

## Wear characteristics of Chilled Zinc-Aluminium Alloy reinforced with Silicon Carbide Particulate composites

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### Abstract

*This paper describes the fabrication and testing of Zinc aluminium – based metal matrix composites (MMCs) reinforced with silicon carbide particles cast in sand moulds containing metallic (copper, steel and cast iron), chills respectively. SiC particles (of size 50-100  $\mu\text{m}$ ) are added to the matrix. The dispersoid added was in steps of 3 wt. % (from 3 wt. % to 12 wt. %). The resulting composites cast were tested for their strength, hardness and wear resistance. Micro structural studies indicate good and uniform bonding between the matrix and the dispersoid. Strength and hardness increase by up to 9 wt.% of the SiC content and is highly dependent on the location of the casting from where the test specimens are taken. In addition, the wear resistance (dry and slurry wear) is significantly affected by the strength and hardness of the composite developed. It was inferred that a small amount of SiC particles are sufficient to cause a fairly large change in mechanical properties.*

**Key Words:** Chill, composite, SiC, strength, hardness and wear

### Introduction

The need for new wear resistant materials for high performance tribological applications has been one of the major incentives for the technological development of ceramic particulate reinforced Zinc aluminium alloys during the last several years. Several investigators have reported that the incorporation of hard particles such as  $\text{Al}_2\text{O}_3$  or SiC in cast Zinc aluminium alloys improve the sliding, abrasive wear resistance of these alloys<sup>1</sup>. Zinc Aluminum metal matrix composites are among the most promising materials for wear and structural applications due to low density, low cost and ease of fabrication of composites<sup>7</sup>.

It has been reported that the abrasive wear resistance of the particle reinforced MMCs increase with the volume fraction of particles, under both high and low stress abrasive wear conditions<sup>10</sup>. On a weighted adjusted basis, many Zn-Al-based composite materials can outperform cast iron, steel, Al, Mg and virtually any other reinforced metal or

alloy in a whole variety of applications. Hence, it seems probable that metal matrix composites will replace conventional materials in many commercial and industrial applications in the near future<sup>14</sup>. In particular, the particle reinforced MMCs are attractive since they exhibit near isotropic properties by comparison with the continuously reinforced matrices<sup>18</sup> fabrication of the discontinuously reinforced Zn- Al-based MMCs can be achieved by standard metal processing technologies such as powder metallurgy, direct casting, rolling, forging, and extrusion and the products can be shaped, machined and drilled using conventional facilities. Thus, they can be made available in quantities suitable for automobile applications. In general, the primary disadvantages for automobile applications are their low hardness, inadequate or poor fracture toughness, and fatigue performance compared to those of the constituent matrix material<sup>21</sup>. The superior properties offered by the particulate-reinforced Zn-Al-based MMCs make these materials attractive for applications in the

automobile, aerospace, defense and leisure industries. The wear resistance of unreinforced Al-alloys is relatively poor. Hence, their applications as structural and automobile parts are often limited. Fortunately, the strength, fracture toughness and wear resistance can be improved drastically by the incorporation of hard particulates such as SiC. In the present work, results are shown for the wear behavior of chilled Zn-Al-alloys reinforced with low weight percentages of SiC particles at ambient temperatures. The Zn-Al-alloys investigated contained 3-12 wt. % of SiC particles. The low cost of SiC particles would allow the wide spread use of MMCs as structural components in the automobile industry.

With the increase in the demand for the quality composites, it has become essential to produce aluminium composites free from unsoundness. Zn-Al-based composite castings, widely used in many structural and automobile applications are prone to unsoundness in the form of micro shrinkage. Micro shrinkage or dispersed porosity in the composite can be minimized by a judicious location of chills. Redemske<sup>23</sup> pointed out from their investigation that chilling has an effect on the structure and soundness of Zn-Al-alloy castings. The ability of the chill to extract heat from the molten metal during cooling of the casting is dependent on the size of the chill and thermo-physical properties of the chill material. In other words, the capacity of the chill to absorb heat from the casting is taken as a measure of its efficiency. The volumetric heat capacity of the chill, which takes into account the volume, specific heat and density of the chill material, has been identified as an important factor in the evaluation of the efficiency of the chill. Thermo-physical properties of some metallic and non-metallic chill materials are shown in table 1.

