# EFFECT OF MECHANICAL PROPERTIES ON ZIRCONIUM OXIDE AND TITANIUM REINFORCED WITH AL-6082 ALLOY METAL MATRIX COMPOSITES

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**Abstract -** *Aluminum matrix composite is a new generation of metal matrix composite which have the tendency to meet the emerging for advanced engineering application. The performance of these materials mostly depends upon selecting right combinations of reinforcing materials. In the current work an effort as been made for the fabrication of Aluminum metal matrix composite for the investigation of its mechanical properties. The preparation of aluminum metal matrix composite is made by choosing AA6082 as matrix and by keeping weight % of reinforcements ZrO2 and the Ti are varied by 2%, 4% and 6%. The wear properties of metal matrix composites were studied by conducting wear test using pin on disc machine as per ASTM G-99 standard. The experiment were conducting by adopting the taquchi technique with an L9 orthogonal array and analysis of variance approach was employed to evaluate the effect wear parameters load, percentage reinforcement and duration on wear rate of composites. These samples were fabricated by means of stir casting technique and the micro structural characteristics of composites are studied by using optical microscope. Mechanical properties such as impact strength, hardness, compression are studied and compared the results with base Aluminum 6082 results.*

***Key Words***: Zirconium oxide, Titanium, aluminum alloy, L9 orthogonal array

## 1.INTRODUCTION

Composites are the engineering materials which are gaining importance because these composite models are desired properties by connect in two or more nano, micro, or macro constituents with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other based on the various applications . Every automotive industry in the recent time keen to manufacture the parts which are light in weight with excellent tribological properties especially in the manufacturing areas where wear resistance is given as the most important consideration. Aluminum, which is light in weight, can be used as a main matrix element in the fabrication of composite materials and these manufactured composite are termed as aluminum matrix composites (AMCs). Aluminum is mostly used industrial and functional metal or alloy because of its unique combination of properties like low density, high corrosion resistance and excellent mechanical properties. Aluminum based Metal Matrix Composites have been developed has the advanced materials for several applications in aerospace, automobile, transportation, marine, mineral processing and electrical packaging industries because they exhibit high specific strength and stiffness. In this paper, the processing, microstructural features, and mechanical behavior of an Al6082 matrix composite which are reinforced with varied weight ratios of ZrO2 and Ti are reported. Proper selection of reinforcing material for Al matrix composite material and techniques process are very important factors in ensuring that desired property combinations are achieved.

## 2. Experimental process and setup

Aluminum 6082 is a medium strength alloy with excellent corrosion resistance and manganese present in it controls the grain structure, which results into a stronger alloy and its application are in the field of high stress application. Al6082 alloy possess high strength to density ratio and improved strength towards 6000 series alloys, where light weight and strength properties are critical. These properties lead its use in bicycle components, rock climbing equipment, hang glider airframes, chasis plates of sport grade. Al6082 alloy possess the capacity of highly polished, they are worn in mold tool manufacturing. These materials exhibited better mechanical and tribological properties required for some automotive components for application basis. Al6082 alloy used as a matrix material. Chemical composition Al6082 alloys is shown in Table 1.

### 2.1 Zirconium Oxide ($ZrO_2$)

Zirconium dioxide is also known as zirconia and zirconium oxide, is a crystalline metal oxide that has found its way into the ceramics industry. It is characterized by its high thermal resistivity, mechanical resistance, and abrasive properties. Zirconium is as strong as tungsten & titanium. It is also corrosion- resistant and is harder than stainless steel or silver. Zirconia Oxide has the highest strength and toughness at room temperature of all the advanced ceramic materials.

| Element | Amount wt% |
|---|---|
| Al | 87.7 - 91.1 |
| Cr | 0.0 – 0.25 |
| Cu | 0.0 – 0.10 |
| Fe | 0.0 – 0.50 |
| Mg | 0.60 – 1.20 |
| Mn | 0.40 – 1.00 |
| Si | 0.70– 1.30 |
| Ti | 0.0 - 0.10 |
| Zn | 0.0 – 0.20 |
| other | Max 0.20 |

**Table -1:** Chemical Composition of AA6082

Zirconium dioxide is highly resistant to cracking (including further development of cracks) and mechanical stress. With a melting point of 2700ºC and a thermal expansion coefficient of $1.08\times10^{-5}$ $K^{-1}$, zirconium dioxide is widely known for its high resistance to heat. This is the reason why the compound has found a wide variety of uses in refractories and high temperature industries.

