of the above important welding processes are discussed as under,

Spot Welding

In this process overlapping sheets are joined by local fusion at one or more spots, by the concentration of current flowing between two electrodes. This is the most widely used resistance welding process. A typical resistance spot welding machine is shown in Fig. It essentially consists of two electrodes, out of which one is fixed. The other electrode is fixed to a rocker arm (to provide mechanical advantage) for transmitting the mechanical force from a pneumatic cylinder. This is the simplest type of arrangement. The other possibility is that of a pneumatic or hydraulic cylinder being directly connected to the electrode without any rocker arm. For welding large assemblies such as car bodies, portable spot welding machines are used. Here the electrode holders and the pneumatic pressurizing system are present in the form of a portable assembly which is taken to the place, where the spot is to be made. The electric current, compressed air and the cooling water needed for the electrodes is supplied through cables and hoses from the main welding machine to the portable unit. In spot welding, a satisfactory weld is obtained when a proper current density is maintained. The current density depends on the contact area between the electrode and the work-piece. With

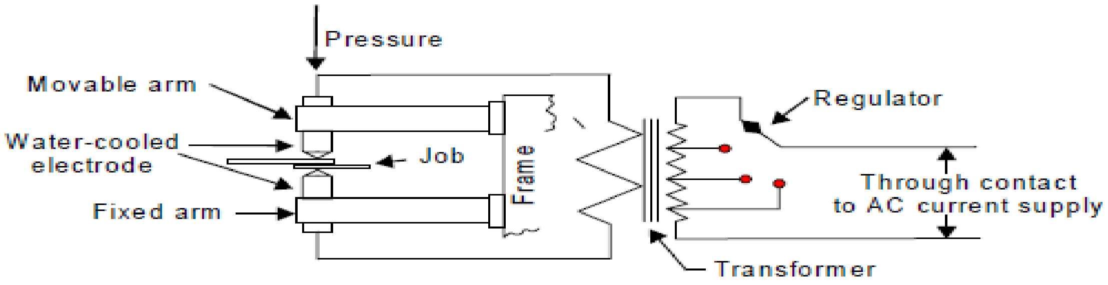
the continuous use, if the tip becomes upset and-
the contact area increases, the current density will be lowered and consequently the
weld is obtained over a large area. This would not be able to melt
the metal and hence there would be
no proper fusion. A resistance welding schedule is the sequence of events that normally take pl
ace in each of the welds. The events are:

1. The squeeze time is the time required for the electrodes to align and clamp the two work-pieces together under them and provide the necessary electrical contact.

2. The weld time is the time of the current flow through the work-pieces till they are heated to the melting temperature.

3. The hold time is the time when the pressure is to be maintained on the molten metal without the electric current. During this time, the pieces are expected to be forged welded.

4. The off time is time during which, the pressure on the electrode is taken off so that the plates can be positioned for the next spot.



Resistance spot welding machine setup

Before spot welding one must make sure that
(i) The job is clean, i.e., free from grease, dirt, paint, scale, oxide etc.

(ii) Electrode tip surface is clean, since it has to conduct the current into the work with as little loss as possible. Very fine emery cloth may be used for routine cleaning.
(iii) Water is running through the electrodes in order to
(a) Avoid them from getting overheated and thus damaged,
(b) Cool the weld.
(iv) Proper welding current has been set on the current selector switch.
(v) Proper time has been set on the weld-timer.

Spot welding electrodes

Spot welding electrodes are made of materials which have
(1) Higher electrical and thermal resistivities, and

(2) Sufficient strength to withstand high pressure at elevated temperatures. Copper base alloys such as copper beryllium and copper tungsten are commonly used materials for spot welding electrodes. For achieving the desired current density, It is important to have proper electrode shape for which three main types of spot welding electrodes are used which are pointed, domed and flat electrodes.

Applications of Spot Welding

(i) It has applications in automobile and aircraft industries

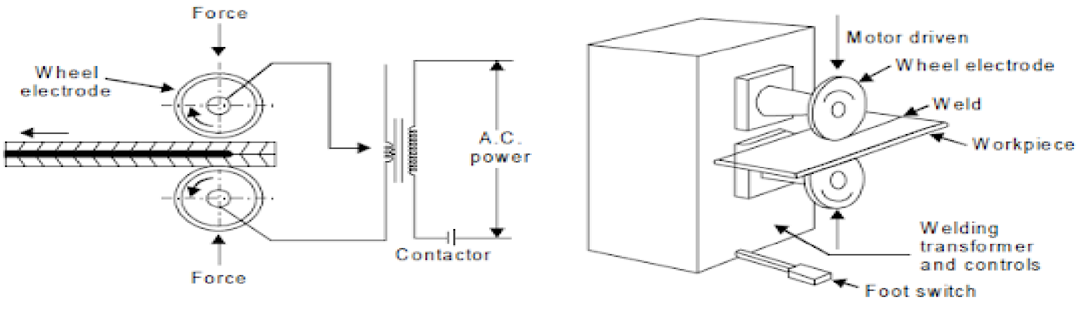
(ii) The attachment of braces, brackets, pads or clips to formed sheet-metal parts such as cases, covers or trays is another application of spot welding.

(iii) Spot welding of two 12.5 mm thick steel plates has been done satisfactorily as a replacement for riveting.

(iv) Many assemblies of two or more sheet metal stampings that do not require gas tight or liquid tight joints can be more economically joined by spot welding than by mechanical methods.
(v) Containers and boxes frequently are spot welded.

Resistance Seam Welding

It is a continuous type of spot welding wherein spot welds overlap each other to the desired extent. In this process coalescence at the faying surfaces is produced by the heat obtained from the resistance to electric current (flow) through the work pieces held together under pressure by circular electrodes. The resulting weld is a series of overlapping resistance-spots welds made progressively along a joint by rotating the circular electrodes. The principle of seam welding and resistance seam welding process set up is shown in Fig. The seam welding is similar to spot welding, except that circular rolling electrodes are used to produce a continuous air-tight seam of overlapping welds. Overlapping continuous spot welds
seams are produced by the rotating electrodes and a regularly interrupted current.



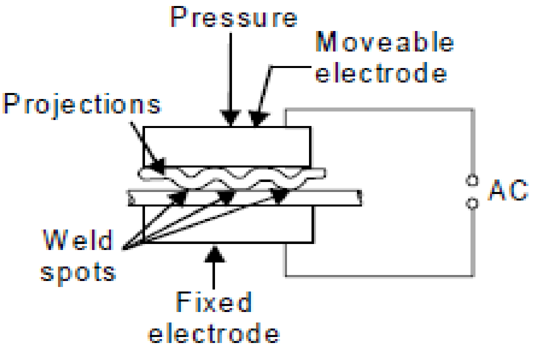
Principle of seam welding process & Resistance seam welding process setup

Application Resistance Seam Welding

1. It is used for making leak proof joints in fuel tanks of automobiles.
2. Except for copper and high copper alloys, most other metals can be seam welded.
3. It is also used for making flange welds for use in watertight tanks.

Resistance Projection Welding

Fig.shows the projection welding. This process is a resistance welding process in which two or more than two spot welds are made simultaneously by making raised portions or projections on predetermined locations on one of the workpiece. These projections act to localize the heat of the welding circuit. The pieces to be welded are held in position under pressure being maintained by electrodes. The projected contact spot for welding should be approximately equal to the weld metal thickness. The welding of a nut on the auto- motive chasis is an example of projection welding.

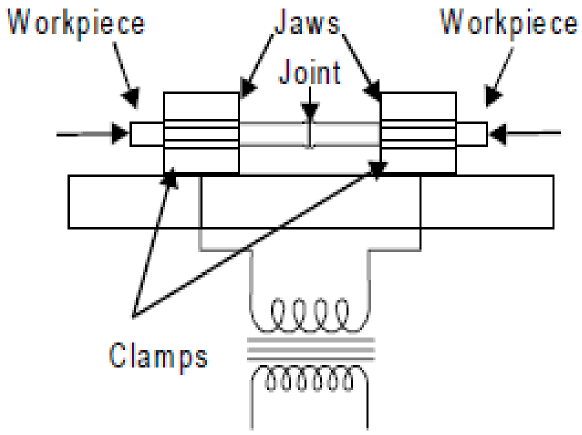


Resistance projection welding

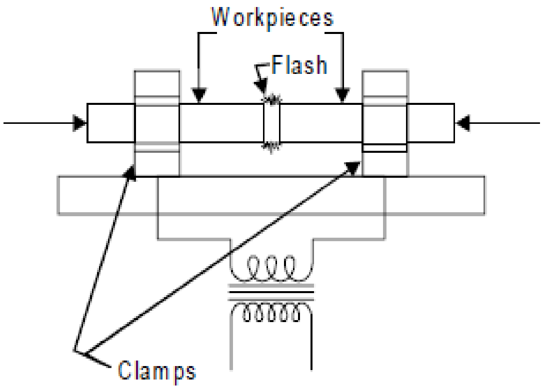
Resistance Upset Butt and Flash Butt Welding

This welding is also used for joining metal pieces end to end but it has largely replaced the butt-welding method for weld articles small cross-sections. It can be used for thick sections also. Initially the current is switched on and then one end the moveable part to be welded is brought gently closer to the fixed end of the other part to localize heat at the ends and thus raises the temperature of the ends quickly to the welding heat. On acquiring contact of fixed end and moveable end with each other, the moveable end is then pressed against one another by applying mechanical pressure. Thus the molten metal and slag to be squeezed out in the form of sparks enabling the pure metal to form the joint and disallowing the

heat .to spread back. The principle of upset butt welding and flash butt welding are depicted in Fig. In this resistance welding single phase A.C. machines are commonly employed.



Resistance upset butt welding



Resistance flash butt welding

The merits and demerit of flash welding over simple butt-welding are follows:

Merits

1. It is comparatively much faster than butt welding.

2. This method utilizes less current in comparison to butt welding as the small portion of the metal is only being heated for getting a good weld

3. Created joint by this welding is much stronger than the butt welding joint. Also the strength of the weld produced is high even more than that of the base metal. The end of the metal pieces to be welded in this welding need not be squared as it is the basic requirement in butt-welding.

4. A high degree of accuracy can be easily achieved in terms of length alignment of weld.

Demerits

1. The periodic maintenance of machine and replacement of insulation is needed as flashing particles of molten metal are thrown out during welding which may enter into the slide ways and insulation of the set up.

2. Welder has to take enough care against possible fire hazard due to flashing during welding.

3. Additional stock has to be provided for compensating loss of metal during f1ashing and upsetting. This increases to the cost of weld.
4. Cost of removal of flash weld metal by trimming, chipping, grinding, etc. will increase to the welded product.

1. Surface of the jobs where they come in contact with the gripping surfaces, should be clean otherwise they will restrict the flow of electric current.

2. The available power, opening between the jaws of the gripping clamps and upsetting pressure of the welding set limit the size and cross sectional area of the jobs to be welded.

Applications of Resistance Welding

All conducting forged metals can be easily be flash welded. A number of dissimilar metals can also be welded by controlling the welding conditions carefully. Metals generally welded metal by the process involves lead, tin, antimony, zinc, bismuth and their alloys, low carbon steels, stainless steel, alloy steels, tool steels, copper alloys, aluminium alloys, magnesium alloys nickel alloys, molybdenum alloys, and titanium alloys. This process is used in automobil e industry, welding of solid and tubular structural assemblies, etc. in air-craft industry, welding of band saw blades, welding of tool steel drills, reamers and taps etc. to mild steel or alloy steel shanks, welding of pipes and tubes.

Common Advantages of Resistance Welding

Some common advantages of resistance welding include:
(a) It is well suited for mass production.
(b) It is economical in operation, since nothing is consumed except electrical power.
(c) Skilled welders are not required.
(d) Welds are quickly made.
(e) It is possible to weld dissimilar metals. Some disadvantages of resistance welding include:
(a) High initial cost of the resistance welding equipment
(b) Certain resistance welding processes are limited to lap joints.

A lap joint has an inherent service between the two metal pieces, which causes stress concentrations in applications where fatigue is present. This service may also cause trouble when corrosion is present

(iii) Thermit welding.

Thermit Welding: Process, Operation and Uses (With Diagram)

After reading this article you will learn about:- 1. Process of Thermit Welding 2. Operation of Thermit Welding 3. Application and Uses 4. Advantages 5. Disadvantages.

Process of Thermit Welding:

Thermit welding is a chemical welding process in which an exothermic chemical reaction is used to supply the essential heat energy. That reaction involves the burning of Thermit, which is a mixture of fine aluminum powder and iron oxide in the ratio of about 1:3 by weight.

Although a temperature of 3000°C may be attained as a result of the reaction, preheating of the Thermit mixture up to about 1300°C is essential in order to start the reaction.

The mixture reacts according to the chemical reaction:

$8\ Al + 3\ Fe_3O_4 \rightarrow 9\ Fe + 4\ Al_2O_3$ + heat (3000˚C, 35 kJ/kg of mixture)

Aluminum has greater affinity to react with oxygen; it reacts with ferric oxide to liberate pure iron and slag of aluminum oxide. Aluminum oxide floats on top of molten metal pool in the form of slag and pure iron (steel) settled below, because of large difference in densities.

Operation of Thermit Welding:

Thermit welding process is essentially a casting and foundry process, where the metal obtained by the Thermit reaction is poured into the refractory cavity made around the joint.

