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A Novel Method for Fabrication of Trimaterial Ceramic Metal Matrix Composite Grinding Roll

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***Abstract*— In order to fabricate trimaterial ceramic metal matrix composite (CMMC) inserted grinding roll for Pulveriser application in thermal power plants, a novel method is established by finalizing the intrinsic process parameters to fabricate grinding roll for bowl mill application with optimum wear resistance properties. In the first step, ceramic pads are fabricated with spherical ceramic particles of size range 1.5-3mm dia as a mixture of ZrO_2 (30 wt %), TiB_2 (6 wt %), Al_2O_3 (60 wt %) with minor addition of Co (4%), using alumina-sodium alginate slurry sintered at 1650^0C for 5 Hrs. In the second step, high chrome metal is poured into the CO2 mould containing the ceramic pads positioned at designated location in the mould cavity to make ceramic metal matrix composite inserts. In the third and final step, the ceramic metal matrix composite inserts are assembled in centrifugal die to occupy the working surface of the grinding roll made by pouring Spheroidal Graphite (SG) Iron while incorporating differential cooling rate at different zones of the roll through a special mechanism devised for the purpose and achieved the desired hardness (64HRC) of the roll. This resulted in a minimum running life of 12000 hours as against the existing 10000 hours running life of Pulveriser bowl mill grinding roll.**

***Key Words*—Ceramic Metal Matrix Composite, Centrifugal Casting, Heat Transfer, High Chrome, Pulveriser Grinding Media.**

I. INTRODUCTION

Turbines of thermal power plants working on steam, necessitate to pulverize the fossil fuel (Coal) to very fine size to feed to the boilers, for effective steam generation. The main objective of any thermal power plant is to have maximum duration of uninterrupted power supply, i.e. the consumable spare parts (grinding media), such as grinding roll and bull ring segments of bowl mill, which have to sustain a minimum wear life matching to the time duration between two consecutive scheduled mill shut down time for maintenance purpose.

The necessity of enhancing wear life of grinding media in different applications such as Coal Pulveriser, Coal Mines etc. has been ever demanding in view of the steep deterioration of the quality of fossil fuel condition.

There has been continuous effort by researchers to enhance the wear life of Pulveriser grinding media and accordingly, there is evolution of Pulveriser grinding media from hard Mn Steels to Ni Hard and then to High Chrome metal. Finally, Ceramic Metal Matrix Composite material is being used as the best material for high wear life of grinding media

Wear life of any material is directly proportional to the hardness, but in the process of enhancing hardness the toughness of the material gets reduced drastically resulting in premature failure of the component due to crack propagation. Hence, the objective is to achieve higher hardness of the material without compromising on the toughness/ impact values and eventually researchers came out with ceramic metal matrix composites there by achieving the desired combination of high abrasion resistance with requisite impact strength. Considerable work has been done in ceramic metal matrix composite technology. Apart from the hardness of ceramic grains, the shape also plays a vital role in determining the abrasion resistance with longer wear life.

Some of the research works related to the present study are described below:

Hubert Francois [3], made composite wear component by casting which includes a metal matrix with inserts that have very high wear resistance. The inserts are made of ceramic pads made of a homogeneous solid solution of 20 to 80% Al_2O_3 and 80 to 20% ZrO_2, with the percentages expressed by weights of the constituents. The ceramic pads are then impregnated with a liquid metal during the casting process.

Sudhir Vaman Bhide [4], invented a methodology to fabricate metal matrix ceramic composite wear-parts that have a metal-impregnated wearing section made of a ceramic cake. Both ceramic and carbide grains are present in the ceramic cake. The invention pertains to a technique of producing the worn parts as well. The invention further includes grinding rolls and table liners for vertical mills, each of which includes one or more wear parts made of a metal matrix ceramic composite.

With the help of above inputs, a novel method is devised in the present study resulting in desired properties of the grinding roll for bowl mill operation

Though considerable work has been done in this field, but the goal of matching the wear life of Pulveriser grinding media, especially the grinding roll and matching bull ring segments of Bowl Mills, with that of duration between two consecutive scheduled mill shut down time has still remained a challenge in case of worst Indian coal condition.

This led to the objective of present work to focus mainly on developing a novel method of fabricating a trimaterial ceramic metal matrix composite grinding roll of bowl mill with the optimum composition and mechanical properties of each material to give the best wear life.

