Slide 1

METAL CASTING

Slide 2

CASTING PROCESS

- Fundamentals of casting process
- Principles of casting process
- Typical examples of the product produced by casting process

  Engine Block, Machine tool parts, etc.

Slide 3

When casting becomes inevitable ??

- For example when you want to machine very large size holes
- For producing parts of complicated shapes

Slide 4

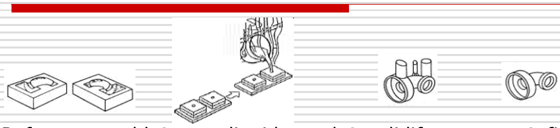
CASTING PROCESS

- Steps involved in casting process
  - Pattern making.
  - Mould making.
  - Core making.
  - Melting of metal and pouring.
  - Cooling and solidification
  - Cleaning of castings and inspection

4

Slide 5

Casting



Refractory mold → pour liquid metal → solidify, remove → finish

- VERSATILE: complex geometry, internal cavities, hollow sections
- VERSATILE: small (~10 grams) → very large parts (~1000 Kg)
- ECONOMICAL: little wastage (extra metal is re-used)
- ISOTROPIC: cast parts have same properties along all directions

5

Slide 6

Sand Casting

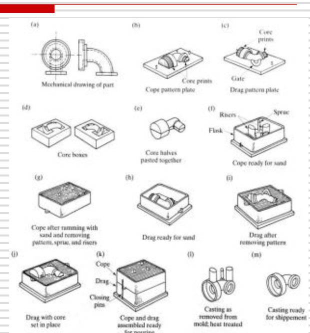
Cope: Top half

Dag: Bottom half

Core: for internal cavities

Pattern: positive

Funnel → sprue →
→ runners → gate →
→ cavity →
→ {risers, vents}



6

Slide 7

Sand Casting Considerations

(a) How do we make the **pattern**?

[cut, carve, machine]

(b) Why is the pattern not exactly identical to the part shape?

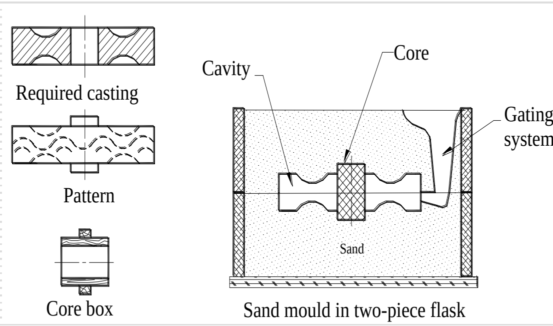
- pattern → outer surfaces; (inner surfaces: core)
- shrinkage, post-processing

(c) **parting line**

- how to determine?

Slide 8

CASTING PROCESS



Slide 9

Sand Casting Considerations..

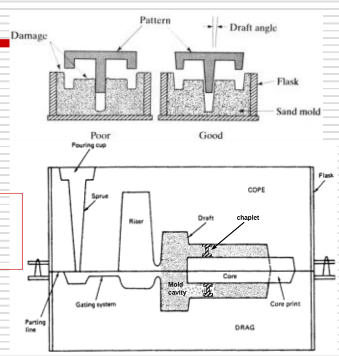
(d) **taper**

- do we need it ?

(e) **core prints, chaplets**

- hold the core in position
- chaplet is metal (why?)

(f) **cut-off, finishing**



Slide 10

PROPERTIES OF PATTERN MATERIAL ...

- It should be easily shaped, worked, machined and joined.
- It should be resistant to wear and corrosion.
- It should be resistant to chemical action.
- It should be dimensionally stable and must remain unaffected by variations in temperature and humidity.
- It should be easily available and economical.

Slide 11

WOOD

- Easily available
- Low weight
- Low cost
- It absorbs moisture and hence dimensions will change
- Lower life
- Suitable for small quantity production and very large size castings.