The various steps involved in Thermit welding are:

1. The two pieces of metal to be joined are properly cleaned and the edge is prepared.

2. Then the wax is poured into the joint so that a wax pattern is formed where the weld is to be obtained.

3. A moulding box is kept around the joint and refractory sand is packed carefully around the wax pattern as shown in Fig. 7.40, providing the necessary pouring basin, sprue, and riser and gating system.

4. A bottom opening is provided to run off the molten wax. The wax is melted through this opening which is also used to preheat the joint. This makes it ready for welding.

5. The Thermit is mixed in a crucible which is made of refractory material that can withstand the extreme high heat and pressure, produced during the chemical reaction.

6. The igniter (normally barium peroxide or magnesium) is placed on top of the mixture and is lighted with a red hot metal rod or magnesium ribbon.

7. The reaction takes about 30 seconds and highly super-heated molten iron is allowed to flow into the prepared mould cavity around the part to be welded.

8. The super-heated molten metal fuses the parent metal and solidifies into a strong homogeneous weld.

9. The weld joint is allowed to cool slowly.

There are different Thermit mixtures available for welding different metals, such as copper and chromium. They use different metal oxides in place of ferrous oxide. Some typical Thermit mixture reactions with their temperature obtained are given below:

$3\,CuO + 2\,Al \rightarrow 3Cu + Al_2O_3$ + Heat (4860°C, 275 Kcal)

$Cr_2O_3 + 2Al \rightarrow 2Cr + Al_2O_3$ + Heat (3000°C, 540 Kcal)

Application and Uses of Thermit Welding:

Thermit welding is a very old process and now-a-days, in most cases, it is replaced by electro-slag welding. However, this process is still in use.

Some applications are:

(i) Thermit welding is traditionally used for the welding of very thick and heavy plates.

(ii) Thermit welding is used in joining rail roads, pipes and thick steel sections.

(iii) Thermit welding is also used in repairing heavy castings and gears.

(iv) Thermit welding is suitable to weld large sections such as locomotive rails, ship hulls etc.

(v) Thermit welding is used for welding cables made of copper.

Advantages of Thermit Welding:

1. Thermit welding is a simple and fast process of joining similar or dissimilar metals.

2. This process is cheap, as no costly power supply is required.

3. This process can be used at the places where power supply is not available.

Disadvantages of Thermit Welding:

1. Thermit welding is essentially used for ferrous metal parts of heavy sections.

2. It is uneconomical for welding cheap metals and light parts.

(iv) Forged welding

What is forge welding?

Forge welding is a process used to join two pieces of metal together by heating them to a high temperature and then hammering them together. Developed in the Middle Ages, forge welding is one of the oldest methods of joining metals. Forge welding is an essential technique and an invaluable skill for a blacksmith. It came from the necessity to integrate little pieces of metal to form a large piece of metal. With practice, forge welding requires hand-eye coordination, speed, and attention to detail. It also requires the blacksmith to understand the ideal temperature of the material being welded.

What is forge welding used for?

Forge welding is used to create a more substantial metal by joining individual pieces of metal to create a larger or longer project. It is the traditional method of creating chains, swords, railroad spikes, and gates in the blacksmith shop. It is also used in the creation of cookware and farming equipment. Granting the blacksmith the ability to forge different types of metals into one, forge welding is a versatile and essential skill in the smithy.

4.3 Effects of welding heat

Heat Affected Zone – Causes, Effects and How to Reduce It

The heat affected zone (or simply HAZ) is something that occurs when metal is subject to high temperatures. It has a negative impact on the design and structure of the metal. This article discusses those effects and how to reduce them.

Some manufacturing procedures that produce the HAZ are mechanical cutting, thermal cutting and welding.

With mechanical cutting, the shear strength of the metal has to be surpassed. The majority of the energy converts into heat that influences both the life-span of the tools and the metal being cut.

Thermal cutting methods, like laser cutting and plasma cutting, actually use heat for cutting. Again, the same structural and aesthetic changes take place.

Welding, similarly to thermal cutting, uses very high temperatures to either add molten metal or melt the parts themselves.

As the formation of the heat affected zone has a considerable effect on the quality of the final product, it is good to understand the different aspects of it.

What is the Heat Affected Zone?

During metal cutting or metal welding, the metal absorbs the generated heat. This heat transmits away from the cutting edge through the metal body, as metal is a good heat conductor.

A zone is formed between the melted metal and the unaffected base metal called the heat affected zone (HAZ). In this zone, the metal is not melted but the heat has led to changes in the metal’s micro-structure. These changes in structure can reduce the metal’s strength.

The HAZ is identifiable by a series of brightly coloured bands between the cutting/welding interface and the unaffected base metal. The colours range from light yellow to purple as shown in the table below.

It is very important to understand that the HAZ accounts for reduced strength to design safe applications. **The weakest sections of a structure** exist in the HAZ.

A structure is as strong as its weakest point. Therefore, recognising the HAZ may be the difference between the success and failure of a particular part.

What Does the Colour Tell?

As a result of using different temperatures during manufacturing processes, a variety of tints are present in the HAZ. These tints range from light yellow to dark blue in increasing order of the temperature.

The band colours in order of temperature progression are:

Colour	**Cutting temperature**
Light yellow	290º C
Straw yellow	340º C
Yellow	370º C
Brown	390º C

Purple brown	420º C
Dark purple	450º C
Blue	540º C
Dark blue	600º C

Factors that further affect the formation of these heat tints are:

- **Surface condition** – Rougher surfaces oxidise faster producing more pronounced colouration.
- **Surface contamination** – Impurities like rust, paint and oil also effect the tint. The contamination may change the heat tint but the extension of the HAZ is unaffected.
- **Oxygen availability** – As limiting access to oxygen reduces oxidation, using an electrode coating or a protective gas for welding can affect the heat tint.
- **Chromium content** – Chromium increases oxidation resistance. Therefore, higher chromium content reduces the intensity of the heat tint.

Heat Affected Zone Formation

The cause of the forming of the HAZ is clearly heat. The width of the zone still depends on several factors, like thermal diffusivity and choice of cutting methods.

Thermal Diffusivity

Thermal diffusivity of metal plays the primary role in determining how HAZ will affect the metal. It is the ratio of thermal conductivity of the metal divided by its density and specific heat capacity at constant pressure.

In simple words, thermal diffusivity of a metal is the measure of how fast heat will be transmitted through its body. If the thermal diffusivity is high, the metal will be able to transmit heat sooner. This leads to faster cooling and the HAZ will be narrower. On the other hand, low thermal diffusivity will keep heat in the metal for a longer duration and create a wider HAZ.

The thermal diffusivity of stainless steel AISI 304 is 4.2 mm^2/s, whereas for structural steel it is 11.72 mm^2/s. This means that structural steel, when subjected to heat, will create a smaller HAZ as it will cool down quicker.

The creation of HAZ depends upon various other factors too. The zone width depends on the amount of heat generated, the duration of the exposure to heat and material thickness.

Thin sheet metal heats up more quickly and therefore creates a larger heat affected zone.

4.4 Weld defects and their causes.

What is Welding Defect?

Contents show

Welding defects are formed in welding work due to the weak or poor technique used by inexperienced or untrained welders or due to structural problems in the welding operation.

Or you can say, in a welding process, the size and shape of the metal structure are varied. It is maybe due to the incorrect welding process or the application of the incorrect welding procedure.

An ideal weld or good weld must be one that exists with good penetration with sufficient fusion between the filler metal and the edge preparation.

You can read also about different welding processes like plasma arc welding, laser beam welding, resistance welding, gas welding, and arc welding you can check them out by clicking on them.

For this article, let's discuss the types of welding defects that appear while welding.

Types of Welding Defects

Following are the **types of welding defects:**

1. Porosity and Blowholes
2. Undercut
3. Weld crack
4. Incomplete fusion
5. Slag inclusion
6. Incomplete penetration
7. Spatter
8. Distortion
9. Hot Tear
10. Mechanical damage
11. Misalignment
12. Excess reinforcement
13. Overlap
14. Lamellar tearing
15. Whiskers

#1 Porosity and Blowhole

Porosity is a group of small bubbles and blowholes are relatively large hidden holes or pores. They are mainly caused by trapped gases. Porosity is a result of weld metal contamination.

Causes and Remedies of Porosity

Causes of Porosity	**Remedies of Porosity**
Using insufficient electrode deoxidant.	Choosing suitable electrode and filler materials.

Applying too large a gas flow.	Checking the gas flow meter and ensuring that it is adapted as needed with appropriate pressure and flow settings.
Using a larger arc.	Make sure that the arc distance is correct.
Existence of moisture in the process.	Cleaning the metal before starting the welding process.
Unsuitable gas shield.	Decreasing welding speed, it will allow the gas to escape.
Dirty job surface i.e. the occupation of scales, rust, oil, grease, etc. on the surface of the job.	Individual cleaning and prevention of pollution from entering the weld zone.

#2 Undercut

Undercut in welding makes imperfection, it is the formation of grooves in the weld toe, which decreases the cross-sectional thickness of the base metal. As a result of this weld and workpiece get weakened.

Causes and Remedies of Undercut

Causes of Undercut	**Remedies of Undercut**
Incorrect use of angle, which will deliver more heat to the free edges.	Using of suitable electrode angle, with more heat delivered towards thicker components.
Because of too fast weld speed.	Decreasing the travel speed of the electrode, but should not be too slow.
Using poor welding methods.	Applying the multipass technique.
Use of incorrect gas shielding and filler metal.	Select the shielding gas with the right structure for the material you are welding.

Doing too high weld current.	When approaching thin areas and free edges, use an appropriate stream to reduce them.
Using larger diameter electrodes.	Decreasing the arc length.

#3 Weld Crack

These are the most dangerous types of welding defects. It is almost not allowed by all standards in production. It can appear on the surface, in the weld metal, or in an area affected by strong heat.

There are different types of cracks that occur during welding, it depends on the temperature.

1. Hot Cracks

Hot cracks happen while the welding process or during the crystallization process of the weld joint. Temperatures at this point can exceed 10,000C.

2. Cold Cracks

These cracks occur after the weld is created and the metal temperature has passed down. They can also be made hours or days after welding steel. This mostly occurs when the deformation is made in the steel structure.

3. Crater Cracks

These cracks occur at the end of the welding process before the operator completes the weld joint. They are usually made near the end of the process.

When the weld pool cools and freezes, the weld must be sufficient in volume to overcome the metal shrinkage. Otherwise, it will make a crater crack.

Causes and Remedies of Weld Crack

Causes of Weld Crack	**Remedies of Weld Crack**
Using hydrogen while welding ferrous metals.	Using suitable metals.
Applying low current with high welding speed.	Utilizing the appropriate welding speed and current.

The design concept is poor.	Using proper design concepts.
Not doing preheating before starting welding.	Preheating the metal before starting welding.
Contamination of base metal.	Cleaning the metal surface before welding.
Residual stress solidification due to shrinkage.	Giving decent cooling of the weld area.
The high mixture of sulfur and carbon in the metal.	Using a correct mixture of sulfur and carbon in the metal.
Improper filling of the crater in welding.	Ensure that the crater is properly filled to prevent crater cracks.

#4 Incomplete Fusion

These types of welding defects occur when there is a shortage of suitable fusion between the metal and weld. It may also be visible between adjacent weld beads. This produces a gap inside the joint that is not filled with molten metal.

Causes and Remedies of Incorrect Fusion

Causes of Incorrect Fusion	**Remedies of Incorrect Fusion**
Contamination of metal surface.	Cleaning the welding area of the metal surface before welding.
Using low heat input.	Utilizing the proper heat input for welding.
The diameter of the electrode is wrong for the thickness of the material you are welding.	Use the correct diameter of the electrode to fit the thickness of the material that you are welding.

Incorrect electrode angle.	Ensure the angle of the electrode is suitable for welding.
Employing too fast travel speed.	Decreasing the speed of arc travel.
The weld pool is very large and it moves ahead of the arc.	Make sure the weld pool that you are using is proper according to the movement of the arc.

#5 Slag Inclusion

Slag inclusion is welding defects that are usually visible in welds. The slag is a dangerous substance that appears as a product of stick welding, flux-core arc welding, and submerged arc welding.

It is can occur when the flux, which is a solid shielding material applied when welding, melts in the weld or on the surface of the weld region. Slag inclusion decreases the strength of the joint and hence makes it weaker.

Causes and Remedies of Slag Inclusion

Causes of Slag Inclusion	**Remedies of Slag Inclusion**
Poor chipping and cleaning of previous passes in multipass welding.	Through the wire brush, clean the weld bed surface before the next layer is deposited.
Due to the incorrect angle of the electrode.	Adjusting the angle of the electrode.
Using too low welding current.	Increasing the current density.
Insufficient space for the puddle of molten weld metals.	Redesigning the joint to allow sufficient space for proper use of the puddle of molten weld metals.
Maybe cooling is very fast.	Decreasing the rapid cooling.

Cleaning of the metal may be improper.	Proper cleaning of the metal before welding.
The speed of welding is fast.	Reducing the speed of the welding.

#6 Incomplete Penetration

In these types of welding defects, penetration is defined as the distance from the uppermost surface of the base plate to the maximum extent of the weld nugget.

Incomplete penetration happens when the metal groove is not entirely filled, which means that the weld metal does not fully spread through the joint thickness.

