Advanced Casting and Welding

MME-111a

A four Module Paper

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5. Gating System Design

The liquid metal that runs through the various channels in the mould obeys the Bernoulli's theorem, which states that the total energy head remains constant.

\[ h + \frac{P}{w} + \frac{v^2}{2g} = \text{CONST} \]

- \( h \) - potential head, m
- \( P \) - pressure, Pa
- \( v \) - liquid velocity, m/s
Another law of fluid mechanics, which is useful in understanding the gating system behaviour is the law of continuity which says that the volume of metal flowing at any section in the mould is constant. An equation thus can be written as

\[ Q = A_1 V_1 = A_2 V_2 \]

where
- \( Q \) - rate of flow \( \text{m}^3/\text{s} \)
- \( A \) - Area of cross section
- \( V \) - velocity of metal flow \( \text{m/s} \)

5. Pouring Time

The pouring time depends on the casting materials, complexity of casting, section thickness and casting size etc.

The following are some standard methods to calculate the pouring time for different casting materials:

1. Grey Cast Iron, mass less than 450 kg

Pouring time \( t = K \left( 1.41 + \frac{T}{14.59} \right) \sqrt{W} \) s

where
- \( K \) = Fluidity of iron \( \text{cm} \) \( \text{min} \) \( \text{inch} \)
- \( T \) = Average section thickness, \( \text{mm} \)
- \( W \) = Mass of the casting, kg
(3) Steel casting
\[ t = (2.4335 - 0.3953 \log w) \sqrt{w} \text{ s} \]

(4) Shell moulded duralumin
\[ t = k_1 \sqrt{w} \text{ s} \]
where \( k_1 = \)
- 2.080 for thinner sections
- 2.670 for sections 10 to 25 mm thick
- 2.970 for heavier sections

(5) Copper alloys
\[ t = k_2 3^{\frac{1}{3}} \sqrt{w} \text{ s} \]
\( k = \text{const.} \)
Top gating 1.3
Bottom gating 1.8
Brass 1.9
Titanium 2.8

Russian Practice

(6) Intricate shaped thick-walled casting
\[ t = k_3 3^{\frac{1}{3}} \sqrt{w} \text{ s} \]
where \( w' = \) mass of casting with gates and runners, kg
\( k_3 = \text{const.} \)
\[ \text{Tom} = \frac{k_3}{1.5 \text{ to } 2.5} \]
1.5 to 2.5 \[ \text{1.62} \]
(7) Castings above 450 kg and up to 1000 kg.

\[ t = \frac{K_y \sqrt{W}}{T} \]

where \( K_y \) is const.

<table>
<thead>
<tr>
<th>T (mm)</th>
<th>( \frac{K_y}{W} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 10</td>
<td>1.0</td>
</tr>
<tr>
<td>10 - 20</td>
<td>1.35 etc.</td>
</tr>
</tbody>
</table>

**CHOKE AREA**

Not normally the choke area happens to be at the bottom of the sprue and hence the first element to be designed in the gating system is the sprue size and its proportions. The main advantage in having a sprue bottom as the choke area is that proper flow characteristics are established early in the mould.

The choke area can be calculated using Bernoulli's equation:

\[ A = \frac{W}{dt} C \sqrt{2gh} \]

where:
- \( A \) = choke area \( \text{mm}^2 \)
- \( W \) = casting mass, \( \text{kg} \)
- \( t \) = pouring time, \( \text{s} \)
- \( \rho \) = mass density of the molten metal, \( \text{kg/mm}^3 \)
- \( g \) = acceleration due to gravity, \( \text{mm/s}^2 \)
- \( H \) = sprue height (effective metal head)
The objective of gate height \( H \) at mould depends on the casting dimensions and the type of gating system used.

The following relations can be taken:

- Top gate: \( H = h \)
- Bottom gate: \( H = h - \frac{C}{2} \)
- Parting gate: \( H = h - \frac{P}{2} - \frac{2}{C} \)

Where:
- \( h \) = height of sprue
- \( P \) = height of mould cavity in cope
- \( C \) = total height of mould cavity

\[
C = \frac{1}{1 + K \frac{A_2}{A_1^2} + K_2 \frac{A_2}{A_1^2} + \ldots}
\]

For other conditions pl. see P.N.R. 153.

8. Gating Ratios

This refers to the proportion of the core sectional area to sprue area, and the area of ingates and gate area. For example, a commonly used gating area is sprue area; ingate area; runner area. There are two types of gating system:

1) Pressureised
2) Non-pressureised

8. Ingate Design.

The ingate are generally made curvier compared to the depth up to a ratio of 4. This facilitates in the severing of gating from the casting after solidification. It may sometimes be preferable to reduce the actual connection between the ingate and the casting by means of neck down. Uchach four in one day sand core so that the removal of the gating is simplified.

