Iron Making and Steel Making
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Module - 10
Lecture - 49
Continuous casting

In the last lecture we have discussed about the ingot casting, and in this lecture we will discuss about the Continuous Casting.

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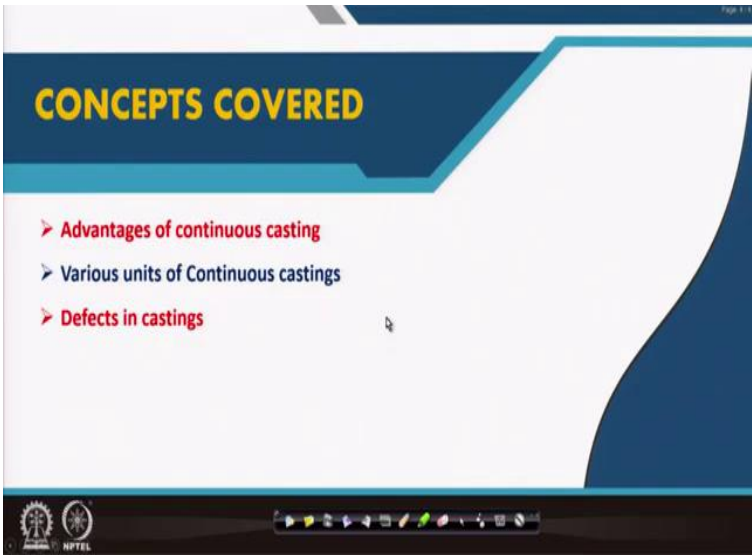
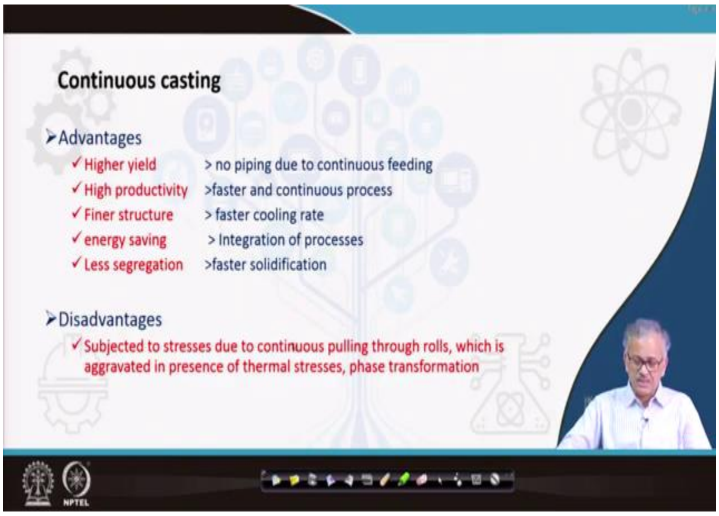


And major topics I would like to cover here are the advantage of continuous casting, various units of continuous casting, and defects in the continuous casting.(Refer Slide Time: 00:55)



Advantages of continuous casting (concast):

- Yield of concast is much higher compared to the ingot casting. Because in this case, no shrinkage cavity or pipe is formed as the mould is continuously fed from tundish; therefore no cavity or pipe loss.
- Productivity is higher because it is a faster and continuous casting process.
- Fine grain microstructure due to faster cooling.
- It yields energy saving as different processes are integrated here. In case of ingot casting, the ingot is cooled after casting and reheated again before mechanical deformation. In case of concast reheating is minimal, and it is directly deformed in hot condition after casting in the concast strand. After the casting gets completely solidified, it is shear cut and passed through reheating chamber to makeup some heat loss and directly goes to rolling mill in the strand.
- Segregation is less because the faster solidification.

Disadvantages:

- Concast has very low impurity tolerance. As the solidification rate is faster, rejected solute during solidification are likely to form inclusions or gasses, which are likely to be embed in the solidified structure in the form of defects. So, it is desired that upstream ladle operation should ensure very low impurity in the liquid steel.
- Since concast is a faster solidification process, it develops lot of thermal stress. This coupled with mechanical stress, presence of inclusions, precipitations and phase transformation leads to generation of various types of cracks and defects.