## 2.2 TITANIUM MATERIAL PROPERTIES

Titanium in its pure form is a silvery metal known for its strength and low density compared to other similarly hard metals. In most industries, however, titanium alloy is much more commonly used. It as the very tight substance to mixture through reinforcement align for further properties depends. At the required consideration the strength and with same light weight theory is accomplished. It is crucially used in industries such as military basis and chemical industries.

## 2.3 STIR CASTING METHOD

Initially 750 g of commercially available pure Al6082 was melted in a resistance heated furnace up to 973 K and casted in a cast graphite crucible. Then Al6082 and zro2 and Ti reinforcements were prepared by reinforcing the aluminum (average size of 30 mm) with 2%, 4% and 6% wt of zro2 and Ti by stir casting. For this we took three split up of 250 gm of commercially pure Al6082 and then 2%, 4% and 6% wt of zro2 & Ti were added to the aluminum melt for production of three different composites. Before doing this the reinforcements zro2 & Ti were preheated up to 473 K to remove moisture. Al6082 was melted by increasing the temperature to 973 K and the preheated reinforcement particles were combined to the melt at the time of development of vortex in the melt due to stirring. Magnesium was added in order to enhance the wettability between the reinforcements and the matrix. The melt temperature was continued at 943–973 K during increase of the particles and the stirrer speed is maintained at 250–300 rpm. Then the melt was casted in a graphite crucible. And then poured in the die for solid shape. And we undergo through Test

1.Wear
2.Hardness
3.Optical microscope
4.Compression
5.Impact

**Fig. 1** describes the experimental setup of the stir casting

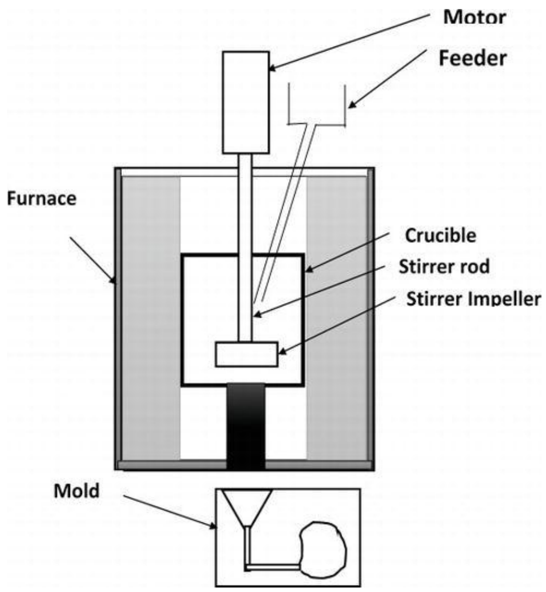


**Fig -1** stir casting

## 2.4 MECHANICAL CHARACTERIZATION
### 2.4.1 WEAR TEST

Wear test specimens of dimension diameter 8 mm and length 32 mm were prepared. The end surfaces of the wear test specimens were properly cleaned and then polished with abrasive paper of grade 400, 600 and 1000, respectively. The wear test has been performed on pin on disc apparatus. The disc of the pin on disc is made of EN31 steel having surface roughness 0.1. The pins and disc were cleaned properly with the help of acetone before and after wear test. The wear was measured by computerized pin on disc wear testing machine as a loss of tare in micron levels.

### 2.4.2. *MICRO-HARDNESS MEASUREMENT*

The micro-hardness of composites was measured using Vickers hardness tester at a load of 500g applied for a duration of 15s at 20s different locations on all specimens.

