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A STUDY ON EFFECT OF CHILLING DURING SOLIDIFICATION AND COPPER ADDITION ON WEAR BEHAVIOUR OF STEEL GROUP MATERIAL

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Abstract— The properties of the ferrous based materials can be modified by changing the composition and/or by adding alloying elements or by many heat treatment processes to suit 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. Low Carbon steel materials are least responsive to heat treatment process. They remain soft and ductile in nature because of low carbon content. On the other hand, medium and high carbon steels are better in response to heat treatment to modify their properties. Hence the properties of these steel group materials can be tailored by any one or combination of the above said method. The present research involved studying the effects of cooling rate during the solidification of a liquid melt. Many researchers tried to modify the material characteristics by altering the cooling rate on tool steels. 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 the rate of cooling during solidification of the liquid melt which is achieved through by using different chills or single chill with the addition of alloying elements. Hence further investigation is necessary to observe the characteristic behavioral 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 the addition of copper and by providing chilling effect to the liquid melt during its solidification and to study its wear characteristics. Research reported that the addition of copper contributes to the improvement of wear characteristics of the steel specimens. Observed the higher wear resistance and hardness in chilled cast specimens with the addition of copper due to metallurgical changes observed in microstructure of chilled specimens with the addition of alloying element.

Index Terms— End chills, Microstructure, Pearlite, Plain carbon steel, Rapid cooling, SEM, VHC.

I. INTRODUCTION

The necessity of studying materials engineering is for selection of right material among the availability of thousands of materials. Therefore, decision in connection with selection of right material is based on several criteria. Discussions are necessary with regard to selection of materials and optimizing the properties for a specific application. A better familiarity with various characteristics, structures, characteristic relationships, and material processing techniques will help to choose materials wisely.

Engineering materials can be broadly classified into metals, polymers and ceramics and composites. Composites represent the combination of two or more of the above basic materials (matrix and the reinforcement).

Metal alloys can be classified into Ferrous and Non-ferrous alloys. Iron is the major element in ferrous alloys. All alloys in non-ferrous group are not iron based.

Steel is an alloy of iron and carbon, and steels generally contain other alloying elements also. Many steel alloys have different compositions and accordingly subjected to different heat treatment processes. Mechanical properties of steels are further complex to the carbon content, which is normally less than 1.0 wt % along with presence of other alloying elements. With respect to carbon content steels can be classified as low, medium, and high carbon steels.

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 properties of iron and steels are linked to the chemical composition, processing path, and resulting microstructure of the material. The metal alloys solidify over a range of temperature. Solidification behavior depends on parameters such as growth rate, temperature gradient and alloy constituents. Temperature gradient and growth rate influence the solidification morphology and solidification substructure respectively [1,2].

Growth rate or solidification rate is the rate of advance of the solid /liquid interface into the liquid. The rate of movement of solidification front determines solute redistribution during solidification, scale of solidification substructure and the growth under cooling. Rapid solidification (faster movement of solid/liquid interface) minimizes the tendency of segregation of elements temperature gradients both in solid and liquid are important. Thermal gradient in liquid is more critical as compared with solid and is strongly affected by mixing in liquid temperature gradient in solid is diffusion dependent [3].

Heat treatment process is widely used to achieve high mechanical properties. The major requirements of medium carbon steel are high yield and tensile strength, toughness, and high fatigue strength. These desirable properties of medium carbon steel can be achieved by adding suitable alloying elements and secondly by heat treatment. Annealing, normalizing, hardening, and tempering are the most important heat treatments often used to modify the microstructure and mechanical properties of engineering materials particularly steels. In normalizing, the material is heated to the austenitic temperature range, and this is followed by air cooling. This treatment is usually carried out to obtain a mainly pearlitic matrix, which results in achieving strength and hardness.

