Effect of Chilling during Solidification on Wear Behavior of Ferrous Based Material

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Abstract*: The properties of the ferrous based materials can be modified by altering the composition and/or by adding elements or subjecting them to many heat treatments processes to suit for specific engineering applications. Further, the effort can also be made to vary the mechanical and tribological behavior of the steel group materials by means of controlling the rate of cooling during solidification of the liquid melt. Many researchers made an effort to modify the material characteristics by altering the cooling rate on tool steel materials. Many investigators made an attempt to improve the properties by adding alloying elements to the carbon steel materials and reported the results. But very few researchers studied on rate of cooling during solidification of the liquid melt which is achieved through by using different chills. Hence further investigation is necessary to observe the characteristic behavioural changes when the material subjected to different rates of cooling where phase transformation occurs from liquid to solid. In the present research an attempt has been made to tailor the engineering properties of the ASTM grade plain carbon steel group material by providing chilling effect to the liquid melt during its solidification and to study its wear characteristics. Research reported that the high wear resistance shown in chilled cast specimens relative to its un-chilled cast samples and higher wear resistance and hardness obtained in water cooled chilled cast specimens due to metallurgical changes observed in microstructure of water cooled copper chilled cast specimen.*

Keywords: End chills, Microstructure, Pearlite, Rapid cooling, SEM, VHC;

1. Introduction

Steel with very low carbon content is generally not responsive for heat treatment and has nearly the same properties as iron. It can be easily formed as they are quite softer. As the carbon content increases becomes stronger and harder by gradually losing its ductility. The steel and cast iron can be classified based on the carbon present in it. Various techniques through which the characteristics/properties of these ferrous based materials can be altered either by controlling rate of cooling of the liquid melt, or by adding alloying elements or also through various heat treatment techniques. The rate of cooling influences on the microstructure of the solidified metal. The various stages such as nucleation, dendrite formation, dendrite growth and grain formation that occur during phase transformation of the liquid metal [1,2]. The amount and number of alloying elements in the liquid metal largely influences on the various stages of the formation of crystal growth that the liquid metal experiences during solidification.

The different ways in which the soundness of the material properties can be achieved. The method by which the material properties can be improved or modified by various heat treatment processes which is directly responsible for the type of structure or phases obtained which in turn reflects on the properties of the materials.

Another method through which the material behavior of the low alloying elements can be appreciably altered to achieved the desired properties by controlling the cooling rate during solidification. The rate of cooling of the liquid metal is directly influences on the morphology of the solidified metal such as inter dendritic cell formation, precipitation of carbides and grain sizes which governs its properties [4].

The gating system, rate of cooling, thermal conductivity of the different chills and alloying elements are directly influencing on the structure of the solidified metal. The nature of phases present in the microstructure of the solidified metal reflects on the properties of material. The chills provided in the molds play a major role in achieving the directional solidification which in turn growth of the crystals in the solidified metal [1].

2. Materials and Method

2.1. Methodology

Wooden pattern is prepared incorporating the location of gating system and sand molds with CO2 is processed by setting up end chills in the mold cavities and sodium silicate is used as binder for sand mold. Zircon fluid is applied by coating the mold cavities to obtain smoothness and to avoid fusing of sand on the cast block surfaces. The prepared liquid melt is poured into the mold cavities. The cast blocks after solidification are removed from the sand mold by knocking process. The cast blocks cleaned and the gating system are removed by fettling process. The adhered sand particles on the surface of the cast samples are removed by shot blasting process. The test specimens are prepared from cast samples as per ASTM standards. Specimens are subjected to mechanical and tribological tests and its analysis.

2.2. *Experimental Procedure*

In the present research, one metallic (copper), one non-metallic (silicon carbide) and one water cooled (4^0 C) copper chill was used to get cast specimens. These end chills were fabricated to required size as per AFS standards (AFS standard of size 115* 75*25mm) and set in CO2 molds with arrangements made to circulate cold water (4^0 C) in one of the copper chills. Zircon fluid coating applied to mold to get good surface finish as well to avoid fusing of sand.

