Advanced Casting and Welding.

MME - 1112.

A four Module paper

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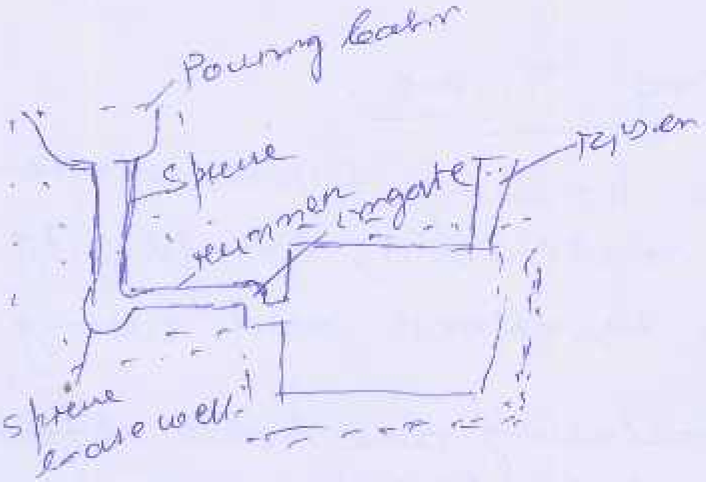
§ Gating System for casting.—

Gating system refers to all elements, which are connected with the flow of molten metal from the laddle to the mould cavity. The various elements that are connected with the gating system are: ① pouring basin ② sprue, ③ sprue base well ④ runner ~~⑤ riser~~ ⑤ runner extension ⑥ In-gate ⑦ riser.



§. 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 const.

$$h + \frac{P}{w} + \frac{v^2}{2g} = \text{Const.}$$

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. In equation this can be written as

$$Q = A_1V_1 = A_2V_2$$

where Q - rate of flow m^3/s
A - Area of cross section.
V - velocity of metal flow 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 $K = \frac{\text{Fluidity of iron in inches}}{40}$
T - Average section thickness, mm
W - Mass of the casting, kg.

(2)

(3) Steel casting

$$t = (2.4335 - 0.3953 \log w)\sqrt{w}\ s.$$

(4) Shell moulded ductile iron

$$t = K_1 \sqrt{W}\ s.$$

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.

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

K = const.

Top gating	1.3
Bottom gating	1.8
Brass	1.9
Tin bronze	2.8

Russian Practice

(6) Intricate shaped thin-walled casting of mass up to 450 kg

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

where W' - mass of casting with gates and risers, kg

K_3 = const.

T mm	K_3
1.5 to 2.5	1.62

(7) Castings above 450 kg and upto 1000 kg.

$$t = K_4 \sqrt[3]{W'T} \quad s.$$

where K_4 is const.

T (mm)	K_4
upto 10	1.0
10 – 20	1.35 etc.

8. Choke Area

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 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

$$A = \frac{W}{d\,t\,C\sqrt{2gH}}$$

where A = choke area mm^2

W – casting mass, kg.

t – pouring time, s

d – mass density of the molten metal, kg/mm^3.

g – acceleration due to gravity mm/s^2

H – sprue height (effective metal head)

The effective sprue height H of 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 $H = h - \frac{p^2}{2c}$.

where h - height of sprue
p - height of mould cavity in cope
c - total height of mould cavity.

$$C = \frac{1}{1 + K\frac{A^2}{A_1^2} + K_2\frac{A^2}{A_1^2} + \cdots}$$

For other conditions pl. see P.N.R. 133.

5. Gating Ratios.

This refers to the proportion of the cross sectional area of sprue ~~base~~ and ingates and as is generally denoted as sprue area : runner area : ingate area : ~~runner area~~. There are two types of gating system.

1) Pressurised
2) Non-pressurised.

More details in PNR. 135-136

8. Ingate Design.

The ingate are generally made wider compared to the depth upto 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. wash burn or dry sand core so that the removal of the gating is simplified.

The following points should be kept in mind while choosing the positioning of in-gates.

1) In gate 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) In gate should preferably placed along the longitudinal axis of the mould wall.

3) In gate should not be placed near a core ~~paint~~ print or a chill.

4) Ingate cross sectional area should preferably be smaller than the smallest thickness of the casting so the ingates solidify first and the isolate the gating system. This would reduce

Small castings may be designed with a ~~simpler~~ single ingate, however larger or complex castings require multiple ingates. to completely fill all the sections of the castings effectively

8. Slag Traps System —

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

9. Risering Design.

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

1) Caine's Method

Since solidification of castings occurs by loosing heat from the surfaces and to volume ratio. Chvorinov 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.

$$t_s = K\left(\frac{V}{SA}\right)^2.$$

where ts - solidification time.