Causes and Remedies of Incomplete Penetration

Causes of Incomplete Penetration	**Remedies of Incomplete Penetration**
There was too much space between the metal that you are welding with.	Assuring that the surface is jointly fine.
You are moving the bead too fast, which does not allow sufficient metal to accumulate in the joint.	Decreasing the arc travel speed.
You are using a very low amper setting, which results in the current not being strong enough to melt the metal properly.	Selecting a decent welding current.
Using improper joints.	Improving the design of the joint.
Wrong position of the electrode.	Make sure the position of the electrode is very accurate.
Using of larger diameter electrode.	You must need to use proper diameter electrodes as suitable for your welding.

#7 Spatter

Spatters are tiny metal particles that are ejected from the arc during welding and accumulate on the base metal throughout the weld bead along its length. This is particularly common happens in gas-metal arc welding.

Causes and Remedies of Spatter

Causes of Spatter	**Remedies of Spatter**
Contamination of metal surface.	Cleaning metal surfaces before welding.
The working angle of the electrode is much more rigid.	Decreasing the arc length and increasing the electrode angle.
Utilizing too high amper current and too low voltage settings.	Using proper polarity with adjusting the weld current.
Using the larger arc and wet electrode.	Make sure to use the proper arc and electrode according to the welding.

#8 Distortion

Distortion is the difference in size and location between the positions of the two metal plates before and after welding due to the temperature grade present at several points along the weld joints.

Or in other words, you can say that the distortion is due to uneven extension and reduction of the weld metal and that all kinds of distortion rise with the number of metal depositions.

Causes and Remedies of Distortion

Causes of Distortion	**Remedies of Distortion**
Employing incorrect welding orders.	Ensure to use the correct welding order.
Using a large number of passes with small diameter electrodes.	Using the appropriate number of weld passes.

Because of high residual stresses in the plate to be welded.	Make sure you use the appropriate amount of weld metal as required by the joint. This will decrease contraction forces.
Due to the slow speed of arc travel.	Maintaining the speed of arc travel.
Not using any measuring instrument for dimension purposes.	If required you can use a measuring instrument, so that dimensional accuracy is accurate.
Using too much time for the welding process.	Decreasing the time of the welding process so that the volume around the metal is not even expanded.

#9 Hot Tear

In these types of welding defects, the deposited metal starts to develop cracks from the nearby edge so that it will solidify the crack increase.

Due to the tearing of grain boundaries of the weld metal before it freezes and the metal is still in plastic condition. Therefore, it is also known as solidification cracking.

Causes and Remedies of Hot Tear

Causes of Hot Tear	**Remedies of Hot Tear**
The thickness of the electrode may be wrong.	Using the right thickness of the electrode according to the base metal to be welded.
Not using a suitable welding current.	Ensure the use of suitable welding current as needed.
It is due to the incorrect choice of proper materials.	Using a suitable type of material for the electrode.

#1 Mechanical Damage

Mechanical damage is an indentation in the surface of the parent metal or weld caused by damage during welding. It is occurred by the incorrect use of welding tools such as hammers, grinders, and other tools used in welding.

Causes and Remedies of Mechanical Damage

Causes of Mechanical Damage	**Remedies of Mechanical Damage**
This is due to the additional force applied during chipping.	This can be easily prevented by operating the welding tools properly.
Due to incorrect handling of the electrode holder.	After welding, make sure that the other part should not fall on the welded metal.
Inefficient use of a grinder.	The process of hammering should be moderate when used.
It is also caused by not engaging the arc to the metal parts.	The arc should be engaged before welding.

#2 Misalignment

Sometimes, the decomposition of filler metals is occur in the welded joint, it is probably of misalignment. It can be recognized as wavy or curvy on the surface.

Causes and Remedies of Misalignment

Causes of Misalignment	**Remedies of Misalignment**
This type of welding defect is caused by the rapid welding process.	To avoid this, apply a slow or steady welding process.
Due to unskilled welder or improper checking while welding.	Employing skilled welders and conducting proper checks before welding.
The welding wire is not inline or not placed properly.	Maintaining welding wire inline or checking wire location.

#3 Excess Reinforcement

It is also a common type of welding defect that occurs occasionally. Unlike underfill defects, this occurs when there is too much filler material in the welding joint. In addition, the excess reinforcement is uneven and ragged.

Causes and Remedies of Excess Reinforcement

Causes of Excess Reinforcement	**Remedies of Excess Reinforcement**
This is caused by over flux or fast/uneven travel speed on the feed wire.	Maintain the torch running at the proper speed.
Because of more current and heat.	Set the current correctly and avoid overheating.
Because of the varying voltage that is mostly low.	Adjust the voltage to make sure it is not too low.
Leaving a big gap between the welding pieces.	Align the pieces so the gap isn’t too big.

#4 Overlap

Overlap is a welding defect in which the filler material at the toe of the weld covers the base metal without bonding. In other words, it is an excessive flow of weld metal.

Causes and Remedies of Overlap

Causes of Overlap	**Remedies of Overlap**
The main reason for this defect is applying improper welding technology.	Achieving improvements in welding techniques.
Due to varying the torch angle.	Maintaining correct torch angle.
Using large-size electrodes in welding.	Be sure not to use large-size electrodes.

#5 Lamellar Tearing

It is a cracking defect that occurs at the bottom of the weld and is mainly found in rolled steel plate fabrication. The tearing always occurs within the parent plate, often outside the heat-affected zone, and usually occurs parallel to the weld fusion boundary.

Causes and Remedies of Lamellar Tearing

Causes of Lamellar Tearing	**Remedies of Lamellar Tearing**
Due to the weld metal deposits on the metal surface where optimum cohesion occurs.	This is prevented by conducting welding rest at the end.
Because of Improper welding orientation and material selection.	Using the proper welding orientation and selecting the best quality materials.

#6 Whiskers

In the case of MIG welding, short lengths of electrode wire are glued through the weld on the root side of the joint, it is known as Whiskers. This is due to the electrode wire protruding from the leading edge of the weld pool.

Causes and Remedies of Whiskers

Causes of Whiskers	**Remedies of Whiskers**
Applying an increase in the electrode wire feed speed.	This can be prevented by reducing the electrode wire feed speed.
Due to excessive travel speed.	Keep the travel speed optimal, and avoid going too fast.

4.5 Safety precautions in welding.

Arc Welding Safety

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Cooperative Extension
The University of Arizona
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INTRODUCTION

The electric arc welder remains one of our most useful and timesaving pieces of shop equipment. Almost every farm, ranch, and Vocational Agriculture shop is equipped with one or more welders which are used for fabrication, repair, and/or educational programs. Most of these welders are typically AC/DC, 240 volt transformer types using electricity as the energy source. Portable welders are of the diesel/gasoline engine powered type. Properly installed and used the arc welder is very safe, but if used improperly the operator can be exposed to a number of hazards including toxic fumes, dusts, burns, fires, explosions, electric shock, radiation, noise, and heat stress. Any of these hazards can cause injury or death. By following suggestions and guidelines in this pamphlet the risks can be greatly minimized.

SELECTING THE ARC WELDER

When purchasing an arc welder you can be assured of design safety if the unit complies with National Electric Manufacturers Association (NEMA) standards or the safety standards for arc welders as determined by the Underwriters Laboratories (UL). Be sure that the welder you purchase carries the seal of approval of one of these organizations.

INSTALLING THE ARC WELDER

Prior to installing the arc welder you should determine if your present electrical system is adequate to handle the increased load required by the welder. Your local power supplier or a qualified electrician can assist you in determining this. It is very important for your safety to install the welder in compliance with State of Arizona, Occupational Safety and Health Administration (AOSHA) regulations and the National Electric Code (NEC) by a qualified electrician. Failure to do so could cause fire, a ground fault, or equipment failure. The following rules are not a complete list but are especially important guidelines which should be adhered to:

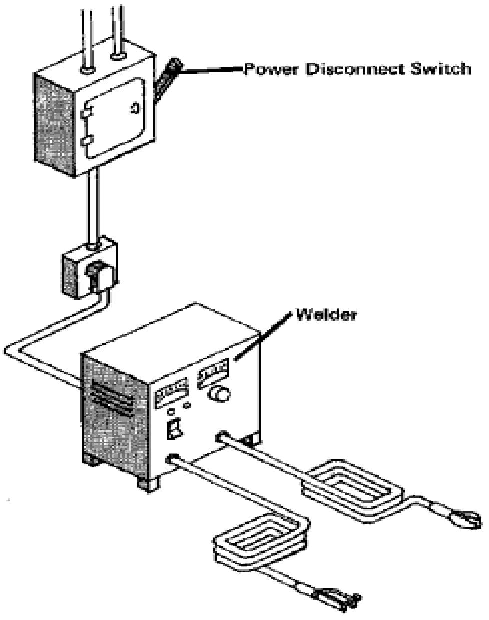


Figure 1. The power disconnect switch should be located close to the operator

- The frame or case of the welder shall be properly grounded.
- A safety-type disconnecting switch or controller shall be located near the machine (See Figure 1).
- The welder or welders shall be protected by a properly sized fuse or circuit breaker on an independent circuit.

VENTILATION

The welder should be located in an area with adequate ventilation. In general, when welding is being done on metals not considered hazardous, a ventilation system that will move a minimum of 2000 cubic feet per minute (CFM) of air per welder is satisfactory. However, many materials are considered very hazardous and should be welded only in adequately ventilated areas to prevent the accumulation of toxic materials or to eliminate possible oxygen deficiency not only to the operator but to others in the immediate vicinity. Such ventilation should be supplied by an exhaust system located as close to the work as possible (See Figure 2). When welding or cutting metals with hazardous coatings such as galvanized metal the operator should use a supplied-air type respirator or a respirator specially designed to filter the specific metal fume. Materials included in the very hazardous category are welding rod fluxes, coverings, or other materials containing fluorine compounds, zinc, lead, beryllium, admium, and mercury. Some cleaning and degreasing compounds as well as the metals they were cleaned with are also hazardous. Always follow the manufacturers precautions before welding or cutting in the presence of these materials.

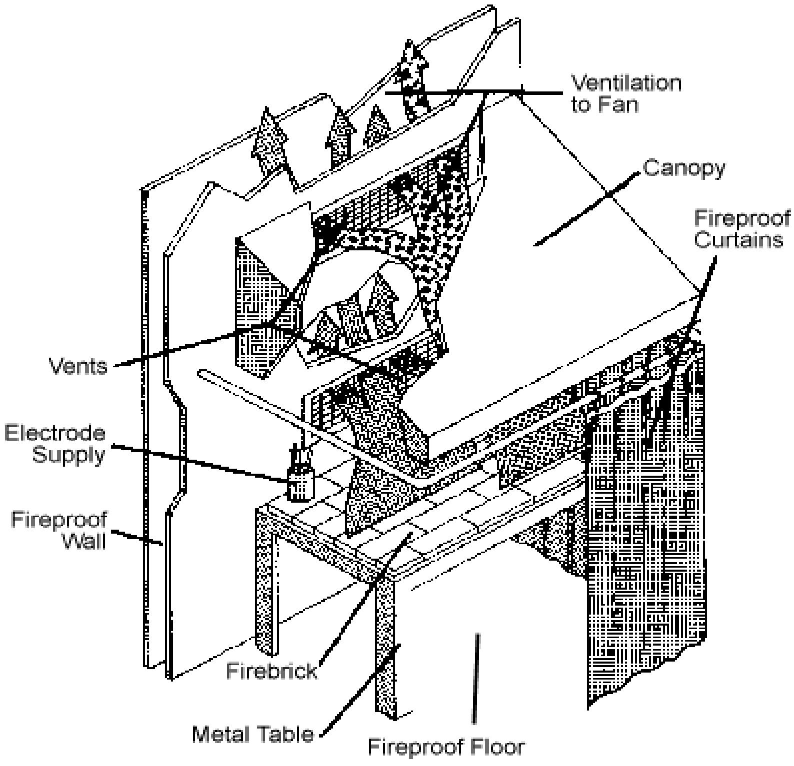


Figure 2. Typical welding area showing proper ventilation and screening

FIRE PREVENTION

The arc welder is capable of producing temperatures in excess of 10,000 degrees F.,therefore it is important that the workplace be made firesafe. This can be accomplished by using metal sheets or fire resistant curtains as fire barriers. The floor should be concrete or another fire resistant material. Cracks in the floor should be filled to prevent sparks and hot metal from entering. When work cannot be moved to a firesafe area then the area should be made safe by removing or protecting combustibles from ignition sources. In certain welding situations it may be necessary to ask someone to watch for fires that could go undetected until the welder has finished the job.

Suitable fire extinguishing equipment such as buckets of sand or a dry chemical extinguisher of the ABC type should be readily available. The extinguisher should be large enough for the situation with a 10# size adequate for most farm and school shops.

