International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 08 | Aug 2019 www.irjet.net p-ISSN: 2395-0072

EXPERIMENTAL INVESTIGATION OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF ALUMINIUM 7075 REINFORCED WITH ZIRCONIUM SILICATE ($ZrSiO_4$) PARTICULATES

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Abstract - *In this research work, an effort has made to prepare Aluminum 7075 reinforced with various weight% (3%, 6%, 9%, 12%) of zirconium silicate fabricated through stir casting technique. Specimens were prepared as per ASTM standards. Series of tests like tensile test, hardness test, tribological tests and microstructure analysis have been conducted on prepared composite specimens of different compositions (3%, 6%, 9%, 12%) of zirconium silicate and compared with the Aluminum 7075 base alloy(as cast). The investigation shows that mechanical properties like hardness have been improved due to the influence of reinforced 9% weight of zirconium silicate particles and there after properties decreases for 12% weight. Wear rate minimizes with increasing in reinforcement particles. Optical microscopic analysis shows the uniform dispersion of ZrSiO4 particles in Al-7075 alloy.*

***Key Words*: Reinforcement, Hardness Test, Tribological Tests, Microstructure Analysis, Strength to Weight ratio, Density etc.,**

1. INTRODUCTION

Traditional intransigent products or metals has drawbacks beyond possible characteristics of Hardness, density and strength. To decrease these difficulties and to get notable growing when related to Base metals, (MMCs) Metal matrix composites possess mainly enhanced features with wear resistance, high specific strength, damping capacity and specific modulus.

Fluid Vortex methods have benefit over other techniques by rejecting the separation distinctive of blending. So liquid casting the blend to attain the consistent circulation of filler Particles in base metal have become a main point in the liquid casting method. Whiskers, fibers, and particulates are the reinforcements used. Particulate-reinforced composites are primarily the finest quality with a cost benefit for their flammability. They are also ingrained with properties that are wear and heat resistant. SiC, Al2O3, Gr, B4C and so on are excessively applied to MMCs.

Zinc is the primary alloying component used in aluminum 7075. It is solid, with eminence related to many steels, and has great fatigue quality and standard machinability, yet has less safeguard from corrosion than frequent other Al composites. Aluminum Alloy 7075 offers best quality of the basic components of machine. The T6 and T651 tempers have reasonable machinability. Metal matrix 7075 is extensively used by the weapons and aero ships manufacturing diligence because of reality of its unexpected quality.

Zirconium silicate ($ZrSiO_4$) have numerous characteristics such as high hardness value low specific gravity and high elastic modulus. These properties support $ZrSiO_4$ to be extensively applied in defence equipment's. It is therefore expected that the mixture of Zirconium Silicate ($ZrSiO_4$) materials in Aluminum metal will boost use of such this reduced-cost by-product and at the same moment have the ability to conserve intensive aluminum and thus reduce the price of aluminum products.

$ZrSiO_4$ got minimum exposure over other additions as a successful strengthening of PRAMC. From restricted data on aluminum matrix composites strengthened by ZrSiO4, several study work focuses primarily on toughness between aluminum and zirconium silicate ($ZrSiO_4$).

2. LITERATURE REVIEW

[1] R. Kartigeyan et.al.[2012], has successfully fabricated Al 7075 alloy and Short Basalt Fiber composite through liquid metallurgy method. The rise in % weight of short basalt fiber enhances the Hardness, yield strength and ultimate tensile strength. The composite comprising 6% wt of short basalt fiber implies higher hardness value of 97.1 Mpa when related to base matrix hardness 92Mpa. The Al-7075/short basalt fiber reinforced 6 vol % enhances the ultimate tensile strength by 65.51%. The circulation of reinforcements in metal matrix is genuinely uniform.

From the above research paper I found that measurements of tensile strength increase under stress charging without interrupting the ductility of the tensile. Short basalt fiber experimental results provide the highest outcome for the Al-MMC.

[2]Arunkumar D T et.al. [2018], effectively prepared the Al-7075 composites with mica and kaolinite reinforcements using fluid casting technique. They used the same bulk fractions of mica and kaolinite [(2 + 2) %, (4 + 4) %,

(6 + 6)%, (8 + 8)%] and carried out a wear experiment at steady load for different intervals of time. The wear loss is seen to decrease at a slower rate in composites with 8 percent quantity of mica and kaolinite. The composite SEM microstructure indicates a homogeneous grid appropriation of assistance and no agglomerate evidence.