V - volume of casting.

SA - surface area.

K - mould casting

The <u>freezing ratio X</u>, of a mould is defined as the ratio of cooling characteristics of casting to riser.

$$X = \frac{SA_{casting}/V_{casting}}{SA_{riser}/V_{riser}}.$$

In order to be able to feed the casting the riser should solidify last and hence its freezing ratio should be <u>greater then unity</u>.

Based on the Chvorinov's rule Caine developed a relationship empirically for freezing ratio as follows:

$$X = \frac{a}{\,} - c$$

where Y = riser volume/casting volume
a, b, and c are constants whose values for different materials are given in Table 4.8 PNR 142.

As discussed above another two methods (1) Modulus Method (11) Naval Research Laboratory Method are discussed in PNR 144 — 150.

§. Chills.

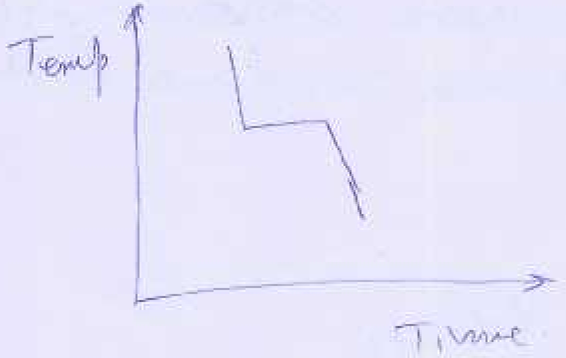
Chills are provided in the mould so to increase the heat extraction capabili of the sand mould. A chill normally provides a steeper temperature so that directional solidification as required i a casting can be obtained. The chills are metallic objects having higher heat absorbing capacity than the sand mould. The Chil can be two types.
(1) external (2) internal.

The chills when placed in a mould 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.

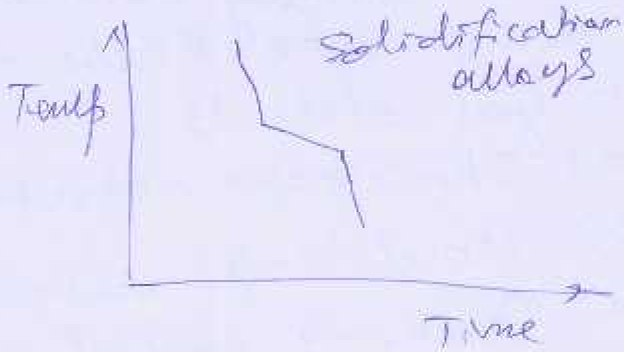
§. Feeding Aids.

in the riser in liquid form for as long a period as required so that it would feed the casting till solidifies. When this is done, the riser volume decreases, resulting in a higher yield. The aids used for this ~~purpo~~ purpose are called feeding aids. They can be either exothermic materials or insulators.

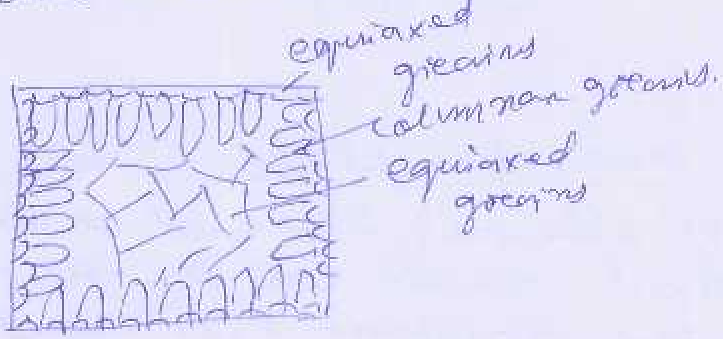
5. Solidification of Metals.

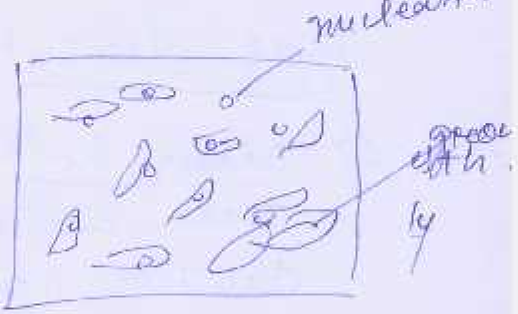


Solidification of pure metals



Solidification of alloys.





