Tribological Behavior of Chilled and Alloyed Cast Iron Surfaces

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Abstract: ***This paper presents data comparing the wear properties of grey, chilled and alloyed cast iron surfaces. Mild steel chills (MSC) of different thicknesses were used to increase the cooling rates during solidification. Alloy materials like chromium and nickel were added as inoculants with different percentage. Wear tests were conducted on grey cast iron (GCI), chilled cast iron (CCI), alloyed cast iron (ACI), alloyed chilled cast iron (ACCI) surfaces. The results were evaluated and analyzed. Microstructure were also examined and analyzed critically to evaluate the effect of graphite flakes, formation of pearlite, cementite on tribological behavior of the material. It has been observed that, use of mild steel chill increases wear resistance. Addition of alloys like chromium and nickel without using chill has not shown appreciable increase in wear resistance. Combined effect of using MS chill and addition of alloys like chromium and nickel as inoculants exhibits more wear resistance.***

Keywords: Mild steel Chill (MSC), grey cast iron (GCI), chilled cast iron (CCI), alloyed cast iron (ACI), alloyed chilled cast iron (ACCI), wear and wear resistances.

1. Introduction

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 capacity, etc., [1][2]. 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]. 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, sulphur, manganese, molybdenum, vanadium, chromium, nickel etc. Silicon forces carbon out of solution. Hence carbon forms graphite which results in a softer iron, reduces shrinkage, lowers strength, and decreases density. Sulfur, when added, forms iron sulfide, which prevents the formation of graphite and increases hardness. Manganese is added to form into manganese sulfide instead of iron sulfide [1],[2]. Molybdenum is added to increase chilling effect and refine the graphite and pearlite structure. Titanium is added as a degasser and deoxidizer, but it also increases fluidity. Vanadium is added to cast iron to stabilize cementite structure which increases hardness, resistance to wear and heat. Zirconium helps to form graphite, to deoxidize, and to increase fluidity [1],[2].

If Chilled cast iron (white iron) is alloyed to certain extent with Vanadium, Neubium or titanium, the matrix of this eutectic seizes to be carbidic (as in Ledeburite), the VC, N_bC or T_iC become inclusions in a pearlitic or ferritic or austentic matrix. This leads to form a ductile white iron, which then improves the properties required for application of white iron. By addition of rare earth metals, the graphite can be spheriodized, thereby increasing the wear resistance and antifriction properties, while retaining reasonably good machinibility [4]. Vanadium is generally considered to be an alloying element for the improvement of the hardness of cast irons by formation of vanadium carbides. It is also known to increase the number of eutectic cells in it [5].

Nickel is one of the most common alloyants because it refines the pearlite and graphite structure, improves toughness, and evens out hardness. When chromium is added to cast iron, a portion of it enters the iron carbide and forms complex Fe-Cr carbides. Carbide present as component of pearlite is first stabilized, and with further addition of chromium, primary or massive carbides are stabilized. The primary role of chromium is therefore to act as a carbide stabilizer [6]. According to American foundry society (AFS) cast hand book, when small amount of chromium is added to cast iron, ferritic structures are replaced by stronger pearlitic types, the size of the graphite flakes is made more uniform, and the grain size is refined [7]. Addition of chromium results in an increase in the fracture toughness [6]. Increase in chromium content, increases significantly the corrosion resistance [8]. Addition of chromium increases hardness [9]. Addition of higher percentage of chromium offers improved abrasion resistance and toughness when compare to nickel chromium martensitic white irons and superior abrasion resistance [10].

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 [11]. High hardness was observed near the chill end than the surface away from the chill end [12]. 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) [13]. Addition of alloys varies the properties of cast iron leads to high cost. Alloy additions to be minimized to reduce the cost of casting [14].

High hardness is noticed at the chill face. Sub zero chilling produces high hardness in the vicinity of chill end face. 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 thicknesses can be tried and tested for future work to optimize the wear resistance. Effective chilling thickness near the chilled face, which gives higher hardness and high wear resistance useful for specific functional requirements on engineering surfaces like brake linings, sliding bed of machine tools, railway wheel wears blocks .etc. Low hardness and high wear is observed away from the chill end which helps in good machinability [15].

In this paper mild steel chills are used as chill material. Tribological behavior of the material using pin and disc method is studied and analyzed. Microstructures of magnification of 100X are used to analyze the graphite morphology and mixing of carbon in the form of iron carbide as per AFS and ASTM standards. The present work outcome for using MS chill and addition of chromium and nickel as inoculants (1-1.5%) is the conclusion remarks from the authors [15]. High hardness tungsten carbide thermal spray coated wear disc is 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	Reminder
%age	3.2	2.0	0.9	0.05	0.075	Fe , 0.0 to 1.5 % Cr and Ni

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 chills of various thicknesses. Chilling effect has been created by using external chills as shown in Figure 1. Cast iron was melted in a Cupola furnace having a capacity of 1-3 tons per heat. Chilling effect has been created by using external chill as shown in Figure 1b and Figure 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 Figure 2. Skim bob in the shape of sprue was used to filter the molten metal.