Slide 12

METAL

- Used for mass production
- For maintaining closer dimensional tolerances on casting.
- More life when compared to wooden patterns
- Few of the material used include CI, Al, Fe, Brass etc. Al is widely used.

Slide 13

PLASTIC

- Low weight
- Easier formability
- Do not absorb moisture
- Good corrosion resistance

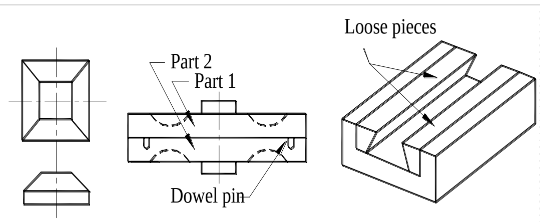
Slide 14

POLYSTYRENE

- Used for prototype (single piece) castings
- Also known as Disposable patterns.

Slide 15

TYPES OF PATTERNS



(a) Solid pattern (b) Split pattern (c) Loose piece pattern

Slide 16

TYPES OF PATTERNS

❖ SOLID PATTERN

Simple shape castings are produced by

this type of patterns

16

Slide 17

TYPES OF PATTERNS

❖ SPLIT PATTERN

Used when patterns cannot be made as a single piece

17

Slide 18

TYPES OF PATTERN

- LOOSE PIECE PATTERN Used when

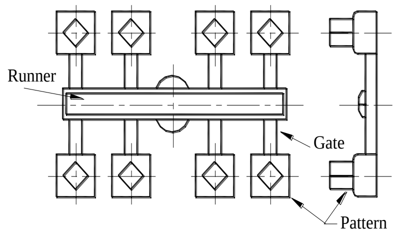
1. Withdrawal of pattern from mould is not possible
2. Castings is having projections, undercuts, etc

After ramming first main pattern is removed and then the loose pieces

18

Slide 19

GATED PATTERN



(a) Gated pattern for 8 castings

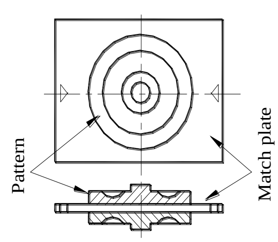
Slide 20

GATED PATTERN

- USED FOR PRODUCING SMALL SIZED CAVITIES IN ONE MOULD

Slide 21

MATCH PLATE PATTERN



(b) Match plate pattern

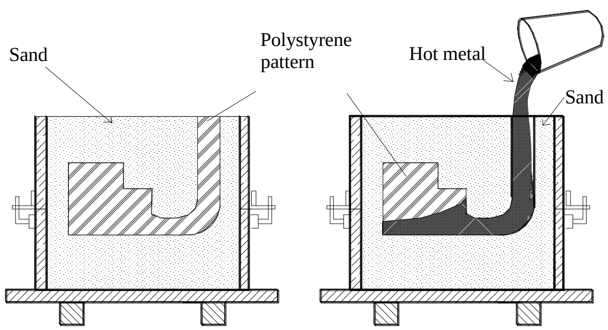
Slide 22

MATCH PLATE PATTERN

- Split patterns attached on either side is known as *Match plate pattern.*
- It increases production and helps in maintaining uniformity in the size and shape of the castings.

Slide 23

DISPOSABLE PATTERN



(a) Disposable pattern in sand mould

(b) Hot metal replacing disposable pattern

Slide 24

PATTERN ALLOWANCE

- WHY ARE ALLOWANCES NECESSARY ?

Slide 25

TYPES OF ALLOWANCE

- SHRINKAGE ALLOWANCE
- MACHINING ALLOWANCE
- DRAFT OR TAPER ALLOWANCE
- DISTORTION ALLOWANCE
- RAPPING OR SHAKE ALLOWANCE

Slide 26

SHRINKAGE ALLOWANCE

- Provided to compensate for shrinkage of material
- Pattern is made slightly bigger
- Amount of allowance depends upon type of material, its composition, pouring temperature etc.