8. Casting Defects.

The following are the major ~~standard~~ 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 blows.
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 of defects proper venting should be provided.

(ii) Air Inclusions.
The atmosphere and other gases absorbed by the molten metal in the furnace, in the ladle and during the flow ~~of~~ in the mould when not allowed to escape

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

(iii) Pinhole Porosity.
This is caused by hydrogen in the molten metal. The hydrogen which

diameter long pin holes showing the path of escape. The main reason of this is high pouring 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 erosion of moulding materials. This can be prevented by proper design of gating system and proper ramming.

(ii) Metal Penetration

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

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

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

(v) Rat-tails and buckles. — This is caused due to the compression failure of the skin

The main cause of these failing defects are that the moulding Sand has got poor expansion properties and hot strength.

(VI) Swell — Under the influence of the metallostatic pressure forces the mould wall may move back causing a swell in the dimension of casting. Proper ramming will correct this.

(VII) Drop — Dropping of loose moulding sand lumps from the cope surface into the mould cavity. Due to improper ramming.

POURING METAL DEFECTS —

(I) Misruns and Cold Shuts. — Misruns 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 spot in the casting

(II) Slag inclusions

When undesirable slags and impurities are not removed properly from the molten metal causes this type of defects

METALLURGICAL DEFECTS

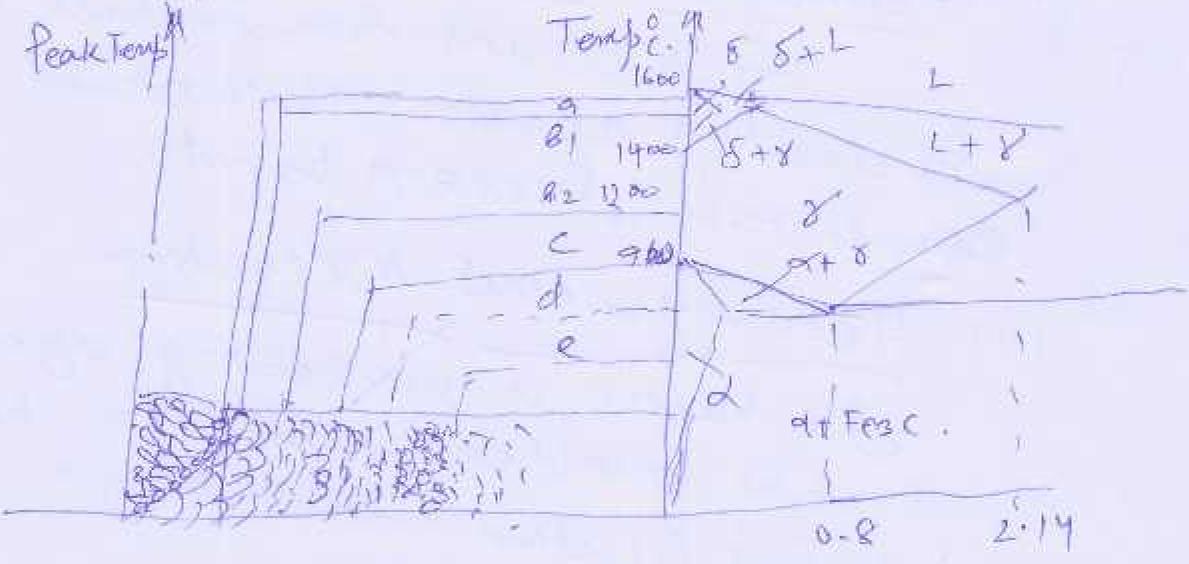
stress may cause rupture of casting.

(11) 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 monolithic structure but such a joint varies ~~from the highest~~ in metallurgical structure from point to point with varies mechanical properties. These changes occur due to varies in temp from the weld pool to HAZ.



a - partly molten zone
b1 - Underbead zone
b2 - Grain growth zone
Grain refined zone

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

§. General Theory of Solidification of Metals and alloys

Solidification of molten metal in a mould 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.

(i) Homogeneous Nucleation.