### 2.4.3 COMPRESSION TEST STUDY

The aim of compression test is to find out the behavior of a material when perceiving compressive load by the measurement of fundamental variables, such as, strain, stress, and deformation. By testing the specimen we can find out the compressive strength, ultimate strength, elastic limit, yield strength among more parameters may all be determined.

### 2.4.4 MICROSTRUCTURE

The fabricated composite were characterized using optical microscope. The samples were generally polished employing the normal metallographic procedure and the polished specimens were etched with keller's agent.

### 2.4.5 IMPACT TEST STUDY

The impact test is useful to designers to analyse the relative impact resistance of specimen. The specimens were prepared for izod impact test of dimensions 10*10 mm2 area and 55mm length to check impact strength by using universal impact testing machine. And also V slot 2*45 degree was created by sawing then filed it.

## 3.RESULTS AND DISCUSSION

### 3.1 wear:

The experiments were conduct as per the standard orthogonal array. The selection of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than or at least equals sum of those of wear parameters. In the present investigation an L9 orthogonal array was chosen as shown in Table 2. The wear parameters chosen for the experiment are (i) applied load (ii) reinforcement percentage (iii) sliding duration. The experiment consists of 9 tests (each row in the L9 orthogonal array) and the columns were assigned with parameters.

The first column was assigned to the applied load (L), second column was assigned to the sliding speed (S), third column was assigned to the sliding distance (D). The experiments were conducted as per the orthogonal array with level of parameters given in each array row. The output to be studied is wear rate and coefficients of friction of the test samples are repeated three times corresponding to 27 tests. The experimental observations are further transformed into Signal to noise ratio.

The response to be studied was the wear rate and coefficient of friction with the objective as smaller the best, which is calculated as logarithmic transformation of loss function as shown below,

| Reinforcement ($ZrO_2$ + Ti) | Load | Duration | Wear ratio (micron) |
|---|---|---|---|
| 2 | 10 | 5 | 214.42 |
| 2 | 20 | 10 | 489.32 |
| 2 | 30 | 15 | 764.27 |
| 4 | 10 | 10 | 536.37 |
| 4 | 20 | 15 | 809.44 |
| 4 | 30 | 5 | 373.44 |
| 6 | 10 | 15 | 856.86 |
| 6 | 20 | 5 | 456.93 |
| 6 | 30 | 10 | 731.63 |

**Table – 2** wear test reading in micron

### 3.1.1 ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) was introduced by Sir Ronald Fisher. This analysis was carried out for a level of significance of 5%, i.e., for 95% level of confidence. The purpose of ANOVA is to investigate the percentage of contribution of variance over the response parameter and to find the influence of wear parameters. The ANOVA is also needed for estimating the error of variance and variance of the prediction error. It can be observed that the load, sliding distance and wt% of reinforcement have the influence on wear of composite material. It can be observed from the ANOVA table that the wt% of Ti was the most significant parameter on the sliding wear of composites followed by applied load and sliding distance. This approach gives the variation of means and variance to absolute values considered in the experiment and not the unit value of the variable.

### 3.1.2 ANALYSIS OF S/N RATIO

In Taguchi method, the term "signal" represents the desirable value (mean) for the output characteristics and the term "noise" represents the undesirable value for the output characteristics. Taguchi uses S/N ratio to measure the quality characteristics deviating from the desired value. The influence of control parameters such as wt% of reinforcement, load applied and sliding distance content has been analysed and the rank of involved factors like wear rate of composite materials which supports S/N ratio response is given in the Table 2.4. It is evident from the table that among these process parameters, normal pressure is a dominant factor on the wear rate. The influence of controlled process parameters on wear rate. It also determines the most influential parameter for in the experiment. wear is taken as the objective function and Taguchi's "smaller is Better" quality characteristic is chosen to maximum the objective function

## Regression Equation

Wear ratio (micron) = -160.2 + 48.12 Reinforcement +4.361 Load + 46.19 Duration

| Level | Reinforcement | Load | Duration |
|---|---|---|---|
| 1 | 489.3 | 535.9 | 348.3 |
| 2 | 573.1 | 585.2 | 585.8 |
| 3 | 681.8 | 623.1 | 810.2 |
| Delta | 192.5 | 87.2 | 461.9 |
| Rank | 2 | 3 | 1 |