PERSONAL PROTECTION

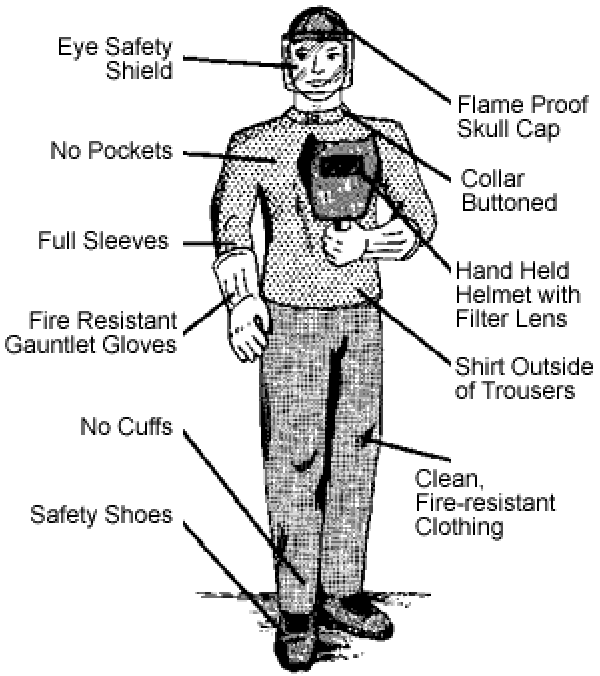


Figure 3. Select clothing to provide maximum protection from sparks and hot metals

It is essential that the operator and helpers be properly clothed and protected because of the heat, ultra-violet rays, and sparks, produced by the arc welder (See Figure 3). For body protection a pair of fire retardant long sleeved coveralls without cuffs is a good choice. Always avoid clothing with tears, snags, rips, or worn spots as these are easily ignited by sparks. The sleeves and collars should be kept buttoned. The hands should be protected with leather gauntlet gloves. A pair o high top leather shoes, preferably safety shoes, is good protection for the feet. If low shoes are worn the ankles should be protected by fire resistant leggings. Eyes should be protected by transparent goggles if the person wears prescription glasses or safety glasses if not. A welding helmet or hand shield with filter plate and cover plate is mandatory for eye protection from the harmful rays of the arc. The filter plate should be at least shade #10 for general welding up to 200 amps. However, certain operations such as carbon-arc welding and higher current welding operations require darker shades. Never use a helmet if the filter plate or cover lens is cracked or broken. A flame-proof skull cap to protect the hair and head as well as hearing protection in noisy situations is recommended.

Plastic disposable cigarette lighters are very dangerous around heat and flame. It is very important that they not be carried in the pockets while welding. Always provide protection to bystanders or other workers by welding inside a properly screened area, if possible. If unable to work inside a screened area then protection to others should be provided by a portable screen or shield, or by their wearing anti-flash goggles.

SAFE OPERATION OF THE WELDER

It is important that anyone operating an arc welder be instructed on its safe use by a qualified teacher or welder.

Because of their potentially explosive nature, we strongly recommend that no welding, cutting, or hot work be attempted on used drums, barrels, tanks, or other containers under any circumstances.

If possible, work to be welded should be placed on a firebrick surface at a comfortable height. Welding should never be done directly on a concrete floor. Heat from the arc can cause steam to build-up in the floor which could cause an explosion. The welder cables should be positioned so that sparks and molten metal will not fall on them. They should also be kept free of grease and oil and located where they will not be driven over.

Electric welders can kill by electric shock. If the welding operation must be done on steel or other conductive material an insulating mat must be used under the operator. If the welding area is wet or damp or the operator is actively perspiring then he/she should wear rubber gloves under the welding gloves.

It is easier and safer to establish an arc on a clean surface than a dirty or rusty one. Therefore, metal should always be thoroughly cleaned by wire brushing or other method prior to welding. When chipping slag or wire brushing the finished bead the operator should always be sure to protect his eyes and body from flying slag and chips. Unused electrodes and electrode stubs should not be left on the floor as they create a slipping hazard. Hot metal should be handled with metal tongs or pliers. When quenching hot metal in water it should be done carefully to prevent painful burns from the escaping steam. Any metal left to cool should be carefully marked "HOT" with a soapstone. When welding is finished for the day or suspended for any length of time electrodes should be removed from the holder. The holder should be placed where no accidental contact could occur, and the welder should be disconnected from the power source.

SAFETY PRECAUTIONS FOR ENGINE POWERED WELDERS

- Always operate in an open well-ventilated area or vent the engine exhaust directly outdoors.
- Never fuel the engine while running or in the presence of an open flame.
- Wipe up spilled fuel immediately and wait for fumes to disperse before starting the engine. *Never remove the radiator pressure cap from liquid cooled engines while they are hot to prevent scalding yourself.
- Stop the engine before performing any maintenance or trouble shooting. The ignition system should be disabled to prevent accidental start of the engine.
- Keep all guards and shields in place.
- Keep hands, hair, and clothing away from moving parts.

FIRST AID

The welding area should always be equipped with a fire blanket and a well stocked first aid kit. It is desirable that one person be trained in first aid to treat the minor injuries that may occur. All injuries, no matter how minor they may seem can become more serious if not properly treated by trained medical personnel.

KEY POINTS TO REMEMBER

- Be sure the welder is properly installed and grounded.
- Never weld without adequate ventilation.
- Take proper precautions to prevent fires.
- Protect your entire body with fire retardant clothing, shoes, and gloves.
- Wear eye protection at all times.
- Weld only in a firesafe area.
- Never do any welding, cutting, or hot work on used drums, barrels, tanks, or other containers.
- Mark metal "HOT" with a soapstone.
- Keep a well stocked first aid kit handy.

Unit-5.0 Plastic Molding and Powder Metallurgy

Metal Injection Molding vs. Powder Metallurgy: What’s the Difference?

It helps to know how metal injection molding and conventional powder metallurgy are related when you’re deciding which process suits your needs. Let’s look at conventional PM first, since it’s been around for a lot longer.

Powder Metallurgy Basics

1. Begin with blending or mixing specific types of metal powders and lubricants.
2. Place the mix in a die to create a certain shape.
3. Use a press to compact the metal powder tightly.
4. Sinter the compressed part in a furnace to form metallurgical bonds in the metal powder.

The mass manufacturing of powder metal parts has been going on for well over 100 years. It’s used to make a wide variety of parts of different shapes and sizes, ideal for a host of automotive and other applications.

Metal Injection Molding Basics:

- Blend metal powders with polymer binders to create a viscous solution
- Inject the solution into a molding machine (Think of toothpaste filled with metal powder that’s injected into the die cavity.)
- Apply heat to remove the binder
- Sinter at high temperatures to form metallurgical bonds and densify the powder

Comparatively speaking, MIM is a fairly new process. It has only become more widely used in the last couple decades, and MIM manufacturing costs are still quite high. **We’ll tell you how high in a bit.**

Primer for Choosing Between Conventional PM and MIM

There are a lot of similarities between metal injection molding and conventional powder metallurgy. At the same time, there are a few drastic differences that make one process preferable over the other depending on the circumstances.

1. MIM is excellent for complex shapes.

MIM is awesome for making parts that can benefit from an intricate design. The **ability to create an essentially liquid feedstock** and injection mold it means you can design molds with more complexity than you could with dies taking metal powders.

Conventional powder metallurgy is still a better option for complex shape making than many other competing process, though.

2. MIM requires high temperatures to sinter.

One of the big downsides to MIM parts is the heat requirements for sintering. Heating these parts to sinter them **can add substantial cost** to the manufacturing process.

3. MIM parts go through approximately 25% shrinkage.

A large part of the volume of MIM feedstock is made up of binders -- much of which needs to be removed during sintering. That means you lose around 25%, which can eat into your materials budget as you **require more powder to compensate** for shrinkage.

4. MIM is expensive.

You can make some impressive parts with MIM -- the kind that will win you fancy awards. But there is a huge tradeoff in cost.

While premixed, press-ready conventional powder for die compaction might run you $1-$2 a pound, the feedstock for a MIM part typically costs **$10-$12 a pound** -- or even higher. High sintering temperature requirement is only one of the factors that contribute to high per-part costs.

With many parts, even if you need additional machining operations, conventional powder metallurgy is often a higher-value option.

5. You really have to look closely at cost versus performance.

Since metal injection molding manufacturing costs far more than conventional powder metallurgy, you have to **look closely at your specific performance needs**.

5.1 Plastic Molding: Concept, working principle, equipment and applications of Compression molding, Blow molding, Injection molding and Extrusion.

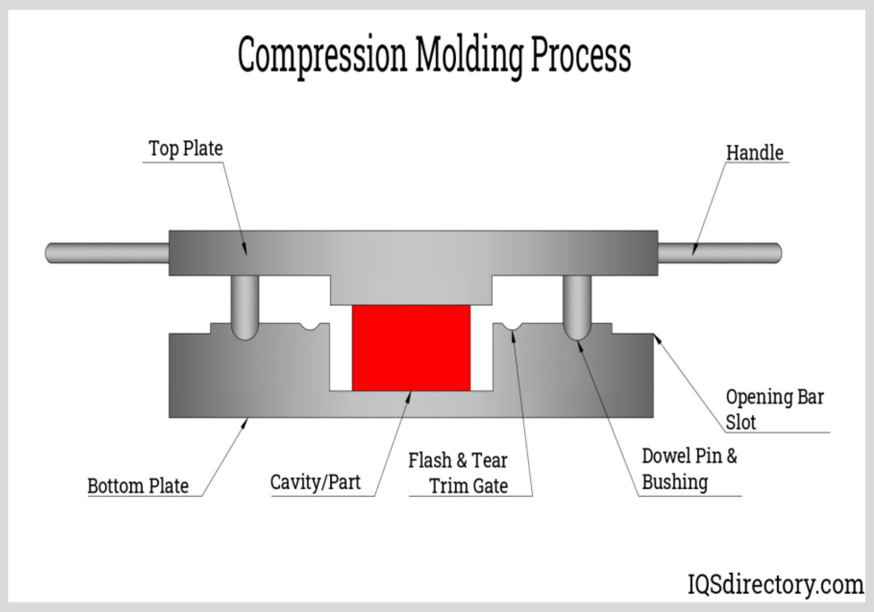
Compression Molding

Introduction

This article will take an in-depth look at compression molding.

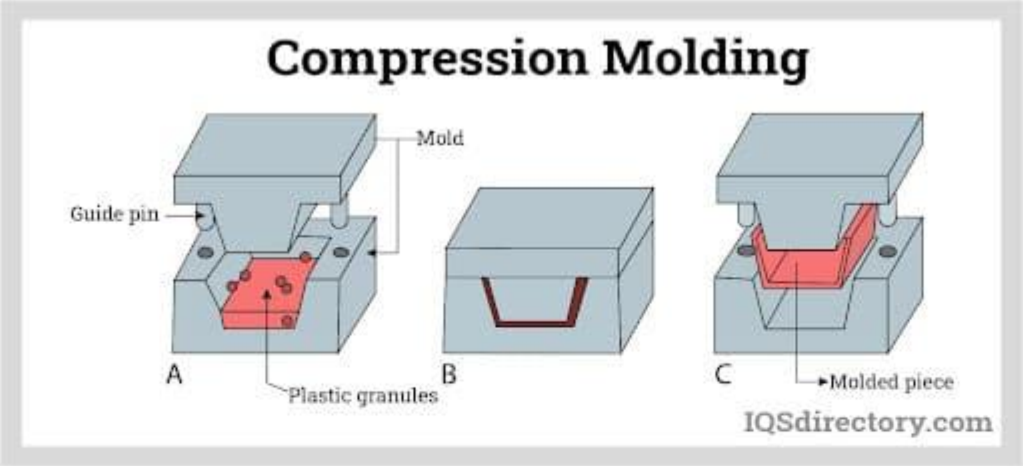
The article will give a better understanding of the following topics:

- Molding – in general
- What is compression molding
- The process of compression molding
- Types of compression molds
- Technology/innovation in compression molding
- Compression molding in comparison to other molding processes
- Applications of compression molding
- Materials used in compression molding
- Advantages of compression molding
- Standards used in compression molding
- And much more…



Chapter 1: Molding – In General

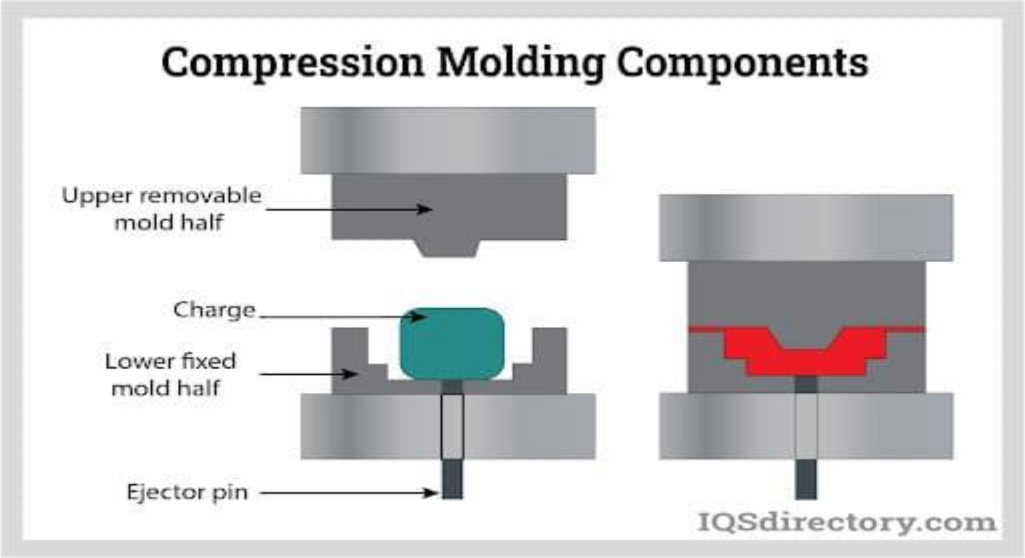
Molding is a manufacturing process that uses a mold – the latter being a solid container used to give shape to a piece of material. It is a forming process. The form is transferred from the mold to the material by subjecting the mold to flow or deform, or both. This implies the use of force(s), in one form or another – from purely gravitational to the application of high pressure.



