Mechanical Characterization of Al6061/ZrO_2/Zirconium Sand Hybrid Metal Matrix Composite

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Abstract— **The present work, the influence of tool rotational speed on wear and mechanical properties of aluminum alloy based surface hybrid composites prepared via Stir Casting was studied. The fabricated surface hybrid composites have been examined by optical microscope for dispersion of reinforcement particles. Microstructures of all the surface hybrid composites revealed that the reinforcement particles (Zircon oxide, Zircon sand and) are uniformly dispersed in the nugget zone. It was observed that the micro hardness decreases when increasing the rotational speed and showed higher micro hardness value in Al6061 surface hybrid composite due to presence and pining effect of hard Zircon sand and Zircon oxide particles. It was also observed that high wear resistance exhibited in the Al6061 surface hybrid composites due to presence of Zircon oxide and Zircon sand acted as load bearing elements and solid lubricant respectively. The observed wear and mechanical properties have been correlated with microstructures and worn micrographs consists of the preparation of Al6061/Zr02/Zirconium sand and subjecting the same to various mechanical tests to characterize the properties of the Metal Matrix Composite (MMC).**

Keywords*— *Metal Matrix Composite, Wear, Hardness, Fatigue, Stir casting.

I. INTRODUCTION

With the advancements in material science and engineering, it is now possible to obtain desirable properties at low costs and relatively simpler production processes. Composite metals have the added advantage of low weight to strength ratio, better fatigue, hardness, wear resistance and other mechanical properties which is of critical importance. In the present study, investigation of the mechanical properties of a MMC type of composite is done. A Metal Matrix Composites is composed of a metallic matrix (Al, Mg, Fe, Cu etc) and a dispersed ceramic (oxide, carbides) or metallic phase(Pb, Mo, W etc).

Ceramic reinforcement may be silicon carbide, boron, alumina, silicon nitride, boron carbide, boron nitride etc. whereas Metallic Reinforcement may be tungsten, beryllium and similar materials. Due to their high strength-to-weight ratios they are used in space crafts and airplanes where this property is of utmost importance. Comparing MMCs to its counterparts such as polymer matrix, they have superior stiffness and creep resistance.

While MMC have the above listed desirable properties they have the limitation of high cost. The technology hasn't been very widely studied hence it is still at its infancy and thus limited service experience. Another downside of the technology is the complex preparation techniques in some cases. In spite of these limitations, the properties of MMC are far superior than "conventional" metal alloys.

Sachin Malhotra et al. [1] observed that influence of varying weight percentage of Zirconia (5% and 10 %) and fixed Percentage fly ash (10%) reinforced Al6061 metal matrix composite by stir casting method. A better hardness 94HV and tensile strength 278 Mpa for 10% Zirconia and 10% fly ash reinforced composite material. Aluminum alloy 6061 had the determinate elongation of 21.66%, which was significantly reduced to a range of 85% to 90% due to the addition of reinforcement material.

K. B. Girisha et al. [2] investigated the effect of different weight fraction of zirconium oxide nanoparticle (0.5%, 1%, 1.5%, and 2%) reinforced Al356.1 metal matrix composite by stir casting method. It was observed that particle agglomeration in composite due to high content of zirconium oxide nanoparticle. Hardness and wear properties increase with increase weight fraction of zirconium dioxide nanoparticle.

Cecilia et al. [6] analyzed Zirconia-alumina composites by controlling the amount of Zirconia in order to achieve higher densities, higher flexural strength and fracture toughness. It was shown that there is an inverse dependence o f K/c on the hardness. The composites can achieve superior flexural strength approximately 90% and fracture toughness of 29% when compared to the pure alumina ceramics.

Based on the literature obtained by the above sources and many others, it is observed that very minimal work was reported based upon Al6061/ZrO_2/ Zircon sand, hence the present investigation is to fabricate a Aluminum 6061/Zircon sand hybrid composite with Zircon oxide as binder. Aluminum is a light metal whose alloys already are widely used in aircraft industries such as aircrafts whereas Zircon has high wear resistant and hardness properties. Therefore Aluminum MMCs have the potential to further improve the application characteristics. In the present investigation, Zircon sand & ZrO_2 was dispersed in molten Al6061, where in ZrO_2 wt% was kept constant at 2% and Zircon sand wt% was varied

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in increments of 2% (2%, 4%, 6%, 8%, 10%) and finally characterized by performing various tests.