$$VHC = V \times C_p \times \rho \quad \text{----- (1)}$$

Where,

V = Volume,

C<sub>p</sub>=Specific heat and

ρ = density of the chill material

## Material and Methods

### Preparation of Aluminium-Glass Chilled Composite:

The metal matrix composite used in this investigation was based on a cast Al alloy, designated by the Al association as A356 which has a nominal composition as shown in table 2. The Al alloy was reinforced with 3, 6, 9 and 12 wt. % of fine grade borosilicate glass particles of average size 50 – 100 μm. The properties of the dispersoid are as follows:

Density = 2.1 gm/cc, Hardness R<sub>c</sub> = 76, Melting point = 1420° C, Youngs modulus = 78 GPa, Chemical Composition: SiC

### Chilled Composite Preparation Procedure:

Details of melting and composite preparation are described elsewhere<sup>28</sup>. After melting the matrix material in a furnace at around 750 deg C in an inert atmosphere, SiC particles preheated to 600 deg C were introduced evenly into the molten metal alloy by means of special feeding attachments. Meanwhile, the dispersoid treated molten Zinc aluminum was well agitated by means of a mechanical impeller rotating at 760 rpm to create a vortex. The moulds for the plate type of castings 225\*150\*25 mm (American Foundry men Society (AFS) standard) were prepared using silica sand with 5% bentonite as binder and 5% moisture and finally they were dried in an air furnace at a temperature of 80°C. The dispersoid treated Zinc aluminium alloy was poured directly into the mould at a pouring temperature of 720°C, which was cooled from one end by a chill block set in the mould.

**Micro Structural Examination:** Microscopic examination was conducted on all the specimens using Scanning Electron Microscope (SEM) and the optical microscope. Various etchants were tried but dilute Keller's etchant proved to be the best and was therefore used.

**Tensile Strength Testing:** The specimens for the strength test were taken from various locations in the casting namely chill end, 75, 150, 225 mm from chill end, the latter being at the riser end. Tension

tests were performed using Instron tension testing machine on AFS standard Tensometer specimens. Each test result was obtained from an average of at least three samples of the same location. Soundness of the test castings was assessed by determining its strength.

**Hardness Testing:** Hardness tests (BHN) were conducted on all the polished specimens for micro structural analysis. Specimens used for hardness tests were selected at the chill end of the casting.

**Wear Testing:** Abrasive wear tests were conducted on a rubber wheel abrader machine. The specimens were of the size 75\*25\*6.5 mm dimensions. Dry abrasive wear tests were performed using sand as the abrasive medium and confirmed to the ASTM G-65 standards.

**Slurry Testing:** Slurry wear tests were conducted on a slurry wear testing machine. The specimens used for this test were of the size 75\*25\*6.5 mm dimensions. Sand was used along with water to form the slurry in the ratio of 1:2 and was confirmed to ASTM G-75 standards.

## Results and discussion

**Micro structural observation of the Composite:** Figure A shows the microstructure of chilled composite, which reveal good bonding without any tearing or the interfacial reaction. The most unique feature of chilling the composite in this investigation is the apparent pushing of the glass particles during solidification and carrying away of the migrated alloying elements into the grain boundaries leaving dispersoids. This may be one of the reasons for good bonding and hence the soundness and strength of the composite. Microstructure of the chilled composite also revealed that there is no evidence of any agglomeration of glass particles.