Compression molding is one of the first molding techniques to be developed for synthetic molding materials. Compression molding remains one of the cheapest molding techniques for several thermosetting material products. These thermoplastics may be more economically molded using injection molding.

Chapter 2: What is Compression Molding?

Compression molding is a molding process that uses compressive force to squeeze a charge of material into shape. The mold consists of the lower part and the upper part. Each of these parts may consist of several components but essentially works as one mechanism when applying the compression. When these two parts meet, a cavity is left between them that defines the desired shape. Therefore, the parts would meet at the widest cross-section of the shape. To facilitate the ejection of the product once it is cured.



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Chapter 3: The Process of Compression Molding

The compression molding process is permanent as this is more practical and commercially viable. In addition, these can be reused for many compression cycles, unlike expendable molds. Which should be disposed of or recycled after each cycle.

The key steps involved in the compression molding process are detailed below.

Mold Preheating or Preparation

Primarily, the mold needs to be prepared. The typical preparation steps include:

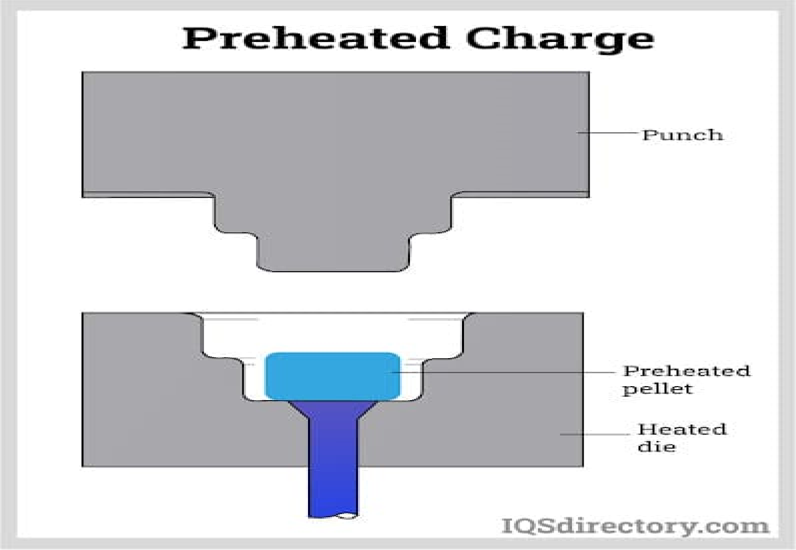
- Cleaning the mold
- Applying release agent
- Heating – this process is done to induce/increase the viscosity of the charge when it is eventually loaded

Charge Preparation

Compression molding is performed on a wide range of materials. As a result, they come in many shapes, sizes, compositions, conditions, and packages.

Preparation changes the material from the state it is delivered into one more ideal for compressing. The charge preparation includes any of the following:.

- Unpacking
- Cleaning
- Cutting
- Sizing and weighing
- Heating



Charge preparation is often the most manually demanding part of the compression molding process. This is because it is generally the least automated.

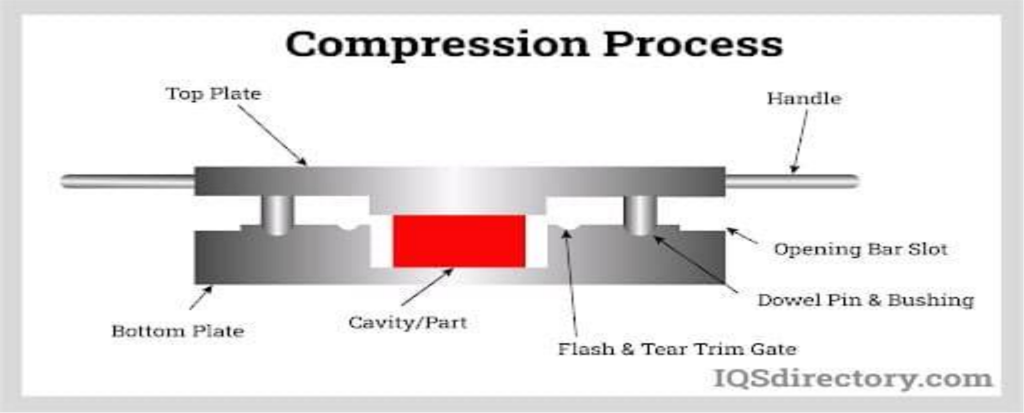
Charge Loading

This involves placing the charge on the lower part of the mold. This way, to ensure the best compression result. Then, the charge is spread on the mold as desired, depending on the shape of the mold, intended thickness, and other factors.

Compression

Relative motion between the two parts of the mold is induced to bring those parts as close as would be desired. As the parts get closer, they compress the charge along the way. Compression is done to achieve any of the following:

- Force the charge to fill the entirety of the intended volume in the cavity left by the mold
- Ensure the desired density of the product
- Facilitate curing



There are three parameters of importance during compression:

1. **Temperature** – This induces or reduces viscosity. Lower viscosity improves the flow and consistency of the charge. In contrast to deformation:

- Flow leaves no residual stresses.

- The charge can be heated during preparation and then pressed in a cold mold.
- The charge may be loaded in the mold cold and heated during compression. This is common with pelletized charges
- Some materials do not require heat at any stage.

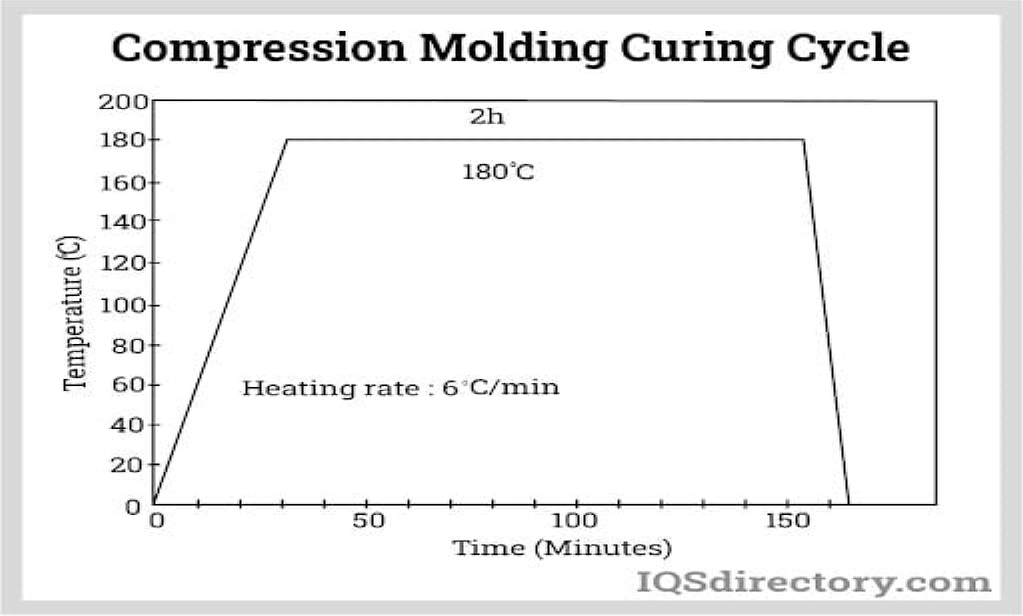
2. **Pressure** – This should be higher for a more dense charge to achieve a comparable effect. Carbon fiber reinforced polymers typically require between 2 - 14 MPa depending on the necessary fiber density. Higher densities need higher pressure.
3. **Time** – The charge may be compressed gradually, sometimes withholding time (a period during which the charge remains compressed and heated). The compressive force may also be applied and removed very rapidly, without necessarily being a sudden blow, as is the case in forging.

Curing

This part of the molding process facilitates the hardening/setting of the compressed charge into the final product. It may simply involve lowering the temperature or using hardening agents and catalysts to enable setting and hardening.

Some of the cure types are:

- Condensation type. This type of cure uses a tin catalyst.
- Addition type. This one uses a platinum catalyst.



Dimethyl stannane and Tetraethoxysilane-based curing agents are used on various materials like resins, polyurethane, silicon, etc. These are condensation-type cures.

Chemicals like organopolysiloxane are used as additional cures for curing a range of silicones.

Other agents include Benzoyl peroxide, Peroctoate, and t-butyl perbenzoate.

Cooling

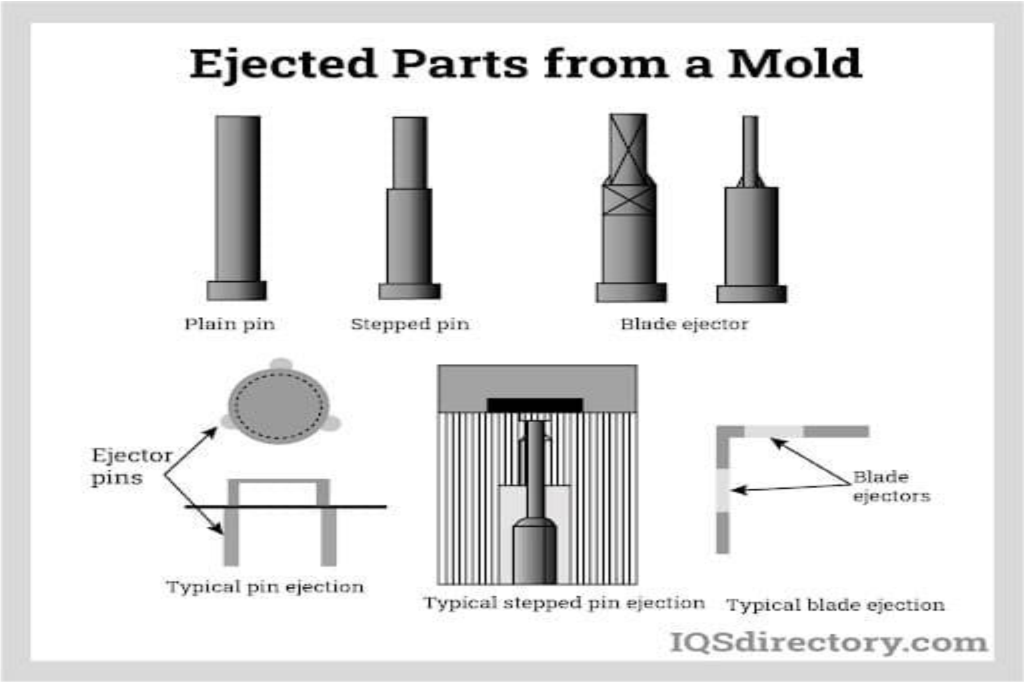
Cooling has numerous purposes that include the following:

- Ensuring the mold has the ideal temperature for subsequent molding cycles.

- Ensuring the mold develops the desired mechanical (and thermal) properties for the subsequent removal and storage/shipment/usage.

Ejection

Ejection refers to the release of the product after curing. It can be manual or automated. Manual ejection is more common in recreational and small-scale molding applications like medical accessories manufacture. Automated ejection typically uses a plunger that telescopes from the underside of the mold when ejection is due or uses a separate mechanism of suckers.



Ejection often comes with a release agent, and some coating applied to the mold to prevent the product from sticking to the mold and ease ejection. Application of the release agent is also known as mold curing (not to be confused with the previously discussed curing). The ejection phase of the process significantly influences (and limits) the geometry of the compression molded products. Products with threads, holes, and grooves can be compression molded, albeit the extra features make the ejection less straightforward and more challenging to automate.

The following substances are examples of release agents:

- PVA (polyvinyl alcohol)
- PTFE (poly tetra fluoro ethylene)
- Polysiloxanes

De-flashing

The charge is often loaded in excess (however slight the excess) to the product volume required. This excess will be “flashed out” of (expelled from) the mold cavity at the mold partition line(s) as the charge is compressed. After ejection, this flash remains attached to the product and should be removed in the next part of the process – de-flashing.

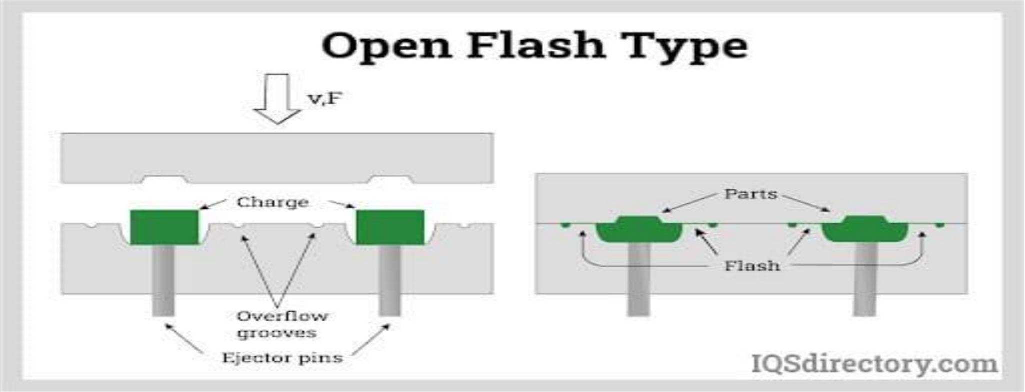
De-flashing can be a manual or an automated process. The flash can be cut off with a blade. Manual de-flashing is typically done where the molded product is exceptionally large and cannot be handled by automated deflashing machines. Other reasons for manual de-flashing are financially motivated. Automated de-flashing typically uses water jets and ice blasting. It is typical to have the blasting done under cryogenic conditions. Another alternative for automated de-flashing is vibration tumbling. The flash can be vertical or horizontal depending on how the two parts of the mold meet, which defines the parting line's geometry.