One of the ASTM grade plain carbon steel group material shown in table 1 and induction furnace set up was used to melt the metal. Ferro-crome around 950 gm added into the melt which may weighing approximately 50 kg and stirred well. The melt will be superheated to 1640 ºC and will be taken into a preheated ladle containing calcium silicide (which acts as deoxidizing agent) for pouring. Hot topping compound which is a mixture of silica, aluminum oxide, iron oxide and carbon were poured into the molten metal to retain the heat in the melt. Then the molten metal is ready to pour into the mold by maintaining the temperature close to 1620ºC until it gets filled up to riser level, during which time cold water (4^0 C) was circulated inside the copper chill.

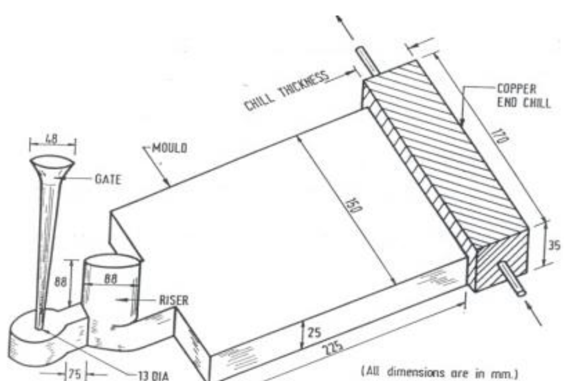

Fig. 1: AFS Standard mould cavity along with an end chill

After solidification of the castings, was degated and cleaned by fettling process and then shot blasting process done to remove sand particles adhered on the surface of cast samples. Then test specimens were prepared from cast samples as per ASTM standards. The ASTM grade steel used in this investigation and its composition is shown in table 1 given below.

Fig. 2. (a) CO2 process sand mold and (b) Mold coated with zircon fluid

Fig. 3. Cast blocks produced using different end chills and without using chill

Table 1. Chemical Composition of the ASTM grade steel

Alloy Designations	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
Composition	0.23	0.45	0.82	<0.008	<0.008	0.06	0.05	0.02	0.008

3. TESTING OF SPECIMENS

3.1. *Microstructural Examination*

The polished specimens were then etched using 3% Nital solution to evolve grain boundaries. Micro-structural studies were conducted on all polished specimens using Nikon optical microscope LV150 with clemex image analyzer. The specimens for microstructural studies were polished according to metallurgical standards and fine polishing was done using alumina powder and diamond paste.

3.2. Hardness Test

The Vicker's hardness number (HV) of the test samples were measured using HWMMT-X7-microhardness tester. The values reported are the average of three repetitions on the same sample.

3.3. Sliding Wear Test

Wear test for the test samples were conducted using computerized DUCOM wear testing machine. The specimen is a pin of size 6mm in diameter and 25mm long whereas the disc is of alloy steel having hardness of HRC 62. Before the test the surface of the pin was cleaned with acetone. The test was carried out by applying normal load on pin of 20 N for 10minutes keeping the disc speed constant. Weight loss method was used in the present investigation and the results obtained were converted to wear rate of the pin.

3.4. SEM Analysis

After the wear test, all the worn surfaces were subjected to SEM analysis to understand the wear mechanism. For the above purpose JEOL make SEM was used.

4. RESULTS AND DISCUSSION

4.1. Microstructural Analysis:

Specimens were prepared for metallographic studies. Test samples are polished by emery paper in sequence with different grades followed by polishing using nylon cloth and alumina powder of submicron size and diamond paste. After polishing samples were etched with 2% Nital solution and rinsed in distilled water to evolve grain boundaries while the microstructural features were examined under an optical microscope Nikon Microscope LV150 with Clemex Image Analyzer at X100 and X500 magnification and the micrograph presented. Equipment used is Nikon Microscope LV150 with Clemex Image Analyzer.