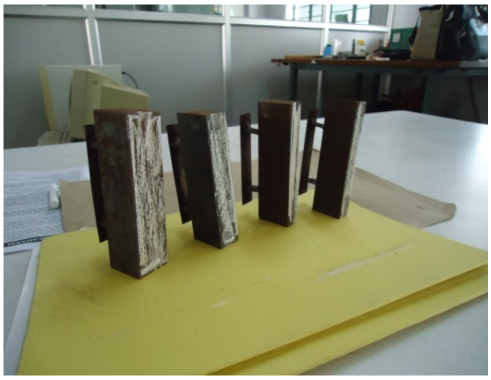

Figure 1a

Figure 1b

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

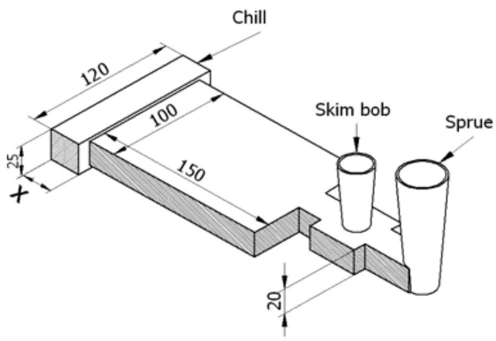

Figure 2: Schematic diagram showing chill, chill position, gating system

Table 2: Casting produced at different conditions

ALLOY	Ref-Table-1 for Main constituents. Other casting 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%
New-Alloy-5	Sand mold using Chill size 30x25x120 mm –Silicon=2%, Chromium=1%
New-Alloy-6	Sand mold using Chill size 30x25x120 mm –Silicon=2%, Nickel=2.3%
New-Alloy-7	Sand mold using Chill size 30x25x120 mm –Silicon=2%, Chromium=1.5%, Nickel=1.5%
New-Alloy-8	Sand mold without using Chill –Silicon=2% ,Chromium=1.5%, Nickel=1.5%

Casting produced at various conditions was:

1. Without using MSC.
2. Without MSC (and addition of Chromium and Nickel)
3. With MSC and
4. With MSC (and addition of Cr and Ni)

2.3 Specimen Preparation

The cast material is finished by surface milling and grinding. Casted work was cut into various dimensions using power hacksaw and hand saw to prepare the specimen for wear and microstructure tests. Specimen was turned for 8mm diameter for a length of 25 to 30mm. Facing operation was performed to the face of the cylindrical specimen to ensure uniform wear. Figure 3 shows the samples prepared for microstructure and wear.

Figure 3a: Specimen for microstructure

Figure 3b: Specimen for wear test

3. Result and Discussion

3.1 Wear Test

Sliding wear test was conducted as per ASTM-G-99. Wear test is conducted using pin on disc wear testing machine. Thermal spray coated tungsten coated disc was 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.

To discuss and analyze without confusion, the casted alloys are grouped as GCI (New-Alloy-1), CCI (New-Alloy-2, New-Alloy-3 and New-Alloy-4), ACI (New-Alloy-8), ACCI (New-Alloy-5, New-Alloy-6 and New-Alloy-7).

Figure 4 is plotted to show the wear results for New-Alloy-1 to New-alloy4. These alloys are manufactured without adding chromium and nickel. Wear of 518 microns was found for a specimen prepared without using chill. Specimen casted using 15, 20 and 30 mm chill thickness was measured as 430, 410 and 269 microns. It is clear from the experimental results that, wear decreases by increasing chill thickness.

Figure 5 is plotted to compare the wear results of alloy casted without using chill and no addition of %age chromium and %age nickel (New-Alloy-1) , without using chill and addition of chromium and nickel (New-Alloy-8) and using chill and addition of chromium and nickel. Addition of chromium and nickel to the basic composition doesn't show appreciable increase in wear resistance (518 to 479 microns). Addition of chromium and nickel and use of chill leads to increase in wear resistance (479 to 161 microns).

Figure 6 highlights the effect of chilling on wear with and without addition of chromium and nickel. Increase in wear resistance is observed with the combined effect of chilling and addition of alloys (269 to 161 microns). It is clear from Figure 7 that addition of only chromium (New-Alloy-5) is having superior wear resistance as compared to other alloys (New-Alloy-6 and New-Alloy-7).

