Evaluation of Hardness, Wear and Compression Strength of Grey and Chilled Cast Iron

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***Abstract*--This paper highlights the experimental results obtained for evaluating the hardness, wear resistance and compression strength of chilled cast iron (CCI).Mild steel chills (MSC) of different thicknesses are used to check the chilling effect. The results show that chill thickness directly influences the hardness and wear resistance of cast iron. Marginal increase in compression strength is also observed by increasing mild steel chill thickness. Microstructure analysis was also carried out to evaluate the graphite morphology and carbide content. Carbon in longer graphite flakes form are more prominent at the un chilled surface. Carbon distribution in the form of low size graphite's and formation of pearlite are observed at the chilled end surface. Effect of mild steel chill thickness and chilling depth on hardness and wear resistance were studied and analyzed.**

Keywords— ***Mild steel Chill (MSC), grey cast iron (GCI), Chilled cast iron (CCI), Hardness, wear, wear resistance, Hardness Vickers (HV_{30})***

1. INTRODUCTION

Foundry Industry is major feeder to the sectors like automobiles, railways, power sector, tractor Industry, Pumps, Compressors, Pipes, Valves, Pipe Fittings, electrical, textile, cement machinery, machine tools, furnaces, Sanitary Castings, Sugar mills etc.,[1]. Cast irons are preferred in place of steel due to relative economical factors and manufacturing advantages like low production cost, moderate machinability, able to cast into complex shapes, ability to cast into huge sizes, high wear resistance, high hardness, improved damping characteristics, etc., [1][2]. In metal castings, cast iron, steel, non-ferrous and the remaining material shares in the ratio of 79:12:8:1. The Indian Foundry industry produces approximately seven million metric tonnes of castings employing estimated 500,000 persons directly & another 1.5 million indirectly[3]. The growth of foundry industry is very important for inclusive growth, other engineering sectors and the overall Indian economy. Properties of cast iron are altered by adding important alloy like silicon. Silicon forces carbon out of solution. Hence carbon forms graphite which results in a softer iron, reduces shrinkage, lowers strength, and decreases density[1][2]. Various alloys are added like Molybdenum(to refine the graphite and pearlite), Titanium(as a degasser and deoxidizer, increases fluidity),Vanadium (to stabilize cementite to increase hardness, resistance to wear and heat),Zirconium (to form graphite, deoxidize, and to increase fluidity) [1][2]. The number of eutectic cells is significantly larger in case of chilled cast iron than the sand casted caste iron without chill. Larger the eutectic cells, the greater will be ultimate tensile strength and fracture toughness [4]. High hardness was observed near the chill end than the surface away from the chill end [5]. Impact toughness of Partially chilled grey iron (PCGI) is in a better position than the Partially chilled ductile iron (PCDI). High wear resistance is obtained near the high carbide region. Field wear test data differs from laboratory test data (lab test data depends on specific tribo system)[6]. Addition of alloys varies the properties of cast iron and leads to high cost. Alloy additions to be minimized to reduce the cost of casting [7]. Wear at the chill end is almost constant for the cast iron castings produced using normal mild steel chill (MSL) and chill with subzero temperature. It is preferable to use normal mild steel chill. Mild steel chill of various thickness can be tried and tested for future work to optimize the wear resistance. Effective chilling thickness near the chilled face is noticed which gives higher hardness and high wear resistance useful for a specific functional requirements on engineering surfaces like brake linings, sliding bed of machine tools, railway wheel wear blocks .etc. Low hardness and high wear is observed away from the chill end which helps in good machinability [8].

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In this paper, mild steel chills of various thicknesses are used to analyze the microstructure, hardness, wear and compression strength. The present work outcome, by using different MS chill thickness, is the conclusion remarks from the authors [7][8]. High hardness tungsten carbide thermal spray coated wear disc was used for wear testing to analyze the wear behavior of material to meet the practical wear challenges.

2. EXPERIMENTAL PROCEDURE

2.1 MATERIAL AND COMPOSITION

The constituents of cast iron produced using Cupola furnace having a capacity of 1-3 tons per heat is shown in Table.1.

Table.1 Chemical Composition of Cast iron

Alloy	C	Si	Mn	S	P	Fe
%age	3.2	2.0	0.9	0.05	0.075	Reminder

2.2 CASTING PROCESS

A pattern made of wood was prepared with shrinkage allowance of 0.01 mm/mm, and finishing allowance of 3mm.Experimentation was carried out using sand molds without chill and with chills of different thickness.

