

FAILURE ANALYSIS OF ROLLERS OF BLOOM
WITHDRAWAL STAND IN CONTINUOUS CASTING
MACHINES AT VISAKHAPATNAM STEEL PLANT

Prof N. V. Rachchh*

Dr. R. K. Misra**

Abstract

In Visakhapatnam Steel Plant, 6 Nos. continuous casting machines (CCM) are installed in Continuous Casting Complex. Each CCM is 12m radius and mould size is 320mmx250mm cross-section. Bloom withdrawal stands are used in continuous casting machines to withdraw and to support the bloom, as the bloom gets solidified from liquid state. Each stand consists of one bottom and one top roller. These bloom withdrawal stands work in a very high temperature zone and corrosion environment. The major problem in these stands is cracks formation on the surface of rollers and subsequent worn-out. Ever year about 70 to 80 rollers needs replacement or reclamation. This premature replacement/reclamation of casting rollers causes machine stoppages and reduces machine availability and incurs production loss and high maintenance cost. Therefore the failure analysis of these rollers carried out in this project, so that by controlling existing parameters to further increase of roller life. Based on the study it is found that roller surface temperature should be maintained below 350⁰c so that low thermal stresses are induced which leads to better life of casting roller. To reduce the scales formation inside the rollers, the water hardness has to be controlled by adding softeners Na₂ CO₃, and poly electrolytes solutions. At the time of reclamation of rollers, all rollers inside should be cleaned with acid solutions.

Keywords Bloom withdrawal stand, rollers, continuous casting machine , failure analysis, finite element

* Department of Mech. Engg., Faculty of Engg- Marwadi Education Foundation Postal Code 360004, Rajkot, India .

** Department of Mech. Engg., Gautam Buddha University, Greater Noida, India.

analysis.

1. INTRODUCTION

Continuous casting may be defined as teaming of liquid steel in a mould with a false bottom through which partially solidified ingot / bar is continuously withdrawn at the same rate.

Facilities at a continuous casting machine include a lift and Turn table for ladles, Copper mould, mould oscillating system, tundish, primary & secondary cooling arrangement to cool the steel bloom. Gas cutting machines to cut the blooms in required lengths (Av. 6 meters long).

At Vishakhapatnam Steel Plant there are six - 4 strand continuous casting machines, capable of producing 2.82 million tons/year with blooms of size 250 X 250 mm and 250 X 320 mm. Entire quantity of molten steel produced (92%) is continuously cast in radial bloom casters which help in energy conservation as well as production of superior quality products[1].

In the continuous casting process, illustrated in Figure 1, molten metal is poured from the ladle into the tundish and then through a submerged entry nozzle into a mould cavity. The mould is water-cooled so that enough heat is extracted to solidify a shell of sufficient thickness. The shell is withdrawn from the bottom of the mould at a "casting speed" that matches the inflow of metal, so that the process ideally operates at steady state. Below the mould, water is sprayed to further extract heat from the strand surface, and the strand eventually becomes fully solid when it reaches the "metallurgical length".

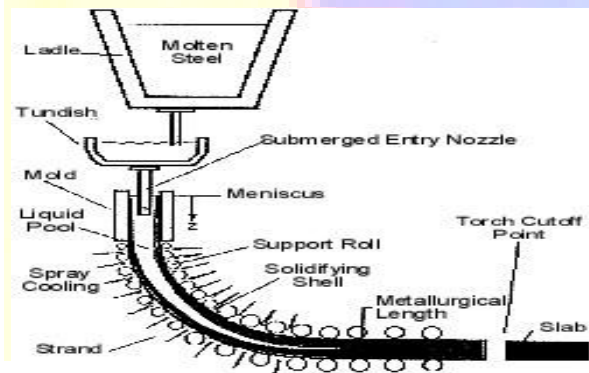


Fig. 1 Schematic representation of the continuous casting process

Solidification begins in the mould, and continues through the different zones of cooling while the strand is continuously withdrawn at the casting speed. Finally, the solidified strand is straightened, cut, and then discharged for intermediate storage or hot charged for finished rolling.

The unbending process in the continuous casting of steel has been analysed by A.Grill[2] using a mathematical model. Material creep behavior and elastic components have been considered. The stand was represented by a set of beams using elementary bending theory. One-point and multi-point straightening has been investigated and profiles of curvatures, strain rate, and roller forces obtained.