The ceramic metal matrix composite grinding roll has two layers, i.e. the outer ceramic metal matrix composite hard facing material duly supported and mechanically bonded by intermittent SG Iron metal protruding from the inner soft layer.

The purpose of having two different layers is to have very hard high wear resistance material on the outer (working surface) layer which crushes the coal sandwiched between the roll and bull ring segments and another softer inner layer to enable easy machining to accommodate jigs and fixtures to fix the roll to the bowl assembly.

The outer layer consists of ceramic metal matrix high chrome insert where in ceramic pads are embedded/interwoven in high chrome metal by mechanical bonding. Ceramic material has got completely different coefficient of thermal expansion as compared to high chrome metal. Similarly, CMMC is completely different than SG Iron. Hence, it is a real challenge to integrate all these materials to form a single unit while ensuring the position of each of these materials at designated location/portion of the unit.

Generally, the ceramic grains, especially the mixture of Al_2O_3, ZrO_2 and TiB_2 having high hardness and wear resistance properties, don't easily gel with high chrome metal due to non-wettability issues. Moreover, for better running life and strength, it demands the ceramic particles to be spherical in shape.

Also high chrome metal is highly prone for cracks due to rapid thermal expansion and contractions happening at every stage of fabrication. However, SG Iron poured into the centrifugal die for making the grinding roll should not attain high hardness (on Internal Diameter-ID side) because of water quenching to be done to the outer surface of the die which facilitates fast quenching/ cooling of the outer layer (CMMC) of roll to achieve the desired hardness and higher strength. For good machinability, it is required that the hardness of inner soft core SG Iron should not exceed 330 BHN.

Keeping the above factors in view, as a first step spherically shaped ceramic grains/ particles of required size, composition, density and hardness were prepared, subsequently in the second step, ceramic metal matrix high chrome inserts were fabricated as per the parameters finalized by the authors in their earlier works [1 & 2].

The major challenge encountered during the third and final step of fabrication, i.e. centrifugal die casting of grinding roll with ceramic metal matrix high chrome inserts being embedded in the SG Iron softer matrix, is the necessity of achieving differential cooling rates of each zone/ layer to attain desired hardness for each layer.

In the present study, a novel method of fabricating bowl mill grinding roll with SG Iron softer inner layer while the outer layer constituting of ceramic metal (high chrome) matrix composite inserts mechanically bonded in the SG Iron matrix through centrifugal casting method could be established successfully.

II. EXPERIMENTAL DETAILS

Step-I (Spherically shaped ceramic grains/ particles of Al_2O_3 with required density and hardness were fabricated)

Spherically shaped ceramic grains/ particles of size range 1.5-3mm dia as a mixture of ZrO_2 (30 wt%), TiB_2 (6 wt%), Al_2O_3 (60 wt%) with minor addition of

Co (4%), using alumina-sodium alginate slurry sintered at 1650^{0}C for 5 Hrs, were prepared as per the parameters finalized by the authors in their earlier works [1 & 2]. These grains were further processed to get the ceramic pads of desired geometry and shape as given below.

Step-II (Fabrication of high chrome insert of ceramic metal matrix composite)

Using the ceramic grains as prepared in Step-I, ceramic metal matrix high chrome inserts were fabricated in line with the parameters frozen in the earlier works by authors [1 & 2].

The chemical composition of high chrome and SG Iron of grinding roll are maintained as per Table 1 and Table 2 respectively, as finalized by the authors in their earlier works [2, 5 & 6]:

Table1: Composition of High Chrome Metal of the Insert:

Description	C	Si	Mn	S	P	Cr	W	Mo	Fe
Actual	2.81	0.78	0.67	0.05	0.05	18.02	1.25	1.5	Bal.

Table 2: Composition of Spheroidal Graphite Iron:

Description	C	Si	Mn	S	P	Residual Mg	Fe
Actual	3.65	2.22	0.67	0.008	0.05	0.05	Bal.

Chemical compositions were analyzed through Spark Emission Spectroscopy (SES) method using SPECTROMAXx machine.

The ceramic metal matrix high chrome inserts after knock out are subjected to stress relieving at 296^{0}C for 8 hours with rate of heating @ 50^{0}C (max) followed by air cooling after soaking. Then the inserts are ground and polished to carry out visual inspection prior to assembly in the centrifugal die for pouring of SG Iron to fabricate grinding roll for bowl mill as detailed below.