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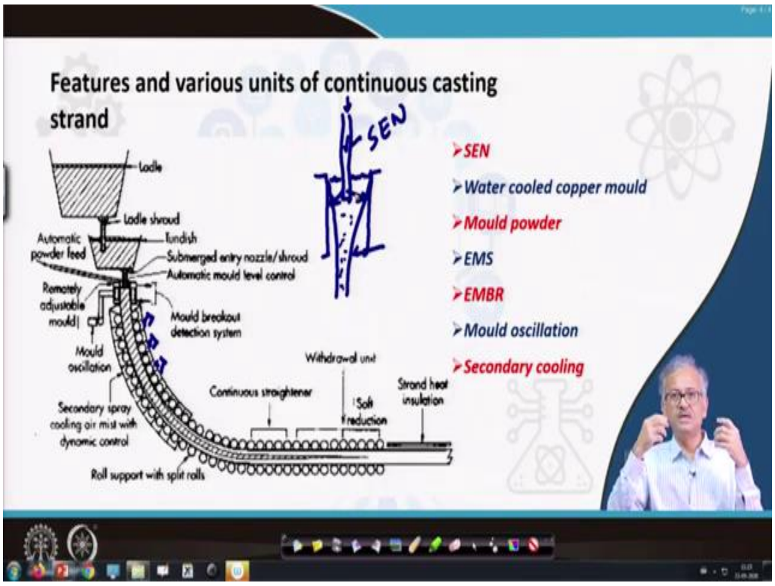

Features and various units of continuous casting: Figure 49.1 shows the various units of continuous casting.

- First the liquid iron is poured from teeming ladle into the tundish through argon shrouding. It is to be mentioned that at the onset of casting process, no additional impurity and inclusion generation is permitted and therefore liquid streaming is done under argon shrouding to avoid any further atmospheric interaction.
- Tundish, as we have discussed earlier, is an intermediate reactor to supply the liquid iron to concast mould at constant velocity and superheat. It also acts as an active reactor to remove inclusions before the liquid moves into concast mould.
- From tundish liquid enters the mould through submerged entry nozzle (SEN). So, the liquid is completely protected from the atmosphere. From SEN liquid enters the mould tangentially below the liquid meniscus.

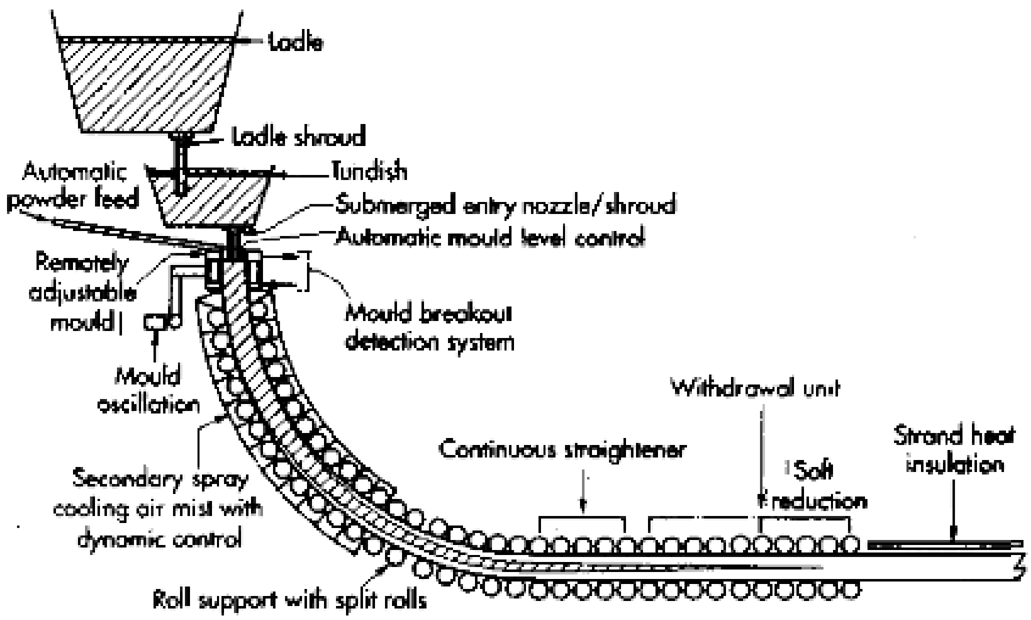

Figure 49.1: Various units of continuous casting

- Copper Mould: Water cooled copper mould is used for concast. The casting comes out of copper mould with a solidified skin with liquid inside. Water cooled copper mould is used for faster extraction of heat leading to formation of solidified skin of sufficient thickness before it comes out of mold. It is to be mentioned the residence time in the mould is not high and may be of the order of 15 seconds only. Therefore, it remains an aim to develop exit skin thickness sufficiently thick that does not allow any skin breakout and liquid leakage. The mould is also tapered downward to accommodate volume reduction due to shrinkage. The casting is subsequently directed through the secondary cooling zone through rolls.
- Secondary cooling: In secondary cooling zone the casting is cooled by water jet to completely solidify the casting. The longitudinal location where liquid is completely solidified and cast structure is developed is called the metallurgical length. After the casting get completely solidified, it is shear cut, passes through heat shield and reheating furnace before it the joins the rolling strand.
- Mould powder: A special flux powder is used in the mould that lubricates the mould wall to avoid any bonding between casting and mould wall. In addition to this, mould is also given a sinusoidal motion called the mould oscillation to avoid any welding between casting and the mould wall. I will discuss it in details in a subsequent section. Mould powder from fluid slag that also protects liquid metal from atmospheric