A. Perkins & M.G.Brooks [3] have carried out a series of comprehensive trials involving different withdrawal roller designs on bloom casters, in which roller behavior during and after casting has been monitored. Both permanent and transient types of bending have been observed the latter occurring only during casting. The onset and extent of this bending has been related to the heat extracted by the internal cooling of the roller and by the secondary-cooling sprays, for which a mathematical model has been developed.

Mr.N.Mihara et al[4] analysed the roller forces in straightening zone of blooms continuous casting machine and emphasized that the design of the withdrawal mechanism requires that strand withdrawal resistance be known in order to determine the roll drive power and also to minimise the tensile forces in the strand caused by differences in withdrawal drive power and resistance.

The required performance for supporting rollers in a continuous casting strand blooms involves many design criteria. Mr.S.Ota[5] had studied and emphasized the main criteria is the rolls are subjected to high thermal stresses and temperatures, as well as transient conditions. These rollers are typically repaired and returned to service.

Mr.O.Kato & Testu-to-Hagane[6] studied on failures of rollers and revealed that the roller wear is a significant factor accounting for half of the failures requiring roll replacement, and also showing that high in the machine, roll deflection is a significant factor in roll replacement.

H.Kuroki & T.Honda [7], metallurgists in Nissan steel company jointly studied the desirable properties of casting rollers and told that required properties are oxidation corrosion resistance, thermal crack resistance, and high temperature hardness or wear resistance.

During steady state casting, the thermal stresses developed on the surface of the roll are not high enough to cause the short term or low-cycle fatigue damage of rollers, which was observed by A.J.Rumler [8].

A. Verduzco, C.L. Wandrei [9] metallurgists worked on the reclamation of rollers and told that the rollers having a carbon content of up to 0.8 % are having good weldability. Rolls, which have received special heat treatment, may pose a problem in welding.

2. PROBLEM FORMULATION

In the continuous bloom casting process, casting rollers are utilized for (1). Solidification containment, (2) strand support, (3) bending and unbending, (4) drive, and (5) transport of the solidifying blooms. The dimensional tolerances, mechanical stability and surface condition of the casting rollers in a strand can affect both the surface and internal quality of the product being cast. Historically, the scheduling of caster roller removal from a segment has been based on the predictive life of the bearing. Recent improvements in lubrication and bearings performance coupled with reductions in non-steady state casting conditions have extended the service life of casting rollers in order to maximize casting machine utilization.



Fig.2 Continuous Casting Machine in operation

These are the roll stands, which withdraw the blooms from the Continuous casting machine. The CCM have 4 strands. In each strand there are 4 stands. In which is the four-roll stand, consists of two bottom rollers and two top rollers. The main purpose of the stand is to hold the Dummy bar before casting and with draw it while casting starts, and guide the bloom.

The remaining three stands are two roll stands, means one top roller and one bottom roller. These stands can with draw the hot blooms, which are at a temperature of 700- 800 degrees Celsius. These stands body have cooling jacket and the rollers are hollow, both are completely

cooled by equipment cooling water supplied at a pressure of 8 kg per sq. cm. The bearings of rollers are continuously lubricated by online lubrication system. The top rollers mounted on the top flap of the stand, and top flap in turn is connected to hydraulic cylinder through tie-rods and fulcrum. While the CCM is under casting, top flap is in its lower position by hydraulic pressure and the top roller slightly pressed the bloom and provides sufficient grip for withdrawing of bloom. Top rollers are idle rollers, they are not mechanically connected. Bottom rollers are drive rollers and they are connected to individual stand co-axial reduction gearboxes. Stand 1&4 directly connected to reduction gearboxes but strands 2&3 are indirectly connected i.e., through intermediate gearboxes due to space constraints, and orientation of stands. This problem can be seen in the lay out of stands.

The life of strand 1&4 stands are more compared to strand 2&3 due to simplicity in its arrangement and direct connection to co-axial reduction gear boxes, but in strand 2&3 stands the bottom rollers are driven by Intermediate Gear Box through spline mechanism. The IGB is only a power transfer unit, it does not either reduce or increase speed. The IGB consists of input gear, intermediate gear and an output gear. The output gear is mounted on a hollow output shaft, which is having internal splines. These splines are matched with the bottom roller external splines.

The problems observed in a CCM while in operation and at the time of repair.

- Cracks formation on the surface of roller.
- Chokage of cooling lines
- Scales & rust formation inside the roller.
- Worn-out & erosion of roller surface.
- Drive roller splines slippage.
- Misalignment of IGB with respective of stand.
- Bearings damage.
- Insufficient lubrication
- Stand base damage.