**Table-3** Response Table for Means

| Level | Reinforcement | Load | Duration |
|---|---|---|---|
| 1 | 52.69 | 53.29 | 50.42 |
| 2 | 54.73 | 55.05 | 55.22 |
| 3 | 56.38 | 55.47 | 58.16 |
| Delta | 3.69 | 2.17 | 7.74 |
| Rank | 2 | 3 | 1 |

**Table-4** Response Table for S/N Ratios

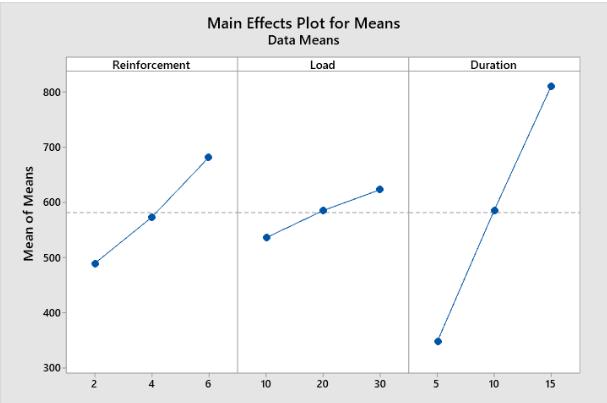


**Fig-3** Main effects plot for Means

Wear ratio is decreases with increases in wt % of zirconium oxide & titanium reinforcement particles. Moreover, the increases in wt % of reinforcement is mainly attributed to grain refined of the matrix. Wear rate of the composites reduced with the increase in the load whereas with higher content of zirconium oxide & titanium reinforcement particles, the composites exhibited higher wear resistance. Therefore, increasing wt % of reinforcement is refine the matrix grain and increases the property