II. EXPERIMENTAL DETAILS

A. *Materials*

In the present investigation, Al6061 alloy was used as the base matrix, while Zirconium dioxide (ZrO_2), sometimes known as Zirconia, a white crystalline oxide of zirconium along with Zirconium sand, a common accessory to trace mineral constituent of most granite and felsic igneous rocks was used as reinforcing materials. Zirconium sand having a hardness of 1300 kg/mm^2, Poisson's ratio of 0.32, tensile strength of 710 Mpa was used as the primary binding material, and density of 5*6.15 Mg/m^3 which was varied from wt % 2-10 was chosen as primary reinforcement material.

TABLE I. CHEMICAL COMPOSITION OF AL6061

Element	Mg	Si	Fe	Cu	Ti	Cr	Zn	Mn	Al
Wt.%	0.9 2	0.76	0.28	0.22	0. 1	0.07	0.06	0.04	Bal

TABLE II. CHEMICAL COMPOSITION & PROPERTIES OF ZrO_2

Properties	Atomic number	Density (g.cm^{-3})	Melting point	Hardness (Gpa)	Young's Modulus (Gpa)	Poisson's ratio
ZrO_2	40	5.7 - 5.75	1852 °C	10-11	205	0.23

B. *Preparation of Composites*

Aluminum 6061/Zircon sand/ZrO_2 hybrid composites was prepared by melting in the electric furnace. The metal rods was first melted in a crucible, Once the metal was fully molten for every 1kg, Now preheated raw materials zircon sand and zircon oxide of 300 microns were added. For the first specimen only pure 1kg aluminum was added. Next 2% zircon oxide with 1kg Al6061 is added and stir casted. The procedure is repeated for different percentage of zircon sand (2%,4%,6%,8%,10%) . 6kg of clean Aluminum bars was added gradually (at about 1500 °C). Being light in weight, Aluminum had a tendency to float on top. This was avoided by constantly stirring the bath with a graphite rod. The resulting product was cast into slabs of 50 mm thickness in an ingot die. Al 6061 bars used and furnace used for the preparation of Al6061/Zircon sand/ZrO_2 hybrid composite is as depicted in Fig 1.

Fig. 1. Aluminum 6061 bars and ZrO2 in powder form used for the preparation of composites.

Fig. 2. Furnace used for melting the Al6061 rods.

C. *Hardness test*

Hardness is the measure of a materials resistance to plastic deformation against indentation with an applied load. A standard way of representing the micro-hardness value of a material is by Brinell hardness number (BHN). A material with a higher BHN value has greater resistance against deformation. Hardness test was conducted as per ASTM standards, a 2.5mm ball indenter was used to calculate BHN. The test was conducted at three different locations to negotiate the possibility of indenter resting on the the harder reinforcement material and BHN was calculated by using the standard formula.

D. *Tensil test*

The cast components were machined as per ASTM standards to obtain standard tensile test specimen and the test was carried out as per ASTM standards B-557 on a servo controlled SHIMATZU DYNAMIC testing machine. All the components were loaded till fracture and the readings of the yield stress, ultimate tensile stress were noted. The machined tensile test specimen is as shown in Fig 2.

Fig. 3. Machined tensile test component.

E. *Wear test*

Dry sliding wear test was carried out using a pin on disc apparatus as shown in Fig 3. The test was performed as per ASTM G99-95 standards under varying load (4.905-14.715N) and a varying sliding distance (1-6KM) at a fixed sliding speed of 1.66m/s, against EN32 steel disc of hardness 65Rc. The wear specimens of 8mm in dia and 25mm in length were machines and polished metallographically. The machined components were subjected to three different loads (4.905, 9.81, 14.715N) and at each load the specimens were subjected to a sliding distances of 1000m-6000m.The wear loss of the specimen was measured as a height loss in micrometers and converted to volumetric loss by multiplying it by cross-sectional area and finally specific wear rate was calculated by dividing volumetric loss by load applied.
The details of the wear testing machine and the test specifications are as shown in fig 3 and table 4.