Step-III (Centrifugal die casting of grinding roll with ceramic metal matrix high chrome inserts being embedded in the SG Iron softer matrix by maintaining differential cooling rates of each zone/ layer to achieve desired hardness for each layer):

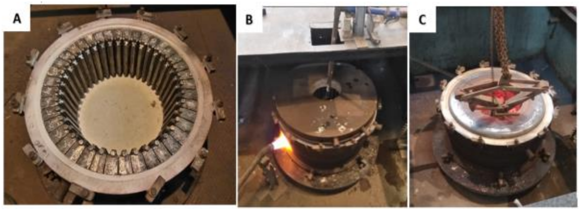

Fig. 1. A) Assembly of Ceramic Metal Matrix Inserts in Die, B) Preheating of Die, C) Roll Removal after Pouring

The stress relieved high chrome ceramic metal matrix composite inserts are then assembled in the centrifugal die (pre-coated with double layer of spirit based zircon paint) in such a way (Figure 1A) that the surface of the inserts having ceramic pad portion abutting to the inner surface of the die and all the pieces are fitted exactly with 8 to 10mm gap maintained between any two pieces by means of male-to-male projections provided on either side of the inserts. A schematic of centrifugal casting machine set up is shown in Figure 2 below:

After perfect fitting of the inserts in the die, the top lid is closed and the total insert assembly is heated to a minimum temperature of 200^{0}C by introducing LPG fired burners through the central opening of the lid at the top as well as from outside (Figure 1B) while the die is in rotating motion at slow speed.

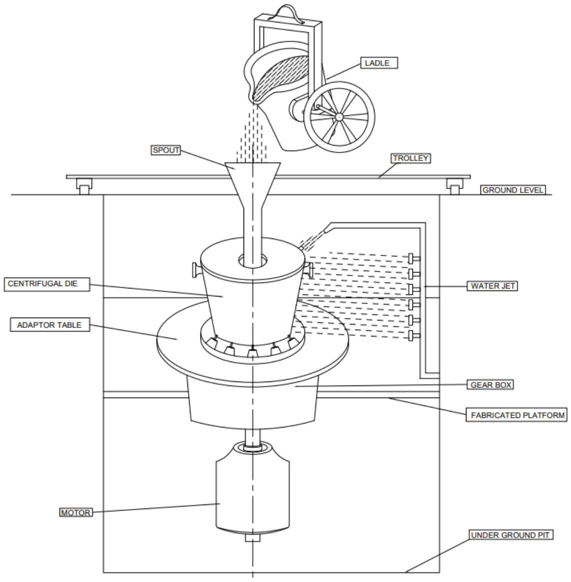

Fig. 2. Schematic of centrifugal casting manufacturing machine

After pouring of the roll, it is die cooled and removed (Figure 1C) to put in sand pit for cooling.

In the present study, grinding roll of bowl mill (Type: XRP1043) was considered for fabrication purpose. The total roll weight is 2400 Kgs, out of which the outer ceramic metal matrix composite layer assembly weighs around 1000 Kgs and the balance is SG Iron which was poured through the central spout.

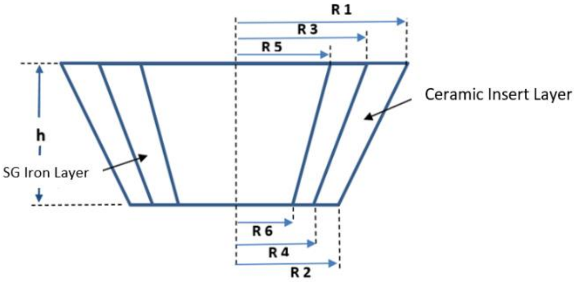

Fig. 3. Sketch of Grinding Roll Layers for RPM Calculations

The SG Iron liquid metal was prepared using 2.5T Induction Furnace (M/s Inductotherm Make) and pouring is done as per the parameters given in Table 3. The RPM required for SG Iron to get lifted in the die to the desired height and thickness is calculated [7, 8] using the following equation with the relevant dimensions as indicated in Figure 3:

$$\text{RPM of SG Iron} = 42.3\sqrt{\frac{h}{R5^2 - R6^2}} \quad (1)$$

Table 3: Technical Parameters of SG Iron Pouring of High Chrome Insert Roll:
[Bowl Mill type: XRP1043, Die: 62”, Total Wt.: 2400 KG]