Strand 2&3 type STAND Strand 1&4 type STAND

Fig. 3 Bloom withdrawal stands

Based on the data collection of failures, worn-out of rollers, drive rollers splines slippage and bearings damage are main problems. Out of that it is found that 60 % of failures are due to worn-out of rollers. It a major problem in continuous casting roller.

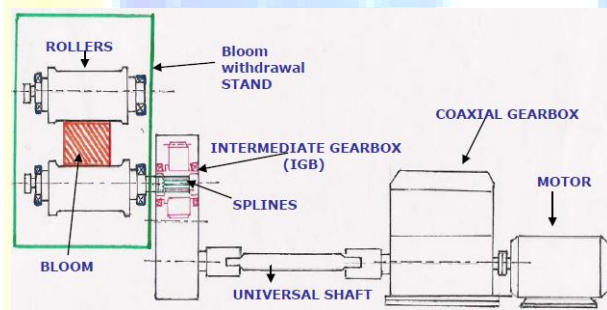


Fig.4 Withdrawal Stand Power Transmission Sytem



Fig.5 Damaged Casting Roller with Thermal Cracks

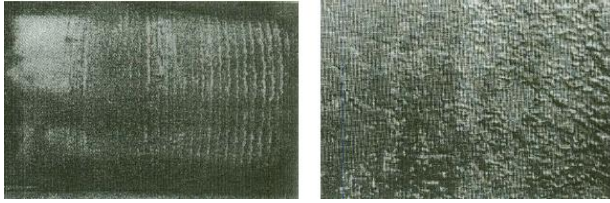


Fig.6 Worn-Out And Erosion On Roller Surface

3. THERMAL AND MECHANICAL ANALYSIS

3.1 Measurement of Roller Temperature and Water Temperature:

The temperature of the roller and the water play a vital role in the analysis of the roller. The mentioned temperatures vary with time because the continuous casting machine is started at a particular time and the above temperatures may be different at different times once the machine is started. Hence the readings should be taken until steady state is obtained.

As the roller will be subjected to high temperatures of the bloom, the roller temperature is to be taken very carefully. The temperature of the roller has been measured by a laser pyrometer. A laser pyrometer is a temperature measuring device mainly used to measure very high temperatures and it is a non contact type device. The temperature of the bloom is also measured with the laser pyrometer. The temperature of water is measured with the help of a contact type thermometer. The fig. 7 shows the temperature variation with time at the start of casting, and the steady state temperature of roller reached after 3hours.

Different withdrawal stands in a CCM exposed to different temperatures due to its position in the Machine, but the particular stand in any other CCM have the same environment and exposed to same temperature. In all 6 CCMs, Stand-4 roller temperatures taken for the analysis purpose.

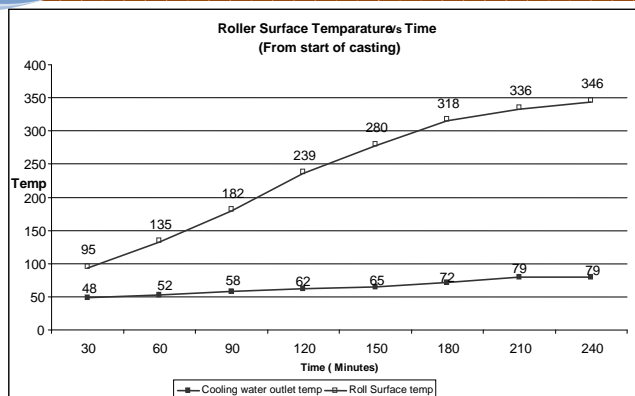


fig.7 Roll surface temp. with time at start of casting

M/c. No	Strand No.	Roll Temp (° c)	Roll Last change	Life of Roll (months)
CCM-1	1	412	Apr-09	20
	2	278	Jun-10	6
	3	329	Feb-10	10
	4	360	Nov-09	14
CCM-2	1	461	Oct-08	28
	2	340	Jul-10	5
	3	238	Sep-10	3
	4	360	Jun-09	18
CCM-3	1	375	Jul-09	17
	2	365	May-09	19
	3	456	Jul-08	30
	4	390	Mar-09	21
CCM-4	1	460	Nov-08	26
	2	268	Aug-10	4
	3	347	Jan-10	12
	4	475	Mar-08	34
CCM-5	1	336	Feb-10	10
	2	425	May-09	20