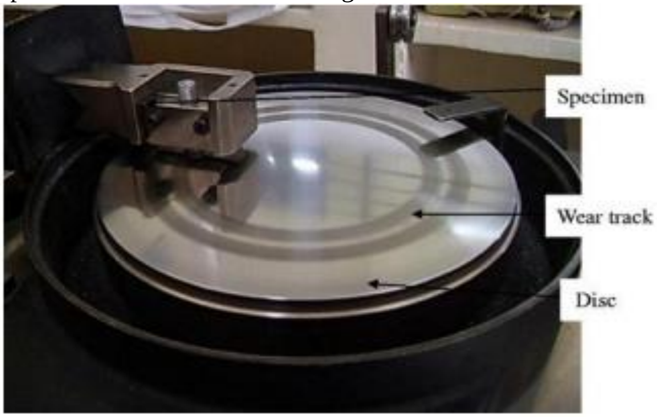


Fig. 4. Pin on Disc wear testing machine.

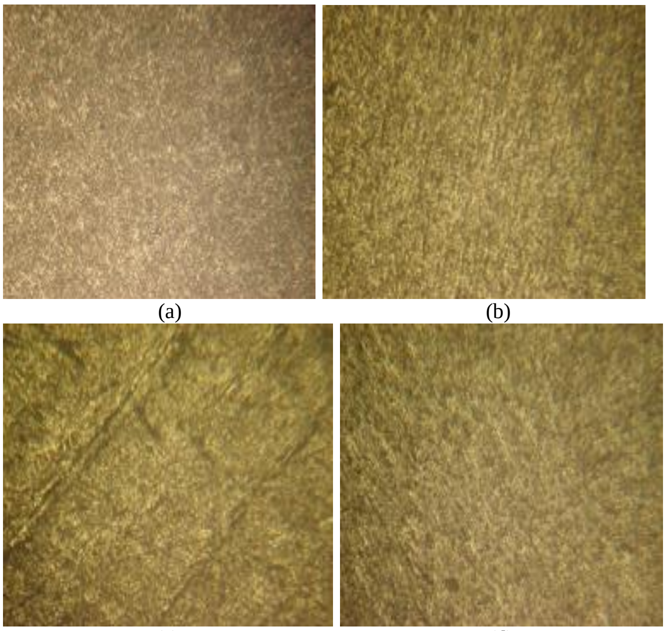
TABLE III. WEAR TESTING MACHINE SPECIFICATIONS.

Pin material	Al6061, Al6061 – Zirconium sand (2-10% wt.)
Disc material	EN32 steel disc - 65 HRC
Pin contact area (mm2)	25
Track diameter (mm)	114
Load (N)	4.905 N, 9.81 N, and 4.715 N
Sliding speed	1.66 m/s
Temperature	Room temperature
Sliding distance (m)	1000 m, 2000 m, 3000 m, 4000 m, 5000 m and 6000 m

III. RESULTS AND DISCUSSIONS

A. *Microstructure Analysis*

Hybrid MMC"s were observed by inverted optical microscope. The specimen surfaces were prepared by grinding through 220 to 1500 mesh size abrasive papers and polishing with velvet cloth. After that the specimens were etched using Keller's regent (1 ml hydrofluoric acid, 1.5 ml hydrochloric acid, 2.5 ml nitric acid and 95 ml distilled water) prior to microscopic examination.
An image analyser was used to observe the distribution of the zircon sand/ZrO_2 particles within the aluminium matrix. Figure 4 shows micrograph of MMC"s for different weight fraction of Zirconium sand particle in Al6061 matrix. The micrograph has shown a relatively uniform distribution of Zirconium sand particles and good interfacial bonding between Al6061 matrix and Zirconium sand particle.