Slide 27

MACHINING ALLOWANCE

- Provided to compensate for machining on casting.
- Pattern is made slightly bigger is size.
- Amount of allowance depends upon size and shape of casting, type of material, machining process to be used, degree of accuracy and surface finish required etc.

Slide 28

DRAFT OR TAPER ALLOWANCE

(a) Pattern with zero or no draft

(b) Pattern with draft

(a) Pattern with zero (no) draft

(b) Pattern with draft

(Not to scale)

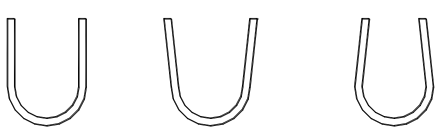
Slide 29

DRAFT OR TAPER ALLOWANCE

- Provided to facilitate easy withdrawal of the pattern.
- Typically it ranges from 1 degree to 3 degree for wooden patterns.

Slide 30

DISTORTION ALLOWANCE



(a) Required shape of casting

(b) Casting produced when no distortion allowance is provided

(c) Pattern with distortion allowance

- Provided on patterns whose castings tend to distort on cooling

Slide 31

MOULDING PROCESS

- Bench Moulding
- Floor Moulding
- Pit Moulding

Slide 32

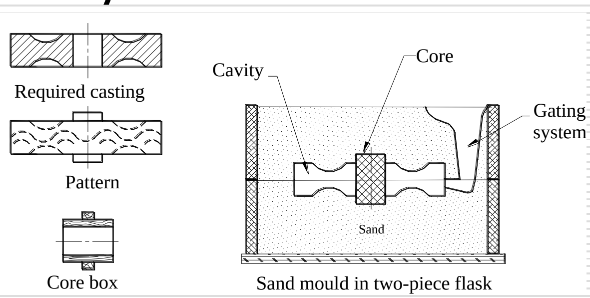
TYPES OF MOULDING OPERATIONS

- Hand Moulding
- Machine Moulding

Slide 33

CORES

- **Why Cores are used?**



Slide 34

CORE PROPERTIES

- It must be strong to retain the shape while handling,
- It must resist erosion by molten metal,
- It must be permeable to gases,
- It must have high refractoriness, and
- It must have good surface finish to replicate it on to the casting.

Slide 35

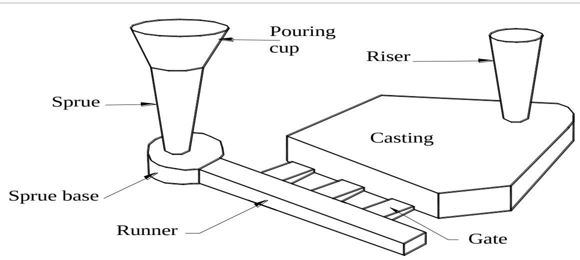
STEPS IN CORE MAKING

- Core sand preparation.
- Core making.
- Core baking.

Slide 36

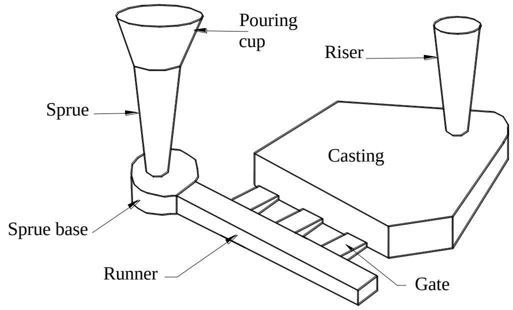
GATING SYSTEM

- It refers to the passageway through which molten metal passes to enter mould cavity.