II. MATERIALS AND METHODS

A. Methodology

Sand mold with CO2 process is adopted to prepare mold and sodium silicate used as binder. Wooden pattern provided with gating system is utilized to produce molds. Mold coating is done by applying Zircon fluid to obtain smoothness and to avoid fusion of sand on the cast block surfaces. The prepared liquid melt is poured into the mold cavities. The cast blocks are removed after the solidification and degating, rough cleaning done by fettling process followed by shot blasting process to clean the sand particles adhered on the surfaces of the solidified cast blocks. The test specimens are prepared from cast samples as per ASTM standards. Specimens are subjected to tribological tests and their analysis.

B. Experimental Procedure

In the present research, water cooled copper chill is used to get cast specimens. This end chills (water cooled copper chills) were made to the required size as per AFS standards (AFS standard of size of size 115* 75*25mm) and set in CO2 molds with arrangements made to circulate cold water (6 degree Celsius) in the copper chills. Mold walls are coated with refractory material zircon fluid to get a good surface finish and to avoid fusion of sand.

The steel having the composition of ASTM grade plain carbon steel group material shown in table 1 was melted in an induction furnace. Ferro-crome around 900 grams added into the melt which may weighing approximately 45 kg and stirred well. The melt will be superheated to 1625 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. Finally, the treated molten metal was poured into the mold around 1600ºC until it gets filled up on the other of the riser, during which time cold water (6º C) was circulated inside the copper chill.

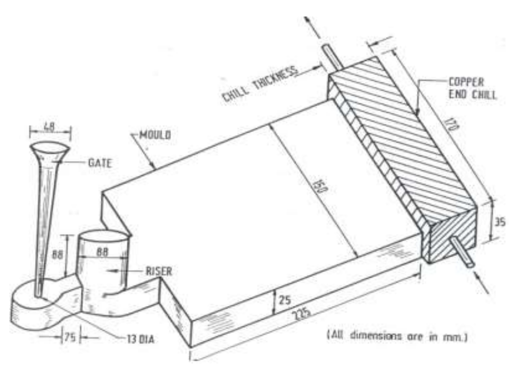

Figure 1: AFS Standard mould cavity along with an end chill

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 chemical composition of steel used in the present investigation is tabulated in table 1 given below.

Figure. 2. (a) CO_2 process sand mold coated with zircon fluid Figure.2(b) Mold ready for Pouring

Figure. 3. Cast blocks are produced using water cooled copper end chills.

TABLE 1. CHEMICAL COMPOSITION OF THE ASTM GRADE STEEL

Elements	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
Cast-A	0.22	0.4	0.85	0.02	0.008	0.05	0.05	0.02	0.5
Cast-B	0.22	0.4	0.85	0.02	0.008	0.05	0.05	0.02	1.0
Cast-C	0.22	0.4	0.85	0.02	0.008	0.05	0.05	0.02	1.5
Cast-D	0.22	0.4	0.85	0.02	0.008	0.05	0.05	0.02	2.0

The wear test is conducted on chilled specimens with the addition of copper. Wear behavior of these specimens studied.

III. TESTING OF SPECIMENS

A. 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.

B. 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 30mm 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 30 N for 15minutes keeping the disc speed constant. The weight loss method was used in the present investigation and the results obtained were converted to wear rate of the pin.

C. 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.

IV. REAULTS AND DISCUSION

A. Microstructural Analysis:

Chilled 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 magnification and the micrograph presented. Equipment used is Nikon Microscope LV150 with Clemex Image Analyzer.

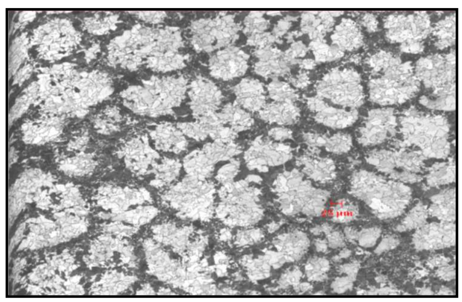

Figure. 4 Presence of ferrite and carbide in coarse pearlite matrix in chilled steel (0.5wt%Cu)