(a) (b)

(c) (d)

Fig. 5. (a) Optical micrograph (100X) of Al6061 (b) Optical micrograph (100X) of Al6061+2.% ZrO2 (c)Optical micrograph (100 X) of Al6061+ 2% ZrO2+6% Zirconium Sand (d) Optical micrograph (100X) of Al6061+2% ZrO2+10% Zirconium Sand

B. *Tensile test*

The tensile strength properties for Al6061/Zircon sand/ZrO_2 sand has been evaluated and it was found from the test results that ultimate tensile strength of the material increases with the increase in wt% of Zircon sand, however the best result was obtained for Al6061+2% ZrO_2+ 10% Zircon sand. The increase in the tensile properties may be attributed due to the following parameters.

- The presence of harder Zircon sand particles.
- Due to the closer packing and uniform distribution of reinforcements & hence the lesser intermolecular spaces.
- Addition of reinforcements may have given rise to larger residual compressive stresses developed during the

solidification process, due to difference in coefficient of expansion between ductile matrix and brittle reinforcements.

TABLE IV. TENSILE TEST CHART FOR VARIOUS COMPOSITIONS OF COMPOSITE

Sl No.	Composition	Yield Stress	Ultimate Stress
1	Al	45.5	67.62
2	Al+2%Zro2	49.3	72.95
3	Al+2%Zro2+2%Sand	52.79	84.08
4	Al+2%Zro2+4%Sand	59.03	88.68
5	Al+2%Zro2+6%Sand	62.47	92.04
6	Al+2%Zro2+8%Sand	65.24	94.11
7	Al+2%Zro2+10%Sand	68.25	98.14

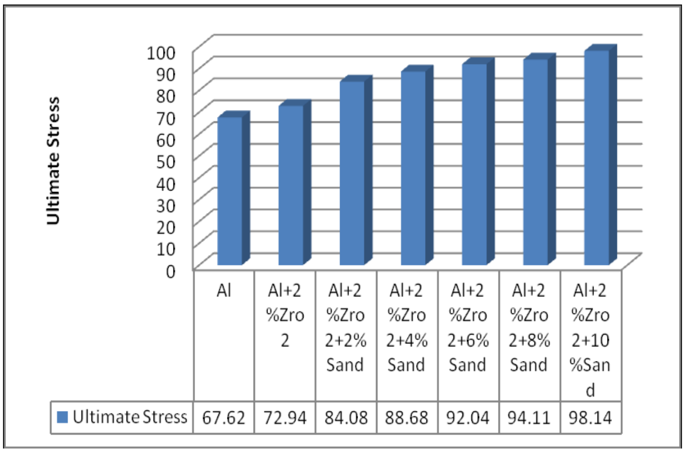


Fig. 6. Ultimate stress variation for various composition

C. *Hardness test*

Brinell hardness of the composites increases with the increase in ZrO_2/Zircon sand composition, this may be because of Zircon sand particles being harder than Al6061 and render it's hardness to the composites. Hardness increases significantly and the best results was obtained for Al6061/2% ZrO_2/10% Zircon sand composition. The hardness variation with the variation of Zircon sand content in the composites is as depicted in table3 & Fig 5.

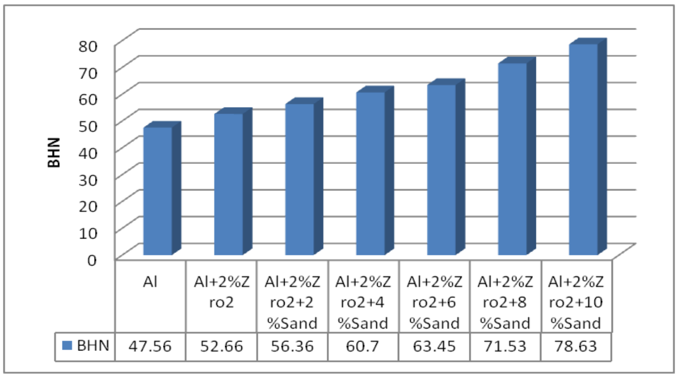


Fig. 7. Hardness variation for various composition

TABLE V. HARDNESS CHART FOR VARIOUS COMPOSITIONS OF COMPOSITE

Sl. No.	Composition	BHN
1	Al6061	50.36
2	Al6061+2%Zro2	54.66
3	Al6061+2%Zro2+2%Zirconium Sand	56.36
4	Al6061+2%Zro2+4%Zirconium Sand	60.7
5	Al6061+2%Zro2+6%Zirconium Sand	62.36
6	Al6061+2%Zro2+8%Zirconium Sand	71.53
7	Al6061+2%Zro2+10%Zirconium Sand	75.66

D. *Wear test*

Figure 6 & 7 shows specific wear rate as a function of load and sliding distance. The specific wear rate of pure Al6061 and for varying wt% of Zircon sand is as shown in the following figures.