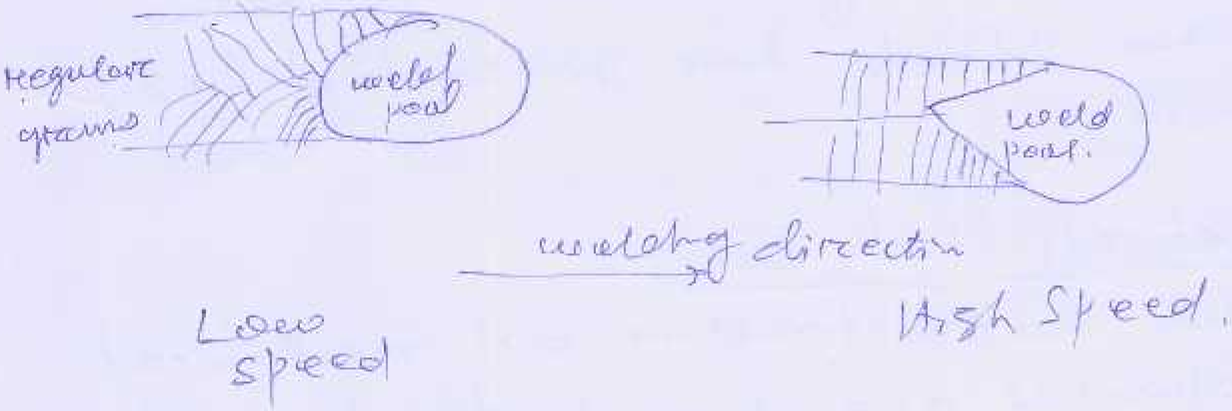
This occurs for liquid metals without any nucleating agents. This occurs below the equilibrium freezing point.

(ii) Heterogeneous Nucleation

If there is nucleating agent present in the molten metal then heterogeneous solidification takes place

§. Effect of Welding Speed on Grain Structure

at high welding speeds the weld pool ~~tends to~~ takes an elongated shape. In low weldg speeds columnar grains will curve and grow in the direction of welding while at high weldg speeds they grow straight towards the weld centreline.



§. Properties of Weld Metals.

In general strength and toughness of the weld metals do not match those of corresponding base metals. Properties of weld 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+δ) ferrite

(II) Heat Affected Zone. —

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

Depending upon peak temperature the HAZ achieved in steels the following chages in zones are observed.

(1) Underbead Zone — That part of HAZ which is heated to beyond the critical temp of grain growth and extends upto the fusion boundary zone.

(2) Grain Growth zone — Beyond 1150°C to peritectic temperature.

(3) Grain Refined Zone — 950 to 1150 °C.

(4) Partially Transformed Zone — 750 to 950°C
Between A_1 to A_3 temp.

(5) Zone of Spheroidized Carbides —
530 to 750°C. Below A_1

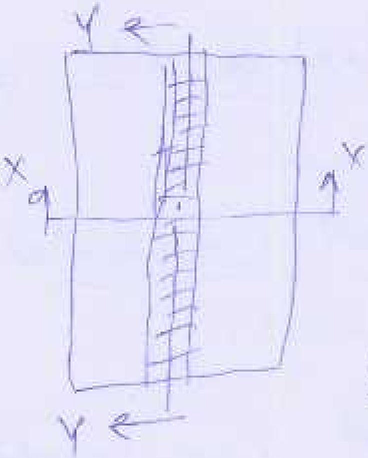
(6) Zone of unchanged base metal.

Up to 530°C.

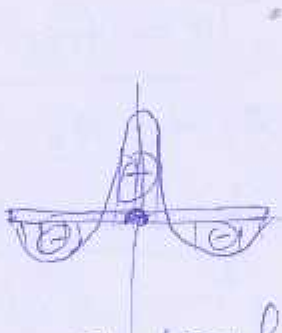
The final microstructure of a section depends upon several factors including compositions, grain size, peak temp, heating and cooling rates etc.

WELDING STRESS and Distrotion —

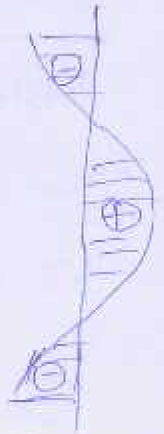
The residual stresses develops in the welding component due to ~~in~~ plastic deformation in a welded body associated with temperature cycle during welding. This hampers the functional efficiency of the components leading to failure of the engineering structure. Tensile residual stresses reduce fatigue strength and corrosion



Butt weld plate



Longitudinal stress pattern along x-x



Transverse stress pattern along Y Y.

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) ~~So~~ Structural changes on solidification.