interaction. Some problems are also there: mould powder also restricts heat loss through the mould wall and the problem aggravates when the powder thickness vary across the length of the mould wall. The axial location where powder layer is thicker, forms a hot spot on the casting where heat extraction rate is comparatively lower. Such hot spot on casting forms weak point and subsequently might develop cracks under thermal strain down the mould. Another problem is that mould powder may also be entrapped inside the liquid steel as inclusions under uncontrolled liquid agitation in the mould. Mould powder consists of Al_2O_3, SiO_2, CaO with minor amount of MnO, FeO, K2O etc.

- EMS: Electromagnetic stirring. It produces the mild stirring in the liquid during solidification. Under faster solidification rate, R remains high and consequently G/R remains moderately high that promotes columnar grain to extend to the center. It is believed that EMS break the columnar grain tips and does not allow it to extend to the center of casting. Such broken grains acts as heterogeneous sites for nucleation of equiaxd grains at the core of the casting. If columnar grain extends to the center, the impurity rich liquid solidify at the center causing center line segregation, which is a defect. EMS helps to alleviate this defect. In case of equiaxed dendritic structure such impurity remains in the form of inter-dendritic micro-segregation at the core which can be eliminated by heating.
- EMBR: Electromagnetic break: Liquid from the SEN is ejected tangentially at a high speed through side nozzles, as shown in the Figure 49.2.

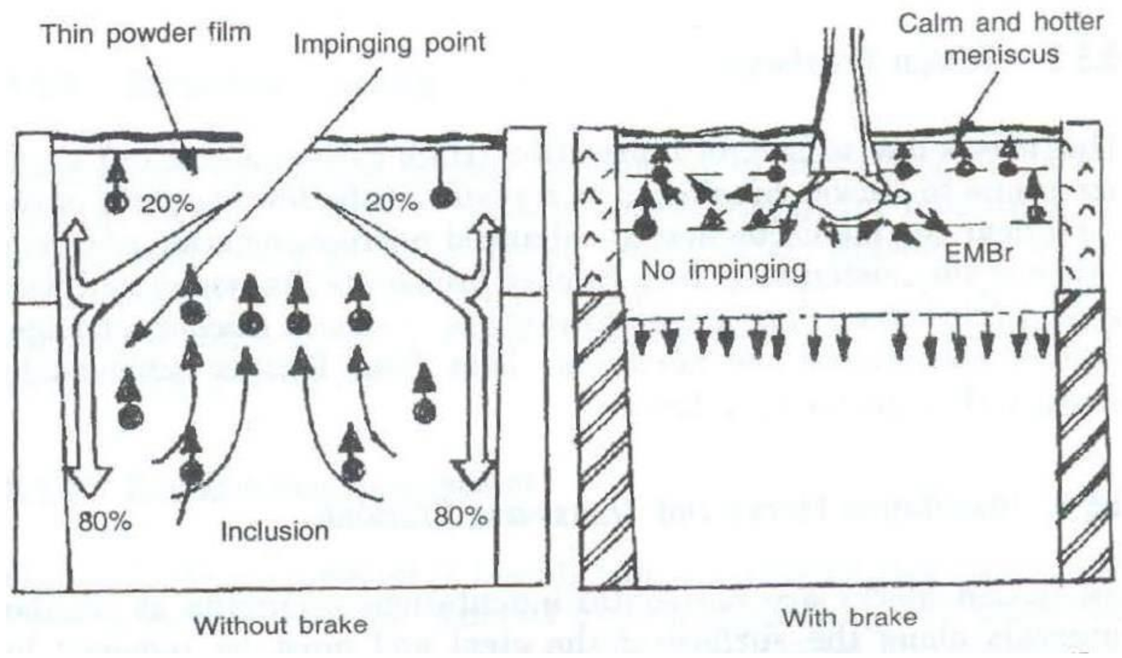

Figure 49.2: Flow field improvisation using EMBR

The liquid jet directly hit the wall and moves along the wall and returns back and it also incorporates lots of mould powder as inclusions and contaminate the steel. Therefore, EMBR is used to break the momentum of the liquid stream and make a smooth flow downward. Such improvisation of flow is shown in the Figure 49.2. It helps in reducing the mould powder incorporation in liquid steel.

