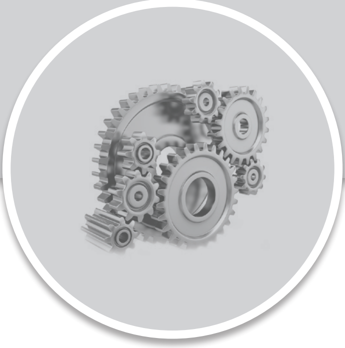
MECHANICAL ENGINEERING

Production Engineering



Comprehensive Theory
with Solved Examples *and* Practice Questions

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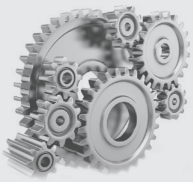

EDITIONS

First Edition : 2015
Second Edition : 2016
Third Edition : 2017
Fourth Edition : 2018
Fifth Edition : 2019
Sixth Edition : 2020
Seventh Edition : 2021
Eighth Edition : 2022
Ninth Edition : 2023

Tenth Edition : 2024

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CHAPTER

1

Metal Casting

1.1 INTRODUCTION

Casting is the oldest and still most widely used process. Casting is a manufacturing process in which a **mould cavity** is created out of sand or some permanent material and **liquid metal** is poured and allowed to solidify into this cavity. The product is taken out after solidification either by breaking the mould or taking the mould apart. If the mould is broken after each cast then it is called **expendable mould**. If the same mould is used for a number of castings, it is called **permanent mould**.

1.1.1 Sand Casting process

- Sand casting uses ordinary silica sand as the primary mould material.
- The sand grains are mixed with small amounts of other materials, such as clay and water, to improve mouldability and cohesive strength, and are then packed around a pattern that has the shape of the desired casting.
- The pattern is removed before pouring of molten metal. To facilitate this, the mould is usually made in two or more pieces.
- An opening called as sprue hole is cut from the top of the mould through the sand and connected to a system of channels called runners.
- The molten metal is poured into the sprue hole, flows through the runners, and entering the mould cavity through an opening called as gate.
- Gravity flow is the most common means of introducing of metal into the mould.
- After solidification, the mould is broken and the finished casting is removed.
- The casting is then fettled by cutting off the ingate and the feeder head.

Advantages of casting

1. It can be used to produce intricate shapes because molten metal can easily flow into small sections in the mould cavity.
2. Both hard and soft, ductile and brittle materials can be casted easily.
3. Large size castings can be produced weighing upto 200 tonnes.
4. Sand casting is a cheap process.

Limitations

1. Dimensional accuracy and surface finish of sand casted products is very poor.
2. Sand casting is labourious and time consuming process.
3. Sand casting are prone to gas defects.
4. Casting do not have uniform mechanical properties due to non-uniform cooling.