Process Description	Parameter
Pouring spout used	3”
Die pre heat temperature	150 – 200^{0}C
Initial RPM of the die	20 ± 5
Pouring temperature of SGI	1290 - 1360oC
Weight of High Chrome Assembly	1000 Kgs
Weight of SG Iron	1400 Kgs
RPM Specified for 1st SG Iron	90 ± 5 (after pouring of 500 Kgs of SGI)
Lag Time Between 1st & 2nd SGI	2.0 – 2.5 Min
RPM Specified for 2nd SG Iron	135 ± 5 (Balance quantity of 700 Kgs)
Spin Time	90 Minutes
Method of Cooling in Die	Only Air Cooling (No Water Cooling)
Method of Cooling in pit	Sand cooling for 10 days

After removing the roll from sand cooling, it is subjected to following hardening cycle followed by tempering cycle to achieve the desired hardness of the high chrome insert portion, i.e. ≥ 64 HRC.

Hardening Cycle: Rate of Heating @ 60^{0}C (max)/ hr from 100^{0}C (max) to a soaking temperature of 675^{0}C ± 15^{0}C for 8 hours and then Rate of Heating @ 60^{0}C (max)/hr to a soaking temperature of 1030^{0}C ± 15^{0}C for 10 Hrs followed by oil quenching to Room Temperature (RT).

Tempering Cycle: Rate of Heating @ 60^{0}C (max)/hr from 75^{0}C (max) to a soaking temperature of 295^{0}C for 6 Hrs followed by air cooling to RT.

Initially, rolls were poured with above parameters but the hardness of inner SG Iron layer was also becoming equally hard as that of high chrome portion. This made the machining of inner SG iron layer extremely difficult or on certain occasions almost impossible. This became a major challenge to achieve a lower hardness (<330 BHN) of the inner layer (SG Iron) while retaining the requirement of outer layer, i.e. High Chrome Insert at 64 HRC (695BHN) or above.

Hence, the only way to achieve the variation in hardness values across the thickness of grinding roll is to incorporate differential cooling rates of the roll subsequent to pouring of SG Iron in the centrifugal die. For this, following arrangement as shown in Figure 4 is done to centrifugal die casting set up:

Upon successful assembly of high chrome ceramic metal matrix composite (CMMC) inserts in the die, it is kept in rotation @ 20 RPM and preheated with LPG fired burners up to a temperature of 200^{0}C as measured using non-contact Infrared Thermometer (HTA Instrumentation EQ-8859 Model). Then the burners are removed and lid is closed. SG Iron is poured as per the procedure elaborated in Table 3 except for the method of cooling.

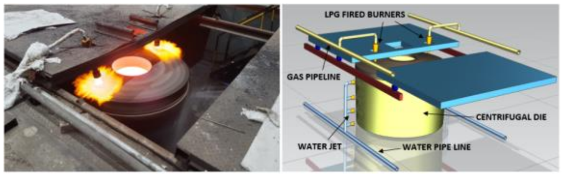

Fig. 4. Modified Arrangement for Differential Cooling of Centrifugal Die Casting of Roll

Immediately, after pouring the following arrangement is done for differential cooling:

Two replaceable additional LPG fired burners are fitted on the movable trolley (used for pouring SG Iron through the central hole provided for the purpose). These two burners are so positioned (Figure 4) that they will be heating exclusively that portion of the top lid which is in direct contact with the SG iron layer of the roll. At the same time, the pump for water jet is also switched on so that water at the calculated mass flow rate will be sprayed with the help of nozzles on the strategic locations of the die so that only that portion of the die which is in direct contact with CMMC insert is cooled.

The main objective is to find out the maximum temperature of internal dia (ID) portion of roll at which it can be removed from the die so that minimum 64HRC is maintained on the HCCI portion of the roll and correspondingly, to find out desired heat extraction rate from the system using water jets to achieve that cooling rate above which Martensite forms in HCCI. Although steady state gives initial conditions (worst conditions), the realistic unsteady state will have desired roll ID temperatures much below the initial steady state conditions. However, steady state conditions give us a brief idea of temperature profile of the system, how the cooling pattern could be under unsteady conditions, heat extraction rate to maintain steady state etc.

Moreover, it is required to find out steady state temperature distribution of roll (though unsteady state distribution study is appropriate, but it is more complex and hence steady state is considered in the present study).

In this new method the heat content of the liquid metal (SG iron) that is being poured into the die has to be utilized to enable the heat treatment of High Chrome Cast Iron (HCCI) portion of CMMC without separately heat treating it to attain the desired hardness and at the same time achieving a lower hardness of the SG Iron layer (<330 BHN).