Chapter 4: Types of Compression Molds

Some of the types of compression molds are discussed below:

Open Flash type

In the flash type of compression molding, the charge is loaded in excess, such that flash is generated at the end of the compression. As a result, the mold parts do not meet – they leave a small space through which flash is expelled. As a result, this type of molding generates significant waste. However, it is less prone to blistering.

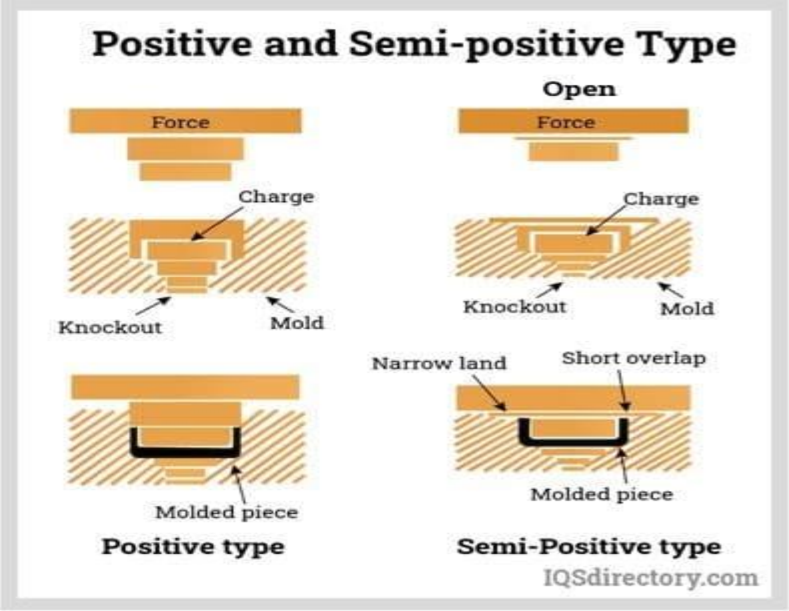


Positive type

This type requires an accurately measured charge. It does not leave space between parts on the mold's parting line. It has the following features:

- It controls part density better.

- It might trap air spaces and cause blistering on the product surface.
- It has the least wastage and is the most convenient when the charge is made up of expensive materials.



Semi-Positive type

This is in between the other two methods of controlling flash and is the most expensive of the three. However, it combines the advantages of the two different mold types.

Charge measurement does not need to be as accurate as with positive type molds. However, there can be an excess that may be allowed to escape during compression.

Chapter 5: Technology/Innovation in Compression Molding

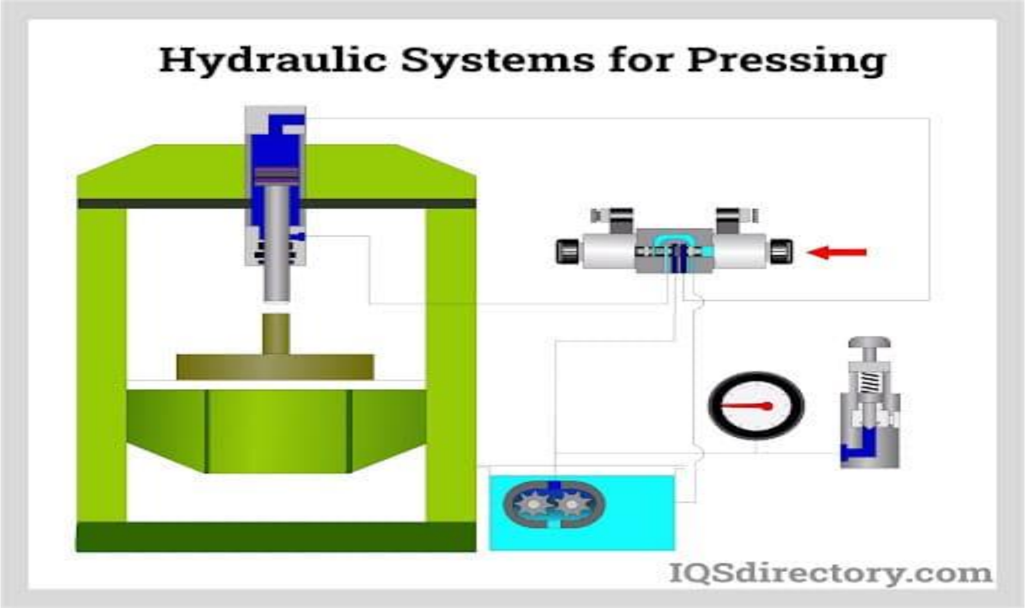
Like the rest of industrial technology, compression molding continues to develop and evolve, particularly in the aspects of automation and environmental sustainability.

There are different technologies used in the following aspects of compression molding:

Press

In most applications, hydraulic systems are used for pressing. However, lighter presses may use pneumatic systems.

The pressing motion is almost always vertical. This aids in simplifying the design of the pressing mechanism and its support structure – also considering that the weight of the mold can be large. Technically, the pressing mechanism is capable of being designed in any orientation. However, bringing the mold parts together (hence applying the compression) is usually achieved through telescoping.



Molds

Compression molding uses non-expendable, non-pliable molds. Commercially, molds are made from steel. They are machined from blocks rather than casting into shape because they are not often mass-produced enough to justify the latter.

The machining can be manual (milling, drilling, etc.) or automated (CNC). The primary material for making molds is steel, and the machining is usually subtractive rather than additive.

Scaling

Compression molding is a scalable technique used in an array of applications. These applications include:

Laboratory

Bench-top compressors are used in experimentation (e.g., improving molding methods and developing new molding materials). Such a scale is also often done in prototyping, in which space it competes with 3D printing.

Molding at such a scale also accommodates recreational molding. Furthermore, with the relatively straightforward underlying principle, it is feasible to put the necessary components together and make demonstrations.

Small scale molding

This may be done as part of the back-office activities that are not part of the core business of an enterprise. An example would be a firm that services irrigation equipment as a third party, then opts to mold some of the components on its own.

Medium-scale molding

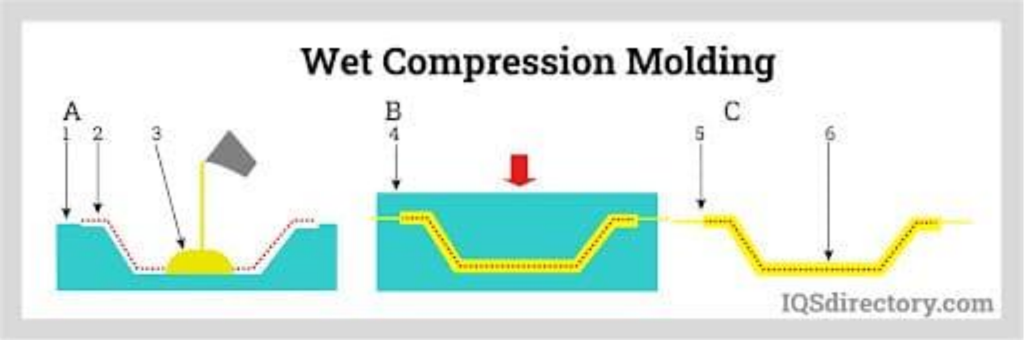
This is often done by enterprises whose main activity is selling compression-molded products (or those with compression-molded components). However, economic factors may constrain the scale of production.

Large scale molding

This involves mass production of molded products and the production of large-sized products. This scale fully justifies the requirement of automation.

Wet Compression Molding

This involves the fusion of fabrics with a liquid (or molten) charge, such as epoxies. Which results in durable products, and technology is increasingly being applied in the automotive industry.



Vacuum Compression Molding

This technology rapidly depressurizes the mold cavity during pressing. Doing so improves the surface finish of the products.

Transfer Molding

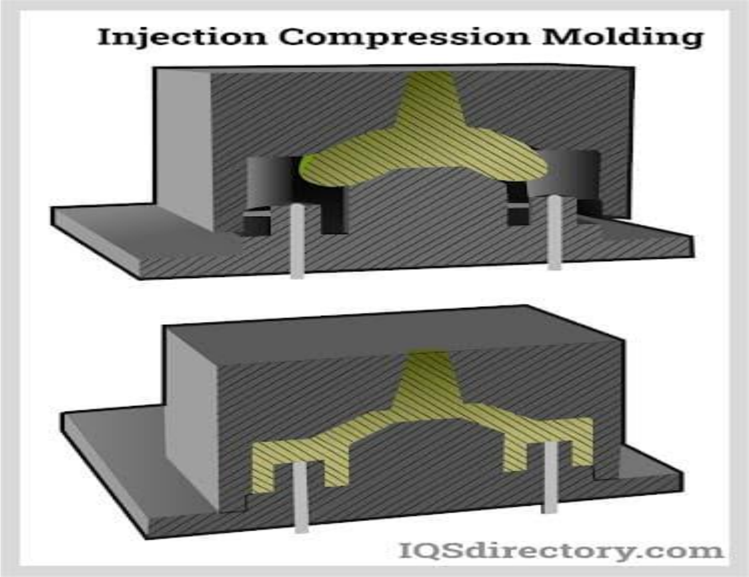
Technologically, this is an extension of compression molding. The charge is held in the transfer port. First, the two parts of the mold are brought together, and then the charge is transferred into the mold cavity. Its main difference with compression molding is the presence of the transfer port in transfer molding and the fact that for compression molding, the charge is placed in the mold cavity before the mold parts are brought together.

Transfer molding is usually used for too intricate products for compression molding.

Injection Compression Molding

This is like transfer molding. The difference is that the charge is injected into a partly open mold. It is partially open because the mold parts would not have fully met, implying that the volume of the cavity during injection will be larger than the final volume after compression.

When the injection is complete, the mold parts come together to meet fully, compressing the injected charge throughout the process. The process is faster than compression molding but uses more expensive equipment.



Insert Molding

In this process, a charge is compressed onto a prefabricated component. Then, the charge encapsulates or is attached to the prefabricated component. The said component is the insert. It is prepared separately before being brought for encapsulation/attachment.

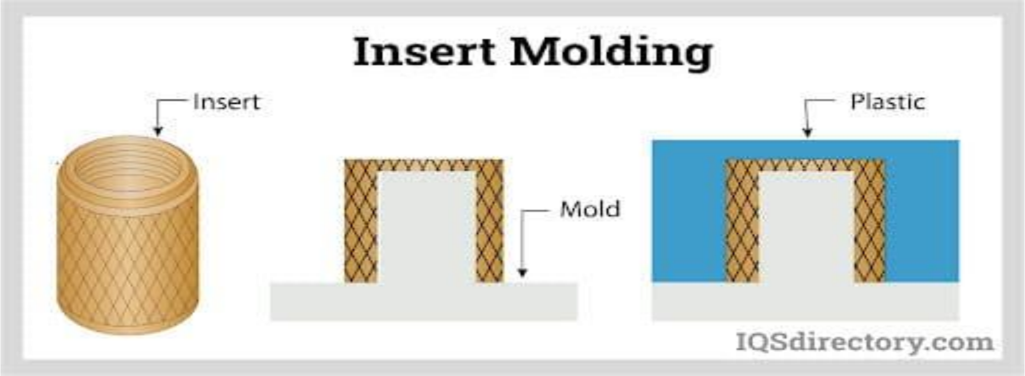
The insert can be a knife blade, and the result of the insert molding process can be the attachment of a plastic handle. Other standard inserts are threads (alternatively called nutsets) and electrical contacts.

Insert molding is an alternative means of assembling components, especially those that do not need to be disassembled once they begin their service life. Insert molding has the following advantages:

- It provides the designer with more flexibility
- It is fast, more so on products that have more than one insert that can be compressed all at once

It also has the following disadvantages:

- It requires more intricately designed molds.
- It also raises the risk of residual stresses in the finished product because a combination of materials with different mechanical properties may be subjected to temperature gradients.



Overmolding

Overmolding involves the molding of material onto a pre molded component. It is usually done on materials with different mechanical properties to combine their advantages.

Examples would be a power tool handle and a toothbrush. To produce the handle, an elastomer can be over-molded onto a PTFE substrate (the PFTE substrate molded in some previous stage). The PTFE would provide rigidity for the handle, and the elastomer would improve the handle's grip, ergonomics, and aesthetics.

Though both methods may be technically feasible, the over-molding is more often injection molded than compression-molded. This is because the substrate onto which the overmolding is done is more likely to have been compression molded.