Slide 37

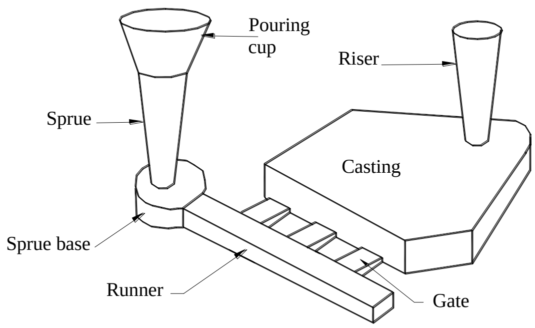
POURING CUP



37

Slide 38

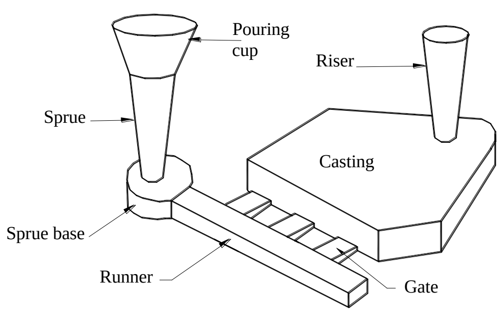
SPRUE BASE



38

Slide 39

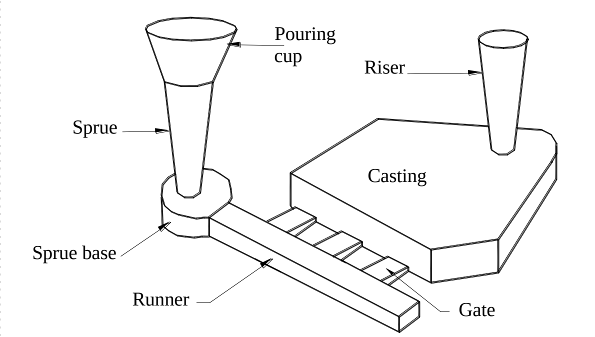
RUNNER



39

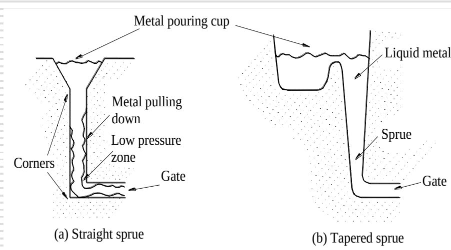
Slide 40

RISER



Slide 41

SPRUE



Slide 42

SOLIDIFICATION TIME
[Chvorinov's Rule]

- **Total Solidification Time[TST]**

$$TST = c\left(\frac{volume}{surface\,area}\right)^n$$

Where c = mould constant depends upon the mould material, metal properties & temperature

Slide 43

Mold Constant in Chvorinov's Rule

- C_m depends on mold material, thermal properties of casting metal, and pouring temperature relative to melting point
- Value of C_m for a given casting operation can be based on experimental data from previous operations carried out using same mold material, metal, and pouring temperature, even though the shape of the part may be quite different

Slide 44

CASTING YIELD

- **What is *casting yield*?**

$$C_y = \frac{W_c}{W_c + W_g} \times 100\%$$

Slide 45

DEFECTS IN CASTING

Slide 46

Basic categories of casting defects

1. Metallic projections:
   - Fins, flash or projections
2. Cavities
   - blow holes, pin holes, shrinkage cavities
3. Discontinuities
   - cracks, cold or hot tears
   - cold shuts- improper fusion of different streams of metals
   - Improper solidification can cause tears

Slide 47

4. Defective surface
   - Surface folds ,laps, scars, adhering sand layers and oxide scales
5. Incomplete casting
   - misruns (due to premature solidifications)
   - insufficient metal poured
   - leaks in the mold
6. Incorrect dimensions
   - incorrect allowances
   - deformed pattern
   - pattern mounting error

Slide 48

7. Inclusions
   - nonmetallic particles usually
   - bad for casting - acts as stress raiser
   - materials from alloys, crucible ,mold etc
   - sand particles, ceramic particles,
   - Can be avoided using filters, good strong molds etc

Slide 49

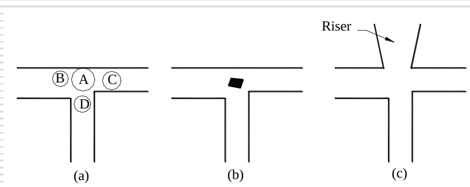
BLOW HOLES

- Appears as small round voids opened to the casting surface.
- Caused by hard ramming and low permeability sands.