The following points should be kept in mind while choosing the positioning of ingates:

1) Ingate should not be located near a protruding part of the mould to avoid the striking of vertical mould walls by the molten metal stream.

2) Ingate should preferably be placed along the longitudinal axis of the mould cavity.

3) Ingate should not be placed near a core or a part of a chill.

4) Ingate cross sectional area should preferably be smaller than the smallest thickness of the casting so the ingated solubility first and the isolate the gating system. This could reduce the feeding of the cavity by allowing more solidification through the ingate.
Small castings may be designed with a single single ring gate, however, larger or more complex castings require multiple ring gates to completely fill all the sections of the castings effectively.

Slag Trench system

In order to obtain sound casting quality, it is essential that the slag and other impurities be removed from the melt as metal fully before it enters the mould cavity. To do this foundries employ a number of methods. Apart from the use of the pouring basket and strainer etc. some other methods used to trap the slag are discussed here. There can be used 1) Runner extension or 2) Whirled gate.

Runner Design

The function of a runner is to feed the casting during during solidification so that no shrinkage cavities are found. There are three methods of runner design.

1) Caine's Method

Since solidification of castings occurs by heating sheets from the surfaces and...
to volume ratio. Chvojman has shown that the solidification time of casting is proportional to the square of the ratio of volume to surface area of casting. The constant of proportionality called the mould constant depends on the pouring temperature, casting and mould thermal characteristics.

\[ L_8 = K \left( \frac{V}{SA} \right)^2 \]

where \( L_8 \) = solidification time
\( V \) = volume of casting
\( SA \) = surface area
\( K \) = mould casting

The freezing ratio, \( X \), of a mould is defined as the ratio of casting characteristic of casting to riser.

\[ X = \frac{SA_{casting}}{SA_{riser}} \div \frac{V_{casting}}{V_{riser}} \]

In order to be able to feed the casting, the riser should solidify last and hence the freezing ratio should be greater than unity.

Based on the Chvojman's rule, Caime developed a relationship empirically for freezing ratio as follows:

\[ X = \frac{a}{1 - c} \]
(9)

\[ Y = \text{cast-in volume/casting volume} \]

\[ a, b, \text{and } c \text{ are constants whose values for different materials are given in Table 4.8 PNR 142.} \]

As discussed above another two methods (i) Modulus Method (ii) Naval Research Laboratory Method are discussed in PNR 144 – 150.

6. **Chills.**

Chills are preheated in the mould so as to increase the heat extraction capability of the sand mould. A chill normally provides a steeper temperature so that directional solidification as required in a casting can be obtained. The chill is a metallic object having higher heat absorbing capacity than the sand mould. The chill can be two types.

1. External
2. Internal.

The chill should be clean and dry otherwise gas inclusions can be left in the casting. The material of the chill should approximately resemble the composition of the pouring metal for proper fusion.

6. **Feeding Aids**
in the feeder in liquid form for as long a period as required so that it would feed the casting till solidifies. When this is done, the feeder volume decreases, resulting in a higher yield. The aids used for this purpose are called feeding aids. They can be either extraneous materials or insulators.
Solidification of Metals

- Solidification of pure metals
  - Equiaxed grains
  - Columnar grains

- Solidification of alloys
  - Nucleation
  - Grains

Graphs showing temperature (Temp) versus time (Time) for both pure metals and alloys.
8. Casting Defects.

The following are the major detect defects which are likely to occur in sand castings:

1) Gas defects.
2) Shrinkage defects.
3) Moulding material defects.
4) Pouring metal defects.
5) Metallurgical defects.

Gas defects:

(i) Blow holes and open bosses.

These are the spherical, flattened or elongated cavities present inside casting. These are caused by the moisture left inside the mould and core. To prevent such types defects proper venting should be provided.

(ii) Air inclusions.

The atmosphere and other gases absorbed by the metal metal in the furnace, in the ladle, and during the flow to the mould, become not allowed to escape.

The remedies would be to choose the appropriate pouring temps. and improve gating properties by reducing the turbulence.

(iii) Pinhole Porosity.

This is caused by hydrogen in the molten metal. The hydrogen content in the...
diameter being pim holes showing the path of escape. The main reason of this is high freezing temperature.

IV. Shrinkage Cavities. — These are caused by the liquid shrinkage occurring during the solidification of the casting. To compensate this proper feeding of liquid metal is required as also proper casting design.

MOULDING MATERIAL DEFECTS

(i) Cuts and washes — Caused by creation of moulding materials. This can be prevented by proper design of gating system and proper reaming.

(ii) Metal Penetration

Molten metal enters the grain size gap. Caused due to large sized sand and grains and high melting temperature. Prevented by choosing a preferable grain size sand.

(iii) Fission — Fusion of sand grains with the molten metal. Main cause is due to addition of low refractory ones clay.