	3	248	Nov-10	3
	4	357	Mar-10	10
CCM-6	1	456	Sep-08	27
	2	241	Dec-10	1
	3	354	Oct-09	14
	4	253	Nov-10	2

Table-1: Temperature of Stand-4 Rolls in all Six CCMs

<u>Avg .Roll life</u>	<u>Avg.temperature measured (⁰c)</u>
Upto 6 months	235 - 300
7 - 14 months	325 - 360
16 - 20 months	360 - 425
Above 24 months	450 - 475

3.2 Mechanical Stresses In Roller

While casting is going on the roller subjected to different stresses. One of the important stresses is static stresses.

According to the orientation of the machine each stand supports at least 6meter length of bloom. The total load of the bloom acts on bottom roller only. The top roller flap connected to hydraulic cylinder which is pulling the roller downwards to create necessary friction grip to withdraw the roller. This hydraulic force acts on the bottom roller. Moreover the top roller weight and its bearings weight, top flap weight acts on the bottom roller. In any withdrawal roller in continuous casting machine the bottom roller is the drive roller. In Visakhapatnam steel plant the drive specifications of withdrawal stand are 11KW, 775 RPM motor. One reduction gear box called co-axial gear box with high reduction ratio 1:678.44 is interlinked the motor and the

bottom roller of the stand. This drive offers heavy torque on the bottom roller to with draw the bloom continuously.

All the above mentioned loads acts combined on the bottom roller and create both bending and shear stresses.

CASTING ROLL MATERIAL AND PROPERTIES

40 Ni2 Cr1 Mo28 / EN24

Composition: C 0.35- 0.45%, Si 0.10- 0.35%, Mn 0.40- .70%,
Cr 0.90-1.30%, Ni 1.25-1.75%, Mo 0.20-0.35%

Modulus of elasticity (E) - $2.06 \times 10^5 \text{ N/mm}^2$

Poissions ratio (v) - 0.3

Coefficient of expansion (α) - 1.2×10^{-6}

Tensile Strength - 1111.2 N/mm^2

Thermal conductivity (K) - $46.1 \text{ Kcal/m-hr} \cdot ^\circ\text{c}$

Bloom weight:

Length of the bloom -6 meters

Cross section of the bloom- 320mm x 250mm.

Specific weight of the bloom- 7850 kgf/m^3

Bloom weight – $7850 \times 0.32 \times 0.25 \times 6 = 3768 \text{ kgf}$
 $= 36964. \text{ N}$

Hydraulic force:

Piston diameter -200mm

Fluid pressure - 80 kgf/cm^2

Hydraulic force - pressure x area

$$= \frac{\pi \cdot 0.22^2}{4} \times 80 \times 10^4$$

$$= 30400 \text{ kgf}$$

$$= 298328.15 \text{ N}$$

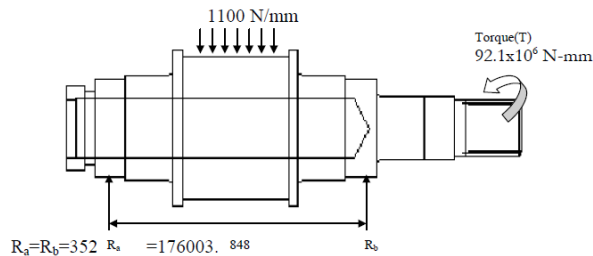
Top roller ,bearings and top flap weight = 1500 kgf (approximately)= 14715 N .

Total load on the bottom roller:

$$= 38964 + 298328 + 14715 = 352007 \text{ N}$$

This total load distributed at length of 320mm on the roll, i.e. the bloom width.

$$Udl = 352007/320 = 1100 \text{ N/mm}$$



Maximum Bending moment (M) =

$$176003.5 \times 424 - 1100 \times \frac{320^2}{8} = 60545484 \text{ N-mm}$$

$$M = 60545.484 \text{ KN-mm.}$$

$$M = \frac{\pi f_b}{32} \left(\frac{D_2^4 - D_1^4}{D_2} \right)$$

Where M - Bending moment

f_b - bending stress

D_2 - Outer dia of roller

D_1 - Inside dia of roller

$$60545484 = \frac{\pi f_b}{32} \left(\frac{400^4 - 170^4}{400} \right)$$

$$f_b = 12.27 \text{ N/mm}^2$$

Power rating of the motor (P) = 11KW

Speed of the motor (N) = 775 RPM

Speed reduction in gear box = 1:678.44

Torque (T)

$$P = \frac{2\pi NT}{60}$$

$$11 \times 10^3 = \frac{2\pi \times 775 \times T}{60}$$

$$T = 92.1 \times 10^6 \text{ N-mm}$$

$$T = \frac{\pi}{16} f_s \left(\frac{D_2^4 - D_1^4}{D_2} \right)$$

$$92.1 \times 10^6 = \frac{\pi}{16} f_s \left(\frac{400^4 - 170^4}{400} \right)$$

$$f_s = 7.576 \text{ N/mm}^2$$

Principal stresses:

P_{n1} = Major Principal Stress

P_{n2} = Minor principal stress.

P_t = Maximum shear stress

$$P_{n1} = \frac{f_b}{2} + \sqrt{\left\{ \left(\frac{f_b}{2} \right)^2 + f_s^2 \right\}}$$

$$P_{n2} = \frac{f_b}{2} - \sqrt{\left\{ \left(\frac{f_b}{2} \right)^2 + f_s^2 \right\}}$$

$$P_t = \frac{P_{n1} - P_{n2}}{2}$$

$$P_{n1} = \frac{12.27}{2} + \sqrt{\left\{ \left(\frac{12.27}{2} \right)^2 + 7.576 \right\}} = 15.88 \text{ N/mm}^2$$

$$P_{n2} = \frac{12.27}{2} - \sqrt{\left\{ \left(\frac{12.27}{2} \right)^2 + 7.576 \right\}} = -3.613 \text{ N/mm}^2$$

$$P_t = \frac{15.88 - (-3.613)}{2} = 9.748 \text{ N/mm}^2$$

3.3 Cyclic Stresses

As the roller is rotating continuously it is subjected to variable stresses. These variable stresses lead to fatigue.

Average or Mean stress $(f_m) = \frac{(f_{max} + f_{min})}{2}$

Reversed component (or) Variable stress $(f_v) = \left(\frac{f_{max} - f_{min}}{2} \right)$

According to Goodman

$$f_v = f_e \left(1 - \frac{f_{av}}{f_u} \right)$$

f_e = Endurance limit

f_u = Ultimate strength

Ultimate tensile strength of roller material -1177 N/mm²

$$f_m = \frac{15.88 - 3.613}{2} = 6.1335 \text{ N/mm}^2$$

$$f_v = \frac{15.88 + 3.613}{2} = 9.7465 \text{ N/mm}^2$$

$$9.7465 = f_e \left(1 - \frac{6.1335}{80} \right)$$

$$f_e = 10.55 \text{ N/mm}^2$$

For Steel the endurance limit is $f_e = 0.5 f_{ut}$

$$f_e = 0.5 \times 1177 = 588.6 \text{ N/mm}^2$$

The actual endurance strength is very low compared with material strength.

3.4 Temperature Distribution across Roller Crosssection

Roller radius (mm)	Temperature(0 °C)	Thermal (N/mm ²)	Stress
200	390.00	1172.39	

190	378.66	1098.10
180	366.71	1018.16
170	354.07	931.62
160	340.67	733.42
140	311.15	618.10
130	294.76	488.51
120	277.07	340.86
110	254.84	169.65
100	236.76	33.06
90	213.47	279.58
85	200.84	424.88

Table-2: Temperature distribution and thermal stresses in a roller

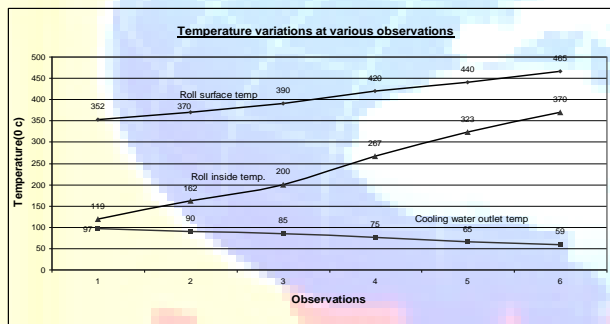


Fig. 8 Temp. of roller surfaces & cooling water.

The Fig. 8 shows the variations of temperatures in roll surface and cooling water inlet and outlet at different rollers.