4.2. Hardness Test:

The experimental results on hardness test for all test specimens conducted and tabulated in table 2. It has been observed that an increase in hardness in the test specimens used water cooled copper chills because of effective directional solidification and more chilling effect causes formation of carbide precipitation [4]. Noticeable improvement in hardness also observed in test specimens produced using copper chills. The test specimens casted without using chills were shown no considerable improvement in its hardness because of the influence of progressive solidification caused by the absence of chills.

Table 2. Results of hardness test of test samples

Samples	Without	Silicon carbide	Copper	Water cooled copper	Copper
Test	201	208	224	250	0.008

4.3. Sliding Wear Test:

Dry sliding wear test was conducted on all test specimens for different loads and speeds. Cylindrical test specimens were prepared to a size of diameter 10mm and length of 30mm. Test conducted using pin-on-Disc Test rig machine of model, Wear and Friction Monitor, Tr-20L. The test specimens cleaned and deburred after machining to a suitable size. Acetone is used to remove the dust, grease from the surface of the pin. The flat surface of the cylindrical pin was held against the rotating disc.

Table 3. wear test parameter keeping rpm of the disc constant for different loads.

Load (N)	N (RPM)	Time (Minutes)	Track diameter (mm)	Sliding distance (mm)
20	400	30	120	Constant
30				
40				

The dry sliding wear test conducted as per ASTM-G-99 against the counter face of hardened and tempered disc made of EN-31 steel having HRC from 62 to 65. The test carried out for a constant sliding distance 4523.89 m for all test samples to different loads 20N, 30N and 40N with a speed of 400rpm, with a wear track 120mm shown in table 3. The many parameters such as weight loss, frictional force, wear loss and coefficient of friction studied and analyzed related to different loads and speeds. Scanning electron micrographs of the worn surfaces of the samples were also examined under SEM and discussed wear mode of the worn surfaces.

Table 4 shows the response of different chilled and un-chilled cast specimens for coefficient of friction to different loads. The presence of carbides in fine pearlite matrix in water cooled cast specimens exhibits lower co-efficient of friction.

Table 4. shows the coefficient of friction (COF) for different loads

Cast specimens produced (without chill and with different end chills)				
Load	Un-chilled (NC)	Silicon Carbide chill	Copper chill (CC)	Water Cooled copper chill
20	0.775	0.75	0.675	0.609
30	0.613333	0.56	0.513333	0.483333
40	0.57	0.4875	0.45	0.3875

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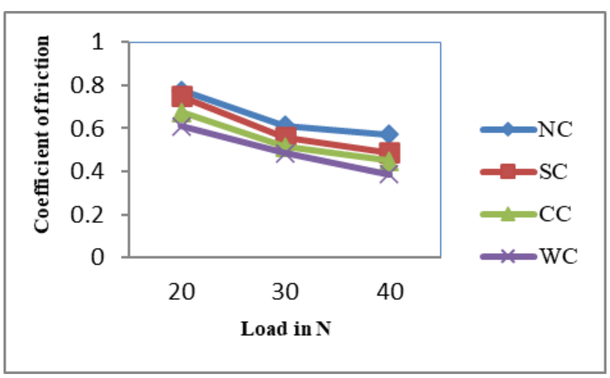

Fig. 4 shows Coefficient of friction for different loads

From the above figure 4, it has been observed that the coefficient of friction was higher at lower load (20N) and the same trend observed in all kinds of cast specimens produced with different chills and without using chill [4]. Initially at lower load (20N) the un-chilled cast specimen experiences relatively higher coefficient of friction compared to cast specimens produced with different chills. The water-cooled copper chill cast specimen shows lower coefficient of friction at lower and higher load (40N) as well. The cast specimen produced with water cooled copper chill exhibit lower COF at all loads due to the presence of carbides in fine pearlite matrix which influences to lower frictional force consequently the lower COF and observation was in line with researcher[1].