(iv) Runout — This is caused when the molten metal leaks out of the mould. This is caused due to faulty mould design.

(v) Rattails and backles. — This is caused due to the combination failure of the stem...
(VI) Suck - Under the influence of the metal's static pressures forces the mould wall may move back causing a suction in the dimension of casting. Proper reaming would correct this.

(VII) Drop - Dropping of loose moulding sand lumps from the cope surface into the mould cavity. Due to insufficient reaming.

POURING METAL DEFECTS

(1) Miserly and Cold Shuts - Miserly is caused when the metal is unable to fill the mould cavity completely and thus leaves unfilled cavities. A cold shut is caused when two metal streams while meeting in the mould cavity do not fuse together properly thus causing discontinuity or weak spots.

(11) Slag Inclusions - All air under-entrapped slag and impurities are not removed properly from the molten metal causing this type of defect.

METALLURGICAL DEFECTS
Stress may cause fracture of casting.

Hot spots - these are caused by the chilling of the casting.

**MODULE-III**

(1) Basic Metallurgy of fusion welds.

Although a weldment formed by fusion welding results in the formation of a monolithic structure, such a joint varies from the base metal in metallurgical structure from point to point with various mechanical properties. These changes occur due to variations in temp from the weld to HAZ.

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**Diagram:**
- Peak Temp
- Temp. 1600
- Temp. 1400
- Temp. 1200
- Temp. 1100
- Temp. 1000
- Temp. 900
- Temp. 800
- Temp. 700
- Temp. 600
- Temp. 500
- Temp. 400
- Temp. 300
- Temp. 200
- Temp. 100
- Temp. 0

Legend:
- a - Partially molten Zone
- b1 - Underbead Zone
- b2 - Growth Grain Zone
- c - At Fe+5
- d - d
- e - e
- f - f
- g - g
- h - h
- i - i
- j - j
- k - k
- l - l
- m - m
- n - n
- o - o
- p - p
- q - q
- r - r
- s - s
- t - t
- u - u
- v - v
- w - w
- x - x
- y - y
- z - z

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Basically, a weldment can be divided into three distinct zones viz. the weld metal, the heat affected zone (HAZ) and the unheated base metal (BM) zone.

**General Theory of Solidification of Metals and Alloys**

Solidification of a molten metal zone would occur by the nucleation of minute grains or crystals which then grow under the influence of the crystallographic and thermal conditions that prevail. The size and character of these grains are controlled by the material composition being cast and the cooling rate.

1. **Homogeneous Nucleation**
   - This occurs from metals containing no nucleating agents. This occurs below the equilibrium freezing point.

2. **Heterogeneous Nucleation**
   - If there is a nucleating agent present in the molten metal, then heterogeneous solidification takes place.

5. Effect of Welding Speed on Grain Structure
at high welding speeds the weld pool tends to take an elongated shape. In low welding speeds columnar grains will form and grow in the direction of welding while at high welding speeds they grow straight towards the weld central line.

Regular grains

Low Speed

Welding direction

High Speed

3. Properties of Welded Metals

In general strength and toughness of the welded metal do not match those of corresponding base metal. Properties of welded metals are generally influenced by the type of microstructure, grain size etc. The microstructure can be affected considerably by welding parameters like welding speed, heat input etc.
(i) **Fusion Boundary Zone**

This is partially melted zone. For low carbon steels, here you can find (L + S) ferrite.

(ii) **Heat Affected Zone**

The microstructure and mechanical properties are changed due to influence of heat during welding on this zone.

Depending upon peak temperature, the HAZ achieved in steels the following changes are observed:

1. **Uncleared Zone** - That part of HAZ which is heated to above the critical temp of grain growth, and extends up to the fusion boundary zone.

2. **Grain Growth Zone** - Beyond 1150°C to peritectic temperature.

3. **Grain Refined Zone** - 950°C to 1150°C.
(4) Partially Transformed Zone — 750 to 938°C between A1 to A3 temp.

(5) Zone 5 & Spheroidized Carbides — 532 to 750°C: Below A1

(6) Zone 8 enriched Case metal — up to 532°C.

The final microstructure of a section depends upon several factors including compositions, grain size, peak temp., heating and cooling rates etc.

WELDING STRESS and Distortion

The residual stresses develops in the welding component due to plastic deformation in a welded body associated with temperature cycle during welding. This hampers the functional efficiency of the component leading to failures in the engineering structure. Tensile residual stresses reduce fatigue strength and corrosion resistance.
The 3 main causes of the development of residual stresses in welded structures are:

1) Local heating and cooling of metal.
2) Shrinkage of solidification.
3) Structural changes on solidification.