This method also has advantage of cooling HCCI using solid-solid interface, i.e. HCCI-Die interface, cooling which prevents cracking of HCCI thin sections that normally occurs during air quenching of HCCI. As in this case the interface cooling predominantly occurs due to conduction, hence heat transfer is continuous and rate of cooling is much faster than air quenching where cooling is predominantly due to convection. In fact in case of air quenching, heat conduction has to happen through different intermediate substances in different states like gas to solid, solid to solid etc. and due to large density differences the cooling rate gets affected.

However, one such method in recent times is designed by Tesla team for casting Aluminum alloys for high performance applications (automobile chassis) where the alloy is press quenchable and subsequent solutionizing heat treatment is not required to attain mechanical properties [9]. In the present study also subsequent solutionizing (destabilization heat treatment) treatment is not required for attaining mechanical properties.

Since steady state conduction heat equation is used to model the system, hence several instantaneous steady state systems were considered for calculation of various parameters like temperatures at interfaces, heat flow rate between various resistances (materials like SG iron and Hi-Cr, Hi-Cr and die etc.) to arrive at the approximate value though in reality it's an unsteady system.

Actual heat extraction is calculated using the following equation:

$$\mathbf{Q = mC_P dT} \qquad (2)$$

Where, "Q" is heat, "m" is mass, "Cp" is specific heat and "dT" is the temperature difference.

Calculation:

Q/t = mCpdT/t, where "t" is time

In the present case, mass flow rate ("m/t") is calculated using power rating of motor used to pump water. It can also be calculated using:

m/t = mass/time = (density x volume)/ time = (density x (area of cross section of pipe x distance travelled by water))/ time = density x area of cross section of pipe x velocity of water in pipe.

Temperature difference of inlet water (25°C) and outlet water (45°C) has to be maintained where the specific heat of water is Cp = 4.186J/kg-K and hence correspondingly dT= 20^0C.

This Q/t value is used in steady state heat equation to find the interface temperatures or temperature at ID of the roll. Based on interface temperatures, the temperature profiles across materials can be found out using steady state conduction heat equation. For this it is required to have boundary conditions of temperatures to find out interface temperatures using Q/t value.

Also the steady state data does not explicitly describe the system, it gives us an overall idea of the system. The martensitic start temperature of HCCI as well as

SG Iron is observed to be around 600^{0}C (>600^{0}C) with reference to ASTM A532 Class III Type A handbooks and other literatures [10-12]. Hence, it is essential to remove the roll when the temperature of the ID portion of the roll attains 600^{0}C while ensuring desired martensitic transformation has already been achieved in high chrome portion by that time.

Following parameters were derived:

Heat Rate Flow and Temperature Calculation of 62” Grinding Roll [Bowl Mill: XRP1043]

In the present study, XRP1043 Grinding Roll (Dia: 62”) is considered whose existing Ni Hard bimetallic grinding roll (whose basic dimensions are considered for making the tri-material roll) drawing (Figure 5) along with die drawing (Figure 6) are given below:

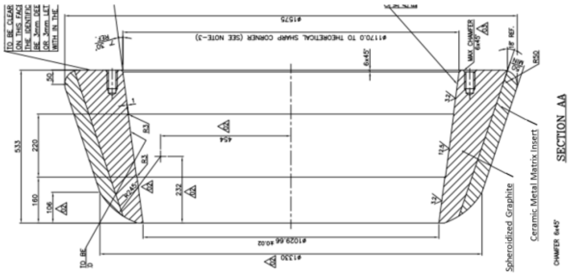

Fig. 5. Existing Ni Hard grinding roll drawing to obtain the dimensional requirement.