1.2 TERMS ASSOCIATED WITH CASTING

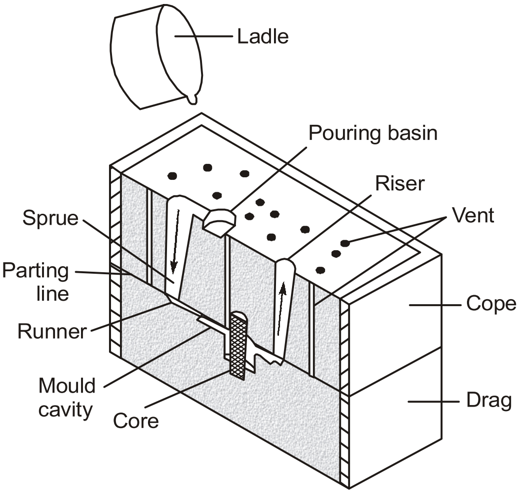


Figure: Cross section of a sand mould

- Flask:
  - (i) A moulding flask is one which holds the sand mould intact.
  - (ii) It is made up of **wood** for temporary applications or more generally of **metal** for long term use.
  - (iii) The top moulding flask is known as cope and the bottom one is known as drag. Sometimes, a third flask is placed in between cope and drag which is known as cheek.
- Pattern: It is the replica of final product to be made with some **allowances**. It is used to make mould cavity.
- Core: It is used for making **hollow cavities** in casting.
- Pouring Basin: A small funnel shaped cavity at top of the mould into which the molten metal is poured.
- Sprue: The passage through which the molten metal from the pouring basin reaches the mould cavity.
- Runner: The passage way in the parting plane through which molten metal flow before it reaches the mould cavity.
- Gate: The actual entry point through which molten metal enters the mould cavity.
- Chaplet: Chaplets are used to support cores inside the mould cavity to take care of its own weight and overcome the metallostatic forces.
- Chills: Chills are metallic objects, which are placed in the mould to increase the cooling rate of casting to provide uniform or desired cooling rate.
- Riser: It is a reservoir of molten metal in the casting so that hot metal can flow back into the mould cavity when there is a reduction in volume of metal due to contraction.
- Parting line : It is the dividing line between two moulding flasks.
- Vent : Small openings created in the mould to facilitate the escape of air and gases.

1.3 PATTERN

Patterns are objects which are similar in shape to that of final casting required. Some modifications in the form of allowances and core prints are done while deciding the size and features of a pattern. Also, some intricate details of final product may be omitted on pattern, specifically for those which are to be used with sand casting.

CHAPTER

7

Non Traditional Machining Methods

7.1 INTRODUCTION

7.1.1 Need for Non Traditional Machining

The machining processes described in chapter 3 (Metal cutting) removes material by chip formation, abrasion or microchipping. There are situations, however, where these processes are not economical or possible because of following reasons:

- The hardness and strength of the work material is very high or the material is too brittle.
- The workpiece is too flexible, slender or delicate to withstand the cutting or grinding forces, or the parts are difficult to fixture, that is difficult to clamp in work holding devices.
- The shape of the part is complex, including features such as internal and external profiles or small diameter holes in fuel injection nozzle.
- Surface finish and dimensional tolerance requirement are more rigorous than those obtain by other processes.
- Temperature rise and residual stresses in the workpiece are not desirable or acceptable.

The requirement led to the development of chemical, electrical, laser and other means of material removal. Beginning in the 1940's, these advanced methods which in the past have been called unconventional or non-traditional machining when selected and applied properly, offer major technical and economic advantage over traditional machining method. This chapter describes these processes, including their typical applications, limitations and consideration of quality, dimensional accuracy, characteristic of surface produced and economics.

Table: Non-Traditional Machining Methods

Energy	**Mechanics of material removal**	**Source**	**Process**
Mechanical	Plastic shear	Mechanical motion of job/tool	Conventional machining
	Erosion	Mechanical/fluid motion	AJM, USM
Electrochemical	Ion displacement	Electric current	ECM
Mechanical and Electrochemical	Plastic shear and ionic displacement	Electric current and mechanical motion	ECG
Chemical	Corrosive reaction	Corrosive agent	CM
Thermal	Fusion and vapourization	Electric spark	EDM
		High speed electrons	EBM
		High power radiation	LBM
		Ionized substance	IBM
		High temperature plasma	PAM

7.2 ULTRASONIC MACHINING (USM)

- In ultrasonic machining, a tool of desired shape vibrates at some frequency over the workpiece and the tool is feed downwards.
- Between the tool and workpiece, the machining zone is flooded with hard abrasive particles generally in the form of water based slurry.
- As the tool vibrates over the workpiece, the abrasive particles act as indenters and indent both the work material and the tool.
- The abrasive particles, as they indent the work material would remove the same particularly if the work material is brittle, due to crack initiation, propagation and brittle fracture of material.
- Hence, USM is mainly used for machining brittle materials (which are poor conductors of electricity and cannot be processed by electrochemical and electric-discharge machining).