Micro structural observations confirmed that the structures of cryogenically chilled MMCs are finer than that of the un-chilled matrix alloy. When the composite melt is solidified under chilled

conditions, the contact between the temperature of the chill and the melt becomes very intimate and at the same time the melt experiences severe super cooling. This results in a higher rate of heat transfer and more rapid cooling of the melt in chilled MMC samples. Because of these facts, the critical nuclei size of the solidified melt is reduced and a greater number of nuclei are generated. Hence, a finer microstructure is obtained in cryogenically chilled MMCs. Additionally, because of rapid cooling of the composite melt, dispersoid particles do not get enough time to settle down due to density differences between the matrix melt (2.7 gm/cc) and the dispersoid (2.8 gm/cc) and this results in more uniform distribution of SiO<sub>2</sub> particles in the matrix. The chilling effect during solidification causes stronger bonding between the matrix and the dispersoid. This may be attributed to the fact that the wettability between the particles and the matrix is improved with chilling effects. This uniform distribution of particles and the finer matrix structure (fig. A) lead to higher mechanical properties of the chilled MMCs as compared against the un-chilled matrix alloy. Thus the strong bonding between the dispersoid and the matrix causes more effective load transfer. This in turn reduces the possibility of pullout of particulates from the matrix of the chilled MMCs. Hence, the possibility of the chilled MMC failure would be due to particle failure rather than particle pullout from the matrix.

**Ultimate Strength of the Composite:** Plot K shows that UTS near the chill end for different composites cast using chills of different materials. The UTS obtained for the MMCs are reported in plot. It is noticed from plot K that all of these aforementioned parameters, except the elongation are higher for the chilled MMCs as compared to those obtained for the matrix alloy. It is further observed that for chilled MMCs the value of the other parameters increases with increasing the dispersoid content (up to 9 wt. %). It may be further noted that with the exception of elongation, all the mechanical properties listed in plot K increases due to chilling and incorporation of hard particles in the matrix alloy. It is observed from the plot K that as

the VHC of the chill increases, UTS also increases confirming that the volumetric heat capacity of the chill has an effect on UTS. In this study, however, chilling of composite with the incorporation of glass particles was aimed at improving both strength and hardness along with wear resistance.

**Hardness of the Composite:** Plot L shows the hardness (Brinell, BHN) near the chill end for composites for different aging durations at an aging temperature of 180 deg C. In ceramic-reinforced MMCs, there is generally a big difference between the mechanical properties of the dispersoid and those of the matrix. This results in incoherence or high density of dislocations near the interface between the dispersoid and the matrix. Precipitation reactions are accelerated because incoherence and the high density of dislocations act as heterogeneous nucleation sites for precipitation. Therefore, if all other factors are kept constant, the aging rate of a composite is generally faster than that of the matrix alloy. After solution treatment, optimum aging conditions can be determined by observing the hardness of the MMCs cast with cryogenic chills for different aging durations. It is known that the optimum aging conditions are strongly dependent upon the amount of dispersoid present. As dispersoid content is increased, there is a tendency for the peak aging time to be reduced because dispersoids provide more nucleation sites for precipitation. As expected, for any fixed aging temperature and duration, increasing the SiC content causes the hardness of the MMC to increase since the SiC of particulates are so much harder than the matrix alloy.

**Wear Behavior:** The wear resistance of Zn-Al alloys is comparatively poor. Hence, their applications as structural materials and machine parts are often limited. Fortunately, their wear resistance can be improved remarkably by the incorporation of hard particles to form MMCs, as proven by abrasive wear test and by slurry wear tests under diverse conditions.

Plot M shows the weight loss in percentage of the abrasive wear tests carried out for different

specimens of Zn-Al-SiC MMCs containing 3, 6, 9 and 12 wt.% of glass, chilled using different chills and tested for wear at sliding speeds of 2.423 m/sec, under a final load of 130 N. From this plot, it can be seen that at such a high sliding speed of 2.423 m/sec, adhesive wear occurs due to the presence of removed material.

Plot N shows the weight loss in percentage of the slurry wear tests carried out for different specimens. It is seen from the plots that a little dispersoid has an effect in wear rate and the same is verified from the strength and hardness plot. Hence, it is concluded that strength, hardness and amount of dispersoid content has an effect on wear behavior.

