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Review Article

Fabrication, micro structural and mechanical characterization of Zircon Particles ($ZrSiO_4$) reinforced Aluminum alloy (MMCs)

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This paper presents the review on fabrication, Microstructural analysis, and Mechanical Characterization of Zircon silicate Particles ($ZrSiO_4$) / Aluminum Alloy composite using the stir casting method. Aluminum alloy is known for its low density, high ratio of strength and weight, improved mechanical property, and corrosion resistance. Particulate reinforcement is widely preferred because of its isotropic properties which ease the homogenous distribution with the aluminum and its alloy. Zirconparticles (ZrSiO4) are the combination of ZrO_2, SiO_2, Fe_3O_2, TiO_2, and Al_2O_3. This review encapsulates the recent research work on different fabrication techniques, different characterizations, Microstructural analysis, and Fractroscopic studies on different Aluminum alloy matrix and ceramic materials reinforcement combination composites which improve physical, Corrosion resistant, microstructural, and mechanical properties.

Keywords: Zircon particle, Aluminum alloy, Stir casting, Mechanical micro structural properties

1 Introduction

Reinforcement in metal matrix composite affects microstructure analysis and mechanical properties of aluminum alloy[1], finer the grain structure of reinforcement is proportional to mechanical and tribological property. The finer and uniform structure of the composite grain depends on the cooling rate during solidification[2]. In the chill casting process, the strength of the composite depends on chill thickness, chilling rate, dispersed content, and location of the chill[3]. Composite fabrication using different reinforcement in a sandwich pattern is recommended to improve the properties[4]. Minimum Stresses develop in the composite machine element like gear etc. than monolithic material[5]. FEA shows that composite machine element improves the life of the machine element[6,7]. Different models propose the estimation of the temperature distribution along pin wear using pin on disc set up[8]. Cryo rolled Aluminum alloy-based composite shows better microstructural and mechanical properties than monolithic materials[9]. Thermal mechanical treatment for the composite increases grain refinement due to an increase in nucleation sites in the materials[10]. Thermal stability, and reduced micro-cracking tendency contribute better wear characteristics of the MMCs[11]. Mechanical properties of the composite depend on the homogenous mixture of reinforcement and matrix in a composite[12,13]. The physical properties of the aluminum improve by adding the different reinforcements at a definite percentage. Different methods of aluminum matrix preparation are smelting process, semi smelting process, powder metallurgy. The main objective of reinforcement in MMCs is to transfer the exterior load on the composite at the edge of the particulate and matrix. There is significant work done on zircon – Aluminum alloy to improve microstructural, mechanical, physical characteristics of composite but the review is limited. Hence the detailed reviews of the effect of fabrication technique on Zircon on Al alloy are discussed in this article.

2 Materials and Methods

The fabrication technique for metal matrix composite involves four types i.e. Stir casting, squeeze casting, spray casting, powder metallurgy. Improved Properties of the composite depend on fabrication techniques. This article discusses stir casting, powder metallurgy, and squeeze casting techniques. Fabrication technique various alloys used in the manufacture of zircon filled Al alloy metal matrix composite in this article. Compositions of different Al alloy and $ZrSiO_4$ are shown in Table 1.

2.1 Stir casting

It is the process of melting the matrix metal to its melting point and mixing reinforcement using a stirrer