From the above research paper I reasoned that the existence of mica and kolonite in the matrix reduced wear loss by maximizing wear resistance.

[3] Z. Hasan et.al.[2011] Composites were manufactured by using a Liquid Metallurgy operation using 2124 Al as the foundation metal with 10 and 20 percent SiC particulates by weight. The impact of load and disk surface on wear volume and weight loss impact of load and disk surface was considered. The plastics weight decline is shown for weight 20 N, 30 N and 50 N. The wear volume is the basis for theAl-20 percent SiC composite in each of the circumstances. There is a secure increase in wear quantity with increasing stress. In the Al-20 percent SiC composite, weight decrease is noted for a specified load and detachment traveled to each portion of the matrix.

From the above research paper I argued that in each of the products regarded, the wear speed is found to be maximized with stress. The development of the aluminum foundation alloy's wear frequency is gradually important due to friendly tough fibers slicing and wrinkling action.

[4] R.S. Raveendra et.al [2016] The study of liquid metallurgy using vortex approach is used to schedule content from Al6061 MMCs. The microstructural tests demonstrate the unchangeable combination of the matrix strengthening ions. The weight range of 6% of α-Al2O3 indicates the greatest hardness of 64 BHN nano-ceramics. With increased manufacturing of α-Al2O3, the strain resistance maximizes. Following inquiries, it should be noted that Al-6061 and Al2O3 are rising in the direction of mechanical characteristics.

From the above research paper, I presumed that Nano ceramic materials from Al2O3 demonstrate good keeping with Al-6061 MMC as well as with each other, which helps to increase the strain when evaluated with Al-6061 foundation matrix. The tough filler layers limit twisting, stress while increasing the composite's characteristics.

3. EXPERIMENTAL PROCEDURE

3.1 Material selection

- Aluminium-7075
- Zirconium Silicate($ZrSiO_4$)

a) Aluminium-7075

It is one of the highest alloys accessible as a part of the 7000 series and is similar to many steel kinds. Aluminum 7075 is suitable for elevated stress / strain strength applications. Because of its strong resistance, it is often used in heavy pressure systems such as airplane seat spar and air defence machinery. Because of its elevated thermal conductivity, it has elevated heat dissipation ability and is appropriate for applications at elevated temperatures.

The supplier of Aluminium 7075 is FENFE METALLURGICALS, Harohalli, Bangalore.

Table 1: composition and properties of Al-7075

Element	Weight %
Zinc(Zn)	5.5
Magnesium (Mg)	2.8
Copper(Cu)	1.5
Iron (Fe)	0.5
Silicon (Si)	0.4
Manganese (Mn)	0.3
Titanium (Ti)	0.2
Chromium (Cr)	0.18
Aluminium (Al)	88.85

Density	2.81g/cm^3
Hardness (brinell)	150
Ultimate tensile strength	572mpa
Tensile yield strength	503mpa
Young's modulus	71.7gpa
Machinability	70%
Shear strength	331mpa
Melting point	635^{0}c

b) ZIRCONIUM SILICATE ($ZrSiO_4$)

Due to its simplest accessibility and elevated heat applicationss, Zirconium silicate (ZrSiO4) is chosen as the reinforcement particles. Zirconium silicate (ZrSiO4) has many appealing characteristics, such as small specific gravity, elevated hardness values, elevated elastic modulus quality, helping to make ZrSiO4 commonly used as armor components. Zirconium silicate is used to produce refractory products for apps where alkali metals require corrosion resistance. Corrosion resistance to crushed metals, wear resistance, high toughness of fracture and high hardness these characteristics produced excellent reinforcement ceramic for MMC manufacturing. The supplier of Zirconium silicate (ZrSiO4) is MINCO METSAL, Indira nagar, Bangalore.

Figure 1: Zirconium silicate (ZrSiO4)

Table 2: composition and properties of $ZrSiO_4$

Element	Weight %
Zircon Di oxide (ZiO_2)	64.80
Silicon Di oxide (SiO_2)	32.50
Ferric oxide (Fe_2O_2)	0.70
Titanium Di oxide (TiO_2)	0.15
Alumina (Al_20_3)	1.20

Melting point	2550 °C
Density	3.9 g/cm^3
Tensile strength	290 Mpa
Grain size	Fine powder

Table 3: weight of Al-7075/ ZrSiO4 for different composition

No of composition	Aluminium-7075	Zirconium silicate($ZrSiO_4$)
1	100% - 350gm	0% - 0gm
2	97% - 340gm	3% - 10gm
3	94% - 330gm	6% - 20gm
4	91% - 320gm	9% - 30gm
5	88% - 310gm	12% - 40gm