8. Effect of weld thermal cycle and shrinkage on residual stresses

In most cases, expansion and contraction, caused by weld thermal cycle produce no harmful results; however under certain conditions they may reduce the strength of the weld, indeed of structure as a whole.

The Schematic representation of

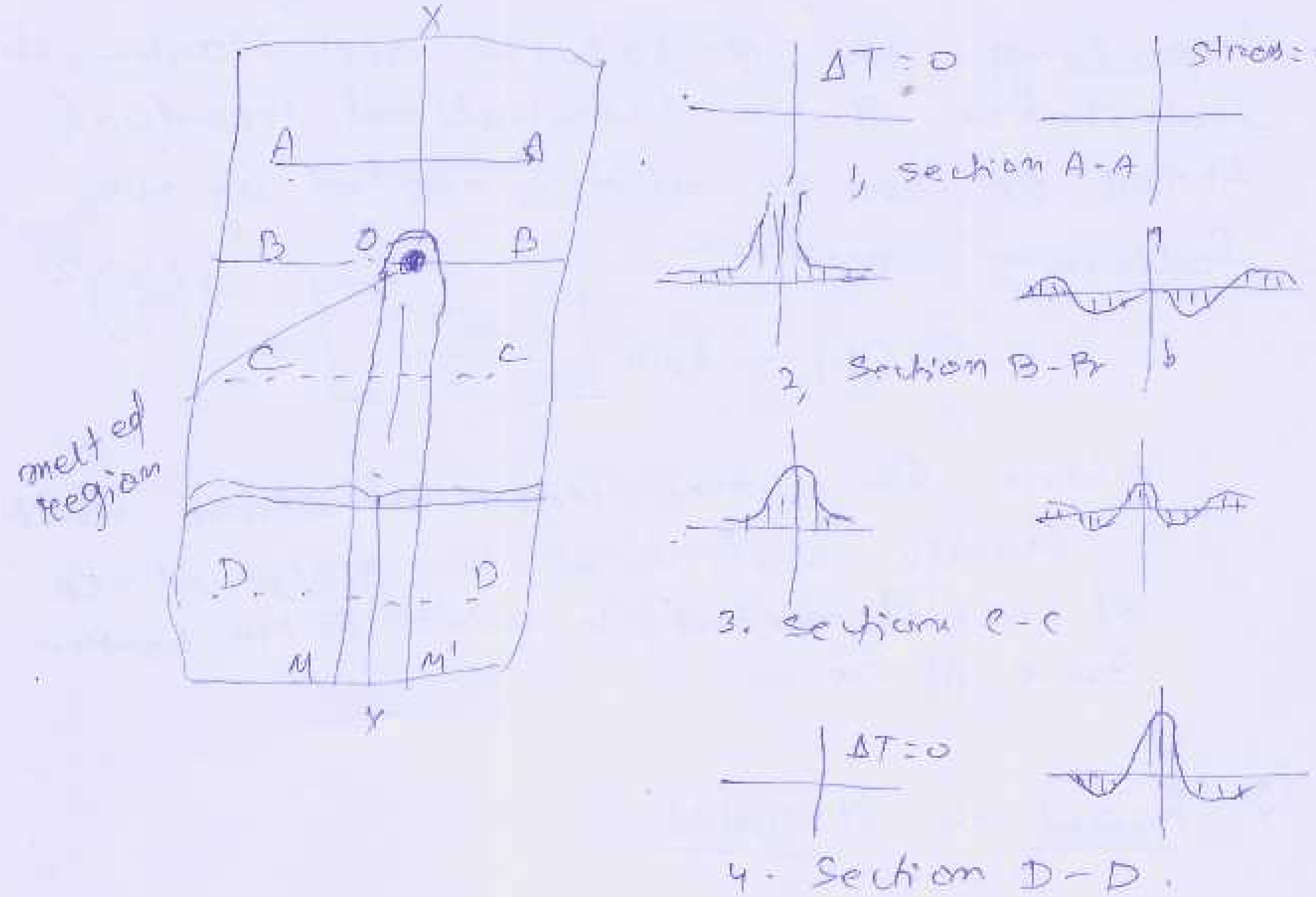


Fig. Schematic representation of changes in Temperature and Longitudinal stresses during Butt welding.