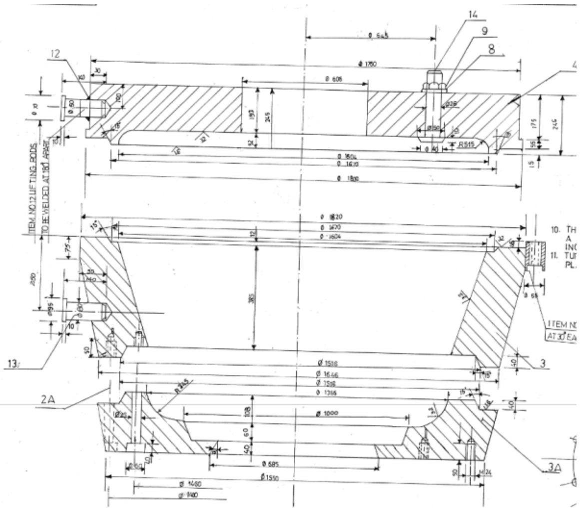

Fig. 6. Centrifugal die dimensions used for making XRP1043 grinding roll

The following heat flow rate equations were compared with Ohm’s law in electricity [13] for calculation purpose:

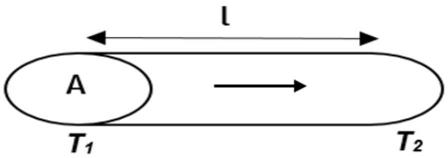

Fig. 7. Sketch to Demonstrate Thermal Conduction Process

The rate of heat transfer/ thermal current is calculated as per the following equation (Figure 7) [13]:

$$Q_i = \frac{dQ}{dt} = \frac{KA(T2-T1)}{l} = -KA\frac{dT}{dx} \qquad (3)$$

Where, Q_i = Rate of Heat Transfer, K = Thermal conductivity, A = Area of cross section, dT = Temperature difference between two ends, l = length, dx = distance.

The temperature gradient (dT/dx) is negative along the direction of flow. Comparing it with Ohm’s law of electricity:

$$i = V R \qquad (4)$$

Where, i = Current, V = Voltage and R = Resistance

Accordingly, $i_{thermal} = \frac{dQ}{dt}$, $V_{thermal} = T_1 - T_2 = \Delta T$ and $R_{thermal} = \frac{dx}{KA}$ (5)

Applying the above formula to the actual situation of the present study is calculated as below:

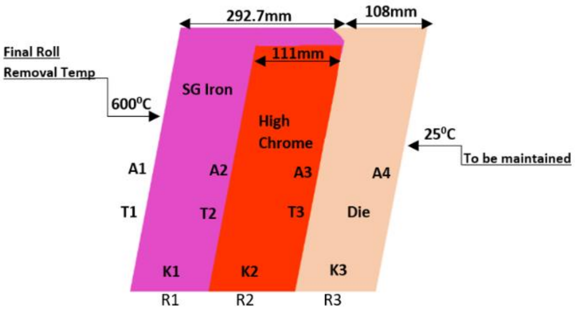

Fig. 8. Sketch of cross sectional view of the roll along with die

The actual dimensions of XRP1043 grinding roll in cross sectional view of trimaterial portion of the roll is given in the Figure 8 (with reference to Figure 5 & 6):

Thermal conductivity of SG Iron [14] =K1=36w/m-K

Thermal conductivity of High Chrome Metal [15] =K2 = 15w/m-K

Thermal conductivity of Die Forging made of mild steel [16] = K3 = 54 w/m-K

Area of the die (both outside and inside area approximately same) = A3 = A4 = 2581129.4 mm^2 = 2.58 m^2

Area of High Chrome Insert portion = A2 = 1895158.8 mm^2 = 1.895 m^2
Area of SG Iron portion = A1 = 1506366.75 mm^2 = 1.506 m^2.

$$\Delta T = \frac{dQ}{dt}\left[\frac{dx1}{K1A1}+\frac{dx2}{K2A2}+\frac{dx3}{K2A3}\right] \quad (6)$$

By applying equation (6) and also as per Ingen’s-Housz’s experiment [23], the following relation is derived:

$$V = \Delta T = i\,R = \frac{dQ}{dt}[R1+R2+R3] = \frac{dQ}{dt}\left[\frac{dx1}{K1A1}+\frac{dx2}{K2A2}+\frac{dx3}{K2A3}\right]$$

Iteration-1
Immediately, after pouring of SG iron into the die, the temperature of the ID portion of the roll was 1350^0C and the outside temperature of the die was maintained at 25^0C.
As per above equation (6):

$$1350\text{-}25 = \frac{dQ}{dt}\left[\frac{dx1}{K1A1}+\frac{dx2}{K2A2}+\frac{dx3}{K2A3}\right]$$

$$1325 = \frac{dQ}{dt}\left[\frac{0.182}{36 \times 1.506}+\frac{0.111}{15 \times 1.895}+\frac{0.108}{54 \times 2.58}\right]$$

Hence, $\frac{dQ}{dt}$ = 164760.01 Watt / sec = 1.6476 x 10^5 Joules/ sec

The above heat rate flow will be in ideal situation of steady state flow where there is no water cooling is considered.
But the requirement is to have at least 600^0C (since martensite start temperature is between 600-650^0C for High Chrome) at the interface of High chrome insert and metal die for which the heat flow rate is calculated as below:
Iteration-2
Considering T3 to be 600^0C:

$$600\text{-}25 = \frac{dQ}{dt}\left[\frac{0.108}{54 \times 2.58}\right]$$

i.e. $\frac{dQ}{dt}$ = 7.41744 x 10^5 Watt/ sec.