3.2 STIR CASTING PROCESS

Base alloy Aluminum 7075 and Reinforcement particle zirconium silicate ($ZrSiO_4$) was successfully fabricated by using liquid vortex method. Crucible and mould box is kept for preheating to remove moisture and other particles from the inner surface. The various volume fraction of reinforcement particles are 3%, 6%, 9% and 12% of $ZrSiO_4$. The different weight % of $ZrSiO_4$ are taken separately in small crucibles and kept for preheat in a muffle furnace. The preheat temperature was held at 750˚C. 340 grams of Aluminium pieces is fed into the crucible which starts melting as the temperature of open hearth go to around 720˚C. As the temperature of furnace reaches to 700˚C, Aluminium pieces in the crucible will melt down. Hexachloroethane (C_2Cl_6) Degasifier is added to semi-solid phase Aluminium, to remove the hydrogen content from molten Aluminum. Slag formed in the crucible is removed and preheated (750˚C) $ZrSiO_4$ powder is poured slowly into the crucible containing Liquid stage Aluminium. Stirring action has performed with a mechanical stirrer continuously for 5 minutes. The Cover flux (45%NaCl+45%KCl+10%NaF) is added to the liquid molten metal. Forms a protective layer over the liquid metal which reduces oxidation. Then liquid Aluminium poured in to the mould box and specimen is obtained. The casted specimens are sent for machining to perform various tests as per ASTM standards.

Figure 2: Stir casting set up

3.3 Mechanical Properties

a) Hardness

Hardness is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. The Vickers Scale may need to be used to measure very tiny components or tiny sections on a micro-hardness tester. The samples of hardness were prepared in accordance with ASTM E18 standards.

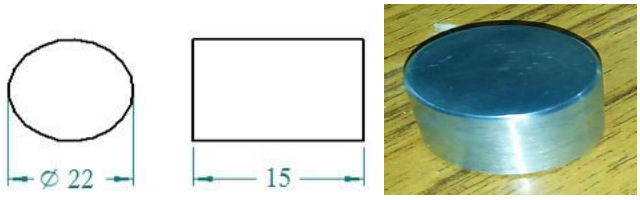


Figure 3: Hardness Test Specimens with dimension (ASTM E18)

The test has been conducted for various weight fractions of ZrSiO4 (0%, 3%, 6%, 9%, and 12%). The surface of the specimen has to be well polished with sand paper. Testing machine consists of square pyramid indenter having a 1360 Cone angle. Hardness test specimen has to be place in anvil and fixed to the indenter by means of elevating screw using hand wheel. 5 kg of load has to be applied on the specimen at a 10 sec dwell time. Load has to withdraw after the dwell time. The measurement of hardness indenter on the specimen should be predicted by using the microscope.

Vickers Hardness Number of a material can be calculated using the formula

$$VHN = 1.854 \times P/d^2$$

P -Applied Load

d –Indentation Diagonal measurement

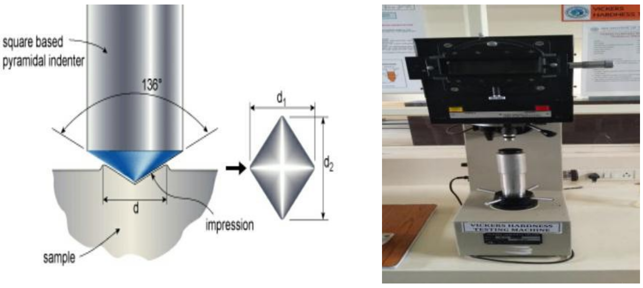


Figure 4: Indentation observed in Vickers hardness testing machine

3.4 Tribological Properties

a) Wear Test

The most common method used to determine the wear rate is dry sliding wear on a computerized pin on disc machine. The DUCOM software has been used in this test. Wear specimen were prepared as per ASTM standard G99. The dimension of wear test specimen is round bars of 40mm length × 10mm dia. The specimens were well polished by using 600 grit emery papers to get good surface finish. The test specimens were made in contact with the rotating disc, made up of EN31 steel (8mm thick, 165mm diameter). Tangential frictional force, wear loss and frictional temperatures monitored and recorded using computerized - data acquisition system.