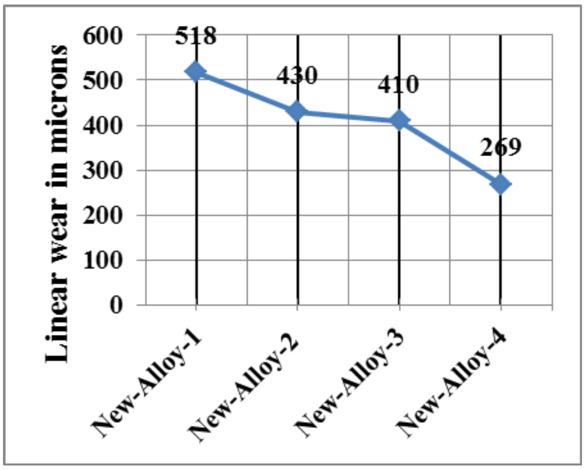

Figure 4: GCI and CCI

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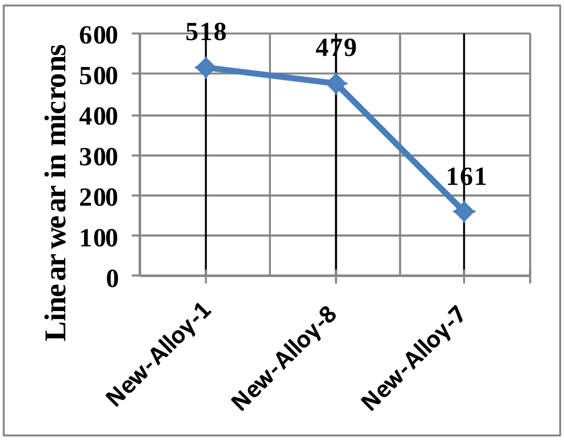


Figure 5: GCI, ACI, ACCI

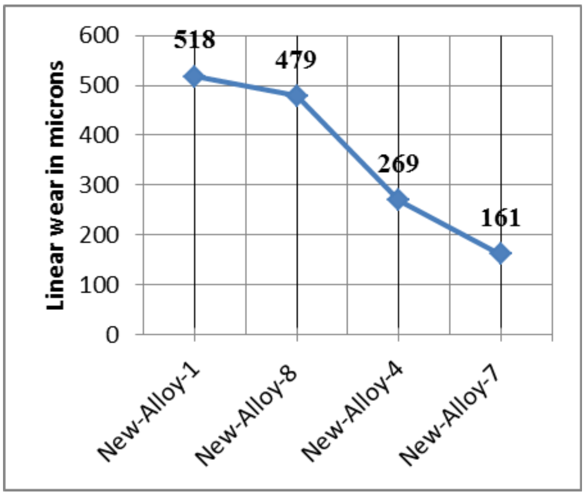
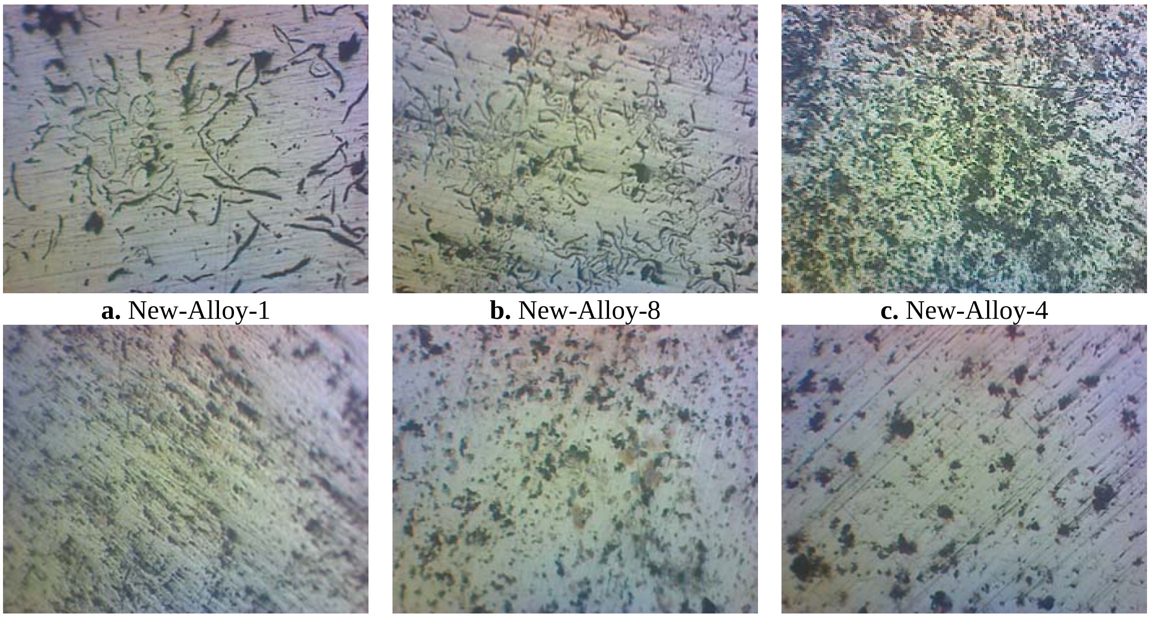