### Conclusion

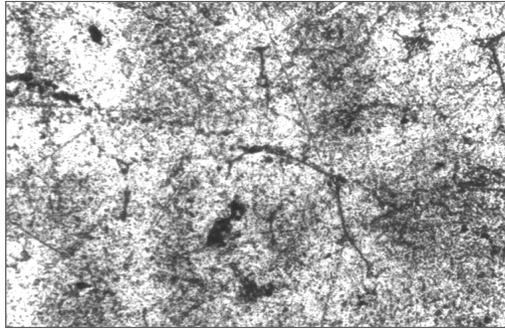
In the present investigation, of all the chill blocks, copper chill block was found to be the most effective because of its high Volumetric Heat Capacity (VHC). Increase in dispersoid content was found to increase the mechanical properties.

**Results of the investigation reveal the following:** Chill thickness (25 mm), chill material (copper) and the dispersoid content however does significantly affect the wear resistance of the composite. Chilled Zn-Al-SiC composites were successfully fabricated by employing chill blocks showed that, in their microstructure it was found that, there is uniform distribution of the dispersoid and good bonding between matrix and the dispersoid. Microstructures of the chilled composites are finer than that of the un-chilled matrix alloy with uniform distribution of SiC particles. Strong interfacial bond was observed with no agglomeration between the matrix and the dispersoid. Strength, hardness and wear resistance of the chilled MMCs are superior to those of the unchilled matrix alloy. It was found that these properties increases with an increase in the dispersoid content up to 9 wt. %. Copper end chill was found to be more effective when compared to the other type of chill blocks. The wear resistance of the MMCs developed improved as the dispersoid content increases and copper chill was

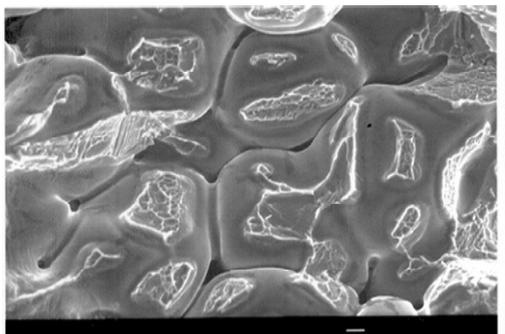
found to have a major effect on wear because of its high VHC.