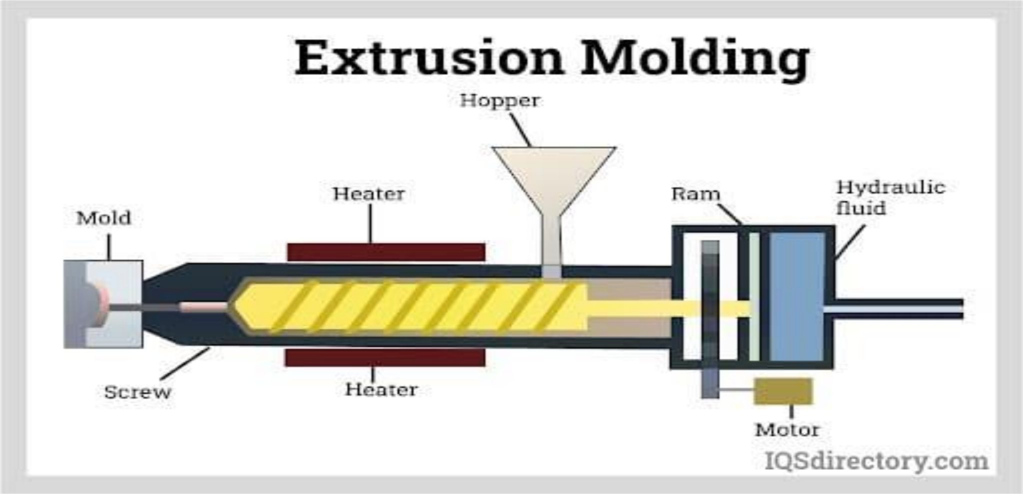
Overmolding has a variant, i.e., two-shot molding. This is entirely done using injection molding.

Chapter 6: Compression Molding in Comparison to Other Molding Processes

Compression molding is acknowledged as one of the more conventional techniques to be developed, with several more coming afterward. Below are some of the other molding techniques:

Extrusion Molding

Extrusion molding is ideal for products with a uniform cross-section or for long products where a mold with the full dimensions of the final product would be inconvenient to make. Even if the dimensions are small, it is faster to produce products with a uniform cross-section using extrusion molding (then subsequently cutting the extruded product to size) than other molding methods like injection molding.

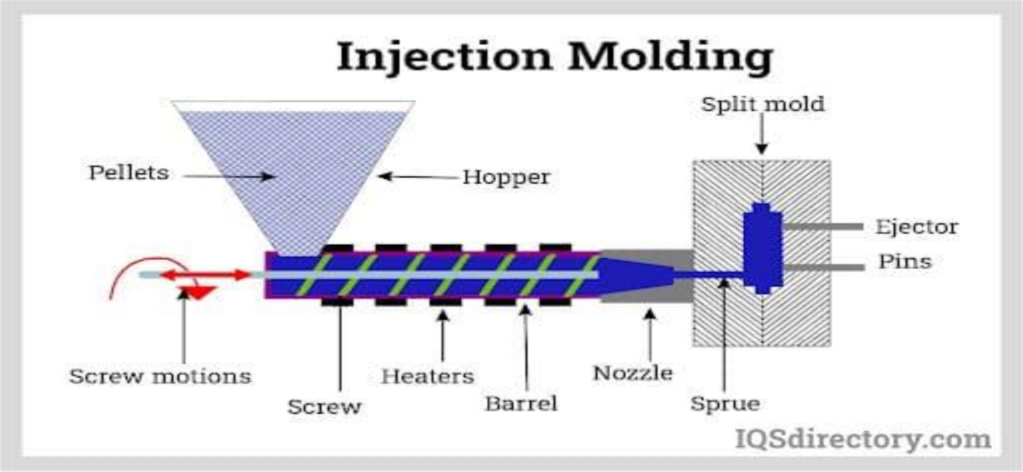


Blow Molding

Blow molding is used for hollow objects, often with an opening smaller than the cavity of the product. Bottles are the most blow molded product. A preform is placed at the beginning of the mold. The mold is closed and heated, and then the preform is blown – filling the mold and taking its shape in the process.

Injection Molding

In injection molding, the material is pushed into a mold. The mold is fully closed before the material is injected. The viscosity of the material should be low enough to facilitate its flow into the intended mold – under the desired pressure. Thus, the charge is continuously heated. Preforms for blow molding are often injection molded. Technically, all thermoplastic products that can be compression molded can also be injection molded. The charge preparation is much more straightforward as they simply use plastic pellets. Injection-molded components suffer the same geometrical limitations as do compression-molded ones. Most thermoplastic products are made more economically using injection molding than compression molding.



Thermoforming

Thermoforming is used for manufacturing very thin products, like fast food packaging material. First, the material is spread over the mold and heated. A vacuum then sucks the material onto the mold.

Rotational Molding

This method is used to manufacture large hollow objects, where blowing would face technical or otherwise limitations.

3D Printing

Technically, 3D printing has a different underlying principle from molding. However, it competes with molding techniques in the application of prototyping. Molding techniques are more suited to mass production, and 3D printing is more suited to variety.

Casting

Casting involves pouring liquid material into molds under gravity. This process cannot be done at scale for plastic products. It is the only method mentioned hereunder that can use pliable and temporary molds.

Chapter 7: Applications of Compression Molding

Most of the compression-molded products are thermosets. Rubber, thermoplastics, and polymer composites are also trendy. The presence and scale of compression molding in various areas are dictated by demand.

Compression molding is practical on products that are generally flat (or solid and flat-surfaced), such as the following:

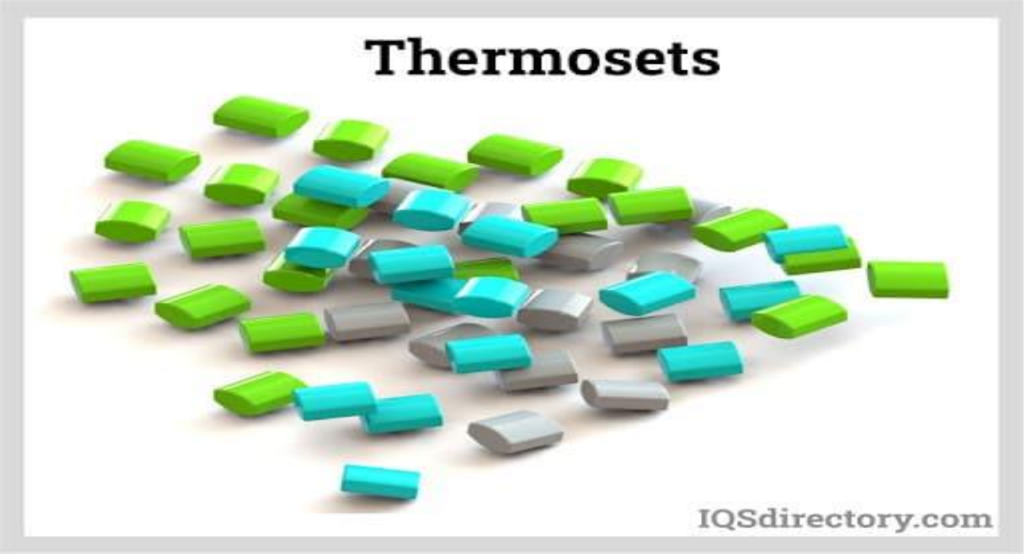
- Kitchenware, e.g., plastic utensils and utensil handles and knobs
- An array of handles, e.g., mirrors, pots, etc.
- Rubber clothing
- Automotive parts, e.g., fenders, casings for engine components, etc.
- Flatware
- Computer and gaming equipment, e.g., keyboards, mouse, and joystick covers.
- Appliance housing, e.g., for irons, kettles, plugs, etc.
- Casings for electrical equipment etc.
- Gaskets
- Biomass (pelletizing) – biomass can be compressed for storage and handling and later used for fuels, amongst other uses.
- Medical accessories, e.g., syringe stoppers and other plastic and silicone components.

Chapter 8: Materials Used in Compression Molding

There are several materials used in compression molding. Some of the examples include the following:

Thermosets

Thermosets are plastic materials that can only be liquefied once. Once they are hardened, these cannot be liquefied again. Thus it can neither be remolded nor recycled (the hardening involves an irreversible chemical reaction – polymerization and cross-linking). In addition, once they set, they would instead smolder and char rather than melt when heated enough.



This incapacity to be recycled comes as the most significant disadvantage of thermosets. They are particularly challenging to dispose of sustainably. However, they do have specific properties that make them more convenient for particular applications:

When compared to metals:

- They are lightweight
- They are good insulators

- It cost less to produce
  When compared to thermoplastics:

- They have good dimensional stability and heat-resistant qualities. In molding, thermosets are often combined with other materials, mainly carbon fibers, to make composites.
  Some of the thermosets used in molding are listed below:

Phenolic molding compound

This is so-called because of the chemical structure of its monomer, which contains a phenyl group. It is commonly called Bakelite. It has good heat-resisting qualities and dimensional stability.

Epoxy resin

This is an array of substances because of the epoxide group found in their chemical structure. Mechanically, they perform almost like phenolic molding compounds.

Polyester

Polyester can be found both as a thermoset and as a thermoplastic.

Polyurethane

This is another thermosetting plastic.

Thermoplastics

Thermoplastics can be melted repeatedly. Polyester is one of the few materials to fit in both lists: thermosets and thermoplastics, depending on how it is hardened. Thermoplastics can be disposed of more sustainably. They are relatively low cost. However, their mechanical performance is bettered by thermosets.

Some of the thermoplastics used in molding are listed below:

Polypropylene

Polypropylene foam is produced using compression molding with a chemical blowing agent (foaming agent).

Nylon

This is another example of thermoplastic.

High-density polyethylene

Polyethylene can be mixed with rubber to make a composite that can be molded as an elastomer.

Polyester

Polyester forms a thermoplastic if it is not mixed with a hardening agent

PTFE

A thermoplastic with very high viscosity and good non-stick properties.

High-temperature materials

Polyaryletherketones (PAEK) are compression molded to replace metals in specific applications. Polyetheretherketones (PEEK) and polyetherketoneketones (PEKK) also fall into this family of materials.

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Glass Fiber

Fibers are added to resins to form composite materials. Composites combine the advantages of their constituent materials and are therefore better than either constituent individually. For example, materials like sheet molding compounds are glass-reinforced composites.

Carbon Fiber

Carbon fibers serve the same purpose as glass fibers but generally give a more rigid composite and cost more.

Sheet Molding Compound (SMC)

Typically, this consists of two layers of polymer resin, e.g., polyester, enveloping a layer of glass fibers. A polythene film covers the compound to facilitate more convenient handling. The film is part of the packaging and is removed before molding. The finished sheets are about 5mm thick. To make products of substantial thickness using SMC, several layers may have to be stacked on top. There is a Thick-walled SMC variant, whose thickness can go up to 50mm.

Bulk Molding Compound (BMC)

BMC is a doughy combination of polymer resins, chopped fibers (those for SMC are left long), and a hardening agent. Loading the BMC onto the mold only involves ensuring the required mass of charge is taken. As a result, BMC tends to be more pliable than SMC.

Elastomers

Chemically, an elastomer is a polymer with viscoelasticity. Their applications arise because of their properties as insulators and their resistance against an array of substances.

The following are some of those used in molding.

Nitrile

This is an acrylonitrile-butadiene rubber. It is an oil-resistant rubber that can be compression molded, injection-molded, transfer molded, over-molded, etc.

Styrene-butadiene rubber

This is a water-resistant rubber and performs well in resisting organic acids. However, it does not perform well with strong acids, ozone, oils, etc.

Ethylene propylene diene monomer rubber

This elastomer has good resistance to ozone and weather elements. Therefore, it finds use in applications like sealing hot water. It also performs well with greases, alcohols, detergents, etc. However, it performs poorly when exposed to petroleum fuels.

Viton (vinylidene fluoride and hexafluoropropylene)

Viton is one of the most expensive and durable elastomers. It performs well in high temperatures or exposure to fuel and water. Viton can be used on O rings, fuel injectors, boat propeller fittings, etc.

Silicone Rubber

These find use in mechanically demanding applications, where the rubber is subjected to significant stretching and temperature variations. They also perform well in very low temperatures. In addition, they find use in aerospace applications and electrostatic discharge protection.

Chapter 9: Advantages of Compression Molding

Compression molding has several benefits/advantages. These advantages include:

- Low-cost operation
- Good surface finish
- Faster than some methods
- Flexible design
- High product uniformity
- Good dimensional accuracy
- No residual stress
- Minimizes wastage
- Extra features to consider like boss attachments, insert, etc.

However, some demerits can be associated with compression molding. These include:

- The product's geometry is limited to enable ejection while ensuring the reuse of the mold. For example, the product cannot have undercuts.
- A product with the shape of a bottle cannot be viably produced using compression molding, chiefly because of ejection and mold reuse concerns.
- It gives a high carbon footprint and energy consumption challenges.
- The energy consumption is typically lower than injection molding but higher than the rest of the molding processes.

Overall, the merits/advantages of compression molding outweigh the demerits.

Chapter 10: Standards Used in Compression Molding

Some of the standards used in compression molding are listed below:

1. ISO 293:2004 Plastics: This details the compression molding of thermoplastic material test specimens.
2. ISO 295:2004 Plastics: This details the compression molding of thermosetting test specimens.
3. ISO 286 Geometrical product specifications (GPS): This is an ISO code system for tolerances on linear sizes, with Part 1 being the basis of tolerances, deviations, and fits.
4. BS EN 289:2014 Plastics and rubber machines: This details the compression molding machine's safety precautions. The transfer molding machine's safety is also considered.
5. ISO 2393 Rubber test mixes detail the preparation, mixing, and vulcanization. Equipment and procedures

Conclusion

Compression molding finds itself amidst a rapidly advancing manufacturing industry, to which new techniques are continually introduced. As a result, it has endured some moderate longevity compared with some methods competing in the same space. Its ability to meet the evolving needs of the industry has been aided by its adaptation into emerging trends, for instance, robotics. In the broader context of the manufacturing industry, compression molding is not an end in itself but a means to some other end.