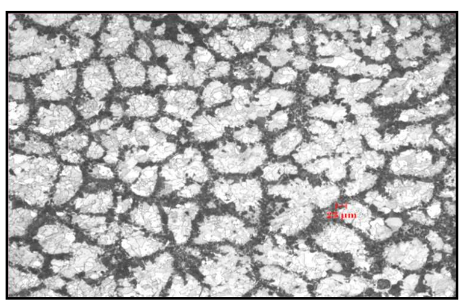

Figure.5 Presence of carbide in course pearlite matrix in chilled steel (1.0wt%Cu)

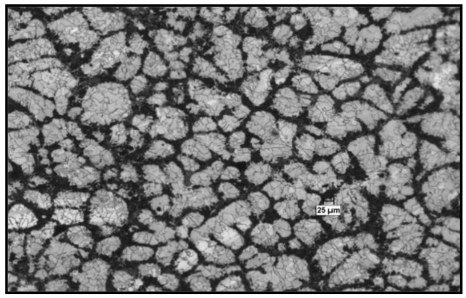

Figure. 6 Presence of carbide in small pearlite matrix in chilled steel (1.5wt% Cu)

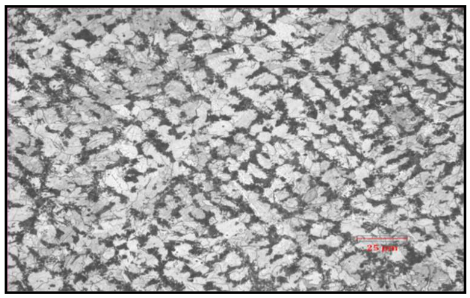

Figure.7 Presence of carbide in finer pearlite matrix in chilled steel (2.0wt% Cu)

B. Hardness Test:

The experimental results on hardness test for all test specimens conducted and tabulated in table 2. It has been observed that no significant effect on hardness with the addition of copper in the test specimens. But chilling effect from water cooled copper chills helps for effective directional solidification and more chilling effect causes formation of carbide precipitation [4] which contributes improved hardness but no noticeable improvement in hardness with the increase in copper addition.

TABLE 2. RESULTS OF HARDNESS TEST OF TEST SAMPLES

Cast specimens produced with water cooled end				
Copper addition in percentage	0.5	1.0	1.5	2.0
Water Cooled copper chill	223	225	224	225

C. Sliding Wear Test:

Dry sliding wear test was conducted on all chilled test specimens for constant load and speed. Cylindrical test specimens were prepared to a size of diameter 6mm 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 30 N LOAD.

Load (N)	N (RPM)	Time (Minutes)	Track diameter (mm)	Sliding distance (mm)
30	500	15	120	Constant

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 was carried out for a constant sliding distance 2827.43m for all test samples to load 30N with a speed of 500rpm, 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 constant load and speed. **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 chilled cast specimens with increase in copper addition for coefficient of friction to constant load. The chilled specimen contains 2% copper and shows lower co-efficient of friction.

TABLE 4. SHOWS THE COEFFICIENT OF FRICTION (COF) WITH INCREASE IN COPPER ADDITION.

Cast specimens produced with water cooled end chills					
Load (N)	Copper addition in percentage	0.5	1.0	1.5	2.0
30	Coefficient of friction (COF)	0.610	0.513	0.450	0.387

Table 4 shows the response of chilled cast specimens with varying copper content for coefficient of friction under a constant load. The presence of carbides in fine pearlite matrix in water cooled cast specimens with highest copper content reveals lower co-efficient of friction as depicted in figure 7.

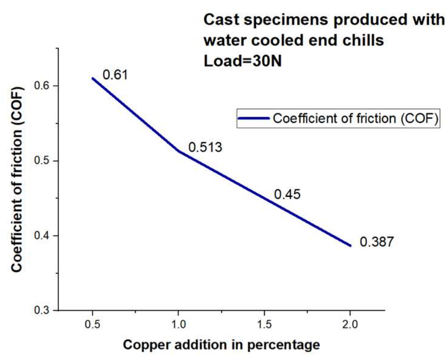

Figure. 8 shows Coefficient of friction for constant 30 N load.