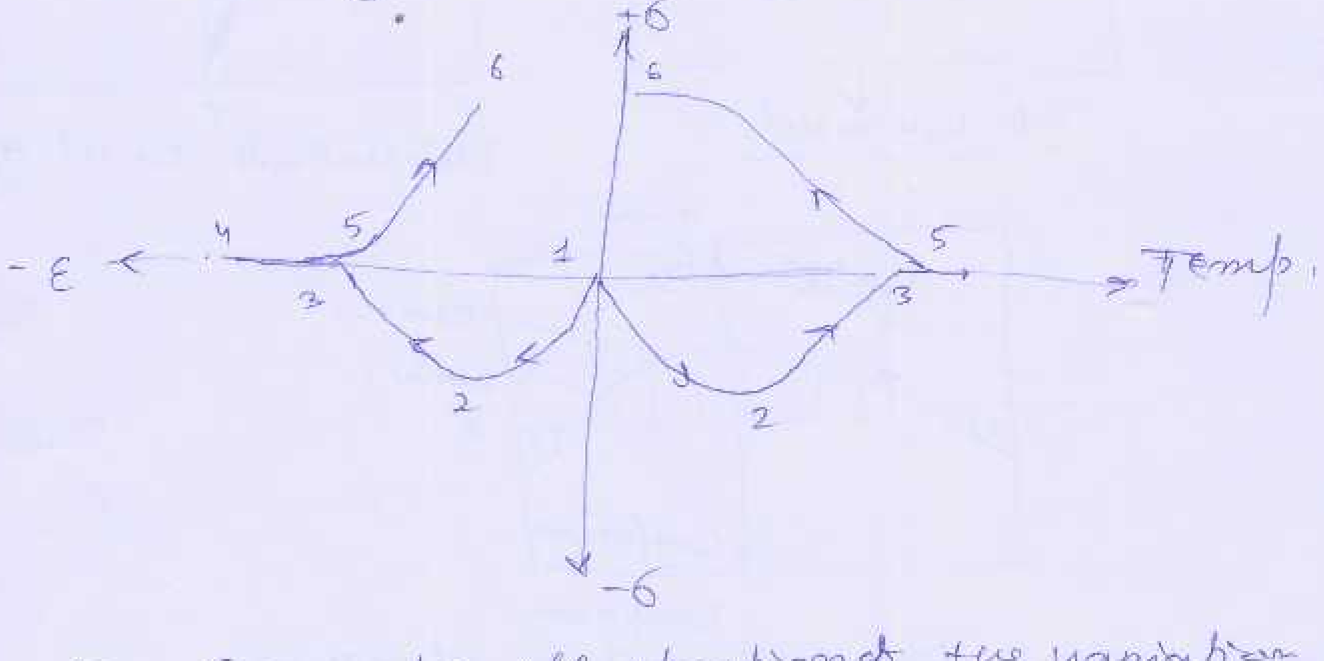


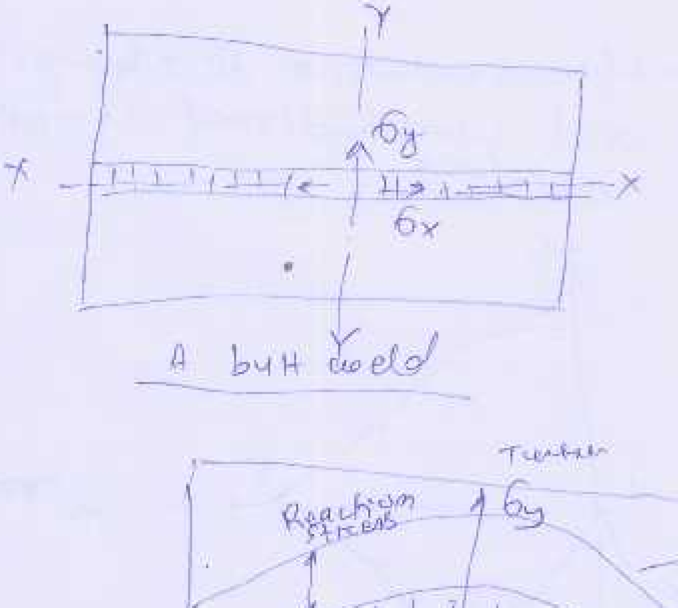
Fig. Schematic illustration of the variation in stress-temperature and stress-strain during

According to Masabuchi and Martin, the distribution of the longitudinal residual stress, σ_x can be approximated by the following equation