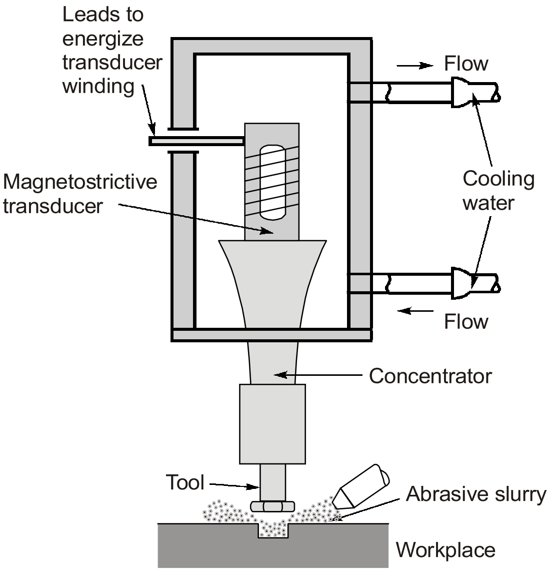


Figure: Machining using ultrasonic machining

Mechanism of Material Removal

As the tool vibrates, it leads to indentation of abrasive grits. During indentation, due to Hertzia contact stresses, cracks will develop just below the contact site and then as the indentation progresses these cracks propagate and ultimately leads to brittle fracture of work material.

Other than brittle fracture of work material some material removal may occur due to impact of free flowing abrasives against work material and related solid-solid impact erosion but it is estimated to be rather insignificant.

Process Parameters and Their Effects

A number of researchers have tried to develop the theories to predict the characteristics of ultrasonic machining, but the model proposed by M.C. Shaw is well accepted.

In the model it is assumed that :

1. The rate of work material removal is proportional to volume of work material removed per impact.
2. Rate of work material removal is proportional to number of particles making impact per cycle.
3. Rate of work material removal is proportional to frequency.
4. All impacts are identical.
5. All abrasive grains are identical and spherical in shape.

It can be concluded that,

$$Q \propto \frac{dF^{3/4}A^{3/4}C^{1/4}v}{H_w^{3/4}(1+\lambda)^{3/4}}$$

where Q = Material removal rate
d = Mean grain diameter
F = Feed force

Solution: (d)

Statement 2 is incorrect as relative motion between the work and the tool is not essential in non traditional machining methods.

EXAMPLE : 7.11 In USM the material removal rate would ________ with increasing mean grain diameter of the abrasive material

(a) increase (b) decrease

(c) increase and then decrease (d) decrease and then increase

Solution: (c)

■■■■

OBJECTIVE BRAIN TEASERS

Q.1 In electric discharge machining, the quantity of material removal due to a single discharge can be determined by considering the diameter of the crater and depth to which the melting temperature is reached. While doing the above process, which of the following assumption is not made?

(a) The spark is a uniform circular heat source on the electrode surface.

(b) The rate of heat input keeps varying throughout the discharge duration.

(c) The electrode surface is a semi-infinite region.

(d) The properties of the electrode material do not change with the temperature.

Q.2 Which of the following method is used for producing a 1 mm × 1 mm square hole with perfect square corners in a tungsten carbide die

(a) Ultrasonic machining method

(b) Electric discharge machining method

(c) Broaching operations

(d) Electrochemical machining method

Q.3 In abrasive jet machining, nozzle diameter is 1 mm, jet velocity is 200 m/s. The volumetric flow rate (cm^3/s) of the carrier gas and abrasive mixture is

(a) 152.8 (b) 157.08

(c) 185.4 (d) 171.5

Q.4 In ECM operation of pure iron an equilibrium gap of 2 mm is to be kept. If the total overvoltage is 2.5 V, the resistivity of the electrolyte is 50 Ω-mm and the feed rate is 0.25 mm/min. What will be the supply voltage? [Atomic weight of iron = 56, valency = 2, density of iron = 7800 kg/m^3]

(a) 3.45 Volt (b) 4.78 Volt

(c) 5.76 Volt (d) 13.7 Volt

Q.5 In case of EDM, if in a RC type generator, to get an idle time of 500 μs for open circuit voltage of 100 V, maximum charging voltage of 70 V and the charging capacitor is 100 μF, then what will be the charging resistance?