This is the rating to be maintained by the motor of the pump used for water jet spray on the die.
The pipe line connected to the pump is of 40 mm dia and the temperature of the outlet from the die should not exceed 45^0C as is dictated by the cooling tower input requirement.
Hence, ΔT = 45^0C – 25^0C = 20
Q (Heat Content) = Mass X Specific Heat of Water X Temperature Difference (^{0}C)
Q/t (Heat Flow Rate)
= Mass/ time x Specific Heat of Water X Temperature Difference (^{0}C)
= (Density of water (Kg/m3) x Area of cross section of pipe (m2) x velocity of water (m/sec)) x Specific Heat of Water x Temperature Difference ΔT (^{0}C)
= (1000 x 3.24 x (0.02)2 x Vw) x 4.2 x 20
Q/t (Heat Flow Rate as calculated in iteration2)
= 7.41744 x 10^5 Watt/ sec
= (1000 x 3.24 x $(0.02)^2$ x Vw) x 4.2 x 20
Accordingly, Velocity of water to be maintained = Vw = 6814 m/sec
Water Volume Flow Rate = Vw x Cross Sectional Area of Pipe = 6814 x 3.24 x $(0.02)^2$ = 8.558384 m^3/sec = 8558 liters/sec = 143 liters/ min = 143 LPM
Hence, by adjusting the water jet flow rate at 143 LPM and simultaneously making arrangements to heat the SG iron layer of the top portion using LPG fired burners (2 Nos) the differential cooling rate of the roll is achieved to the desired level.
After the roll has been removed from the die, it is allowed to air cool to room temperature in 36 hours, then it has been tempered at 276°C for 6 hrs with rate of heating @ 50^0C (max)/hr and air cooling after soaking, to remove residual stresses formed due to casting process. No destabilization treatment has been carried out before the tempering process.

III. RESULTS AND DISCUSSION

The differential cooling rates of the roll was established. The two LPG fired burners positioned on the top of the lid kept the temperature of the SG iron portion of the roll much above 600^0C to avoid Martensite transformation as otherwise would have led to fast cooling rate so exercised on the High Chrome portion.
In the beginning, immediately after pouring of the liquid SG Iron, it is allowed to rotate without any water jet spraying and burner heating for 12 minutes to allow the temperature of the high chrome insert to go beyond 965^0C to attain the desired destabilization temperature. Then both the water jet cooling as per the calculated water flow rate and firing of LPG burners (2 Nos) were done simultaneously. The calculated quantity of water jet spray on the die surface resulted in fast quenching of the high chrome resulting in increase of as normal cast hardness of HCCI from 42-46HRC to the range of

64-67 HRC after SG iron pouring and cooling treatment.

Due to continuous heating of the top lid, the temperature of SG Iron portion could be maintained above 600^0C. Though there was temperature gradient from the ID portion of the roll to the OD of SG Iron layer, but the hardness on ID could be maintained within 180-200 BHN whereas hardness of OD part of SG Iron layer was within 330-380 BHN. Still this has resolved the machining problem as up to the machining depth from ID, hardness was well below 280BHN.

IV. CONCLUSIONS

1. Differential cooling mechanism in centrifugal casting manufacturing process for achieving softer inner core of SG Iron (< 330 BHN) and harder outer layer of ceramic metal matrix composite (>64 HRC) is established.
2. The intrinsic process parameters are finalized for fabrication of trimaterial grinding roll to achieve a steep gradient of hardness starting from 180-200 BHN in ID portion of roll to greater than 64 HRC (695 BHN) on the OD of the grinding roll.
3. The process of destabilization treatment for achieving higher hardness has been eliminated completely there by making the process economically viable while drastically reducing the process cycle time.
4. The total running life of grinding roll could be enhanced by minimum 2000 hours in worst Indian coal conditions.

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