Slide 50

SHRINKAGE DEFECTS

- *Caused by inadequate feeding of molten metal.*



Slide 51

HOT TEARS

- Appears as external cracks or discontinuities on casting surface.
- Caused by hard ramming, too much of shrinkage of molten metal and poor design of casting.

Slide 52

MISRUNS

- Mould cavity remaining unfilled (casting is too thin or temperature is too cold)

52

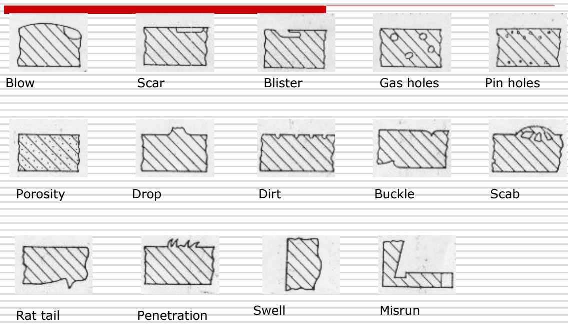
Slide 53

- COLD SHUT
- Imperfect fusion of molten metal in the mould cavity.
- POUR SHORT
- Mould cavity is not completely filled for the want of molten material.
- INCLUSIONS
- Foreign material present within the metal of a casting.

53

Slide 54

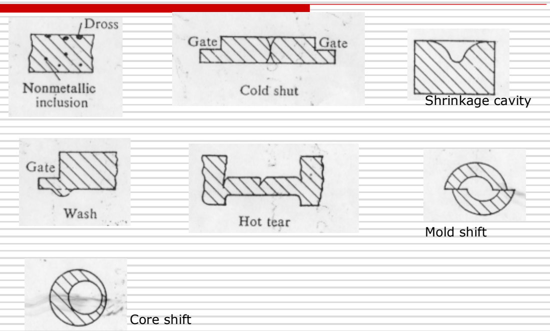
Common Casting defects



54

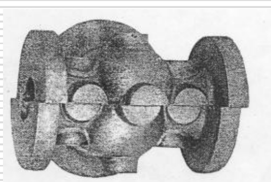
Slide 55

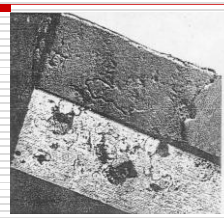
Common Casting defects



Slide 56

Casting defects



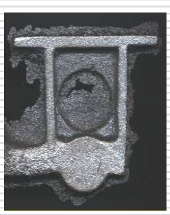


- A crossjoint in a large gray iron valve body casting produced by mismatch of top and bottom parts of the mould

- Inclusions in spheroidal graphite cast iron.
- Part of the surface has been machined away to show the inclusions more clearly

Slide 57

Flash



Mold Shift

Porosity

Slide 58

Inclusions

Gas pockets

Short Casting

58

Slide 59

Summary of casting defects

Defect	Cause	Foundry remedy	Design remedy
Flash	Flow into mold join	Lower pouring temperature, Increase mold box clamping,	
Oxide and dross inclusion	Entrapment of foreign material	Increase care and cleanliness during pouring,	
Shrinkage cavities	Lack of sufficient feed metal	Promote directional solidification by controlling heat flow, Raise pouring temperature,	Relocate risers and ingates
Misruns	Low metal fluidity	Raise pouring temperature	Reconsider position, size and number of ingates and vents

59

Slide 60

Inspection of casting

1. Visual Inspection
   - Most surface defects can be seen
2. Pressure test
   - The casting is filled with pressurized air after closing all the openings
   - E.g. gear boxes, pressure vessels, look for leaks by submerging in special liquids
   - Pressurized oil can also be used in some cases
3. Radiographic Examination
   - Usually x-rays or g rays
   - x-ray method is used for voids,non metallic inclusions, porosity, cracks
   - Defects appear darker than surrounding