Chilling effect has been created by using external chills as shown in Fig.1.Schematic diagram showing chill, chill position, gating system is shown in Fig.2. Casting produced at different conditions are listed in table.2.

Cast iron was melted in a Cupola furnace having a capacity of 1-3 tonnes per heat. Chilling effect has been created by using external chill as shown in Fig.1b and Fig.2.Molten metal from the furnace is transferred into the ladle. Silicon is added to the molten metal and stirred. Molten metal is poured in to the cavity through the sprue as shown in Fig.2. Skim bob in the shape of sprue was used to filter the molten metal.

2.3 SPECIMEN PREPARATION

The cast material is finished by surface milling and grinding. Locations of hardness test is identified as Chilled face (F) where chill is touching the casting, Chill end (C) near to the chill face. Casted work was cut into various dimensions using power hacksaw and hand saw to prepare the specimen for hardness, wear, compression strength and microstructure tests.

Fig.3 shows the samples prepared for various tests.

Fig.1a.

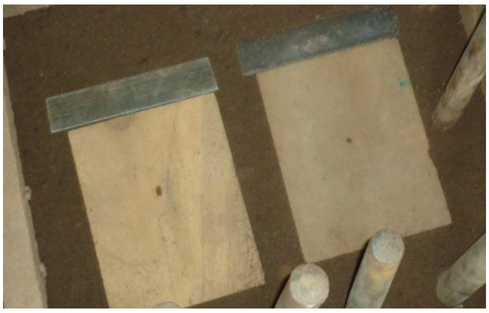

Fig.1b.

Fig.1 a) M.S.Chills of various thickness
b) MS Chill and pattern position

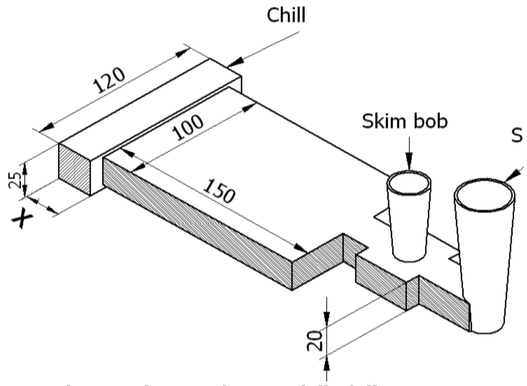

Fig.2 Schematic diagram showing chill, chill position, gating system

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Table.2 Casting produced at different conditions (X=15,20 and 25 mm)

ALLOY	conditions are listed against respective alloys
New-Alloy-1	Sand mold without using Chill – Silicon=2%
New-Alloy-2	Sand mold using Chill size 15x25x120 mm–Silicon=2%
New-Alloy-3	Sand mold using Chill size 20x25x120 mm–Silicon=2%
New-Alloy-4	Sand mold using Chill size 30x25x120 mm–Silicon=2%

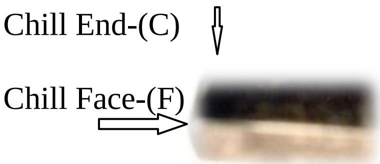


Fig.3a Specimen for hardness test

Fig. 3b Specimen for Microstructure Fig. 3c Specimen of wear test

3.RESULT AND DISCUSSION

3.1.HARDNESS TEST –VICKERS-HARDNESS-HV_{30}

The cast material is finished by surface milling and grinding. Locations of hardness test is identified as Chilled face (F) where chill is touching the casting, Chill end (C) near to the chill face (0-18 mm from F – as referred in Fig.3). Hardness test was carried out at different locations of the cast specimen using Vickers hardness tester with 30 Kg load. Table.3 shows the hardness(HV_{30}) values measured at a distance of 0 to 18 mm from the chill face(F). Fig.4 highlights the details data labels for New alloy-1 to New alloy-4.

Chill effect on hardness is observed for 4-6 mm for New alloy-2, 6-8 mm for New alloy-3 and 8-10 mm for New alloy-4. New alloy-1 has not shown appreciable change on hardness (Fig.4). Higher the chill thickness leads to high hardness near the chill face (New Alloy-4- 331 HV_{30}).