### References

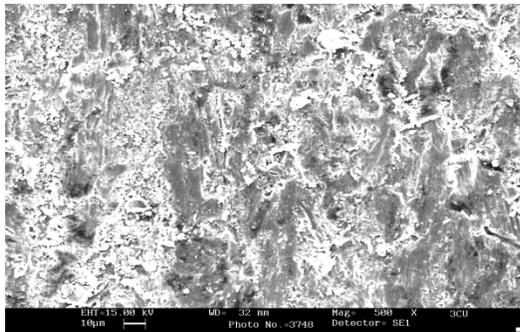
1. Alpas A.T. and Zang J., Effect of Sic particulate reinforcement on the dry sliding wear of aluminium-silicon alloys, *Wear*, **155**, 83-104 (1992)
2. Hosking F.M., Fabrication and wear behaviour, *J.Mater*, **17**, 477- 498 (1982)
3. Surappa M.K., Prasad S.V. and Rohatgi P.K., Wear and abrasion of cast Al-alumina particle composites, *Wear*, **77**, 295-302 (1982)
4. Anand K. and Kishore, on the wear of aluminium-corundum composites, *Wear*, **85** (1983)
5. Prasad S.V. and Rohatgi P.K., Tribological properties of Al alloy particle composites, *J.Met.*, **39(11)**, 22-26 (1987)
6. Saka N. and Karalekas D.P., Friction and wear of particle reinforced metal-ceramic composites in K.C.Ludema, ed., *Wear of Metals*, ASME, New York, 784-793 (1985)
7. Rogati P.K., Cast metal matrix composites, ASM Handbook Castings, **15**, 840-854 (1992)
8. Sachin Y. and Acilar M., Composites part A, 709-718 (2003)
9. Prasad S.V., Rohatgi P.K. and Kosel T.H., Mechanisms of material removal during low stress and high stress abrasion of aluminium alloys-zircon particle composites, *Material Sci. Engg.*, **80**, 213-220 (1986)
10. Banerjee A., Prasad S.V, Surappa M.K. and Rohatgi P.K., Abrasive wear of cast aluminium alloy-zircon particle composites, *Wear*, **82**, 141-151 (1982)
11. Gurcan A.B., Baker T.N., Wear behaviour of AA6061 Aluminium alloy and its composites *Wear*, **188**, 185-191 (1995)
12. Bransali K.J. and Mehrabian R., Abrasive wear of Aluminium matrix composites, *J.Met*, **32**, 30-34 (1982)
13. Razaghian A., Yu D., Chandra T., *j.Composites Sci and Technol*, **58**, 293 (1998)
14. SQ Wu, Wang H.Z. and Tjong S.C., *Composites Sci and Technol*, **56**, 1261 (1996)
15. Seah K.W.H., Hemanth J., Sharma S.C., *J. of Material and Design*, **24**, 87-93 (2003)
16. Divecha E.P., Fishman S.D. and Karmakar S.D., *J. of Metals*, **33**, 12 (1981)
17. McDaniels D. L., *Metal Transactions*, **16A**, 105 (1985)
18. Srinivasan T.S., Auradkar R. and Prakash A, *Engg. Frac. Mech*, **40**, 227 (1991)
19. Crowe C.R., Grey R.A. and Haryson D.F., Metals Soc. of AMIE, *Warrandale, Pennsylvania, USA.*, 843 (1985).
20. Lewandowski J.J., Liu C. and Hunt W.H., Metals Soc. of AMIE, *Warrandale, Pennsylvania, USA.*, 163 (1985)
21. Reddy G.P. and Paul P.K., *Be. Foundryman*, **69**, 265-272 (1976)
22. Ruddle R.W., *J. of Inst. of Metals*, **77**, 37 (1950)
23. Hemanth, *J. of Mater. Design*, **21**, 128 (2000)



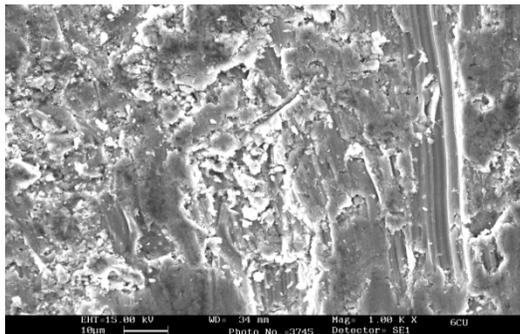
**Figure-1: Microstructure of Zn-Al-SiC chilled MMC with 9 wt. % dispersoid.**



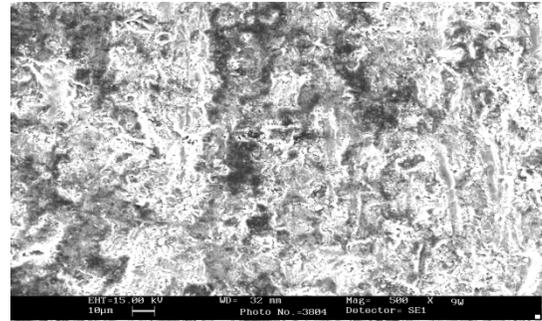
**Figure- 2: Fractograph of Zn-Al-SiC chilled MMC with 9 wt. % dispersoid**



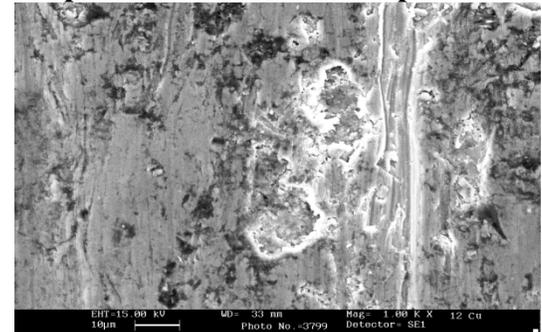
**Figure-3: SEM photograph of dry wear specimen with 3 wt.% dispersoid.**