Figure 6: GCI, ACI, CCI, ACCI



a. New-Alloy-1 **b.** New-Alloy-8 **c.** New-Alloy-4

d. New-Alloy-6 **e.** New-Alloy-5 **f.** New-Alloy-7

Figure 8: Micrographs of GCI, ACI, CCI and ACCI- Magnification-100X

3.2 Microstructure

Figure 8a to Figure 8f is selected to analyze the microstructure of GCI, ACI, CCI and ACCI casted products at various conditions. Figure 8a shows the longer size graphite's with uniform and random distribution. Figure 8b shows the smaller size graphite's as compare to Figure 8a with rosette and random distribution. In Figure 8c, graphite distribution is not clear. From the image analyzer (Material plus) data, graphite flakes length are smaller than Figure 8a and Figure 8b.Pearrlite formation is dominated as compare to ferrite. Figure 8d, Figure 8.e and Figure 8f, graphite flakes are not clear as shown, but smaller compact graphite's with domination of pearlite and cementite. Due to this, machining was difficult near the chilled surface because of absence of prominent graphite.

4. Conclusions

The following inferences are made from the test results.

a. Variation in chill thickness:

New-Alloy-1 is dominated with graphite flake size of 4. Few graphite flakes size of 3 and 5 are also noticed. In New-Alloy-1 (No Chill), graphite flakes are clear and shows the microstructure similar to normal grey cast iron. Uniform and random distribution of graphite flakes leads to reduce the wear resistance (High wear of 518 microns). In New-Alloy-2, wear of 430 micron was measured. In New-Alloy-3, higher thickness MSC was used as compared to New-Alloy-2, hence wear is reduced from 430 to 410 microns. New-Alloy-4 (MSC-30X25 mm) shows the dominance in flake size of 6. Precipitation of carbon in iron to form iron carbide. Microstructure shows the formation of pearlite and cementite (High concentration of black zone- Fe_3C). This lead to decrease the linear wear (269 microns).

Graphite flake size number varies inversely with length of the flakes. Flake size number-3 is longer in length than flake size number-8 (1-2 inch –AFS and ATM). Higher the flake length leads to increase the wear. Concentration of pearlite and cementite (Figure 8c) decreases the wear.

Figure 4 clearly indicates that, higher the chill thickness leads to decrease the wear on the cast surfaces. Comparing the values of wear, there is a marginal difference in wear results 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 wear (430 to 410 microns). Using higher MS chill thickness of 30 mm resulted in reducing the wear to 269 microns.

33% increase in chill thickness (15-20mm) leads to reduce the wear by 5% (430 to 410 microns).
50% increase in chill thickness (20-30mm) leads to reduce the wear by 34% (410-269 microns).
100% increase in chill thickness (15-30mm) leads to reduce the wear by 37.5% (430-269 microns).

b. GCI, ACI and ACCI:
Addition of chromium (1.5%) and nickel (1.5%) without using chill has not shown any appreciable change in wear (518 to 479 microns). Combined effect of using chill and addition of above alloys leads to reduce the wear from 479 to 169 microns. Micrographs (Figure 8a and Figure 8b) shows longer graphite flakes leads to increase the wear. Whereas Figure 8f shows the concentration of pearlite/cementite which leads to reduce the wear drastically (High wear resistant).

c. GCI, ACI, CCI and ACCI:

- Using chill of 30mm thickness leads to reduce the wear (518 to 269 microns).
- Nickel addition (2.3%) with chilling effect leads to reduce wear (182 microns).
- Only addition of chromium (1%) and chill effect leads to higher wear resistance (131microns).
- Adding both chromium and nickel (1.5% each) with chill effect leads to increase the wear (169 microns).

Wear ratio **ACCI: CCI: ACI: GCI** is given as:

(182/ 169/ 131): 269: 479:518 microns.

By considering ACCI wear of 131 microns, the ratio can be written as **1: 2: 3.6: 3.9.**
It is understood from experimental results that wear is less with the combined effect of alloyed chilled casting. Only MSC effect leads to increase the wear by two times than ACCI.
Use of only alloys without MSC leads to increase the wear by 3.6 times than ACCI.
Present results concludes that addition of only chromium is preferred with MSC to increase the wear resistance (reduce wear).
Machining near to the chill end needs to have skill in selection of machine tool, tool material etc. It is observed by the micrographs and past results [15] that chilling effect is drastically decreases after 8-10mm from the chill end.

5. Scope for Future Work

MS chill thickness can be increase and tested for wear. Research can be extended by increasing %age addition of chromium with MS chill effect to increase wear resistance and optimize the same considering the economical factors.

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