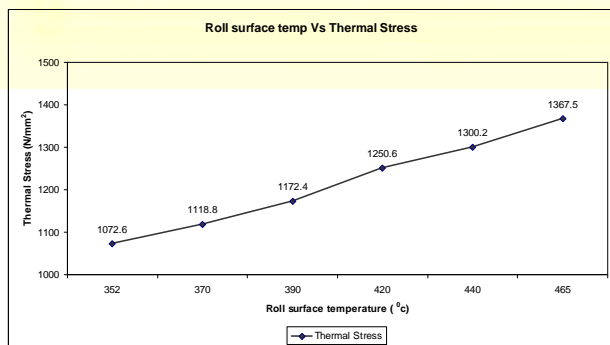


Fig. 9 Thermal stresses at different temperatures

The Fig.9 shows the trend of thermal stresses induced on roller at the outer surface at different surface temperatures.

The reason for the increasing the roller temperature is due to ineffective heat transfer. Over a period of time, the water scales deposited inside of the roller surface which offers high thermal resistance.

3.5 Cooling water and scales analysis

The continuous casting withdrawal roller inlet and outlet cooling water samples collected and tested in laboratory. The analysis given below:

Property	Inlet water	Outlet water	Norms
p ^H	8.4	8.3	7 -8.5
Conductivity ($\mu\text{mho/cm}$)	525	505	<1000
Total Hardness (as CaCO ₃) mg/liter	<u>151</u>	<u>148</u>	<u>< 125</u>
Ca- Hardness	76	76	75
Mg- Hardness	<u>75</u>	<u>72</u>	<u>50</u>
P-Alkalinity (phenolphalein)	4.0	2.0	Nil
M-Alkalinity (methyl orange)	126	124	< 200
Cl ⁻ (chlorides)	52	52	< 75
So ₄ ²⁻ (sulphates)	56	50	< 200
Turbidity (NTU) (Nephelometry units)	8	4	< 5

Table-3: Roll Cooling water analysis

The scales collected inside the casting roller collected and tested in the laboratory for its composition. The major ingredients in the composition are:

Percentage (%)		
Calcium Oxide (CaO)	-	28.851
Magnesium Oxide (MgO)	-	20.243
Ferric Oxide (Fe ₂ O ₃)	-	20.024
Silica (SiO ₂)	-	18.198
Aluminum Oxide (Al ₂ O ₃)	-	6.618
Sodium Oxide (Na ₂ O)	-	0.951
Potassium oxide (K ₂ O)	-	0.441
Manganese Oxide (MnO)	-	0.376
Chromium Oxide (Cr ₂ O ₃)	-	0.346
Prosperous pentaoxide (P ₂ O ₅)	-	0.222

From the above analysis it is found that Calcium oxide (CaO), Magnesium oxide (MgO), and Ferric oxide and silica are the major ingredients in the water scales and reduces the heat transfer.

From the water analysis, it is noted that, the total hardness (as CaCO₃) is around 151 mg/liter, it is higher than the total hardness of Industrial Cooling water norm i.e., < 125 mg/liter.

To improve the water quality and reduce the total hardness some softeners are to be added. One of the best water softeners is Sodium carbonate (Na₂ CO₃), and corrosion inhibitor is Na₃ PO₄. These softeners are to be added through Ion-exchange process and Zeolite process to get soft water.

4 FINITE ELEMENT ANALYSIS

The stresses formed in the roller checked with the help of ANSYS software. The below mentioned figures shows the results.

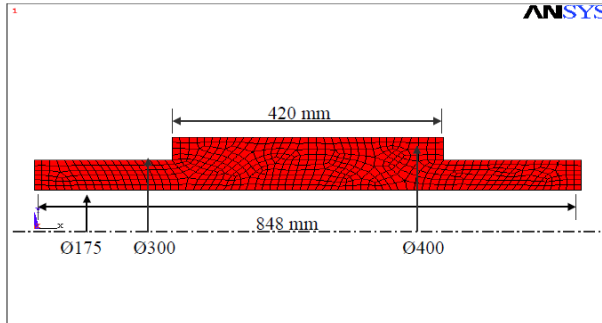


Fig. 10 Meshed model- of roller (axi- symmetric)