Figure 5: Wear testing set up and wear specimens after test

Test parameters

- Machine: DUCOM Pin On disc tribometer
- Specimen dimension: 40mm length × 10mm dia
- Disc material: EN 31 Steel
- Disc diameter(D): 0.1m
- Time (T): 5 minutes
- Speed of disc (N): 400 RPM
- Temperature: Room temperature

3.5 MICROSTRUCTURE ANALYSIS

Microstructure analysis is widely used in the industries for quality control of the materials. Optical microscope is used to investigate the Microstructure analysis. All specimens with various weight % of Zirconium silicate subjected for micro structural investigation. The specimens were made good mirror polished using 100, 220, 400, 600, 1000 grit emery paper sequentially. The specimens were kept on the moving table of computerized microscope and investigated at 10X, 40X, 60X magnification. The micro images obtained are stored in computer.

Figure 6: Computerized optical microscope

4.2 Hardness Test

The machine used for hardness test was Vickers Hardness testing machine with a magnification of optical measuring device. The surface finish were polished with 100, 300, 600, 1000 grit emery paper. Total 5 hardness test specimens were prepared as per dimensions of ASTM E-18 standards for 5 different compositions of Aluminum 7075 and Zirconium silicate materials. The hardness of all 5 compositions were evaluated and listed in below table 6.

Test parameters

- Machine: Vickers hardness tester
- Specimen dimension: 22mm dia × 15 mm length
- Test load: 5KG
- Hardness indentation angle: 136^0
- Magnification of optical microscope: 70X
- Dwell time: 10sec

Table 5: Hardness test results

Sl no.	Composition	Load in (Kgf)	Diagonal length of indention			Vickers Hardness Number (VHN)
			d1	d2	$d = \frac{d1 + d2}{2}$	
1	Al7075	5	0.287	0.301	0.294	97
2	Al7075-3%ZrSiO$_4$	5	0.269	0.275	0.272	115
3	Al7075-6%ZrSiO$_4$	5	0.263	0.254	0.258	128
4	Al7075-9%ZrSiO$_4$	5	0.232	0.256	0.243	142
5	Al7075-12%ZrSiO$_4$	5	0.264	0.246	0.255	136

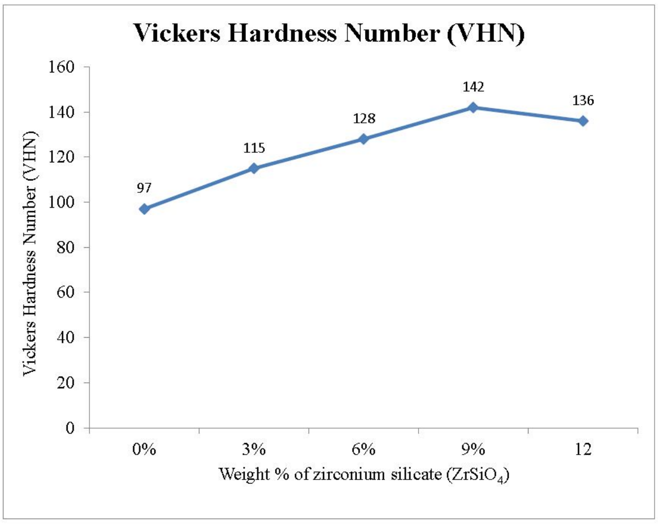


Figure 7: Hardness V/s weight % of ZrSiO4

The above graph shows the Hardness test results of 5 different composition of Al-7075 reinforced with ZrSiO4. It is observed that the hardness property improves with increase in weight % of ZrSiO4 up to 9% of ZrSiO4, after that hardness decreased for 12% of ZrSiO4. Hardness of aluminium 7075 base alloy was 97VHN after the reinforcement of 9% of ZrSiO4, hardness increased to 142VHN. Better the grain size better is the hardness of composites. This expansion in hardness of the composites might be because of the reason the Reinforcement material is a lot harder than the base material and great interfacial holding among filler particles and alloy matrix.

4.3 Wear Test Results

Tribological properties of the materials evaluated through the wear test, total 10 wear specimens were prepared as per ASTM G99 standards for 5 different composition of Aluminium 7075 and zirconium silicate MMC's.