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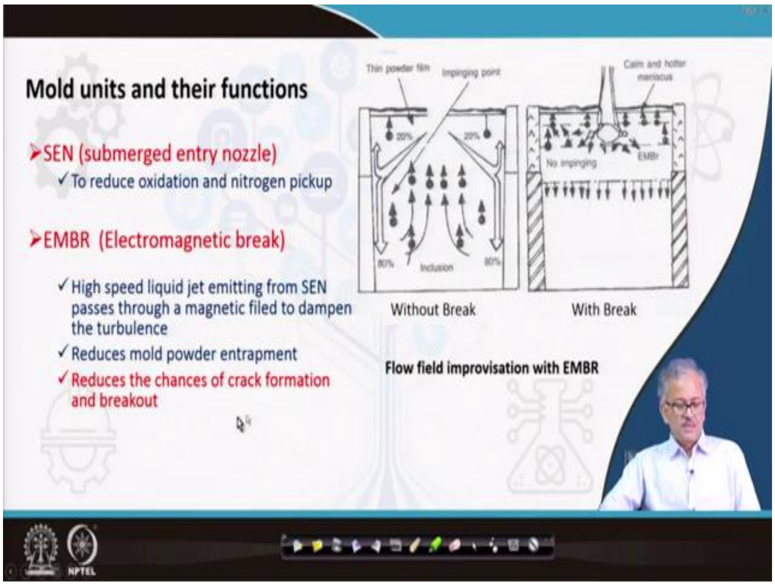

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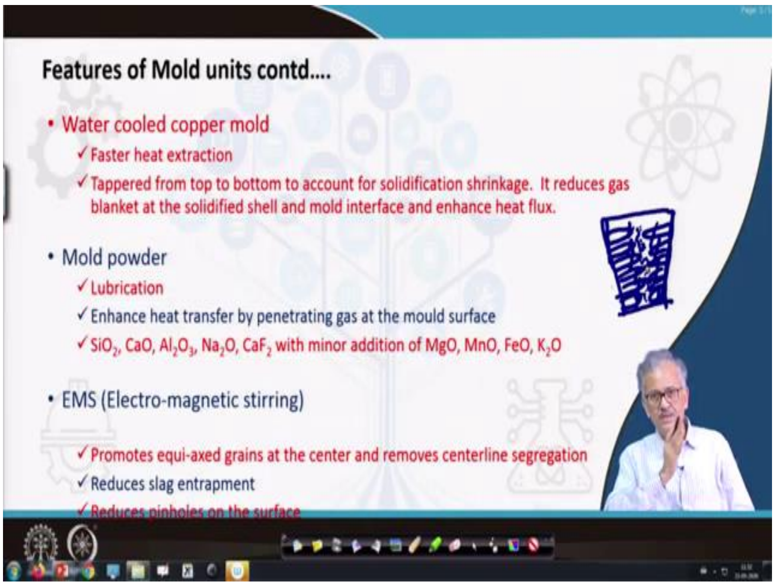

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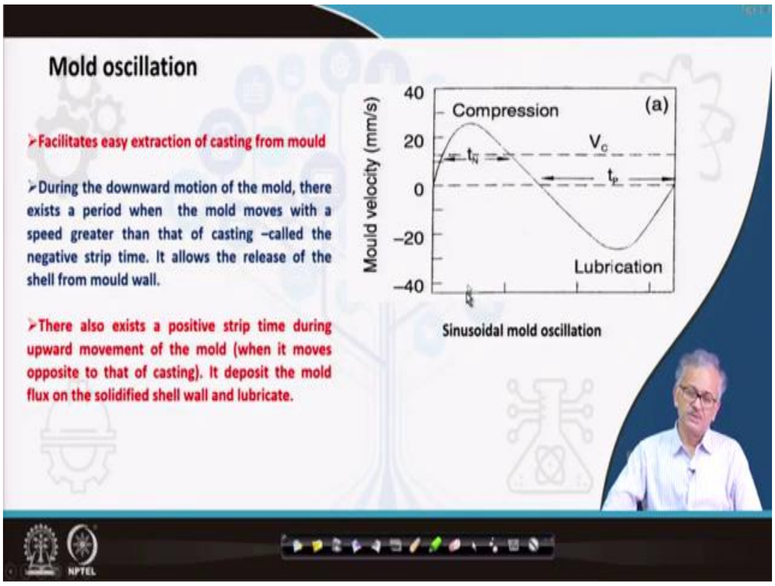

Mould oscillation: Mould oscillation facilitates the easiest extraction of the casting from the mould. The mould oscillates in a sinusoidal motion as shown in the Figure 49.3.