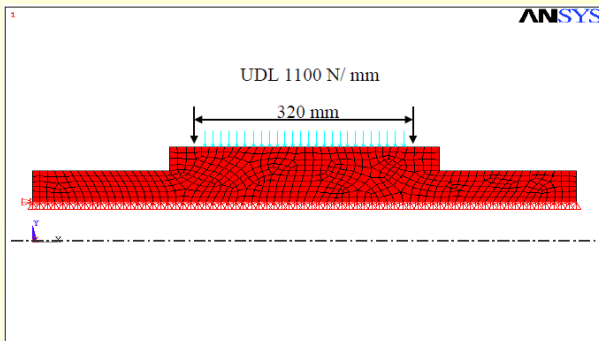


Fig-11: Meshed model with uniformly distributed load and boundary conditions

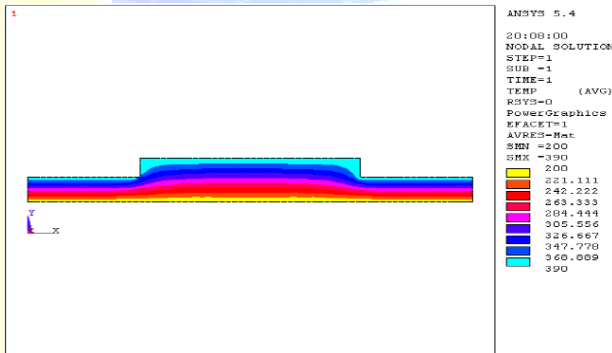


Fig. 12 Temperature Distribution in the roller

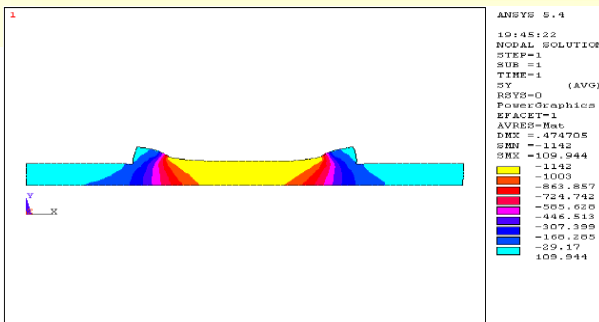


Fig. 13 Stress analysis in z-direction

Max compressive stress is -1142 N/mm^2

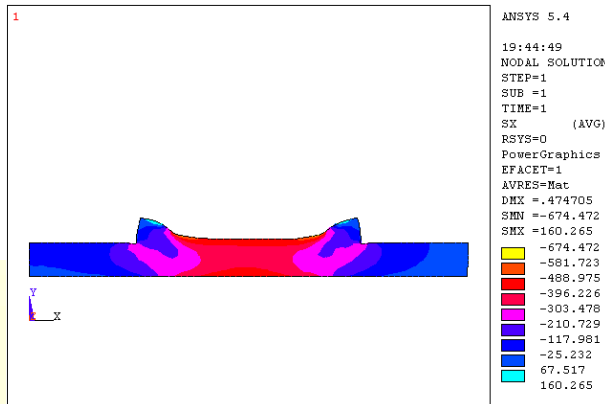


Fig. 14 Stresses in x-direction

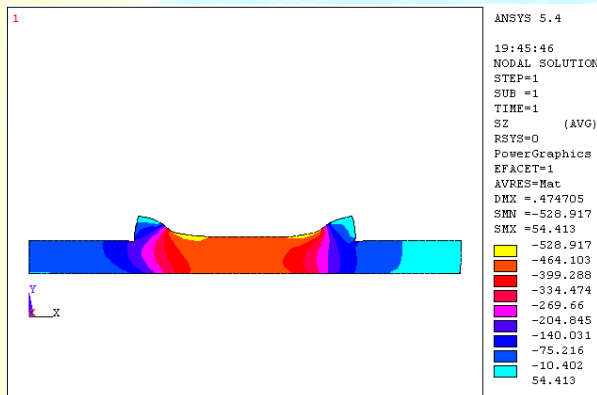


Fig. 14 Stresses in y-direction

5. RESULTS & DISCUSSIONS

➤ The measured force on the roll due to Ferro static head and weight of the stand ranges between 350KN to 370KN. This is equivalent to a mechanical rotational bending stress range from 15.8 N/mm^2 to 18 N/mm^2 , which is not high enough to initiate fatigue cracks on the roll. This stress. However, it will work with other load mechanisms to propagate to cracks which are initiated on the roll surface due to thermal stress.

➤ The roller surface temperature exceeds 390°c thermal stresses in addition to mechanical bending stresses i.e., total stresses (1187.8 N/mm^2) more than the tensile strength of casting roller

material (1177 N/mm^2) and leads to thermal cracks on the surface. The increasing trend of roller surface temperature with the same water flow rate shows, the scaling formation inside roller increased over a period of time.