(a) 4 Ω (b) 5 Ω

(c) 6 Ω (d) 7 Ω

Q.6 By using USM, glass is being machined at a MRR of 6 mm^3/min by Al_2O_3 abrasive grits having a grit diameter of 150 μm. If 100 μm grits were used and keeping rest of the parameter constant, then the MRR __________ (mm^3/min). [Round off to the nearest integer]

Governing equation of MRR is

$$MRR \propto \frac{C^{1/4}A^{1/4}F^{3/4}a_0^{3/4}d_g f}{\sigma_w^{3/4}(1+\lambda)^{3/4}}\mu^{3/4}$$

where,

Frequency of vibration = f

Amplitude of vibration = a_0

Feed force = F

Feed pressure = p

Contact area of the tool = A

Volume concentration of abrasive in water slurry = C

Grit's diameter = d_g

Q.7 Which one of the following statements is not correct for abrasive jet machining?

(a) Preferred for soft materials.

(b) Abrasive powders cannot be reused.

(c) Delicate workpiece cannot be machined.

(d) It can be used for non-conductive materials.

Q.8 During ultrasonic machining, the metal removal rate is affected by the

(a) Hammering action of abrasive particles

(b) Rubbing action between tool and workpiece

(c) Low frequency of sound waves

(d) High frequency of eddy currents

Q.9 In an abrasive jet machining (AJM) process, the metal removal rate (MRR) for Q flow rate of abrasives of 'd' mean diameter is 40 mm^3/s. If flow rate of the abrasives is halved and mean diameter of abrasive is doubled, then MRR is______ mm^3/s.

■■■■

ANSWER KEY

1. (b)	2. (a)	3. (b)	4. (d)	5. (a)
6. (4)	7. (a)	8. (a)	9. (160)	

HINTS & EXPLANATIONS

1. (b)

The rate of heat input remains constant throughout the discharge duration.

2. (a)

Broaching cannot be used because such a small size tool cannot be made, EDM can be used but perfect corners cannot be made and ECM is not preferable for producing holes. So best method is USM.

3. (b)

Mixture of abrasive and carrier gas will come out from the nozzle

$$Q = A \times v$$

$$= \frac{\pi}{4} \times (0.1)^2 \times 200 \times 100$$

$$= 157.08 \text{ cm}^3/\text{s}$$

4. (d)

Given: Gap, h = 2 mm; Resistivity, r = 50 Ω-mm

Feed rate, f = 0.25 mm/min; Supply voltage = V

In ECM,

$$\text{MRR (mm}^3\text{/min)} = \frac{A_{Fe} I}{F \cdot \rho \cdot \nu_{Fe}} = \frac{A_{Fe} dV}{F \cdot \rho \cdot R \cdot \nu_{Fe}}$$

$$\text{Resistance, } R = \frac{r \cdot h}{Area}$$

$$\frac{MRR}{f} = \frac{A_{Fe} \cdot dV}{F \cdot \rho \cdot R \cdot \nu_{Fe} \times f}$$

$$\text{Area} = \frac{A_{Fe} \cdot dV}{F \cdot \rho \cdot R \cdot \nu_{Fe} \times f}$$

$$\frac{r \cdot h}{R} = \frac{A_{Fe} \cdot dV}{F \cdot \rho \cdot R \cdot \nu_{Fe} \times f}$$

$$h = \frac{A_{Fe} \cdot dV}{F \cdot \rho \cdot \nu_{Fe} \times r \cdot f}$$

$$2 = \frac{56 \times (V - 2.5)}{96500 \times 7.8 \times 10^{-3} \times 2 \times 50 \times \frac{0.25}{60}}$$

$$V = 13.7 \text{ Volt}$$

5. (a)

Given: Idle time, t_c = 500 μs; V_0 = 100 V

V_d = 70 V; C = 100 μF;

Charging resistance, R_C = ?