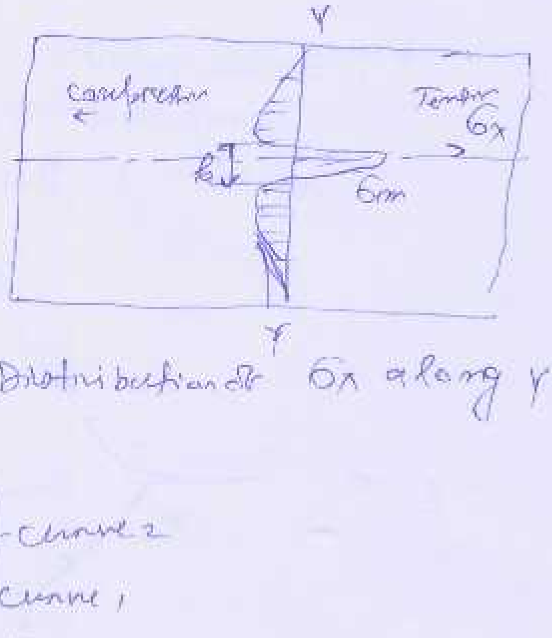
$$\sigma_x(y) = \sigma_m\left[1-\left(\frac{y}{b}\right)^2\right]e^{-\frac{1}{2}\left(\frac{y}{b}\right)^2}$$

where σ_m - max residual stress, which is usually as high as the yield stress of weld metal, b - width of the tension zone of σ_x.

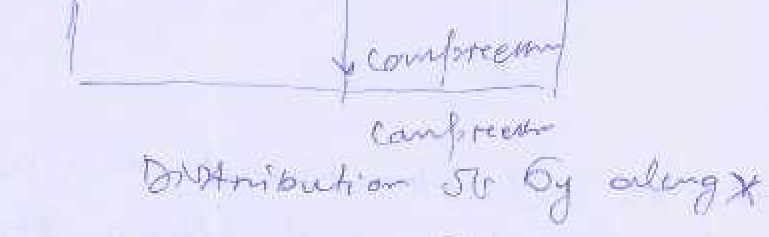
5. Reaction Stresses



A butt weld



Distribution of σ_x along Y-Y.



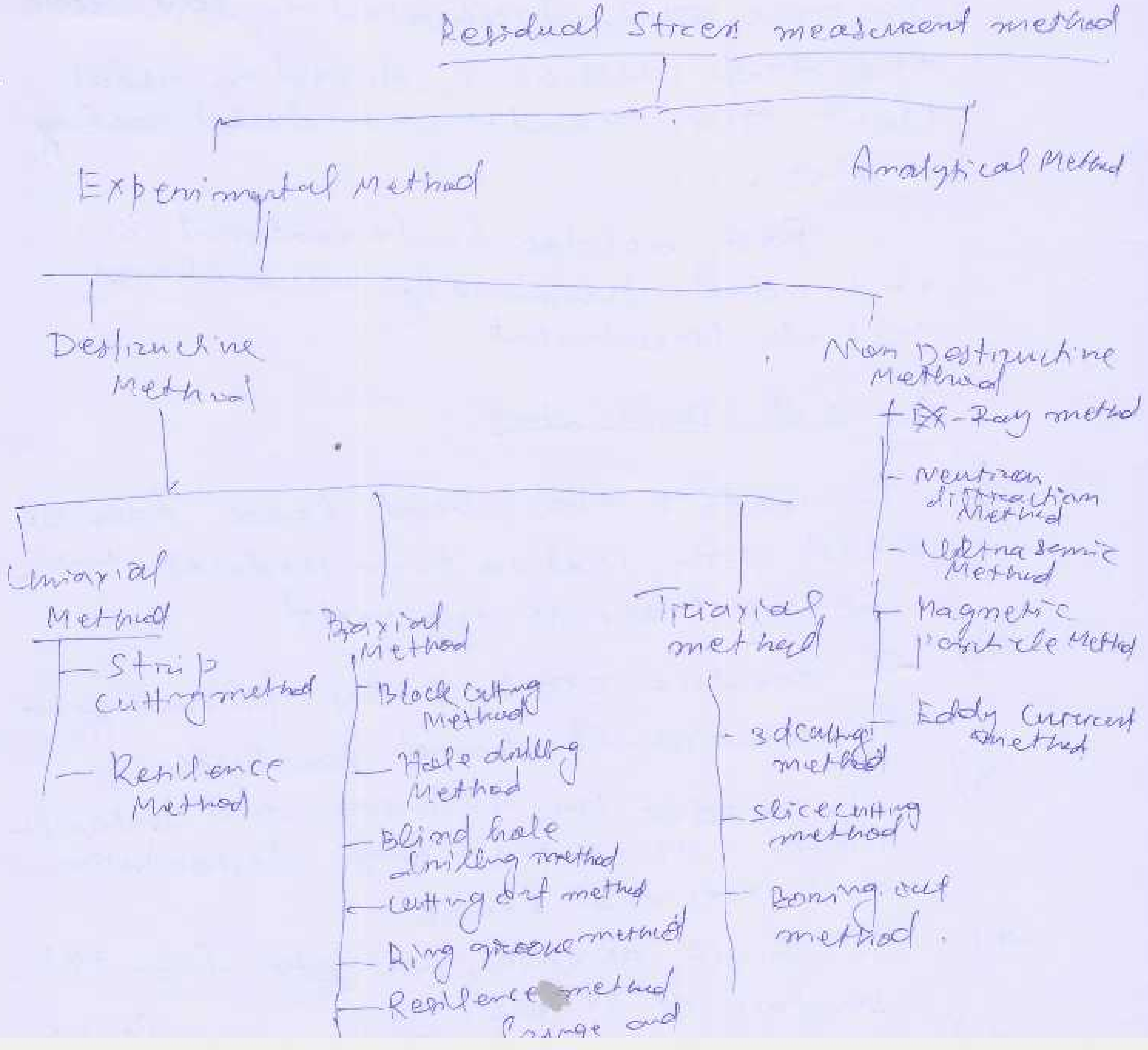
Distribution of σ_y along X-X.