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that rotates at a high rpm to ensure uniform and homogeneous mixing. Initially, reinforcement particles were preheated to avoid the moisture content and prevent agglomeration of the particles. Stirring avoids the agglomeration of reinforcement particles during mixing. Homogenous mixing is an important criterion for better boding of matrix and reinforcement phase can be observed in optical microscope/SEM. Mechanical properties of the composite improved with an increase in weight percentage of reinforcement to a certain point and then it decreases. Stir cast molten composite was poured into a mold with the desired dimension. Researchers used chills with lower temperatures adjacent to the mold to have direction solidification. Sufficient care was to be taken in the casting stage to avoid pores/ Air traps in the composite. Runner and raisers were removed and the composite was cut into definite dimensions as per the requirement. Some recommended standards are ASTM, AFS, etc. These techniques are recommended for the fabrication of particulate reinforced MMCs because of their low cost and are extensively used for a wide range of materials, flexibility for different low melting temperatures, processing conditions, and better bonding of reinforcement and matrix. A metal matrix can be melted using different furnaces like induction furnaces, electric arc furnaces, etc. This setup involves a stirrer that gives a homogenous dispersal of reinforcement in the molten matrix and prevents the coalition of particulates. Stirring action is required to combine the two phases of the composite to prevent the wet ability of reinforcement. The reinforcement was added in increments to the matrix phase to study its effect on the composite. Vortex method in stir casting is often preferred, where rigorous stirring causes homogenous distribution of reinforcement in matrix. Preheated (700ºC) Borosilicate glass powders were added to avoid the thermal mismatch of matrix and reinforcement. Cover flux is an aggregate of 45% NaCl, 45% of KCl, and 10Wt. %NaF, which were added to the molten matrix to generate a protective layer to prevent oxidation. In hybrid metal matrix composites, reinforcement is kept constant and otherswere varied constantly in the matrix. A schematic diagram of stir casting is shown in Fig. 1. Molten composite was poured into molds made as per American foundrymen society (AFS) standard which is mixture prepared using silica sand and Bentonite as binder with 5% each respectively.

Table 1 — Different Aluminum alloy composition

Composition (Wt. %)	Alloy Designation
Al–91.74%, Si-7.22%,Fe-0.30%	Al 356.1 Alloy
Al-98.8%,Si-0.43%,Fe-0.102%	Al 6063 Alloy
Al-88.85%, Cr -0.18%,Ti 0.2%	Al7075
Al-90.9%,Si-7.5%,Fe-0.3%	Al-Si-Mg Alloy
Al- 77.96%,Si-16.56%,Fe0.59%	LM 30
Al-84.255%,Si-11.8%,Fe-0.3%	LM 13 Alloy
Al-97.69%,Si-0.43%,Fe-0.43%	Al 6061
Al-97.4%,Mg-0.69%,Si-0.91%	AA6082-T6
Composition of $ZrSiO_4$ (Wt. %)	
Zircon oxide	65.3
Silicon oxide	33.1
Titanium oxide	0.22
Fe_2O_3	0.05
Al_2O_3	0.44
Other	0.43

3 Results and Discussions

3.1 SiC and $ZrSiO_4$ on LM13 Al alloy

Assessed the effect of SiC and $ZrSiO_4$ on LM13 al alloy. Its compositions are shown in Table 1. The size of SiC and Zircon sand is 38 and 30 µm respectively. The fabrication of the composite is done by a two-step stir casting process. The reinforcements are added in a wt. % combination of (9+3), (6+6), (3+9) of SiC and $ZrSiO_4$ respectively and prepared specimens are exposed to slurry wear erosion test and it is observed that wear resistance property of dual reinforced particle (DRP) is more than single reinforced material. Slurry wear erosion test results prove that (3+9) wt. % of SiC and $ZrSiO_4$ shows excellent microstructure hardness and wear resistance reduces concerning other combinations[14].

3.2 $ZrSiO_4$-Al7075

It describes the effect of preheated (750 ºC) ZrSiO4 of wt. % (3, 6, 9, and 12) with the molten Al7075 matrix. Reinforcement is preheated in a muffle crucible