Table.3 Hardness (HV_{30}) measured 0mm- 18mm from chilled face

Distance from chill end -mm	New-Alloy-1	New-Alloy-2	New-Alloy-3	New-Alloy-4
	NO CHILL	CHILL 15X25 mm	CHILL 20X25 mm	CHILL 30X25 mm
	Si=2%	Si=2%	Si=2%	Si=2%
0	**223**	**241**	**263**	**331**
2	223	223	241	301
4	**214**	223	241	301
6	206	**214**	**223**	241
8	191	214	**223**	241
10	206	214	214	**223**
12	191	206	214	214
14	191	206	214	214
16	191	206	214	214
18	191	206	214	214

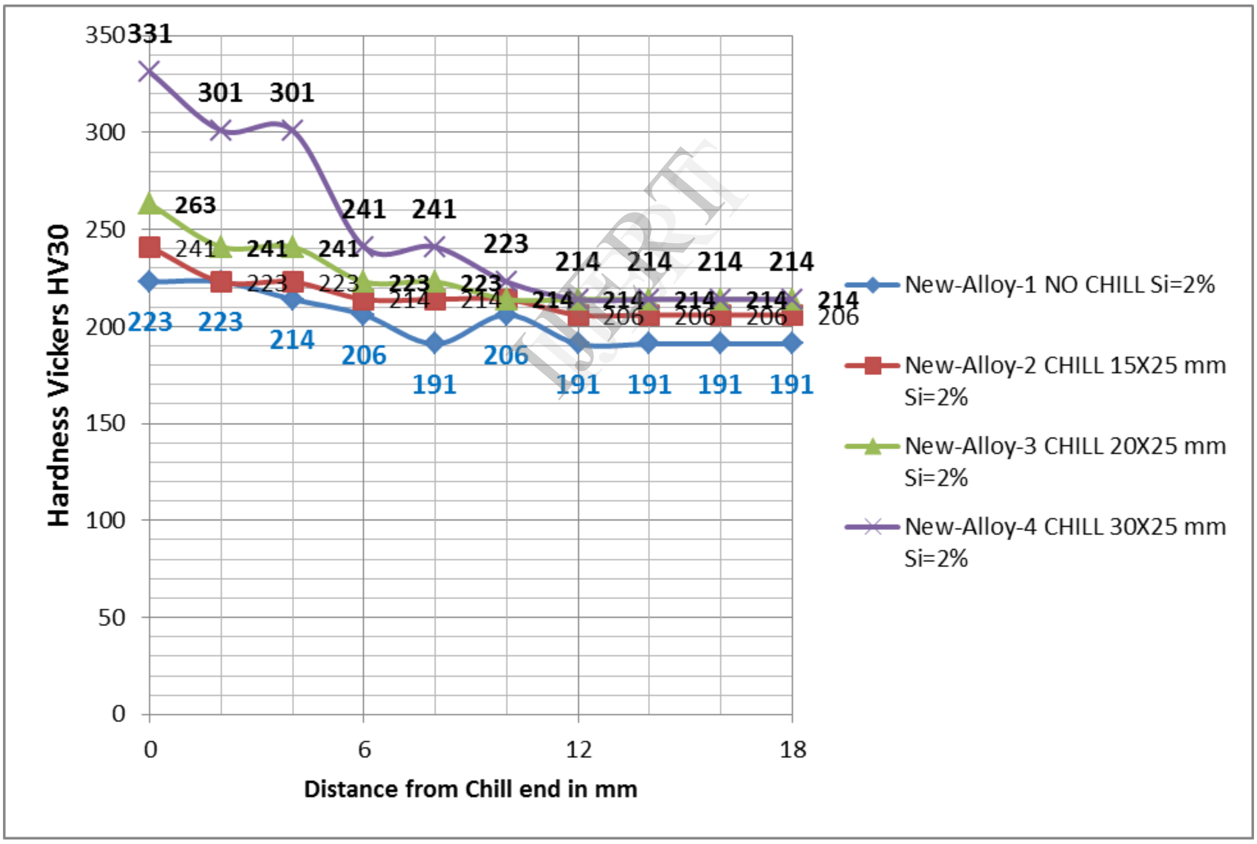


Fig.4 Hardness (HV_{30}) Values showing effect of chill thickness

3.2 WEAR TEST:

Sliding wear test was performed as per ASTM-G-99. Fig.5 shows the change is linear wear for different chill thickness. Wear test is conducted using pin on disc wear testing machine. Thermal spray coated tungsten coated disc is used considering the hardness of tested specimen. Specimens of 8 mm diameter were prepared and a load of 10,20 and 30 Newton was applied for 700 meters sliding distance. Linear wear of 518 microns was observed for a specimen prepared without using chill. Specimen casted using 15, 20 and 30 mm chill thickness showed as 430, 410 and 269 microns as linear wear for 700 meter sliding distance. It is clear from the experimental results that, wear decreases by increasing chill thickness.