Test parameters

- Machine: DUCOM Pin On disc tribometer
- Specimen dimension: 40mm length × 10mm dia
- Disc material: EN 31 Steel
- Disc diameter(D): 0.1m
- Time (T): 5 minutes
- Speed of disc (N): 400 RPM
- Temperature: Room temperature

Table 6: Wear test results for different loads

Sl no	composition	Load (kg)	Specimen weight loss			Wear rate 10^{-6} g/m
			Initial	final	difference	
1	Al7075	1	8.6744	8.6725	0.0019	3.0240
2	Al7075-3%ZrSiO$_4$	1	8.5644	8.5627	0.0017	2.7057
3	Al7075-6%ZrSiO$_4$	1	8.7899	8.7883	0.0016	2.5465
4	Al7075-9%ZrSiO$_4$	1	8.6345	8.6331	0.0014	2.2282
5	Al7075-12%ZrSiO$_4$	1	8.8564	8.8553	0.0011	1.7507

Sl no	composition	Load (kg)	Specimen weight loss			Wear rate 10^{-6} g/m
			Initial	final	difference	
1	Al7075	2	8.6532	8.6511	0.0021	3.3423
2	Al7075-3%ZrSiO$_4$	2	8.5485	8.5467	0.0018	2.8648
3	Al7075-6%ZrSiO$_4$	2	8.7632	8.7615	0.0017	2.7057
4	Al7075-9%ZrSiO$_4$	2	8.6126	8.6111	0.0015	2.3873
5	Al7075-12%ZrSiO$_4$	2	8.8378	8.8366	0.0012	1.9099

Sl no	composition	Load	Specimen weight loss			Wear rate 10^{-6} g/m
			Initial	final	difference	
1	Al7075	3	8.6397	8.6374	0.0023	3.6606
2	Al7075-3%ZrSiO$_4$	3	8.5242	8.5222	0.002	3.1831
3	Al7075-6%ZrSiO$_4$	3	8.7492	8.7474	0.0018	2.8648
4	A l7075-9%ZrSiO$_4$	3	8.5984	8.5968	0.0016	2.5465
5	Al7075-12%ZrSiO$_4$	3	8.8177	8.8163	0.0014	2.2282

Sl no	composition	Load	Specimen weight loss			Wear rate 10^{-6} g/m
			Initial	final	difference	
1	Al7075	4	8.6212	8.619	0.0024	3.8198
2	Al7075-3%ZrSiO$_4$	4	8.5067	8.5048	0.0021	3.3423
3	Al7075-6%ZrSiO$_4$	4	8.7308	8.7293	0.0019	3.0240
4	Al7075-9%ZrSiO$_4$	4	8.5764	8.5751	0.0017	2.7057
5	Al7075-12%ZrSiO$_4$	4	8.8012	8.8001	0.0015	2.3873

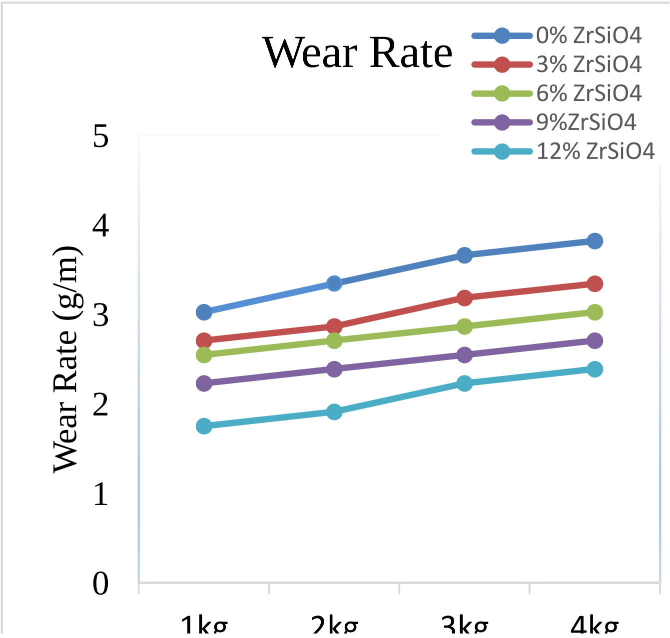
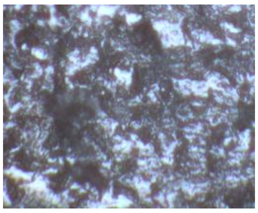


Figure 15: Load V/s Wear Rate

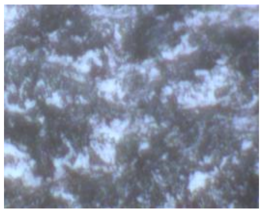
The graph shown in figure 5.5 revels the wear behavior of Al-7075 reinforced with different weight % (3, 6, 9, 12) $ZrSiO_4$. The tests were conducted by varying load and temperature, speed, time were kept constant. The results shows that wear rate decreases with adding the weight % of zirconium silicate. The minimum wear rate obtained at 12% of $ZrSiO_4$. By observing graph we can conclude that wear rate increases with increase in applying load. At 1kg load wear rate is $1.7505*10^{-6}$ g/m at 12% $ZrSiO_4$ and for 4kg load the wear rate is $2.3873*10^{-6}$ g/m. Decrease in Wear rate mainly depends on the ceramic particles present in the Matrix material. The factor that effects the wear rate are particle sizes, hardness of reinforcement particle. Wear rate decreases with increase in hardness. The hard particles present in the reinforcement materials minimize the material loss when a metal contact with the moving surface and increases the wear resistance.