60

Slide 61

4. Ultrasound examination

- Ultrasound across the casting
- Sound transmitted across homogenous metals
- However discontinuities reflect sound back.
- Not good for cast iron

5. Dye Penetration Inspection

- To detect invisible surface defects in non magnetic castings
- A dye of fluorescent material is sprayed or applied near the surface. The surface is then wiped and viewed in darkness
- Cracks will be visible

Slide 62

6. Magnetic Particle inspection

- Induce magnetic field through section under inspection
- Powdered Ferro-magnetic magnetic material is spread onto the surface
- Voids or cracks result in abrupt changes in permeability of material – leads to leakage in magnetic field
- Particles concentrate on the disrupted field or on the crack.

Slide 63

ADVANTAGES OF CASTING PROCESS

- No restriction on type of metal or alloy.
- No restriction on size of the component that can be casted.
- Economically suitable for batch and mass production.

Slide 64

DISADVANTAGES OF CASTING PROCESS

- High energy consuming process.
- Highly labor intensive.
- Raw material requirement is quite high.
- For producing 1 ton of steel casting about 2.2 tons of metal, 0.3 tons of facing sand and 4 tons of baking sand are needed apart from many other materials.
- More time is involved.
- High environmental pollution.

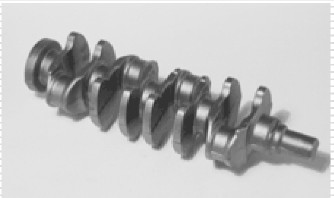
Slide 65

SELECTION OF CASTING PROCESS

- Quantity to be produced.
- Requirement of the product in terms of surface finish, accuracy, complexity etc.
- Physical properties of the material.
- Process capability to meet the requirement of point 2 and 3.
- Initial investment required and operational costs.
- Other factors such as environmental pollution, availability of skilled operator (if required), possibility of automation.

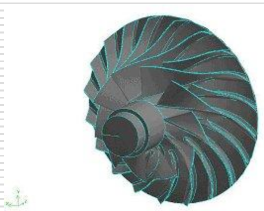
Slide 66

Crank Shaft



Slide 67

Impellers



Slide 68

V6 engine block

Slide 69

AUDI engine block

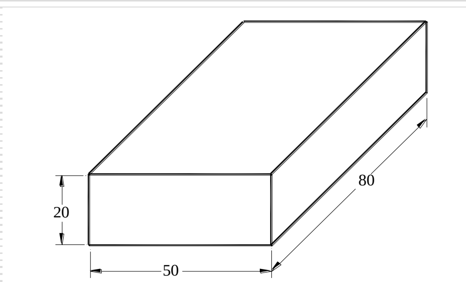
Slide 70

EXAMPLE 1

- A job shown in the Figure is to be made of steel by casting process. The mould for this job is made from a wooden pattern. Determine the dimensions of the wooden pattern. Assume machining allowance of 2 mm on each side, shrinkage allowance of 2% and a taper allowance of 1 degree.

Slide 71

EXAMPLE -1



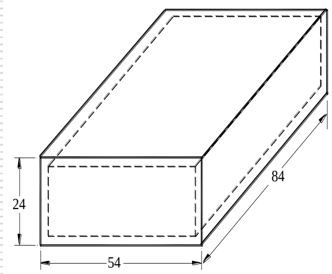
Slide 72

EXAMPLE-1

- ***Solution***
- **Step-1: Machining Allowance**
- It is given that machining allowance of 2 mm on each side is to be given. Thus, each side is increased by 2 mm resulting in the basic dimension of the pattern as shown in Figure (a). The required casting is shown with dotted lines.

Slide 73

EXAMPLE-1



(a)

Slide 74

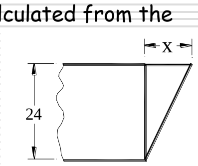
EXAMPLE-1

- **Step-2 : Taper Allowance**
- We decide to cast the job horizontally and use a solid pattern for this casting. For this design, the draft allowance is to be provided on the vertical sides (24 mm long). Considering the given taper allowance of 1 degree, the side view of the pattern would be as shown in Figure (b).