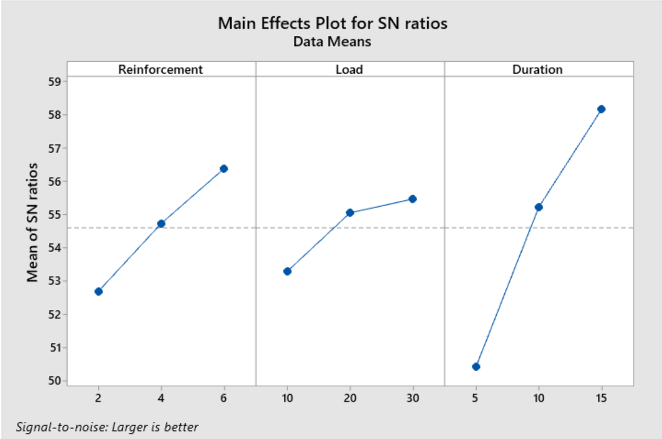


**Fig-2** Main effects plot for SN ratio

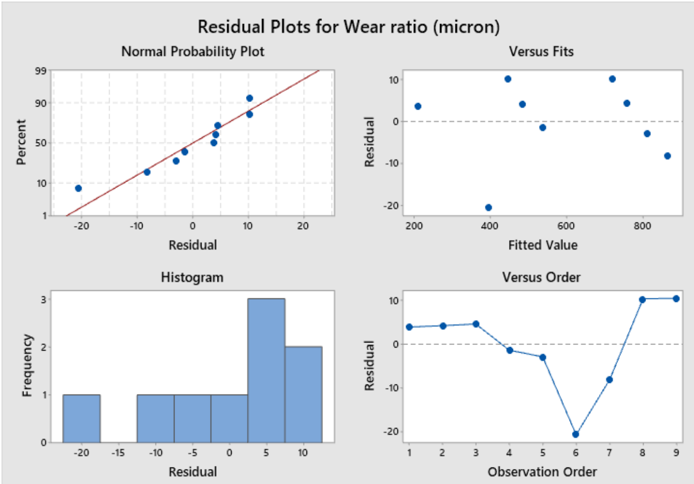


**Fig-4** Residual plots for a wear ratio(micron)

## 3.2 HARDNESS MEASUREMENT

Generally hardness of the composites increases as the ceramic particle reinforcement increases in composites. But inAl6082-zro2 & Ti composites due to the presence of chemical reinforcement which is hard in nature we can observe significant increases in the hardness of reinforcement composites. From Fig. 5 we can observe that the hardness of the reinforced composites is greater than the hardness of the unreinforced alloy. Maximum hardness value 63.79HV was observed for sample 4. Hardness of alloy and composites observed that micro vickers hardness values are increases when increasing of reinforcement volume fraction compared to base alloy Al6082. Because of two reasons they are mainly zro2 and Ti with alumina. And values are indicated in given below graph.

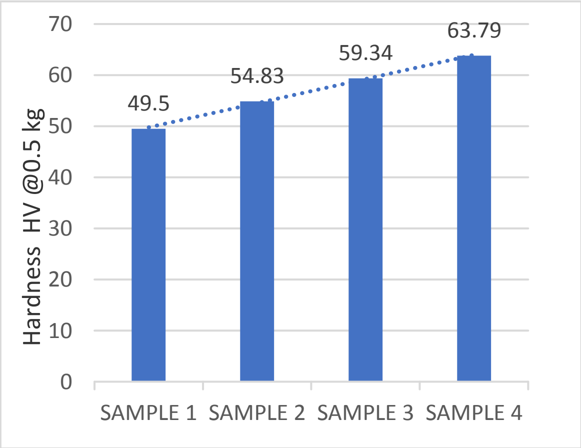


**Fig- 5** Hardness of the reinforced composite

### 3.3 COMPRESSION STRENGTH STUDY

Compressive strength is the capacity of a material or structure to withstand loads Leaning to scale down size, as disputed to tensile strength, which withstands loads are disposed to elongate. Compressive strength abide compression where as tensile strength resists tension. In present investigation of strength of materials, compressive strength can be evaluated. Some materials fracture at their compressive strength limit; others deform irreversibly, so a given amount of deformation may be considered as the limit for compressive load. Compressive strength is a key value for design of structures. Fig-6 describes the individual Compression test results of each sample and we can conclude that the maximum compression strength is 394.82MPa for sample 3 which is increased 12.5% compared to the sample 1. As the reinforcement content increases compression strength value increases.

### 3.4 IMPACT TEST

The impact test is useful to find the notch sensitivity and toughness of engineering materials. This test is convenient to analyses the toughness of metals and the identical tests are used for ceramics, polymers and composites. Izod V-notch test is useful to find percentage of energy consumed by a material. It is generally applied in industry, because it is very accessible to prepare and to conduct test and the results will be obtained very quickly, accurately. From the results, it is noticed that the percentage of energy consumed by the manufactured composite remind same. The impact strength observed from results energy absorbed by the alloy is lower than composites. When reinforcement volume fraction increases then impact specific power would increases.

Fig-7 describes the individual Impact test results of each sample and we can conclude that the maximum Impact strength is obtained at sample 4.