Charging time or idle time,

$$t_c = R_C \cdot C \ln\left(\frac{V_0}{V_0 - V_d}\right)$$

$$500 \times 10^{-6} s = R_C \times 100 \times 10^{-6} \ln\left(\frac{100}{100 - 70}\right)$$

$$\Rightarrow \quad R_C = 4\ \Omega$$

6. (4)

As given, MRR ∝ d_g

$$(\text{MRR})_1 = 6 \text{ mm}^3/\text{min}$$

$$(d_g)_1 = 150\ \mu\text{m}$$

CHAPTER

8

Additive Manufacturing

8.1 INTRODUCTION

Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. This process can be said as " What You See Is What You Build (WYSIWYB) Process".

8.1.1 Difference between Rapid Prototyping and Additive Manufacturing

AM, also known as 3D printing, rapid prototyping or freeform fabrication. Although the terms “3D printing” and “rapid prototyping” are casually used to discuss additive manufacturing, each process is actually a subset of additive manufacturing.

8.1.2 Additive vs Subtractive Manufacturing

- Additive manufacturing adds material to create an object.
- By contrast, when you create an object by traditional means, it is often necessary to remove material through milling, machining, carving, shaping or other means.

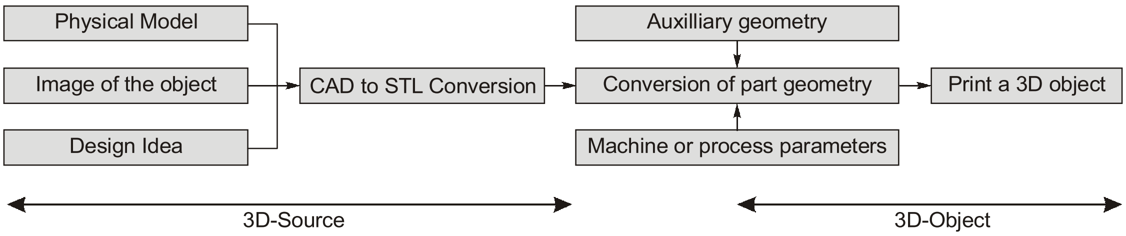
8.1.3 How does additive manufacturing works?

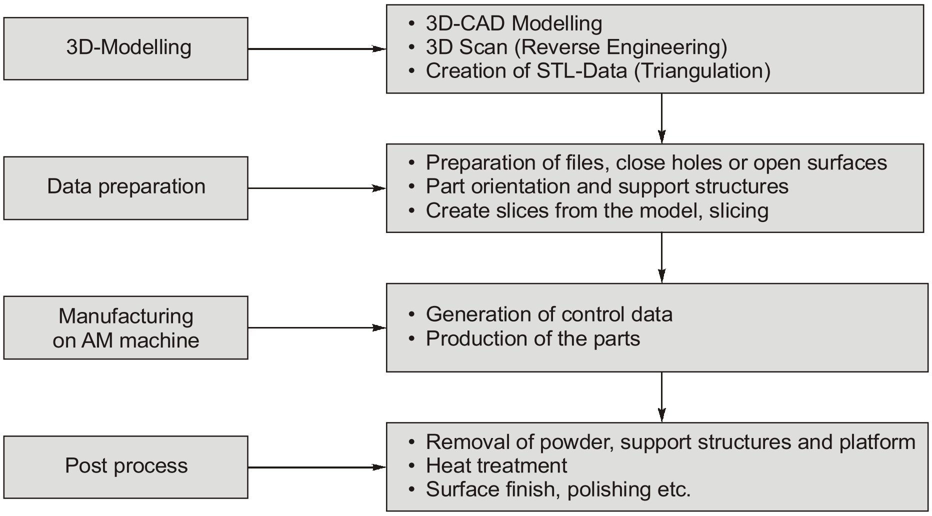
AM technologies grow three dimensional objects one superfine layer at a time. Each successive layer bonds to the preceding layer of melted or partially melted material. Objects are digitally defined by computer-aided-design (CAD) software that is used to create .stl files that essentially “slice” the object into ultra-thin layers. This information guides the path of a nozzle or print head as it precisely deposits material upon the preceding layer. Or, a laser or electron beam selectively melts or partially melts in a bed of powdered material. As materials cool down or are cured, they fuse together to form a three-dimensional object.