Slide 75

EXAMPLE-1

- The taper allowance value *x* is calculated from the geometry of the Figure (b) as



- $x = 24 \tan 1 = 0.419$ mm.
- Thus, the top surface dimension is increased to provide for draft allowance from
  54×84 mm to 54.838×84.838 mm.

Slide 76

Step-3 Shrinkage Allowance:

Given shrinkage allowance is 2%. Now, the dimensions of pattern are increased by 2% on all sides.

That is, dimension 54 mm will become

54 + (54*2)/100 = 55.08mm or 55.1mm

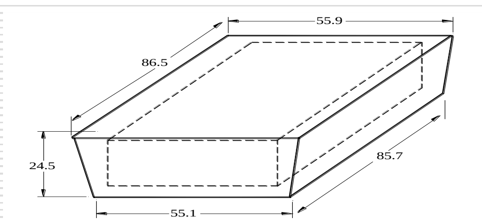
The dimension 54.838 will become

54.838 + (54.838*2)/100 = 55.9mm

76

Slide 77

- Similarly, all other dimensions are calculated and the final dimensions of the pattern are shown in Figure



77

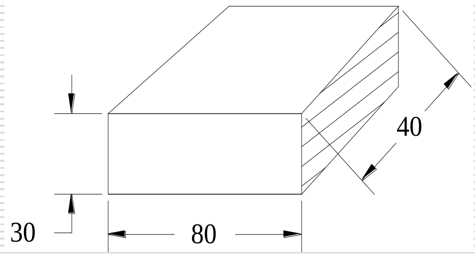
Slide 78

- ***Example 2***

- A job shown in Figure 2 is to be made from steel by casting process. The mold for this job is made from wooden pattern. Determine the dimensions of the wooden pattern assuming machining allowance of 3 mm on each side, shaking allowance of 1 mm on length and width, shrinkage allowance of 3%

78

Slide 79



Slide 80

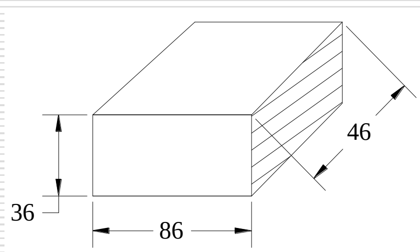
- ***Solution***

Step-1 : Machining Allowance

- Since given machining allowance is 3 mm on each side, add 3 mm on each side of the part shown in Figure. The dimensions of the pattern after machining allowance will be:
    - L = 80 + 2 × 3 = 86 mm
    - W = 40 + 2 × 3 = 46 mm
    - H = 30 + 2 × 3 = 36 mm

Slide 81

The dimensions of the pattern after adding machining allowance are shown in the following figure …



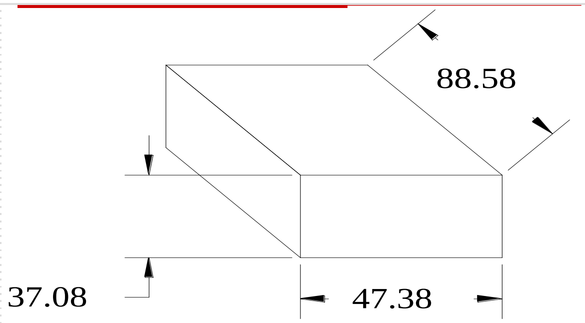
Slide 82

Step-2 : shrinkage allownce

- The shrinkage allowance of 3% is added to all the dimensions of the pattern shown in Figure. Dimension of the pattern after providing shrinkage allowance of 3% will be:
  - L = 86 + 86 × 3/100 = 88.58 mm,
  - W = 46 + 46 × 3/100 = 47.38 mm
  - H = 36 + 36 × 3/100 = 37.08 mm

Slide 83

EXAMPLE #2



Slide 84

Step -3 : Shaking Allowance

- Given shaking allowance is 1 mm on length and width.
- Recall that, shaking allowance is a negative allowance.
- Hence, 1 mm has to be reduced from the calculated values of length and width side.
- Students are advised to note that the height of the pattern doesn't require any shaking allowance.

