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Evaluation of copper chill on tribological behaviour of LM13/$ZrSiO_4$/C hybrid metal matrix composites

Composites place a vital role in applications of material science I,e aerospace, automobile, marine, etc... Dual reinforcement composites are a trending research area in the field of metal matrix composites. In this research article dual reinforcement i.e zirconium silicate and carbon are added to molten LM13 using the stir casting process in terms of (3+3), (6+3), (9+3) and (12+3) wt.% respectively using copper as a chill kept toward one end. Tensile, hardness, and microstructural studies are done on the composite specimen at the chill end and non-chill. It is found an increase in reinforcement and chilling effect increases the properties of the composite.

Keywords: Dual reinforcement, copper chill, stir casting, tensile strength.

1.0 Introduction

Composites acquire high strength due to reinforcing brittle ceramic materials in the metal matrix phase and it gains many applications in the field of aerospace and automobiles[1]. Zircon is one of such ceramic materials reinforced to gain maximum strength for the composites and also it is most preferred by foundrymen due to its very good mixing property with metal matrix when melted above its melting point [2]. In a selection of metal, matrix aluminum plays a vital role because of its low cost and ease in casting, and low melting point. Since aluminum has lower mechanical properties so aluminum alloy is selected for the fabrication. We have different types of alloys available in the market few of them are LM13, LM30, A6061, A7075, etc. LM13 and LM30 are called light metal alloys and silicon is the major constituent with aluminum around 13 to 18 per cent [3]. Ceramic particle reinforced matrix provides a wide range of applications [4]. Bio fibers embedded in epoxy provide high stiffness to weight ratio for a composite [5]. Application of the composite can be used as design and development of progressive tool for mold tag [6], CFD analysis can be done for NACA 0012 aerofoil composite wing [7]. Finite element analysis is done by considering the mild steel as matrix and rubber as reinforcement [8]; provides the FEA on bending stresses and wear reduction studies for involute composite spur gear [9].

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There are many fabrication processes used for metal matrix composite preparation, few are the stir casting process, powder metallurgy, and squeeze casting. Stir casting is the most conventional type of casting used for many years and still it is most used because of its stirring action of graphite metal rod stirrer which can sustain higher temperature and creates vortex flow of molten metal for homogenous mixing of reinforcement with molten metal matrix [10]. Metallic chills are used to have uni-direction solidification of molten to improve the properties of the composite. Venkatesha, B K et al. [16-17] studied the mechanical properties of hybrid composites. In this research article LM13 is used as matrix material, $ZrSiO_4$-carbon as reinforcement, and stir casting is used for the fabrication process. Tensile strength, hardness, and SEM analysis are evaluated for the composites using copper metallic chill.

2.0 Materials

2.1 $ZrSiO_4$ and carbon particles

$ZrSiO_4$ is a ceramic material of better refractoriness and is brittle. It is amorphous in mature with the grain size of 0.4-0.5 microns. Due to its heat-resistant property, it uses linings in the furnace and crucibles. It is also used for the preparation of gemstones in the jewelery industry. Zirconium silicate contains 64.80 wt.% content of zirconium dioxide. $ZrSiO_4$ composition is shown in Table 1 [11]. In thermal processing, it is used as an insulating ring. It is a widely used ceramic oxide. Carbon is taken in the form of graphite powder for the study. Carbon is mixed with $ZrSiO_4$ as a supporting reinforcement to provide better mechanical properties to the metal matrix composite. Since both $ZrSiO_4$ and carbon are used as reinforcement for the composite so it is called a hybrid metal matrix composite. The combination of the $ZrSiO_4$ and carbon is used to provide better thermal, mechanical, and wear-resistant property for the composite. Properties of $ZrSiO_4$ and carbon are shown in Table 2 [12]. Figs.1 and 2 shows the pictures of $ZrSiO_4$ and graphite powder.

2.2. LM13

LM13 is a well-known aluminum metal matrix. It is also known as piston alloy because the piston of the engines is manufactured using LM13. It has a better castability, ductility, tensile strength, and bonding nature when it is melted and mixed with different reinforcements. LM13 contains 11.8-13wt.% of silicon which acts as the main constituent for the higher strength of LM13 alloy. The composition of LM13 is shown in Table 3. [13]. Fig.3 shows the schematic picture of the LM13 alloy used for experimentation.