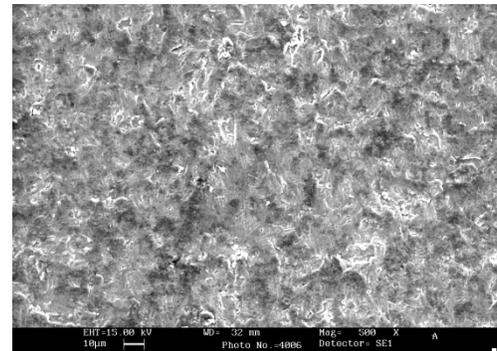
**Figure-4: SEM photograph of dry wear specimen with 6 wt.% dispersoid.**



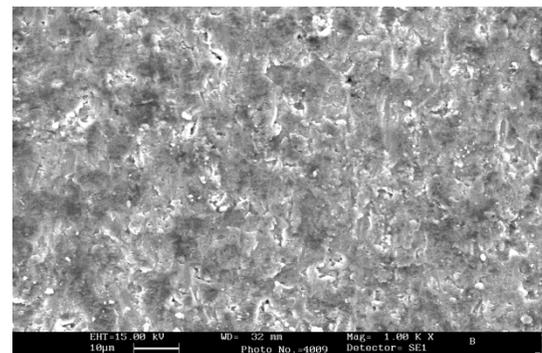
**Figure-5: SEM photograph of dry wear specimen with 9 wt.% dispersoid**



**Figure-6: SEM photograph of dry wear specimen with 12 wt.% dispersoid.**



**Figure-7: SEM photograph of slurry wear specimen with 3 wt.% dispersoid.**



**Figure-8: SEM photograph of slurry wear specimen with 6 wt.% dispersoid.**

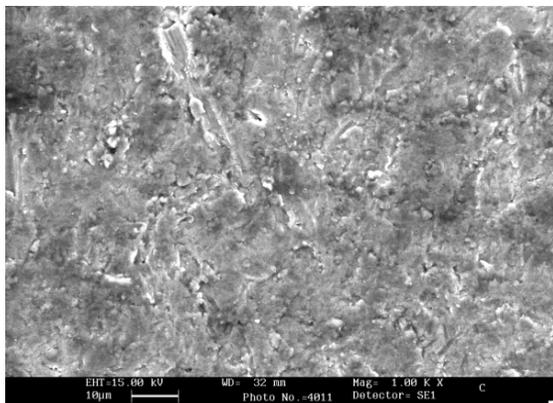


Figure-9: SEM photograph of slurry wear specimen with 9 wt. % dispersoid.

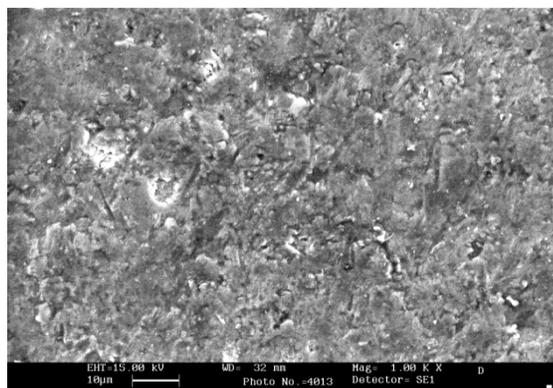
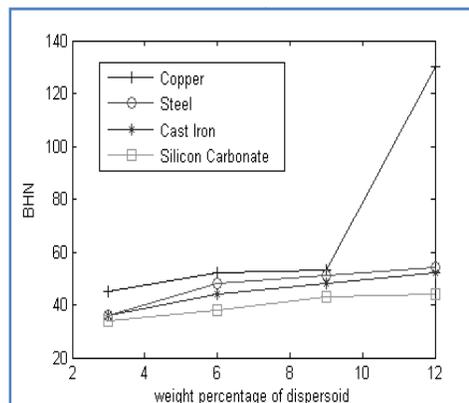
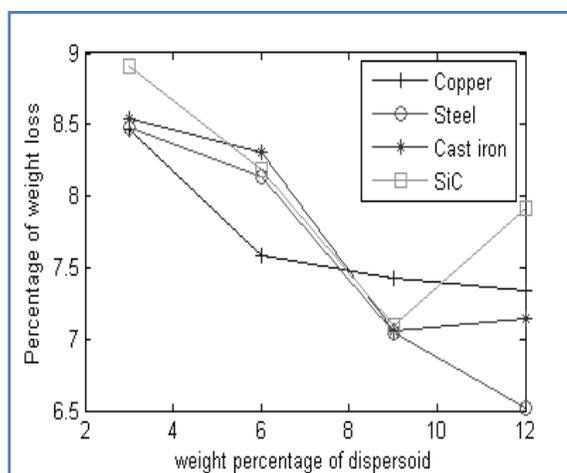