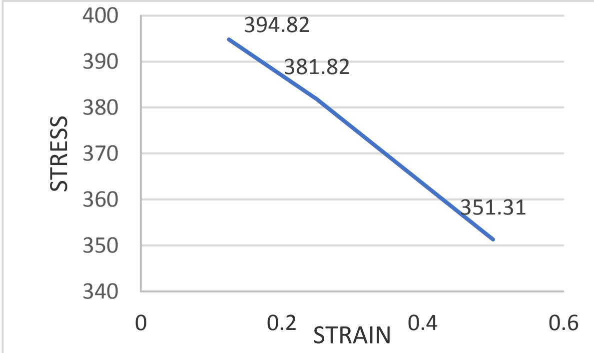


**Fig-6** compression strength

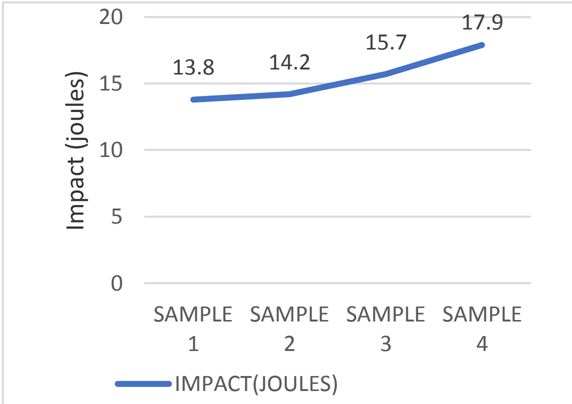


**Fig-7** Impact strength result

### 3.5 Microstructure Study

Zro2 & Ti used in composites was characterised by optical microscope. It can be seen that the reinsed are coarse compared to Figures (a), (b) and (c) with finer grains when reinforcement of 100μm was used as the filer. Zro2 & Ti of smaller particle size with higher surface area refined the grains of the alloy. It was also observed that reinforcement dispersed in Al6082 alloy as seen from the homogeneity of the microstructures. Figures (b), (c) and (a) respectively show the micrographs of the composites reinforced with 2,4 and 6wt% reinforcement(Zro2 & Ti) of 100μm particle size. This observations showed that there was uniform distribution of particles throughout the matrix

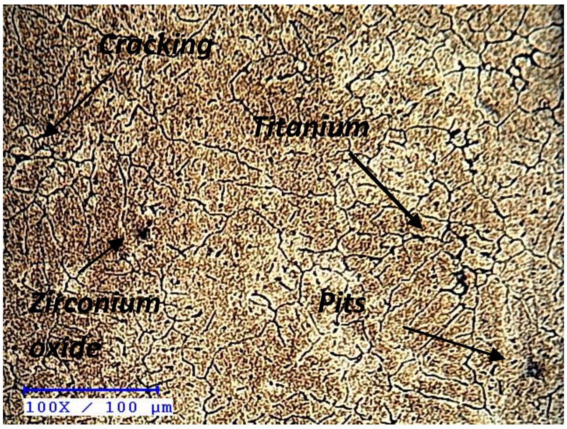


Fig (a) Al6082 +2% of Ti & ZiO2

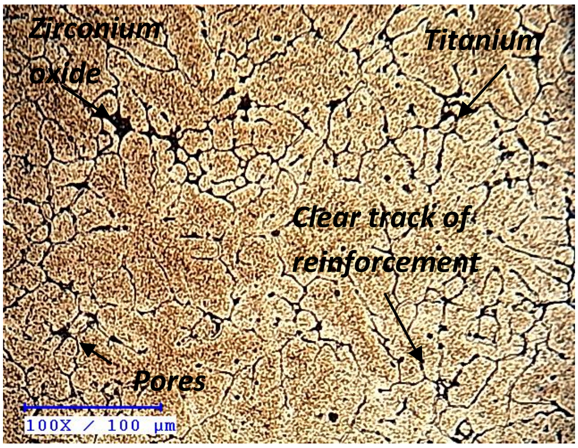


Fig (b) Al6082 +4% of Ti & ZiO2

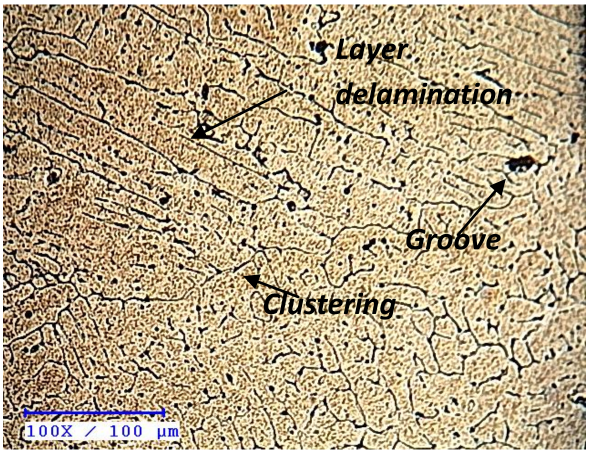


Fig (c) Al6082 +6% of Ti & ZiO2

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