Fig.1: $ZrSiO_4$

Fig.2: Graphite powder

TABLE 1: COMPOSITION OF $ZrSiO_4$

Element	Wt.%
Zirconium dioxide (ZrO_2)	64.80
Silicon dioxide (SiO_2)	32.50
Ferric oxide (Fe_2O_2)	0.70
Titanium dioxide (TiO_2)	0.15
Alumina (Al_2O_3)	1.20

2.3 FABRICATION OF HYBRID METAL MATRIX COMPOSITE (STIR CASTING PROCESS)

Stir casting is the conventional and most widely used fabrication process. Equipment includes graphite stirrer, furnace, and crucible as shown in Fig.4 [13]. It is preferred

TABLE 3: COMPOSITION OF LM13

Compositions	Wt.%
Si	11.8
Cu	1.2
Mg	0.9
Ni	0.9
Fe	0.3
Zn	0.2
Ti	0.02
Pb	0.02
Sn	0.005
Mn	0.4
Al	Balance

Fig.3: LM13 ingots used for experimentation

TABLE 2: PROPERTIES OF ZRSIO4 AND CARBON

Properties of $ZrSiO_4$	Values	Properties of carbon	Values
Melting point (ºC)	2500	Atomic number	6
Limit of application	1870	Molecular weight (g/mol)	12.011
Hardness (Mohr's scale)	7.5	Apparent density (g/cm3)	2.25
Density (gm/cm3)	4.5-4.70	Bulk density (gm/cm3)	3
Linear coefficient of expansion(μm/mºC)	4.5	Melting point (ºC)	3600
Fracture toughness (MPa)	5	Boiling point (ºC)	4200
Crystal structure	Tetragonal	Surface area (m^3/g)	7.2

because of the vortex route mixing nature and ease dispersion of reinforcement into the molten metal. The vortex route method of mixing will minimize the agglomeration of reinforcement in the molten metal matrix and hence providing a uniform mixture. In this research work, graphite is kept constant i.e 3wt.% and $ZrSiO_4$ is varied with the increment of 3wt.% i.e 3wt%, 6wt%, 9wt.% and 12wt.%. Details of the reinforcement and matrix material are shown in Table 4. Schematic pictures of the stir casting process and liquid composite pouring to the mold is shown in Fig.4.

2.4 Effect of different metallic chills

Metallic chills are used for unidirectional solidification of the molten composite when it is poured into the mold. From the metallurgy, it is seen that solidification is also the major factor to increase the properties of the material. Copper metallic chills which are taken for the experimentation purpose. The volumetric heat capacity of the chill influences the chilling action on the molten metal [14]. Chills are placed on one side of the mold to compare the properties of the chill end and nonchill end as shown in Fig.5.

Thermo-physical properties of the different chills are shown in Table 5[15].

3.0 Results and discussions

Tensile and hardness tests are conducted on the chill and non-chill end of the specimens. Chill end composite

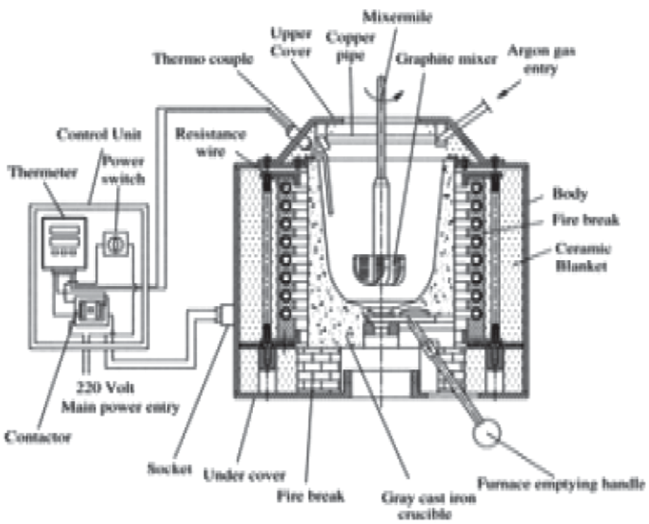

Fig.4: LM13 ingots used for experimentation

Fig.5: Stir casting process

Table 5: Thermophysical properties of the different chills

Material of chill block	Density (kg/m_3)	Specific heat (J/kgK)	Thermal conductivity
Copper	8.96	0.448	1.022

properties of each specimen are evaluated and compared to the nonchill end composite.

3.1 Tensile test

Prepared composite slab of 150*75*25 mm^3 is cut into ASTM B557M-15 standard. Average of three specimens tensile test results are taken for evaluation and comparison. It is seen that the tensile properties depend on two major factors i.e increase in reinforcements and chilling action which

Fig.6: Copper chill and composite after casting

Table 4: Percentages of LM13, $ZrSiO_4$, and carbon used for casting

LM13	$ZrSiO_4$		Carbon	
2600 gms (as cast)	0wt.%	0 gms	0wt.%	0 gms
3080 gms	3wt.%	92.4 gms	3wt.%	92.4 gms
3084 gms	6wt.%	184.5 gms	3wt.%	92.52 gms
3104 gms	9wt.%	279.36 gms	3wt.%	93.12 gms
3324 gms	12wt.%	398.88 gms	3wt.%	99.72 ms

Table 6: Copper chilled tensile specimen results

	Tests	As cast	3% $ZrSiO_4$	6% $ZrSiO_4$	9% $ZrSiO_4$	12% $ZrSiO_4$
Chill end of the copper	Tensile Test	164.36	188.86	195.7	230.54	210.65
Non-chill end of the copper	Tensile Test	159.44	160	162.2	192.54	170.2

Table 7: Copper chilled hardness specimen results

	Tests	As cast	3% $ZrSiO_4$	6% $ZrSiO_4$	9% $ZrSiO_4$	12% $ZrSiO_4$
Chill end of the copper	Hardness test	178.68	188.98	198.65	256.87	220.58
Non-chill end of the copper	Hardness test	164.12	172.5	182.3	204.5	195.6

provides unidirectional solidification. The tensile test results of the copper chill end and the non-chill end are tabulated in Table 6 and shown in Fig.6.