From the above figure 4, it has been observed that the coefficient of friction was higher at lower copper content. Initially the cast specimen with lower copper content experiences relatively higher coefficient of friction compared to cast specimens produced with higher copper addition. The water-cooled copper chill cast specimen with 2% copper addition shows lower coefficient of friction at the applied load of 30N. The cast specimen produced with water cooled copper chill exhibit lower COF due to the presence of carbides in fine pearlite matrix which influences to lower frictional force consequently the lower COF which supports the researcher [1].

TABLE 5. SHOWS THE FRICTIONAL FORCE (N) WITH INCREASE IN COPPER ADDITION.

Cast specimens produced with water cooled end chills					
Load (N)	Copper addition in percentage	0.5	1.0	1.5	2.0

30	Frictional force (N)	14.87	14.52	13.51	13.02

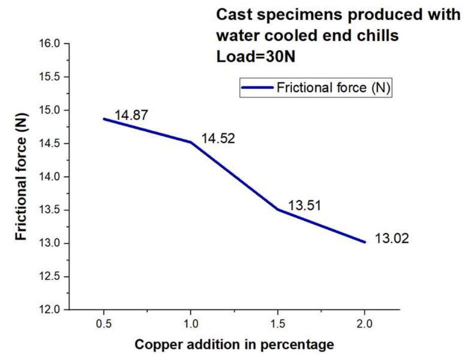

Figure. 9 shows frictional force for different copper content under a constant load.

From the above figure 5, the result of the wear test shows that chilled cast specimens which were subjected to wear for constant load and for a constant speed of the disc at 500rpm. The test result revealed that, there was a marginal difference in their frictional force being subjected by all cast specimens. At 30 N load the specimen with lower copper content experiences more frictional force because of the presence of ferrite in coarse pearlite matrix as represented in figure 4. The cast specimen produced with water cooled copper chill with higher copper addition exhibits 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] as depicted in figure 7.

TABLE 6. SHOWS WEAR IN MICRONS FOR 30 N LOAD.

Cast specimens produced with water cooled end chills					
Load (N)	Specimen- Copper addition in percentage	0.5	1.0	1.5	2.0
30	wear in microns	718	553	329	164

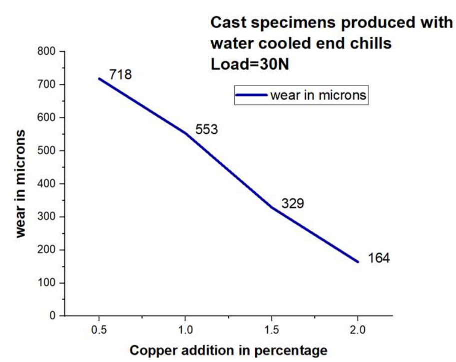

Fig. 10 shows wear in microns for different copper content under a constant load.

The chilled cast specimens with different copper content were produced and being subjected to wear test keeping rotational speed of the disc at 500rpm for a constant load and the report revealed that, at load 30N the cast specimen with lower copper content shows higher wear. The presence of carbide in fine pearlite matrix observed in cast specimen produced with higher copper content. The cooling rate which influences the formation of carbides in a fine pearlite matrix observed in combined effect of water-cooled copper chill and higher copper content cast specimen which contributes an increase in wear resistance relative to the other cast specimens produced with lower copper content and it supports the investigator [4].

V. CONCLUSION

It is to be noted here that the effect of cooling makes the structure morphology and refines the crystal grains, which is desirable to enhance the mechanical properties. Copper being a grain refiner is also added to chilled steels in different amounts has its own effect on the microstructure of chilled steels.

Incorporating chilling effect during solidification of a melt influences smaller grain structure of a steel and exhibits good wear properties. Carbide particles observed in pearlite matrix which was responsible for superior properties. Water cooled copper chilled cast steel with higher copper content exhibit superior properties than the other cast specimens having lower copper contents. The rate of chilling and copper addition play a substantial role in exhibiting a superior wear behavior of the steels.

VI. FUTURE SCOPE

Investigation needs to be carried out for different loads and by using different chills having different thermal conductivity to vary the rate of cooling for the attempt to modify the microstructure which in turn influences its properties.

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