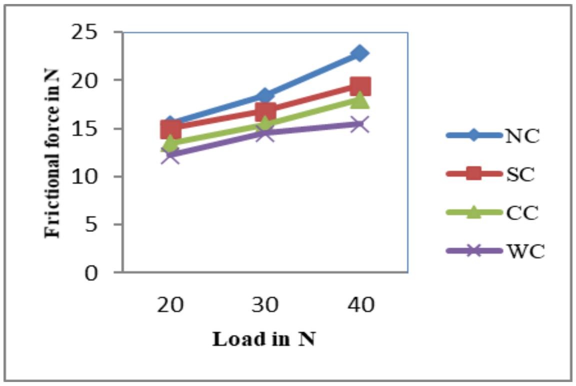

Fig. 5 shows frictional force for different loads

From the above figure 5, the result of the wear test shows that for un-chilled and different chilled cast specimens which were subjected to wear for different loads for a constant speed of the disc at 400rpm. The test result revealed that, at relatively lower load (20N) there was a marginal difference in their frictional force being subjected by all cast specimens. At higher load the un-chilled specimen experiences the more frictional force because of the presence of ferrite in coarse pearlite matrix. The cast specimens produced with different chills reveals lower frictional forces relative to un-chilled cast specimen. The cast specimen produced with water cooled copper chill exhibit lower frictional. force due to the presence of carbide in fine pearlite matrix which influences to reduce frictional force because of the presence of carbides in its structure [2,4].

Table 6. shows wear in microns for different loads

Cast specimens produced (without chill and with different end chills)				
Load	Un-chilled	Silicon Carbide chill	Copper chill	Water Cooled copper chill (WC)
20	239	104	75	63
30	789	450	350	154
40	1423	850	697	315

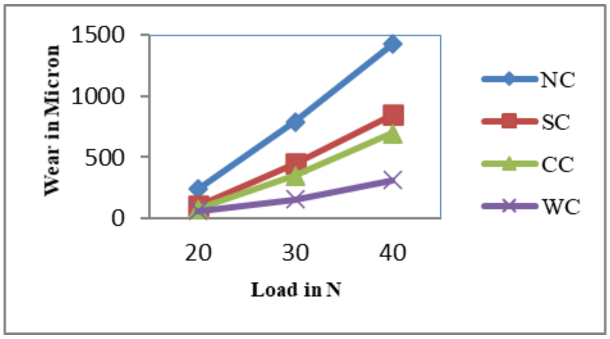

Fig. 6 shows wear in microns for different loads

The un-chilled and different chilled cast specimens produced were being subjected to wear test keeping rotational speed of the disc at 400rpm for different loads and the report revealed that, relatively at lower load (20N) all cast specimens shown marginal difference in their wear. But at higher loads the more wear observed in un-chilled cast specimen (NC) due to ferrite grains in coarse pearlite matrix. The presence of carbide in fine pearlite matrix observed in cast specimen produced using water cooled copper chill. The cooling rate which influences the formation of carbides in a fine pearlite matrix observed in water cooled copper chilled cast specimen which contributes an increase in wear resistance relative to the other cast specimens produced with different chills and without chill and it supports the investigator [4].

5. CONCLUSION

Finer grain structure of the chilled steel exhibited better properties than the un-chilled steel. Carbide particles observed in pearlite matrix which was responsible for superior properties. Chilled steel shows better wear resistance and hardness than the un-chilled steels. Water cooled copper chilled cast steel exhibit superior properties than the other cast specimens. At lower load, cast specimens produced with different chills experiences mild wear loss with high COF. But at higher loads shows better wear resistance than the un-chilled steel cast. Rate of chilling play a significant role in exhibiting a superior mechanical and wear behavior of the steels.

6. FUTURE SCOPE

Investigation need to be carried out by using different chills having different thermal conductivity to vary the rate of cooling to modify the microstructure which inturn responsible for its properties.

Further, Addition of minute alloying elements accompanying with different cooling rates need to be examined.

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