- The stresses calculated theoretically are checked through ansys software. The results obtained through ansys are supported the theoretical stresses.
- To avoid the thermal stresses in the rollers, the surface temperature maintained below 390°C . From the existing conditions the roll life is 20 months only. Above that the roll surface temperature increased due to scales formation.
- The roll cooling water inlet and outlet analysis done laboratory, the total hardness of cooling water is 151 (as CaCO_3), which is more than the norm 125, which is the one of the main reason for formation of scales.
- The reason for the increasing the roller temperature is due to ineffective heat transfer. Over a period of time, the water scales deposited inside of the roller surface which offers high thermal resistance
- The scales tested in laboratory for its analysis, and it is found that Calcium Oxide (CaO)-28.851 % and Magnesium Oxide (MgO)-20.243 % are the major ingredients. These oxides are bad heat conductors and reduce the heat transfer from roller to cooling water.
- When the stand is stopped (ex. For submerged entry nozzle or tundish change or any other operational / mechanical / electrical problems temporarily), a severe non-uniformity in temperature is developed in the roller. During such events, the temperature on the surface of the roll was measured as high as 600°C . At this high temperature the thermal stress induced upto 1790 N/mm^2 .
- During strand stoppages severe distortion occurs in the shape of the roller, due to non uniform heating. When the strand is stopped, the non-uniformity of temperature distribution in the roll causes it to distort and bend toward the strand. When the strand resumes motion, the roll wobbles, due to its bent shape, for a few revolutions until the temperature in the roll is more uniformly distributed, as it is during steady state casting conditions. This effect was observed to be similar in character in both top and bottom rolls. With both bending inward toward the stand. Typically the bottom rolls under goes a higher degree of distortion than the top roller. When the

distorted rolls bent come face to face, it pressed the bloom and causes bloom bulging, means inaccurate dimensions.

6. CONCLUSION

This project was carried out on the failure of Continuous casting rollers. The reasons for crack formation and worn-out of rollers is studied. Mechanical bending and thermal stresses are calculated. Only mechanical bending stresses not high enough to cause any crack formation on the rollers. The combined thermal and bending stresses cause crack formation. If the roller surface temperature maintained well below 370°C the thermal stresses induced in the roller are less than the material strength of roll material and rollers less prone to cracks.

The accumulation of water scales inside the roller is the main reason for poor heat transfer, and causes the accumulation of heat in the roller and leads to temperature rise. This high temperature causes high thermal stresses on the rollers and leads to formation of cracks.

From the water analysis, it is noted that, the total hardness (as CaCO_3) is around 151 mg/liter, it is higher than the total hardness of Industrial Cooling water norm i.e., < 125 mg/liter.

To increase the life of casting roll it is proposed that:

1. Water softeners are to be added to reduce water total hardness. One of the best water softeners is Sodium carbonate (Na_2CO_3), and corrosion inhibitor is Na_3PO_4 . These softeners are to be added through Ion-exchange process and Zeolite process.
2. At the time of reclamation of rollers, all rollers inside should be cleaned with acid solutions. If scales thickness is high, such rollers boring to be done on the machine and ensured there should not be any scales inside. In shut down periods wherever possible the cooling water rotary joint to be opened and scales to be removed.

7. REFERENCES

- 1) Detailed project report of VSP.
- 2). A.Grill, 1985- Journal of The Institute of metals.
- 3). A. Perkins, M.G.Brooks, Withdrawal roller performance in continuous Bloom casting machine.
- 4). N.Mihara et al, 1986, Analysis of roller forces in straightening zone of a large size bloom casting machine, Nippon steels technical report .
- 5) Ota, 1979, Rollers for continuous casting machines, Kobe steelengineering reports.
- 6) O.Kato, Testu-to-Hagane, Deterioration of rollers of continuous casting machine
- 7). H.Kuroki, T.Honda, As for materials of a pinch roll for a continuous casting machine, Nissan steel company.
- 8). A.J.Rumler, 1991, Volume-74, Steel making conference proceedings,
- 9). A.Verduzco, C.L.Wandrei, Sr.Inland steel company, Roll reclamation and repair.
- 10) Advanced Mechanics of solids, L S Srinath.
- 11)Heat & Mass transfer ,Domukundwar &Arora
- 12) Machine design, R.S.Khurmi
- 13) Design data book,PSG data
- 14) 36 th Mechanical working and Steel processing conference proceedings
- 15) 1991-steel making proceedings