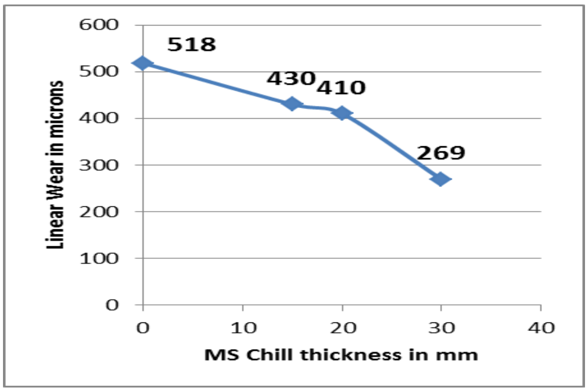


Fig.5 Wear in microns for different chill thickness

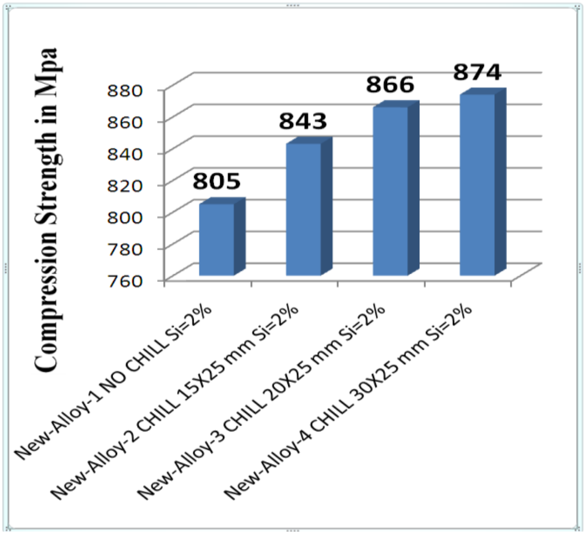
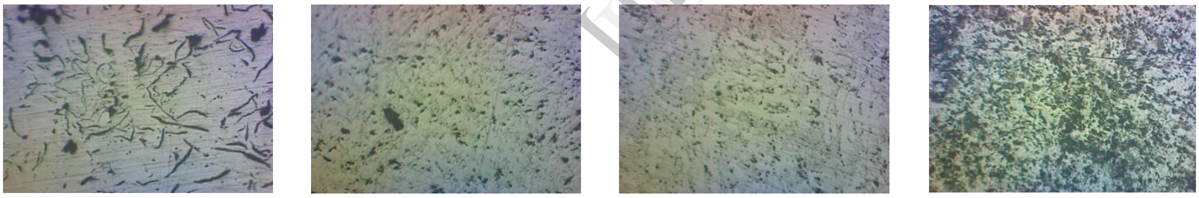


Fig.6 Maximum Compression strength for the castings produced using different chill thickness.

3.3 COMPRESSION TEST:

Compression test was performed using universal testing machine by preparing the specimens of 10x10x20mm (±0.5mm) Fig.6 highlights the compression strength for the castings produced at different conditions. New Alloy-1 was manufactured without using chill is having low compression strength (805 MPa). New alloy-2, New alloy-3 and New alloy-4 doesn't show appreciable change in compression strength (843, 866 and 875 MPa).

3.4 MICROSTRUCTURE STUDY :



a. New-Alloy-1 b. New-Alloy-2 c. New-Alloy-3 d.New-Alloy-4

Fig.7 Micrographs of the cast specimens for various chill thickness – Magnication-100X

Fig.7 shows the micrographs of New-Alloy-1, New-Alloy-2, New-Alloy-3 and New-Alloy-4 highlighting graphite flake size of 2,3,4,5,6,7 and 8 with B and D type of distribution (AFS and ASTM standards). Only chill end is used for analyzing the data.