4.4 Microstructure Analysis

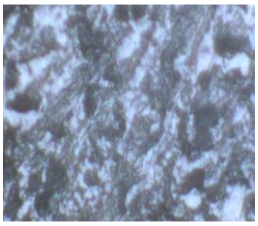
The microstructure image of reinforced material clearly shows the uniform distribution of $ZrSiO_4$ particles in the Aluminium matrix. The micro segregations of $ZrSiO_4$ particles has been observed in 12% $ZrSiO_4$ particles. The $ZrSiO_4$ particles improve the wettability and several other Metallurgical characteristics of metal matrix composite. The uniform distribution of ZrSiO4 grains in core matrix alloy and the thinner crystal structure of base steel matrix have improved MMC's mechanical characteristics relative to core resin alloy. The hard particles present in the $ZrSiO_4$ helps in wear resistance of the material. Various mechanical properties like hardness, strength, toughness, etc. strongly influence the microstructure of the materials. Microstructure analysis is widely used in the industries for quality control of the materials.



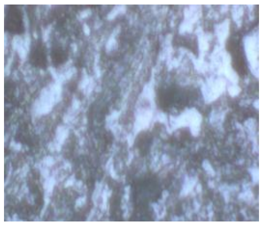
a) Al-7075



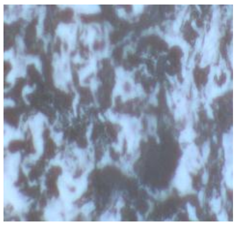
b) Al 7075-3% $ZrSiO_4$



c) Al 7075-6% $ZrSiO_4$



d) Al 7075-9% $ZrSiO_4$



e) Al 7075-12% $ZrSiO_4$

figure 16: Microstructure images of all 5 compositions

The microstructure images of reinforced material clearly shows the uniform distribution of $ZrSiO_4$ particles in the Aluminium matrix. The micro segregations of $ZrSiO_4$ particles has been observed in 12% $ZrSiO_4$ particles. The $ZrSiO_4$ particles improve the wettability and several other Metallurgical characteristics of metal matrix composite. The uniform distribution of ZrSiO4 grains in core matrix alloy and the thinner crystal structure of base steel matrix have improved MMC's mechanical characteristics relative to core resin alloy. The hard particles present in the $ZrSiO_4$ helps in wear resistance of the material. Various mechanical properties like hardness, strength, toughness, etc. strongly influence the microstructure of the materials. Microstructure analysis is widely used in the industries for quality control of the materials.

5. CONCLUSIONS

The experimental study has been carried out for the investigation of mechanical and tribological properties of Aluminium 7075 reinforced with various weight % (3, 6, 9, 12) $ZrSiO_4$. The specimens has been fabricated as per ASTM standards through Stir casting technique. Various tests like tensile test, hardness test, fracture toughness test and wear test has been carried out for determination of mechanical and tribological properties. The following remarks has been made after obtaining all the test results.

1 Hardness of Al-7075 enhances with increase in 9% weight of $ZrSiO_4$ and after for 12% $ZrSiO_4$ hardness decreases.
2 Maximum hardness of 142 VHN obtained for 9% weight of $ZrSiO_4$, whereas hardness of base metal Al-7075 is 97VHN.
3 Wear rate decreases with increasing in weight % of $ZrSiO_4$. Maximum wear rate obtained for 12% weight of $ZrSiO_4$. The results revels that as the applied load on the wear specimen increases wear rate also increases. The hard particles present in the $ZrSiO_4$ helps in wear resistance of the material.
4 Microstructure images of Al7075 reinforced with 3%, 6%, 9% $ZrSiO_4$ shows uniform distribution. Whereas microstructure images of Al7075 reinforced with 12% shows non uniform distribution of $ZrSiO_4$. Micro segregation of $ZrSiO_4$ has been found in 12% weight of $ZrSiO_4$.

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