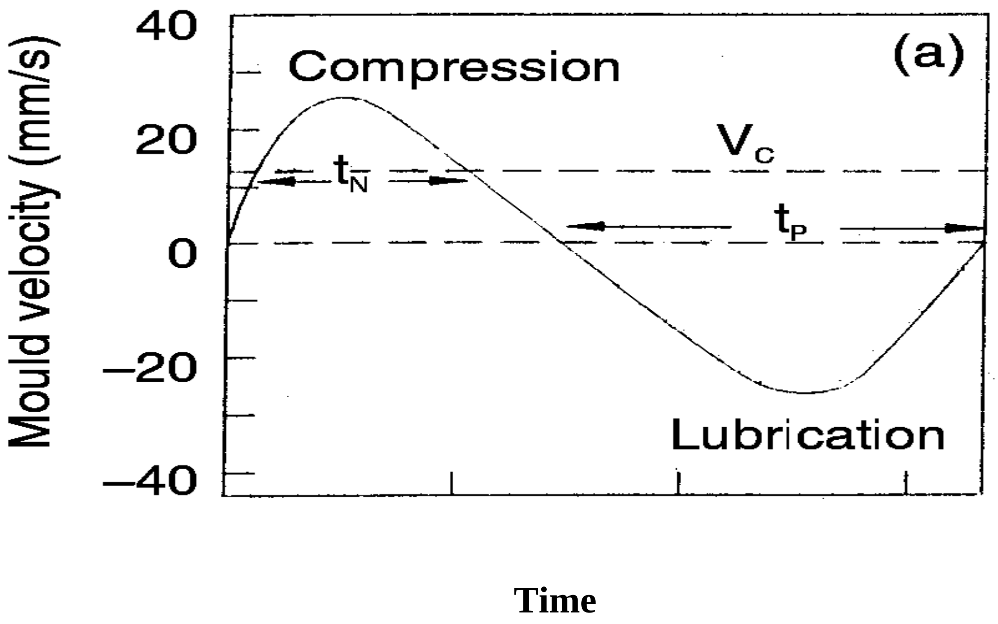

Figure 49.3: Schematics of mould oscillation

Figure 49.3 plots the mould velocity versus time. Initially the mould moves in the similar direction to that of the casting; that is the mould is moving down, as casting is always moves down.

Mould velocity increases first, reaches casting velocity (shown by horizontal line), then exceeds the speed of casting, attains a peak velocity, and then starts decreasing and again attains the casting velocity and further goes down and become 0. The period during which the mould velocity remains higher than the casting velocity is called the negative stripping. Then mould moves in the opposite direction. The mould starts moving up opposite to casting attains a peak velocity and comes down to 0 completing an oscillation. The time period during which the mould velocity remains higher than the speed of casting in opposite direction, is called the positive stripping.

During negative strip period, the mould flux enters in the gap between the mould wall and the solidified skin that helps in releasing the casting from mould wall. During positive stripping time the mould applies shear stress on the mould wall accompanied with deposition of the infiltrated mould slag on the mould wall and lubricates it. The friction force is found to be higher during positive stripping; and it is minimum during negative stripping suggesting the decoupling of the casting from mould wall.

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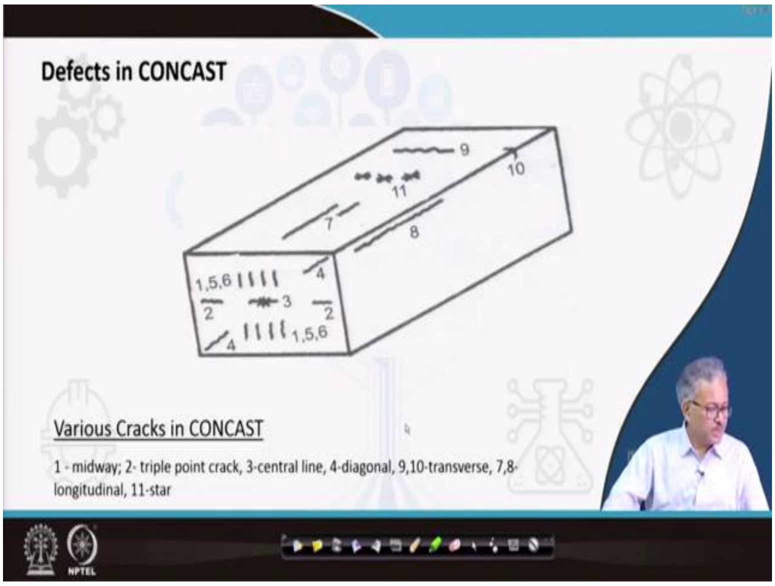

Defects in concast: Concast is subjected to thermal stress due to fast non-uniform cooling and mechanical stress due to movement of casting with soft core inside under roll guide. These stresses accompanied with presence of inclusions, precipitation of intermetallic compounds and phase transformation, generate several cracks take place in the concast. Figure 49.4 shows the schematics of various cracks that forms in a concast.