From the tensile results, it is confirmed that tensile strength increases till 9wt.% of reinforcement and it decreases at 12wt.% of reinforcement. The reason for this was analyzed using microstructural studies of the specimen as shown in Fig.7. This is because of the movement of dislocations caused by $ZrSiO_4$ to the interface of matrix and reinforcement.

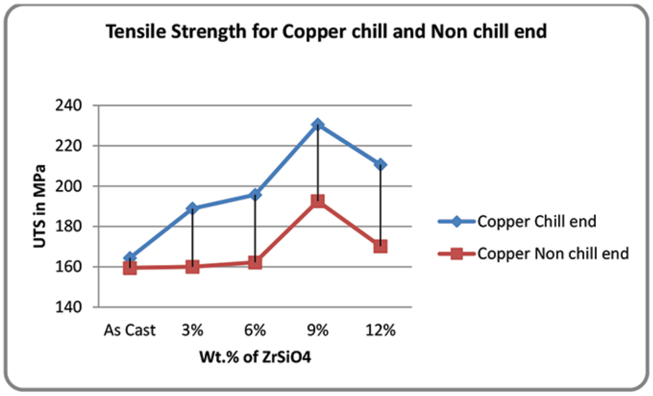

Fig.7: Tensile strength for copper chill and nonchill end

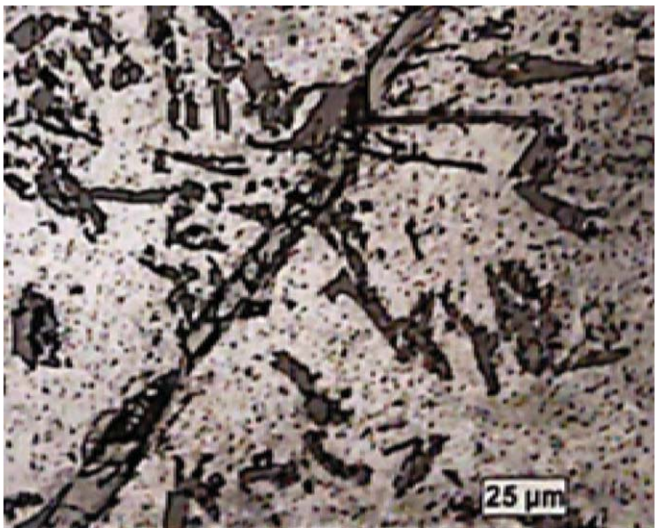

Fig.8: Microstructure image of 9wt.% of $ZrSiO_4$

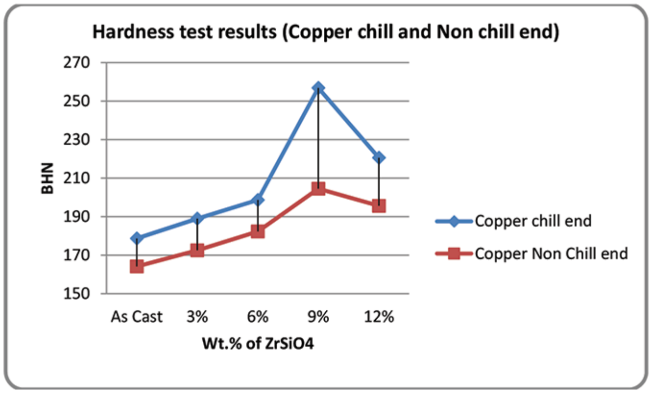

Fig.9: Copper chilled hardness specimen results

3.2 Hardness test

Hardness tests were performed using a Brinell hardness testing machine. Each test result was obtained from an average of at least three samples of the same location. The soundness of the test castings was assessed. Copper chilled hardness specimen results are as shown in Table 7 and Fig.8.

From the results it is observed that hardness value increases up to 9wt.% of $ZrSiO_4$ and decreases for 12wt.% of $ZrSiO_4$. This is because of movement of dislocations caused by $ZrSiO_4$ to the interface of matrix and reinforcement as shown in Fig.9.

4.0 Conclusion

It is concluded that stir casting is the preferred method for the casting process because it enables the homogenous mixture of a matrix with reinforcement. An increase in reinforcement and chilling effect increases the property of composite. The properties increase till 9wt.% of $ZrSiO_4$ then it decreases at 12wt.% of $ZrSiO_4$ because due to the addition of $ZrSiO_4$ in large quantity dislocations are created which move towards the interface of matrix and reinforcement.

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