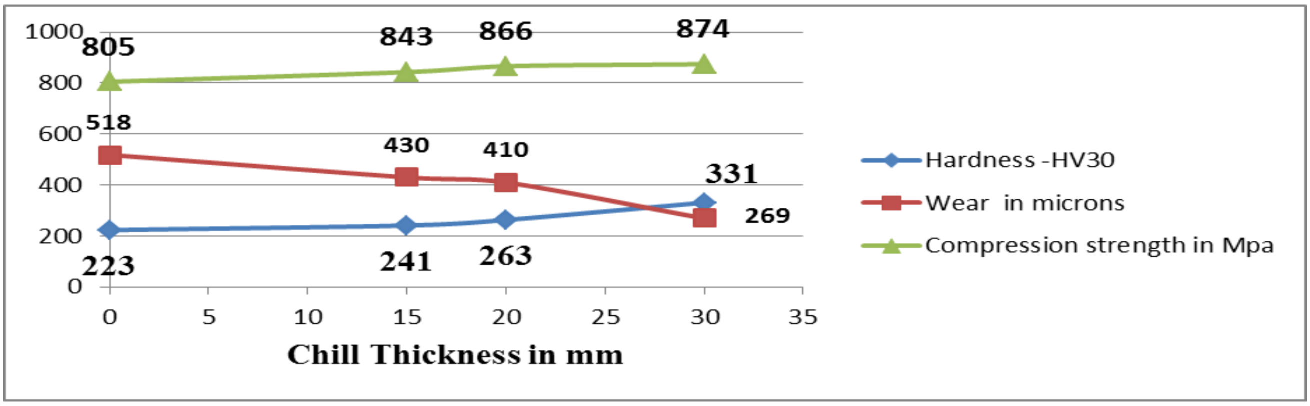


Fig.8 combined graphs are plotted to compare hardness, wear and compression strength with respect to chill thickness

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4. CONCLUSIONS

The following inferences are made from the test results

1) New-Alloy-1 is dominated with flake size of 2,3 and 4. In New-Alloy-1 No Chill), flakes are clear and shows the microstructure similar to normal grey cast iron. Low wear resistance (High wear of 518 microns) and low hardness (223HV_{30}) are measured for the casting manufactured with out using chill.
2) New-Alloy-2 (MS Chill 15X25 mm) is dominated with flake size of 4, 5 and 6. Due to chilling few carbon precipitates in iron to form iron carbide. Wear resistance of 430 micron and hardness of 241$HV_{30}$are resulted by using MS chill of 15x25x120mm size. A slight improvement in hardness and wear resistance is felt as compared to New-Alloy-2.
3) New-Alloy-3 (MSC-20X25mm) is dominated with flake size of 5,6 and 7.Chilling effect leads to precipitate carbon in iron. Further increase in hardness(263HV_{30}) is resulted by increasing the chill thickness which amounts to decrease the in wear from 430 to 410 microns.
4) New-Alloy-4 (MSC-30X25 mm) shows the flake size of 7 and 8 and precipitation of carbon in iron to form iron carbide. Microstructure shows the formation of pearlite with the higher percentage of cementite (High concentration of black zone- Fe_3C). This lead to increase the hardness to 331HV_{30} and decrease the linear wear (269 microns)
5) Graphite flake size varies inversely with length of the flakes. Flake size number-2 is having higher flake length and flake size number-8 is of less in length. Higher the flake length leads to reduce the hardness and increase the wear. Higher concentration of cementite (Fig.7d) leads to increase hardness and decreases the wear.
6) Fig.8 clearly indicates that, higher the chill thickness leads to decrease the wear and increase in hardness. Comparing the values of hardness and wear, there is a marginal difference in hardness and wear values between New-Alloy-2 and New-Alloy-3. It is clear from the experimental results that small MS chill thickness from 15 to 20 mm has not shown significant change in hardness (241 and 263 HV_{30}) and wear (430 to 410 microns). Using higher MS chill thickness 30 mm resulted in the increase in the hardness to 331HV_{30} and reducing the wear to 269 microns.
7) 33% increase in chill thickness (15-20mm) leads to increase the hardness by 9% (241 to 263 HV_{30}) and reduce the wear by 5% (430 to 410 microns).
   50% increase in chill thickness (20-30mm) leads to increase the hardness by 26% (263-331 HV_{30}) and reduce the wear by 34% (410-269 microns).
   100% increase in chill thickness (15-30mm) leads to increase the hardness by 37% (241-331 HV_{30}) and reduce the wear by 37.5% (430-269 microns).

Machining allowance at the chilled surface can be reduced during pattern design. Macroscopic examination reveals that chilled surface are smooth with low R_a value. Grinding is advisable to finish the chilled surface to remove the excess stock of 0.1 to 0.5 mm depending on the quality of the foundries where castings are produced. For the un chilled surface, series of machining operations like turning/ milling /shaping are preferred to remove the excess stock of 1.5-3 mm.

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