8.2 GENERIC AM PROCESSES

1. CAD
2. STL Convert (StereoLithography)
3. File transfer to machine
4. Machine setup
5. Build
6. Remove
7. Post Processes
8. Application

8.3 DATA PATH FOR AM

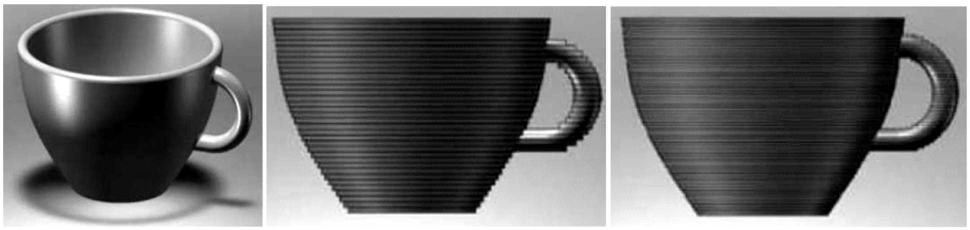




8.4 CAD MODEL INTO STL FORMAT

STL uses triangles to describe the surfaces to be built. Each triangle is described as three points and a facet normal vector indicating the outward side of the triangle.

8.5 EFFECTS OF BUILDING USING DIFFERENT LAYER THICKNESSES



8.6 GENERATION OF GEOMETRICAL LAYER INFORMATION ON SINGLE LAYERS

To produce three-dimensional models by layer-oriented additive manufacturing processes, the 3D CAD solid must be mathematically split into the same layers as those produced physically by the AM machine. This process is known as "slicing”. There are two basic methods of doing this:

1. Triangulation, which leads to the STL format .
2. Direct cutting in the CAD system, which leads to the CL (SLI) format.

8.7 STL FORMAT

STL (StereoLithography) is a file format native to the stereolithography CAD software. It is widely used for rapid prototyping, 3D printing and computer-aided manufacturing. The main purpose of the STL file format is to encode the surface geometry of a 3D object. It encodes this information using a simple concept called “tessellation”.

8.7.1 Tessellation

Tessellation is the process of tiling a surface with one or more geometric shapes such that there are no overlaps or gaps. Tessellation can involve simple geometric shapes or very complicated (and imaginative) shapes

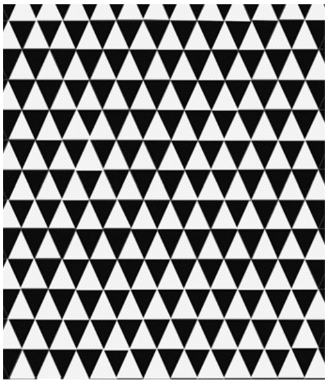


Figure: Tessellation using triangles

8.7.2 ASCII STL file format

File starts with mandatory line:

solid <name>

File ends with mandatory line:

endsolid <name>

The file stores information about the covering triangles.

8.7.3 Binary STL file format

If the tessellation involves many small triangles, the ASCII STL file can become huge. This is why a more compact binary version exists.