5. Effect of welded thermal cycle and shrinkage on residual stresses

In most cases, expansion and contraction, caused by welded thermal cycle produce no harmful results; however, under certain conditions, they may reduce the strength of the weld, indeed its structure as a whole.
Fig. Schematic representation of changes in temperature and longitudinal stresses during butt welding.

Fig. Schematic illustration of the variation in stress-temperature and stress-strain during butt welding for point E regions to the right.
According to Makabuchi and Martin, the distribution of the longitudinal residual stress, $6x$, can be approximated by the following equation:

$$6x(y) = 6m \left[ 1 - \left( \frac{y}{b} \right)^2 \right] e^{-\frac{1}{2}(\frac{y}{b})^2}$$

where $6m$ is the maximum residual stress, which is usually as high as the yield stress of the weld metal, $b$ is the width of the tension zone at $6x$.

5. Reaction Stresses

![Diagram of reaction stresses](image)

A butt weld

Distributin of $6x$ along $x-x$.

Residual stresses without action.
8. Stresses generated by phase transformation.

Stresses generated by in welded joints due to phase transformation in welded joints are to be discussed here.


Residual Stress measurement method

Experimental Method

- Destructive Method
  - Universal Method
    - Strip Cutting Method
    - Resilience Method
  - Knoop Method
    - Blade Cutting Method
    - Hole Drilling Method
    - Blind Hole Drilling Method
    - Cutting drill method
    - Ring groove method
    - Resilience method
      - Resilience and

Analytical Method

- Non-Destructive Method
  - X-Ray Method
  - Neutron Reflection Method
  - Ultrasonic Method
  - Magnetic particle Method
  - Echo current method
  - Slice cutting method
  - Boring, self method.
Module IV

Preheat and Postheat Weld Heat Treatment.

A steel is cooled without preheat then the total drop in temperature will be from 1500°C to 30°C i.e. about 1500°C. In case if it is preheated to say 300°C the drop will be reduced to about 1200°C. This results in reduced cooling rates.

Post-heat or stress relief treatment is intended primarily as a stress relief treatment.

Aims of Preheating:

1) To reduce the heat losses from the weld area, that in turn reduces the cooling rate of the weld.
2) To reduce cracking by preventing the formation of hard surfaces.
3) To reduce the expansion and contraction rates thus reducing distortion and residual stress.
4) To burn greases, oil, etc. from the surface or stress.
5) To enhance the weldability of the base metal.
3. Methods of Preheating

1. Flame heating method
2. Induction or resistance heating
3. Infrared heating
4. Quarte Carps heating

5. Advantages and Limitations of Different Preheating Methods

1. Flame Heating
   - Advantages are low cost
   - Disadvantages: minimal precision, poor repeatability, and non-uniform heating
   - Temperature distribution needs operator skill

2. Electrical Resistance Heating
   1) Even heat can be maintained throughout the welding operation.
   2) Temp can be adjusted quickly.
   3) Welders can work in relative comfort.
   4) Uniform heat can be obtained easily.
   - Limitations:
     1) Elements may burn out during operation.
     2) A resistance element may short itself out to the welding lead; this occurs fairly frequently.
3. **Induction Heating**

Adv.: High heating rates are possible.

Limitations:
1) High initial cost.
2) Equipment is bulky and not easily portable.
3) The process is too slow during welding.

4. **Gas Flame Induction Heating**

Adv.: This process uses economical fuel and suitable control equipment is also available.

Disadv.: Separate furnaces are too used.

5. **Quartz Lamp Heating**

Adv.: Fast response time, efficiency, cleanliness, fast cooling, ease of use, and quick turn around.

Disadv.: High initial equipment cost. Quartz lamps are fragile, etc.
5. Weld Defects.

These are divided into six groups:

1) Cracks — includes all types of cracks such as crevice cracks, hot cracks, cold cracks, etc.

2) Cavities — including blow holes, porosity, shrinkage, etc.

3) Scaled Inclusions — including slag, flux, metal oxides, etc.

4) Incomplete Fusion — including lack of fusion, lack of penetration, etc.

5) Imperfect Shape — including dimensional deviations, undercuts, underfills, overlap, excessive reinforcement, excessive penetration, etc.

6) Miscellaneous Defects — including arc strike, excessive spatter, rough surface, uneven ripples, pace marks, etc.

8. Arc Welding Defects:

1) Internal defects
2) Surface cracks
3) Distortion
4) Incorrect root profile
5) Dimensional defects
8. **Weld Defects in Other Than Arc Welding Processes**
   1. Resistance welding defects.
   2. Friction welding defects.
   3. Spot welding defects.
   4. Flash welding defects.

8. **Weld Inspection**
   1. Visual inspection.
   2. Destructive Testing.
   3. Non Destructive Testing (NDT)
      1. Liquid penetrant testing.
      5. Radiographic Testing.
   7. Acoustic emission Testing.