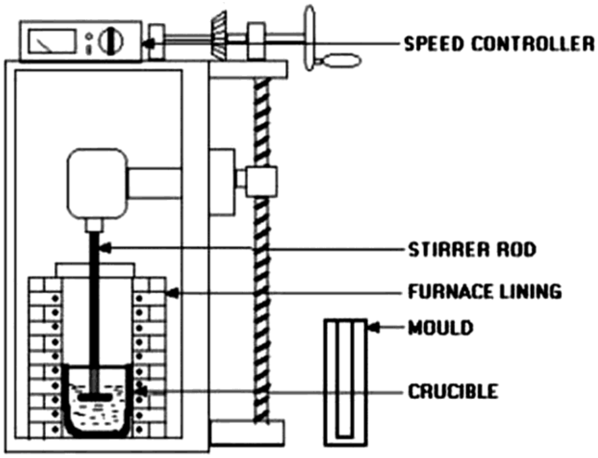
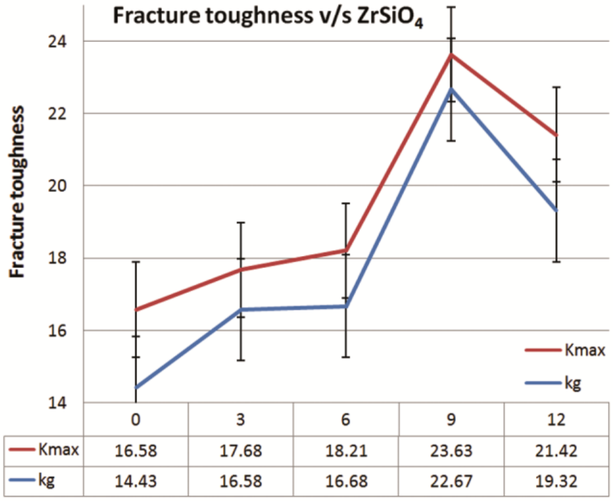


Fig. 1 — Stir casting set up.

to eliminate moisture content. The Cover flux consists of 45 % of NaCl, 45% of KCl, and 10% NaF is added to the liquid molten metal to generate a protective layer over the liquid metal to reduce oxidation. Specimens are subjected to tensile test (ASTM E8M) standard to analyze Ultimate tensile strength, yield strength, and percentage of elongation and fracture of the samplings of standard (ASTM E399). Pre fatigue crack is made on the composite specimen because to stimulate straight propagation of the crack. Three-point bending load is acted on the specimen to measure crack opening displacement. The bending Load on the composite specimen increases until it reaches catastrophic failure. Fracture toughness was obtained experimentally and compared the same with theoretical results. It is noticed that ultimate tensile, yield strength improves with an increase in wt. % of $ZrSiO_4$ till 9wt.% and slightly decrease at 12wt% shown in Fig. 2 and SENB specimen in shown in Fig. 3. It is seen that theoretical results coincide with analytical results.[15].

3.3 $ZrSiO_4$ - LM30

Emphases on the experimental study of wear properties of preheated $ZrSiO_4$ (300 ºC) of wt. % (3, 6, 9) with the hypereutectic Aluminum alloy (Si % > 12.6) LM 30 matrix. Reinforcements are preheated at 300 ºC for 30 minutes in a stir casting set up at a stirring rate of 700 rpm. Specimens are subjected to wear test and hardness test using in pin on disk experimental set up and Brinell hardness tester respectively. The hardness of the specimen is proportional to wt. % of $ZrSiO_4$. Pin load of 15N, 25N, and 35N acts on prepared polished composite disc and slides for a sliding distance of 1000m, 1400m, 1800m. It is perceived that wear resistance in a prepared composite than the monolithic LM30 metal. Taguchi's (DOE) method is used for experimentation study. Optimum conditions are obtained for wear for load 25N, sliding distance 1000mand improved hardness for the reinforcement 6% as shown in Fig. 4 respectively[16].



	0	3	6	9	12
Kmax	16.58	17.68	18.21	23.63	21.42
kg	14.43	16.58	16.68	22.67	19.32

Fig. 2 — Experimental results of fracture toughness.