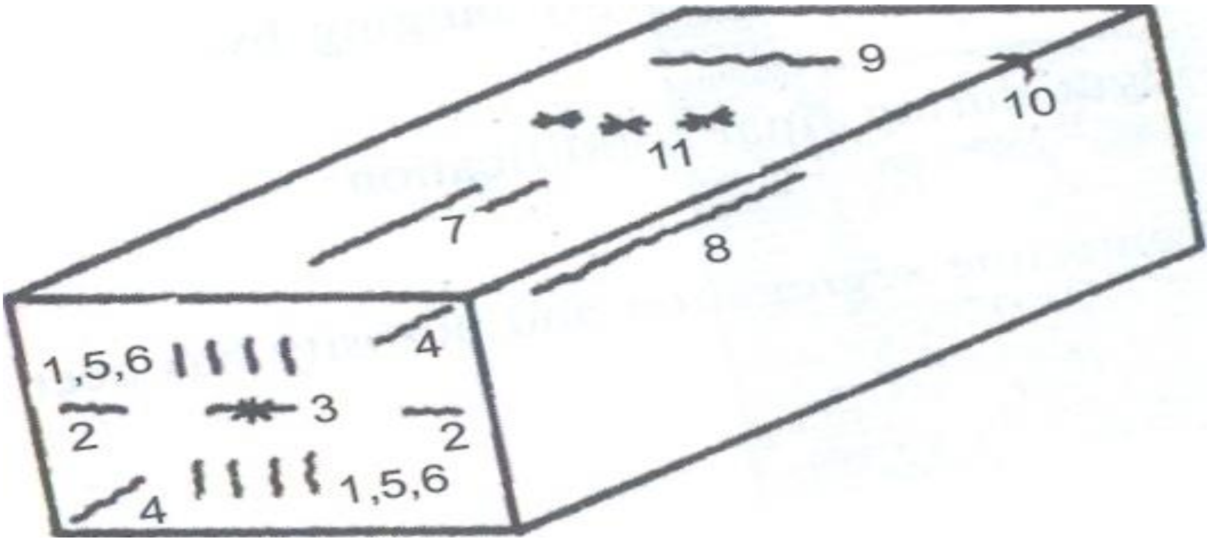

Figure 49.4: Various cracks in concast

Among the cracks shown in the figure 49.4, most of those are internal cracks. During rolling such internal cracks are rolled and does not cause problem. On the other hand surface cracks are exposed to atmosphere, get oxidized and could not be rolled and are considered as defects. Two major surface cracks are longitudinal and transverse cracks. Such defects needs to be milled before rolling and cases yield loss depending on the penetration of such cracks below the surface.

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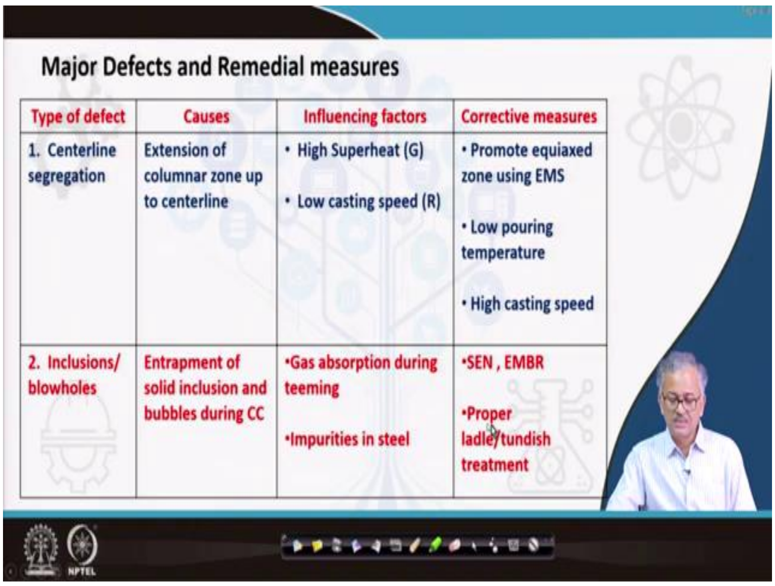

Other important defects in concast are the center line segregation, blow holes and inclusions. Table 49.1 summarizes the various major defects, their causes, influencing factors and corrective actions.