Residual stresses without

§. Stresses generated by phase Transformation:

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

§. Measurement of Residual Stresses.



Module IV

5. Preheat and Post ~~heat~~ weld Heat Treatment.

If steel is welded without preheat then the total drop in temperature will be from 1540° to 30°C i.e. about 1500°C. In case it is preheated to say 300°C the drop will be reduced to about 1200°C. This results in reduced cooling rates.

Post weld heat 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 distortation and residual stress
4) To burn greases, oil, etc. from the surface of steels

3. Methods of Preeheating.

(1) Flame heating method
(2) Induction or ressistance heating.
(3) Infrared heating.
(4) Quartz Lamp heating.

5. Advantages and Limitations of Different Preeheating Methods.

1. Flame Heating.

The advantages are low cost
The drawbacks : minimal precision, ~~heating~~ repeatability and non uniform 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) Uneven heat can be obtained easily.

Limitations.

1) Elements may burn out during preheating.
2) A resistance element may short itself

3. Induction Heating.

Adv. High heating rates are possible

Limitations –

1) High initial cost.
2) Equipment is bulk and not easily portable.
3) The power is to be turned up during welding.

4. Gas Flame Infra Red Heating.

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

Disadv. — Separate furnaces are to be used.

5. Quartz Lamp Heating. –

Adv – Fast response time, efficiency, cleanliness, fast cooling down and quick turn around.

Disadv. — High initial equipment cost. Quartz lamps are fragile etc.

S. Weld Defects.

These are divided in to six groups.

1) Cracks - Includes all types of cracks such as creater cracks, hot cracks, cold cracks etc.
2) Cavities — Including blow holes, porosity, shrinkage etc.
3) Solid Inclutions — Including slag, flux, metal oxide etc.
4) Incomplete Fusion — Including lack of fusion, lack of penetration etc.
5) Imperfect Shape — Including dimentional deviations, underscut, underfill, overlap excessive reeinforcement, excessive penetreation. etc.
6) Miscellaneous Defects — Including arc strike, excessive spatter, rough surface, uneven ripples, pock marks etc.

S. Arc welding Defects.

1) Visual defects.
2) Surface cracks.
3) Distortation.
4) Incorerect weld profile.
5) Dimensional defects.

§. Weld Defects in Other than Arc Welding-Processes.

1) Resistance welding defects.
2) Friction welding defects.
3) Spot welding defects.
4) Flash welding defects.

§. Weld Inspection.

1) Visual inspection.
2) Destructive Testing.
3) Non Destructive Testing. (NDT)
    1) Liquid penetrant Testing.
    2) Magnetic particle Testing
    3) Eddy current Testing.
    4) Magnetographic Testing.
    5/ Radiographic Testing
    6) Ultrasonic Testing.
    7) Acoustic emission Testing.