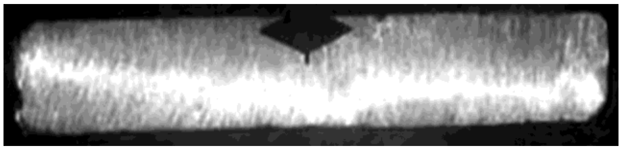


Fig. 3 — SENB specimen dimensions (ASTM E399).

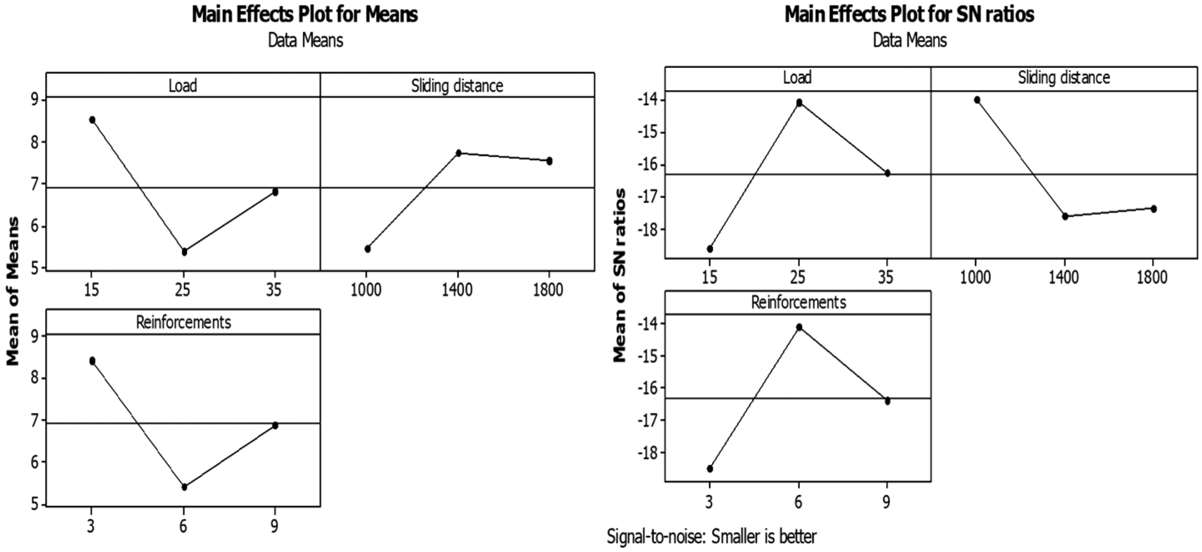


Fig. 4 — (a) Mean S/N ratio v/s load, slide distance, % reinforcement, and (b) Mean of means v/s load, slide distance and % reinforcement.

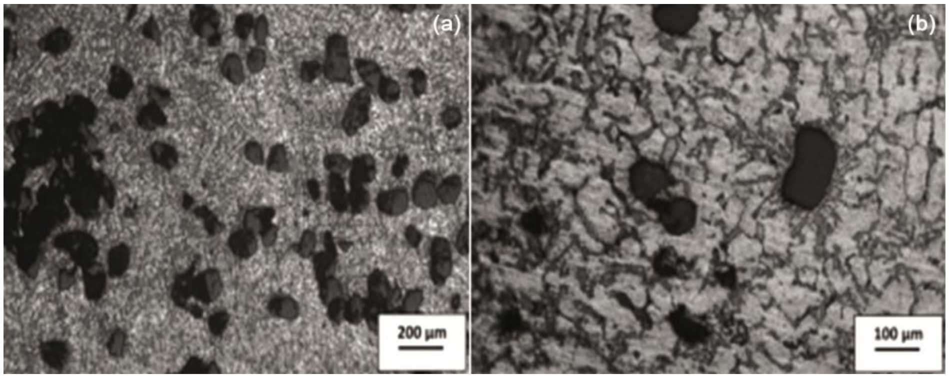


Fig. 5 — Optical micrographs of (a) LM13-20% of Zircon composite, and (b) LM13-15% of Zircon composite.