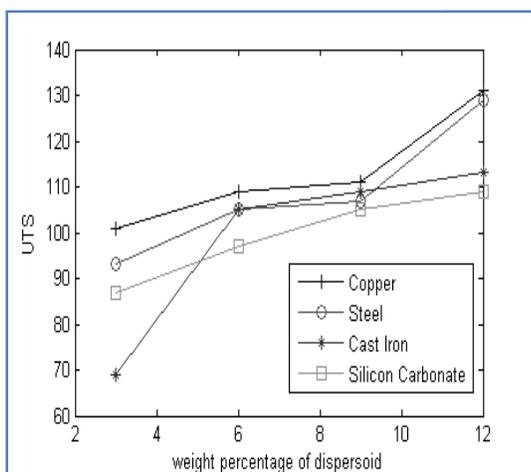
Figure-10: SEM photograph of slurry wear specimen with 12 wt. % dispersoid.



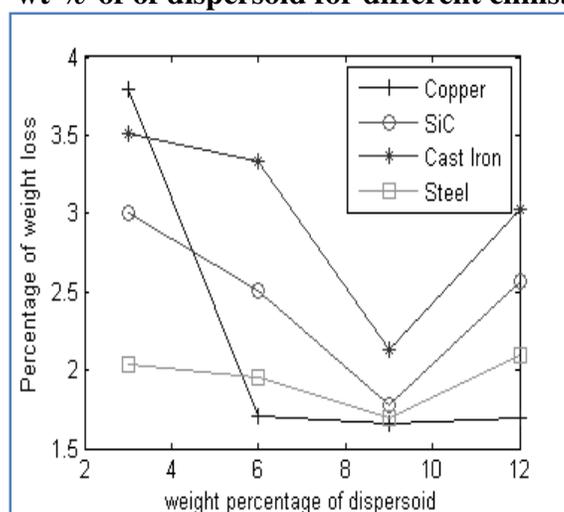
Plot-2: Plot of BHN vs. wt. % of dispersoid for different chills



Plot-3: Plot of % weight loss in abrasive wear Vs. wt % of dispersoid for different chills.



Plot-1: Plot of UTS vs. wt. % of dispersoid for different chills.



Plot-4: Plot of percentage weight loss in slurry wear vs. wt. % of dispersoid for different chills

**Table-1: Thermal properties of commonly used chill materials**

<b>Material of the Chill</b>	<b>Density (g/cc)</b>	<b>Specific Heat (J/Kg.K)</b>	<b>Thermal Conductivity (W/m.K)</b>	<b>VHC for 25 mm chill (J/K)</b>
Copper	8.96	0.448	1.022	597.0
Steel	7.85	0.421	0.109	491.5
Cast iron	7.61	0.401	0.160	453.9
Silicon carbide	2.36	1.095	0.039	384.3

**Table-2: Chemical composition of the matrix alloy (Zn- Al-alloy)**

<b>Elements</b>	<b>Zn</b>	<b>Mg</b>	<b>Si</b>	<b>Cu</b>	<b>Mn</b>	<b>Fe</b>	<b>Al</b>
<i>%wt.</i>							
Composition	72.11	0.25	0.02	0.20	0.10	0.20	26.06