Table 49.1: Table depicting various concast defects and their remedial actions

Type of defect	Causes	Influencing factors	Corrective measures
1. Centerline segregation	Extension of columnar zone up to centerline	• High Superheat (G) • Low casting speed (R)	• Promote equiaxed zone using EMS • Low pouring temperature • High casting speed
2. Inclusions/ blowholes	Entrapment of solid inclusion and bubbles during CC	•Gas absorption during teeming •Impurities in steel	•SEN , EMBR •Proper ladle/tundish treatment

Type of defect	Causes	Influencing factors	Corrective measures
Transverse surface cracks	Straightening through an unfavorable temperature range (700-900°C)	Strongly influenced by steel composition: Al, V, Nb, Mn>1 % being the most important factor	• Maintain surface temperature above 900°C during straightening • Reduce N_2 in liquid steel
Longitudinal cracks	Strain generated in the in mold and upper spray zone	• Carbon level of 0.12% ($\delta \rightarrow \gamma$), shrinkage • Overcooling in the upper spray zone • Lower Mn/S and high S • Weak spots generated in the mold	• More uniform cooling in the mold • Reduce cooling in the upper spray zone • Lower casting rate • Low superheat

Centerline segregation: It represents a casting with large positive segregation of solutes at the centerline. It happens when columnar zone extends up to the center line, which pushes impurity rich liquid to the center of the casting.

Influencing factors: Columnar grains are promoted at comparatively higher G/R. So, higher pouring temperature (higher G) and lower casting speed (lower R), will promote columnar grain and centerline segregation.

Corrective measures: Lower pouring temperature and higher casting speed (lower G/R) will promote equiaxed dendritic grain at the core, reducing centerline segregation. EMS that breaks the dendritic tips and promote equiaxed grain at the core also reduces centerline segregation.

Inclusions and blowholes: The source of inclusions and blow holes are the impurities in steel and atmosphetic interaction and mould flux.

Corrective actions: To reduce such defects upstream processing of steel should be efficient to produce steel with minimal impurities in it. All kinds of atmospheric interactions of liquid stream should be avoided during casting stage using argon shrouding and SEN. Inclusion removal in tundish. Damping liquid agitation in the mould using EMBR to restrict mould powder incorporation in liquid steel.

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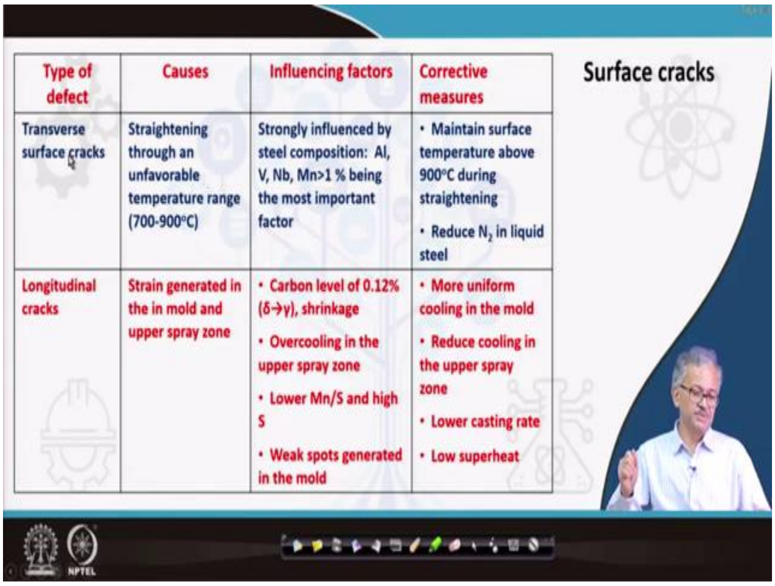

Surface defects:

Transverse cracks: It occurs across the width of the casting and penetrate few mm in the casting. Experimentally, lots of nitrides precipitates are found on the transverse cracks. And it is supposed to form during straightening of casting guided by rolls in an unfavorable temperature regime (700 to 900^{o}C), when nitride precipitates are likely to form.

Strongly influenced by the steel composition like aluminum, vanadium, niobium, manganese, which are the strong nitride formers. Corrective actions (i) Ladle treatment will reduce these elements to the minimum level possible. (ii) Maintain the surface temperature above 900 during straightening of the casting which will avoids such undesirable precipitations under mechanical deformation.

Longitudinal cracks: Longitudinal cracks occurs along the length of the casting and it could be of few mm deep.

It has been found longitudinal cracks more likely occur in low carbon steel. Because, in low carbon steel a phase transformation from delta to gamma gives volume expansion and stress generation. High Sulphur and low Mn to S ratio promotes low melting FeS formation, and hot shortness. Hot spots generated in the casting in the mould also assists in such crack generation. Overcooling in the upper spray zone, leads to reheating of the surface below the upper spray zone generating thermal strain.