3.4 Zircon sand - LM13

Focuses on wear performance of Zircon - LM13 alloy composite at increased temperatures with change in load. Zircon particles of wt. % (5, 10, 15, and 20) are preheated to 750 ºC and reinforced with molten LM13 alloy composite using stir casting set up with a graphite stirrer at 630rpm to obtain vortex flow of the melt. Prepared specimens undergo XRD analysis where the presence of aluminum and silicon are seen with the base alloy. α – Al (Dendric growth) and eutectic phase are observed between inter dendric sections in LM13 alloy. The microstructural analysis (XRD) patterns, are mechanically polished and etch educing Keller’s reagent. Siliuminate (Al_2SiO_5) is formed at its interfaces of matrix and reinforcement shown in Fig. 5. Reinforcement distribution is found randomly with minimum clustering. Minor particles are pushed at the interface which forms clusters. The hardness of the specimens is obtained on the points of the matrix, reinforcement, and interface region. It is observed that the hardness value decreases from particle to interface then to matrix. Good bonding is established between $ZrSiO_4$ and LM 13 due to interface element Siliuminate (Al_2SiO_5)[17].

i Wear rate due to change of load and sliding distance - It is done using Pin on disc set up by varying the external load (Pin) from 1 kg to 5kg. The wear resistance is proportional to wt. % of zircon. Wear rate is observed maximum at the initial stages of the run because of its adhesive nature of wear. Wear rate is proportional to pin load and sliding distance. It is seen that $ZrSiO_4$and LM13 combination composite shows better wear resistance than monolithic base alloy. The wear rate decreases to 15wt% of $ZrSiO_4$but increases at 20wt% due to particles getting agglomerated because of poor bonding between them. resistance

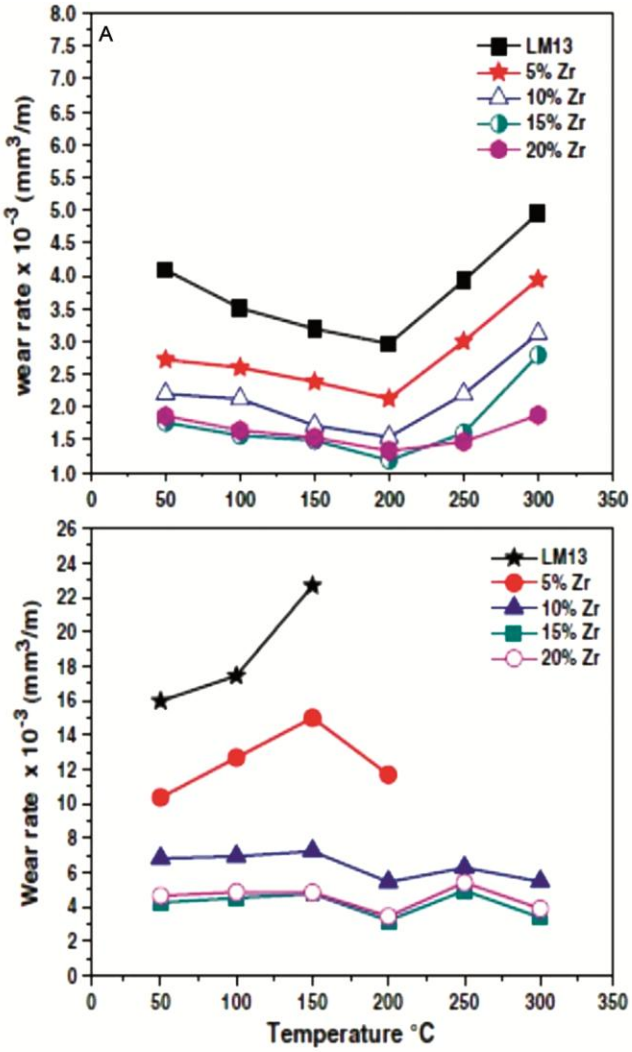


Fig. 6 — Variation in wear rate with temperatures for sample tested at (a) 1 kg load, and (b) 5 kg load