5.2 Safety precautions.

Safety rules for injection molding follow:
1. Do not operate the machine unless you have been instructed in its operation and safety devices.
2. Be certain all safety devices are working properly before operating the machine.
3. If any safety equipment is missing, damaged, or inoperative, notify your supervisor immediately and do not operate the machine.
4. Report any hazard to your supervisor, no matter how minor it is.
5. Report any open receptacles, junction boxes, bare wires, oil leaks, or water leaks to your supervisor.
6. Keep oil and water off the floor around the machine.
7. Keep the platform and work area clean.
8. Use safety devices provided and do not bypass, change, or otherwise make inoperative any such safety device or equipment.
9. Shouting or horseplay is strictly forbidden.
10. Never block fire extinguishers, fire exits, or other emergency equipment.
11. Use only tools and equipment that are in good condition.
12. When lifting, keep your back straight and lift with your legs. If the load is too heavy, get help o r notify your supervisor.
13. Report all injuries to your supervisor immediately.
14. Wear safety shoes and safety glasses at all times.
15. Follow directions for mold setup as posted on the setup sheet. No unauthorized deviations are to be made.
16. Be sure barrel and mold temperatures are maintained. Report deviations to your supervisor.
17. Maintain correct hydraulic-oil temperature and level
18. Check to see that the nozzle tip is properly seated in the mold before starting.
19. Check pressure gauges for proper settings.
20. When in doubt, ask your supervisor.
21. Never climb on the machine while it is running.
22. Whenever you leave your machine, be sure it is turned off.
23. At the start of each shift, be sure the machine is operating properly and that molding parameters are set properly.
24. If the machine must be shut down, plastic materials should not be left in a plasticizing cylinder heated to operating temperatures.
25. Material should never be left in the mold. Remove the molded parts and sprue before shutting down the machine.
26. Before working on the machine or between plates, be sure proper lockout procedures have been followed.
27. When purging material from the plasticizing cylinder or changing materials, be sure of the compatibility of materials being used. Check with your supervisor for this information.
28. Follow all posted danger and caution signs.

5.3 Powder Metallurgy: Introduction, advantages and disadvantages,

Powder Metallurgy Process with its Advantages and Disadvantages

Powder Metallurgy or P/M is a manufacturing process of producing finished or semi-finished objects by compressing the metal powder into suitable dies. It is one of the cheapest process which gives high quality, high strength, complex shapes with high degree of accuracy. These factors make this process most suitable for mass production. It mainly involves four basic steps.

1. Powder Preparation:

2. Mixing and Blending:

3. Compacting:

4. Sintering:

Sometimes, this process accomplished with some secondary operation like sizing, coining, infiltration, hot forging etc.

Powder metallurgy is continuously growing technology. Almost all metals can cast by P/M technology but mostly iron powder is used with some alloying elements like copper, graphite which gives greater strength.

Learn more about this process with its pros and cons in this article.

Powder Metallurgy Process:

As we discussed earlier, P/M involves basic four processes. These are:

1. Powder Preparation:

This is first and basic step for producing any object by powder metallurgy process. Any material can convert into powder. There are various processes of producing powder such as atomization, grinding, chemical reaction, electrolysis process etc.

2. Mixing and Blending:

As the name implies, this step involves mixing of two or more material powder to produce a high strength alloy material according to the product requirement. This process ensure even distribution of powder with additives, binders etc. Sometime lubricants also added in the blending process to improve flow characteristic of powder.

3. Compacting:

Compacting means compressed the prepared powder mixture into pre-defined dies. This step ensures to reduce voids and increase density of the product. The powder is compacted into mould by the application of pressure to form a product which is called green compact (the product get by compacting). It involves pressure range from 80 to 1600 MPa. This pressure depends on the properties of metal powder and binders.

For soft powder compacting pressure is about 100 – 350 MPa.

For steel , iron etc. the pressure is in between 400 – 700 MPa.

4. Sintering:

The green compact, produced by compressing, is not very strong and can’t be used as final product. This step involves heating of green compact at an elevated temperature which ensure permanent strong bond between adjacent particles. This process provides strength to green compact and converts it into final product. The sintering temperature is generally about 70 to 90 percent of melting temperature of metal powder.

5. Secondary Operation

The sintered object is more porous compare to fully dense material. The density of product depends upon press capacity, sintering temperature, compressing pressure etc. Sometimes, the product does not require high density and the sintered product is directly used as final product. But sometimes, a highly dense product is required (for example manufacturing bearing etc.) where sintered product cannot be used as finished product. That’s why a secondary operation required to obtain high density and high dimensional accuracy. The most common secondary operation used are sizing, hot forging, coining, infiltration, impregnation etc.

Advantages and Disadvantages:

Advantages:

- P/M is Cost effective for mass production due to absence of labour cost, further machining cost etc.
- This process does not require high skilled operator.
- Some alloys can only produce by P/M technology.
- High production rate. It can produced 500 to 1000 pieces in one hour.
- Complex Shape can produce.
- Bimetallic and laminated product can be easily produced by P/M method.

Disadvantages:

- High equipment cost.
- It is economical only for mass production.
- Intricate designs is difficult to produce due to less flow ability of metal powder.
- It cannot produce a complete uniform dense product.
- Size of the product is restricted due to capacity of press.
- Some metals powder, which can produce explosion in powder form, cannot be used.
- Low impact and fatigue property of final product.
- It is difficult to cast low melting point metals by P/M technology.

Application:

- Cutting tools like cemented carbide tool, ceramic tool etc. are Powder metallurgy product.
- Electric bushes made by mixing Cu and Ag with graphite is P/M product.
- Nozzles for rocket and missiles.
- Small parts in automotive and appliance applications where the ability to produce a nearly final shape requiring a minimum machining, provides a strong economic advantage.
- Bearing, Bushes etc.
- Magnetic soft metals like Fe, Fe-3Si etc. can easily formed into final shape by P/M.

Powdermetallurgy processes: Powder making, blending, compacting, sintering, infiltration and impregnation, Applications Safety Precautions.

Powder Metallurgy Process: Definition, Application, Advantages

Powder Metallurgy Definition:

Powder Metallurgy is can be defined as the process of preparation and process the powdered iron and nonferrous metals are called as powder metallurgy.

Powder Metallurgy Process:

These factors make this process most suitable for mass production. It mainly involves four basic steps.

1. **Powder Preparation:**
2. **Mixing and Blending:**
3. **Compacting:**
4. **Sintering:**

Sometimes, this process accomplished with some secondary operations like **sizing, coining, infiltration, hot forging,** etc.

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- The sintering temperature is generally about 70 to 90 percent of the melting temperature of metal powder.

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- The sintered object is more porous compared to fully dense material. The density of the product depends upon press capacity, sintering temperature, compressing pressure, etc.
- Sometimes, the product does not require high density and the sintered product is directly used as a final product. But sometimes, a highly dense product is required (for example manufacturing bearing, etc.)
- Where a sintered product cannot be used as a finished product. That's why a secondary operation required to obtain high density and high dimensional accuracy.
- The most common secondary operation used is **sizing**, **hot forging**, **coining, infiltration, impregnation,** etc.

Powder Metallurgy Advantages:

- The parts can be produced clean, bright and ready for use.
- The composition of the product can be controlled effectively.
- Articles of any intricate shape can be manufactured.
- Close dimensional tolerance can be achieved.
- The machining operation is almost eliminated.
- Parts have excellent finish and high dimensional accuracy.
- There is the overall economy as material wastage is negligible.
- Metals and non-metals can be mixed in any proportion.
- A wide range of properties such as porosity, density, etc.
- can be achieved effectively.
- A high production rate can be achieved.
- Reduced production time.
- Highly skilled labor is not required.
- Saving in the material through reduced wastage.
- Composition structure and properties can be controlled easily.
- A wide range of parts with special electrical and magnetic properties can be produced.

Powder Metallurgy Disadvantages:

- The high initial cost of metal powder.
- The size of the parts produced is limited due to large presses and needed to get required compressing pressure.
- The equipment used for the operation is costly.
- The impossibility of having a completely dense product.
- Pressure up to 100 tonnes capacity is used even for a small product.
- The metal powder is expensive and in some case difficult to store.
- Some power may present explosion hazards.
- Dies used must be of high accuracy and capable of withstanding high pressure and temperature.
- Parts produced have poor ductility.
- High tooling cost.
- The difficulty of sintering low melting powder.
- Poor plastic properties.

- The necessity of protective atmospheres.

Powder Metallurgy Application:

- To produce a porous product and
- Babbitt bearing for automobiles.
- To produce oil pump gears for automobiles.
- Used for production of cutting tools, wire drawing dies and deep drawing dies.
- To produce refractory metal composites, eg: tungsten, molybdenum, tantalum For manufacturing the tungsten wires for filaments in the lamp industry.
- Diamond impregnated tools are produced by a mixture of iron powder and diamond dust.
- To produced electrical contract material, eg: circuit breakers, relays and resistance welding electrodes.
- Parts of cars, aircraft, gas turbine, electric clocks, etc.
- Parts of vacuum cleaners, refrigerators parts of guns, sewing machines.

Powder Metallurgy Necessity or Need:

Power metallurgy becomes very much in the following cases:

1. The difference in the melting temperature of the two elements.
2. Melting and solidification cause poor quality.
3. Melting causes loss of identifying the constituents.
4. Some metals do not form a liquid solution.

Powder Metallurgy Characteristic:

- Powder metallurgy should be heat resistant.
- The size of the powder particles is to pass the powder through the screen (sieves) having a definite number of meshes.
- The powder should have good plasticity.
- It should have the ability to be cold-pressed.
- The powder should have an excellent parking factor.
- It should have a good flowability.
- The powder should be free from oxides and should have a clean surface.
- The ratio of the density of the compact to the apparent density of the powder should vary between 2:1 to 3:1

J) Suggested Specification Table (For ESE of Laboratory Instruction*):

Laboratory Instruction Number	**Short Laboratory Experiment Titles**	**Assessment of Laboratory Work (Marks)**		
		Performance		**Viva-Voce**
		PRA	**PDA**	
LE1.1	Identify five domestic/industrial components, select the type of manufacturing process required	15	10	5

	to produce them with justification			
LE2.1	Prepare a pattern drawing, pattern and core for a given component or component drawing.	15	10	5
LE2.2	Prepare a sand mould using a given single piece pattern.	15	10	5
LE2.3	Prepare a sand mould using a given split piece pattern.	15	10	5
LE2.4	Prepare casting using the mould made in LE2.2 and wax in place of molten metal.	15	10	5
LE3.1	Prepare aluminum washer using flywheel press.	15	10	5
LE3.2	Prepare two jobs using hot forging.	15	10	5
LE4.1	Prepare a lap joint using spot welding equipment.	15	10	5
LE 4.2	Use seam welding to join two sheets of metal.	15	10	5
LE 4.3	Prepare a V – Butt joint using TIG welding.	15	10	5
LE 4.4	Use MIG welding to join given metal pipe.	15	10	5
LE 4.5	Prepare a Balcony grill using welding of stainless Steel pipes.	15	10	5
LE5.1	Prepare a given job using blow molding process.	15	10	5
LE5.2	Prepare a job using injection molding process.	15	10	5

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K) Suggested Learning Resources:

(a) Books :

S. No.	Title	Author	Publisher and Edition*
1	Material Science and Metallurgy	O. P. Khanna	Dhanpat Rai Publishing Company Private Limited, New Delhi ISBN 13: 9789383182459
2	Manufacturing Science	Amitabha Ghosh and Asok Kumar Malik	Affiliated East West Press Pvt Ltd. ISBN 13: 9780745800592
3	Manufacturing Technology	R. K. Rajput	CBS,2 edition, 2006, ISBN-10: 8123908946 ISBN-13: 978-8123908946
4	Manufacturing Process	O. P. Khanna	Dhanpat Rai Publishing Company Private Limited, New Delhi ISBN: 9788189928230, 8189928236
5	Introduction to Basic Manufacturing Processes and Workshop Technology	Rajender Singh	New Age International ISBN (13) : 978-81-224-2316-7
6	Production Technology	R. K. Jain	Khanna Publishers ISBN 10: 8174090991 ISBN 13: 9788174090997

7	Production Technology	P. C. Sharma	S. Chand Publishing ISBN:9788121911146
8	Basic Manufacturing Processes, Theory & Practice	R. C. S. Mehta, N. S. Gaira	Viva Books Pvt. Ltd. ISBN: 9789386243928,
9	Elements of Workshop Technology Vol. I	Hajra Choudhury	Media Promoters and Publishers Pvt Ltd. ISBN 090621601X, 9780906216019
10	Workshop Technology Vol. I	B. S. Raghuwanshi	Dhanpat Rai and Sons ISBN-13: 5551234001924.
11	Manufacturing Technology Vol. I & II	P. N. Rao	McGraw Hill ISBN: 9781259062575 (Vol. 1) ISBN:9789332901018 (Vol 2)
12	Workshop Technology Vol. I	H. S. Bawa	Tata McGraw Hill ISBN (13): 9780074600269

*Latest edition of all above books should be referred