Corrective actions: More uniform cooling in the mold. Reduction of the cooling rate in the upper spray zone. Intensity of cooling in the secondary cooling zone should be tapered down progressively rather than in steps. Sulphur should be controlled by proper ladle treatment. Low pouring temperature and low casting speed are found to be helpful.

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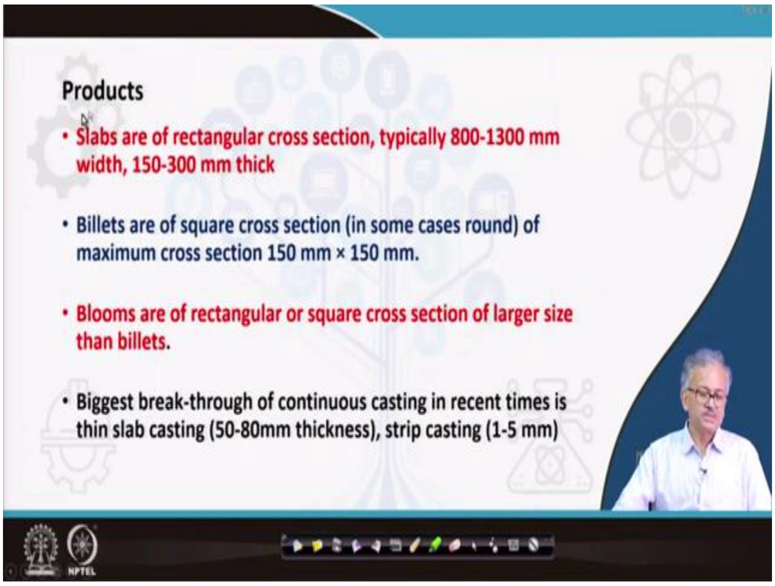

Products of continuous casting: Slab, billets and the bloom ate three products of concast. Slab are widest typically 800 to 1300 mm wide, and its thickness is 150 to 300 mm. Billets are cast in a cross square cross section 150 by 150. And blooms are bigger than billets, they can be both square as well as rectangular.

And the biggest breakthrough of continuous casting in recent time is the thin slab casting they can cast 50 to 80 mm thickness, which we will discuss in the next lecture.

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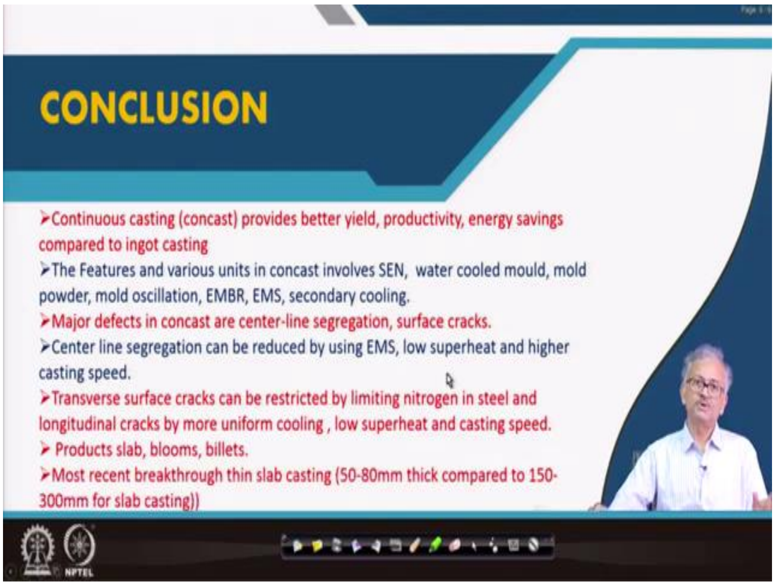

Conclusions: Continuous castings or concast provides better yield, productivity and energy savings.

During continuous casting the liquid stream is protected from atmospheric interaction using argon shrouding and SEN. Mould powder lubricates the mold wall and also protects the liquid iron from atmospheric interaction. EMS (Electromagnetic stirring) is provided in the mould to restrict the centerline segregation. EMBR (Electromagnetic break) is used to dampen the high speed liquid jet entry through SEN to restrict mould powder incorporation in liquid iron. The mould is also put on oscillation to facilitate release of casting from the mould wall. The minimum frictional force between mould wall and casting occurs during the negative stripping period defined as the period when the mould moves at higher speed than that of casting speed in the same (downward) direction.

Major defects in the concast are surface cracks, centerline segregation, inclusions and blowholes. Such defects are caused by thermal strain generated due to fast and non-uniform cooling, mechanical stress due to guiding rolls, which is aggravated by precipitation, phase transformation, impurities in liquid steel.