Oxide layer is formed on the surface which reduces the wear rate of the composite. CTE of LM13-$ZrSiO_4$ is better than the base alloy shown in Fig. 6. So it shows better wear resistance at higher

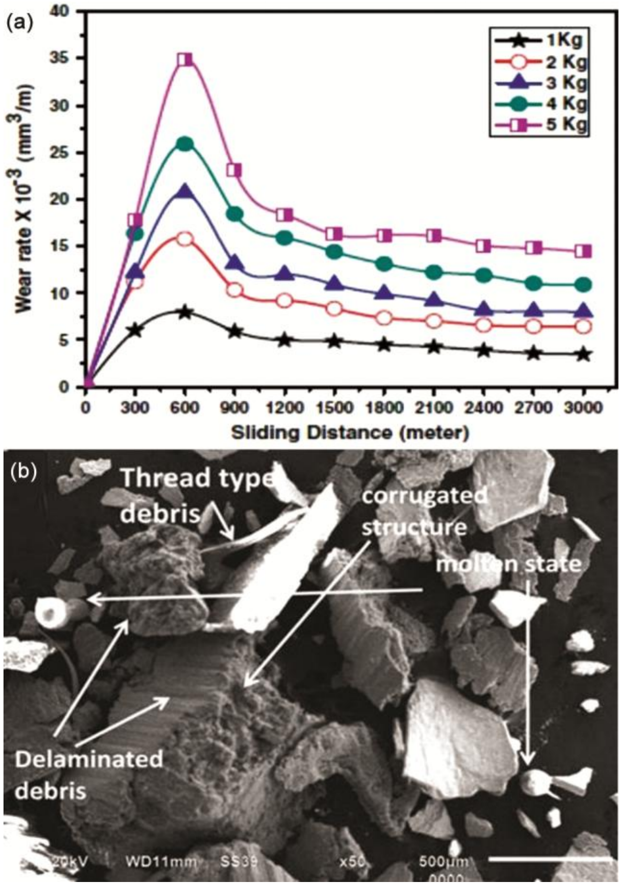


Fig. 7 — (a) Wear rate V/s sliding distance of 1 kg and 5 kg load LM13 alloy, and (b) SEM images of wear debris of LM13 - 15% of Zr composite for 5 kg loads.

temperatures up to (200ºC) then wear rate increases severely which leads to extensive plastic deformation.

ii Wear rate due to temperature change - At the critical temperature, i.e 0.4Tm-0.5Tm material becomes softer adjacent to the contact surface. An increase in Zircon increases thermal resistance and wear

iii Micro structural Analysis (SEM) of Wear Tracks and Debris - It is seen the appearance of abrasive grooves, cavities and delamination of the surfaces along the flow direction and it is observed maximum for the higher loads. Grooves are formed due to entrapment of hard particles along the sliding way. It is observed that fractured zircon sand particles indicate higher stresses on the surface shown in Fig. 7.

4 Conclusion

A combination of aluminum alloy and zircon sand will improve wear resistance, tensile strength, compressive strength, and other mechanical properties. Reinforcement is preheated before the casting process to remove the moisture content. In stir casting, a stirrer with high speed is stirred to obtain uniform distribution of reinforcement in the matrix. Wear resistance, tensile strength, compressive strength, hardness, and fracture toughness are directly proportional to its Wt. % of reinforcement content. Wear resistance reduces initially for the initial run of the disc in contact with the pin by gradually remaining constant. Microstructural analysis (XRD, SEM) shows homogenous dispersal of reinforcements in the matrix phase and the better interfacial bonding between matrix and reinforcements. In conclusion, by considering technical and economic factors it is observed that zircon appears to be the promising reinforcement for Aluminum alloy metal matrix composite.

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