Fig 6 depicts that specific wear rates decreases with the increase in loads, which indicates higher wear resistance at higher loads, this may attributed because asperities/uneven surfaces come in contact with the rotating disc hence higher wear rate is observed during initial stages and as the load increases material becomes softer and better wear resistance is observed at higher loads.

Fig 7 shows specific wear rate as a function of sliding distance and it is observed that wear rate decreases gradually with the increase in sliding distance. The graph exhibits two regions called as running in period & steady state periods. During running in period wear rate increases rapidly.

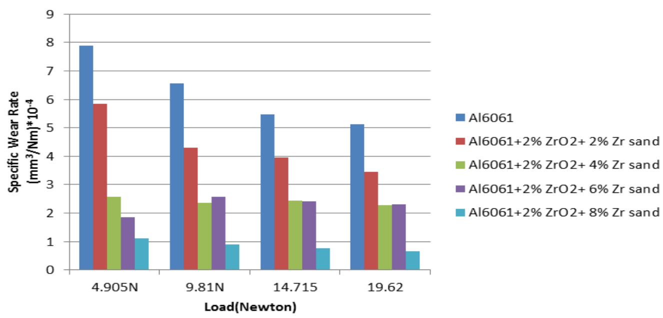


Fig. 8. specific wear rate as a function of load for various composition

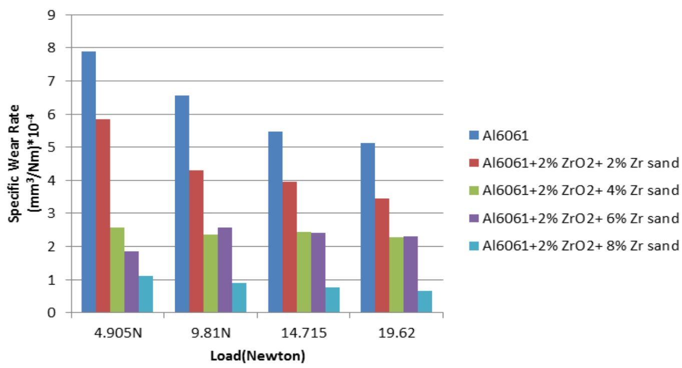


Fig. 9. specific wear rate as a function of load for various composition

E. CONCLUSIONS

The Al6061-Zirconium particulate composites were successfully produced by liquid metallurgy technique with different wt% of (2%, 4%, 6%, 8%, 10%) of reinforcements. For all the processed conditions microstructure, mechanical and wear characteristics were evaluated. Within the purview of the study on Zirconium sand reinforced aluminum alloys the following conclusions can be drawn.

- Aluminium based metal matrix composites have been successfully synthesized by stir casting technique and further the optical images clearly indicates uniform distribution of Zirconium sand and Zro2 particles.
- Microstructure results showed the presence of Zirconium sand particles in the alloy matrix. The oxide phases like ZrO_2 have dispersed uniformly throughout the aluminium MMC.
- The results confirmed that stir cast Aluminium alloy 6061 with uniform distribution of Zirconium sand and ZrO_2 particles enhances both tensile strength and hardness. With 10% wt. of Zirconium sand and 2% wt.of ZrO_2 showing reasonably high strength and hardness when compared to matrix alloy. The addition of Zirconium sand and Zro2 particles to the alloy reduces the wear loss.
- Zirconium sand and Zro2 particulates can be successfully used as reinforcing material to light weight Metal Matrix Composites (MMCs). It can replace other higher density and expensive reinforcements. Also results in a „lighter composite material" as compared to composite reinforced with conventional particles such as SiC, and Al 2 O 3 etc. Hence these composites can be used in light weight aerospace applications.