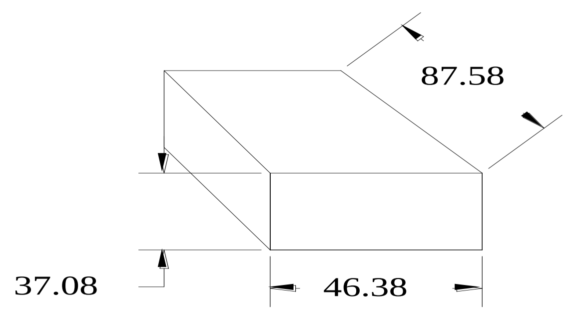
Slide 85

EXAMPLE #2

- Therefore, final dimension of the pattern will be:
  - L = 88.58 – 1 = 87.58 mm
  - W = 47.38 – 1 = 46.38 mm
  - H = 37.08 mm

Slide 86

EXAMPLE #2



Slide 87

Example 3

The downsprue leading into the runner of a certain mold has a length = 175 mm. The cross-sectional area at the base of the sprue is 400 mm^2. The mold cavity has a volume = 0.001 m^3.Determine: (a) the velocity of the molten metal flowing through the base of the downsprue, (b) the volumetric flow rate, and (c) the time required to fill the mold cavity.

Slide 88

Example 3: Solution

- (a) Velocity $v = (2gh)^{0.5}$

  $= (2 \times 9810 \times 175)^{0.5}$

  = 1853 mm/s
- (b) Volume flow rate $Q = vA$

  $= 1853 \times 400$

  = 741,200 mm³/s
- (c) Time to fill cavity MFT = V/Q

88

Slide 89

Example 4

In casting experiments performed using a titanium alloy and a zircon sand mold, it took 155 s for a cube-shaped casting to solidify. The cube was 50 mm on a side. If the same alloy and mold type were used, find the total solidification time for a cylindrical casting in which the diameter = 30 mm and length = 50 mm.

89

Slide 90

Example 4: Solution

- Cube Volume V
  $= (50)^3$
  $= 125,000\ mm^3$
- Cube Area A
  $= 6 \times (50)^2$
  $= 15,000\ mm^2$
- Cube (V/A)
  = 125,000/15,000
  = 8.33 mm
- $C_m = TST/(V/A)^2$
  $= 155/(8.33)^2$
  = 2.23 s/mm²

- Cylinder Volume V
  $= \pi D^2 L/4 = \pi(30)^2(50)/4$
  $= 35,343\ mm^3$
- Cylinder Area A
  $= 2\pi D^2/4 + \pi DL$
  $= \pi(30)^2/2 + \pi(30)(50)$
  $= 6126\ mm^2$
- Cylinder (V/A)
  = 35,343/6126
  = 5.77 mm
- $TST = C_m(V/A)^2$
  $= 2.23\ (5.77)^2 =$ **74.3 s**

90

Slide 91

Example 5

A mold cavity has the shape of a cube, 100 mm on a side. Determine the volume and dimensions of the final cube after cooling to room temperature if the cast metal is copper. Assume that the mold is full at the start of solidification and that shrinkage occurs uniformly in all directions. For copper, solidification shrinkage is 4.9%, solid contraction during cooling is 7.5%.

Slide 92

Example 5: Solution

- Volume of cavity V

  $= (100)^3$

  $= 10^6$ mm^3

- Volume of casting V

  $= 10^6(1-0.049)(1-0.075)$

  = 879,675 mm^3

- Dimension on each side of cube

  $= (879{,}675)^{0.333}$

  = 95.82 mm