REFERENCES

[1] Sachin Malhotra, Ram Narayan, R. D Gupta, "Synthesis and Characterization of Aluminium 6061 Alloy-Fly ash& Zirconia Metal Matrix Composite", International Journal of Current Engineering and Technology, Vol. 3, No. 5, pp. 1716-1719, 2013.

[2] K.B.Girisha, Dr.H.C.chittappa, "Preparation, characterisation and wear study of aluminium alloy (al356.1) reinforced with zirconium nano particles", International Journal of Innovative Research in Science, Engineering and Technology (ISO 3297: 2007 Certified Organization) Vol. 2, Issue 8, August 2013 .

[3] J. Jenix Rino, Dr. D. Sivalingappa, Halesh Koti, V. Daniel Jebin, "Properties of Al6063 MMC Reinforced with Zircon Sand and Alumina", IOSR Journal of Mechanical and Civil Engineering, Vol. 5, Issue 5, pp. 72-77, 2013

[4] K. L. Meena, Dr. A. Manna, Dr. S.S. Banwait, Dr. Jaswanti, "An Analysis of Mechanical Properties of the Developed Al/SiC-MMC's", American Journal of Mechanical Engineering, Vol. 1, No. 1, pp. 14-19,2013

[5] Sandeep Kumar Ravesh, Dr. T. K. Garg, "Prepration& Analysis for Some Mechanical Property of Aluminium Based Metal Matrix Composite Reinforced with SiC & Fly ash", International Journal of Engineering Research and Applications, Vol. 2, Issue 6, pp. 727-731,2012

[6] Maria Cecilia, Carlos Nelson EliasI, Jamil Duailibi FilhoII, Leandra Guimarães de OliveiraII, "Mechanical properties of Al2O3- ZrO2 composites for composite abutments", Mat. Res., Vol. 7, No. 4, 2004, 643-649

[7] K. S Tan, P. Hing, and P. Ramalingam, The elastic moduli and diametrical compressive fracture stress o f AkOa-ZrCh ceramics J. Phys. D: Appl. Phys. 30 (1997)ppl029.

[8] M. Kok, Journal of Materials Processing Technology, Volume 161, Issue3, 30 April 2005, PP. 381-387.

[9] C. S. Ramesh, ―Processing and Characterization of Metal Matrix Composites,‖ *Proceedings of the National Seminar on Recent Trends in Liquid Crystals, Polymer, and Composite Materials*, Ramanagaram, 2003, pp. 10-13.

[10] Sunny Chung, Bing H. Hwang, Tribology International, Volume27, Issue5, October1994, PP. 307-314.

[11] P.MuhamedAshraf, S.M.S.Shibli, ―Reinforcing aluminum with cerium oxide: A new and effective technique to prevent corrosion in marine environments‖, 26, August, PP.443-448.

[12] A.S.Anasyida, A.R.Daud, M.J.Ghazali. ―Dry sliding wear behavior of Al-4si-4mg Alloys by addition of cerium‖, vol4 (2009), No.2, 127-130.

[13] M. N. Wahab, A. R. Daud and M. J. Ghazali: Preparation and Characterization of stir cast—Aluminum nitride reinforced Aluminum Metal matrix: International *Journal of Mechanical and Materials Engineering* (IJMME), Vol. 4 (2009), No. 2, 115-117.

[14] K.R. Suresh, et al., Dry sliding wear of Al 356—beryl metal matrix composite, in: Proceedings of the Third Australasian Conference on Composite Materials (ACCM-3), 15–18 July 2002,Auckland, New Zealand.

[15] G. E Dieter, ―Mechanical Metallurgy,‖ 2nd Edition, Mc- Graw-Hill, Kongakusha, 1981, pp. 221.

[16] D. M. Taylor, ―Metals Hand Book,‖ ASM, Materials Park, 1982, pp. 859-863.

[17] D. L. McDanieal, ―Analysis of Stress-Strain, Fracture and Ductility Behavior of Al MMCs Containing Discontinuous Silicon Carbide Reinforcement,‖ *Metallurgical and Materials Transactions A*, Vol. 16, No. 6, 1985, pp. 1105- 1113.