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# Evaluation of Wear and Hardness of Al-Si-Mg Based Hybrid Composite at Different Aging Conditions

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***Abstract-*** The Mechanical properties of Al-Si-Mg (Al 6061) based hybrid composites containing mica particulates of 200 microns and short e-glass fibres of 2-3 cm length in different compositions are studied with stretching/straining and aging. Vortex type of stir casting was employed in which preheated reinforcements were introduced. The test specimens were machined to ASTM standards and were subjected to solution heat treatment and artificial ageing. Double aging was carried out on the specimens with strain and without strain. The properties like Specific wear rate and Hardness are studied and results are presented. A degree of improvement in both Specific wear rate and Hardness was observe in double aged casting with strain over double aged without stress, single aged and as-cast condition. The microstructures of the composites were studied to know the dispersion of the mica and e-glass fibre in matrix. It has been observed that addition of reinforcements significantly improves Wear rate along with Hardness properties as compared with that of unreinforced matrix.

***Index Terms***- Mica, E-glass, Al6061 hybrid composite, single aging, double aging, straining.

## I. Introduction

Metal Matrix Composites (MMCs) have received increasing attention in recent decades as engineering materials. The introduction of a ceramic material into a metal matrix produces a composite material that results in an attractive combination of physical and mechanical properties, which cannot be obtained with monolithic alloys.(1-6)There is an increasing need for knowledge about the processing techniques and mechanical behaviour of particulate MMCs in view of their rising production volumes and their wider commercial applications(7). Interest in particulate reinforced MMCs is mainly due to easy availability of particles and economic processing technique, adopted for producing the particulate reinforced MMCs.

The most conventional method of production of composites by casting route is vortex method, where the liquid aluminium containing 2-5% Mg is stir with an impeller and ceramic particles are incorporate into vortex formed by stirring of the liquid metals. Addition of Mg into the liquid metal reduces the surface tension (8) and there by avoids the rejection of the particles from the melts. Without addition of Mg recovery of the particles into the melt is quite low. Hence 2-5% Mg is generally add to the Al melts before incorporation of the particles

Multi-stage heat treatment known as retrogression and re-ageing (RRA) is a process used to enhance the mechanical and corrosion resistance properties of aluminium. The RRA process was first developed by Cina and Gan and their results showed that 7xxx series of aluminium alloys are known to respond to retrogression and re-aging thermal treatments (9). This paper presents preliminary findings on the influence of strain, aging and re-ageing called double ageing heat treatment on the wear rate and hardness properties of aluminium alloy 6061 based hybrid composite.

## II. MATERIALS AND METHODS

**Matrix Material**

Al 6061 alloy, which exhibits excellent casting properties with reasonable strength, was used as a matrix material. This is a popular aluminium alloy with good strength and is suitable for mass production of starting lightweight metal castings. The chemical composition of the Al 6061 alloy is shown in the Table-1.

White Mica of 200 microns was selected as particulate form reinforcement. E-Glass fibre of 2-3 mm length and 9μm in diameter is also considered as fibre reinforcing material. The chemical composition of the E-Glass fibre is given in the Table-2.

| Mg | Si | Fe | Cu | Ti | Cr | Zn | Mn | Be | V | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.92 | 0.76 | 0.28 | 0.22 | 0.10 | 0.07 | 0.06 | 0.04 | 0.003 | 0.01 | Bal |

**Table-1 Chemical composition of Al 6061 by weight percentage.**

| $SiO_{2e}$ % by wt | $Al_2O_3$ % by wt | CaO % by wt | MgO % by wt | $B_2O_3$ % by wt |
|---|---|---|---|---|
| 54.3 | 15.2 | 17.2 | 0.6 | 8.0 |

**Table-2 Chemical composition of E-Glass fibre by weight percentage.**

**Preparation of the composite**

Al 6061 alloy was melted at 700°C, which is superheated by 100°C above the liquidus temperature of the matrix alloy. The vortex technique was adopted to fabricate the specimens in which a vortex was created in the melt of the matrix alloy using $Al_2O_3$ coated mechanical stirrer. The preheated Mica particulates and E-Glass fibres (400°C) were introduced into the molten slurry.

A small amount of Mg [14], which improves the wetability of the reinforcements, was added before introducing reinforcing materials. Stirring was carried out continuously till the interface between the particles, fibers and the matrix promotes wetting and then finally poured into the metallic mould. 10 specimens of various compositions were produced as shown in table 3.

**Heat-Treatment**

The procedure for heat treatment involves the following steps

i) Solutionizing
ii) Quenching
iii) Stretching/Straining
iv) Two-step aging

a) First step at lower temperature(single aging)
b) Second step at higher temperature(double aging)

**Solutionizing & Quenching:**

Solution treatment for 2 hrs, soaking temperature of 480 ±5°C was adopted followed by oil (SAE30/40) quench at room temperature was carried out. Figure.1 show the heat treatment cycle.

**Stretching/Straining:**

One set of specimens are permanently deformed by 10% max. by applying external pressure.

This is carried out immediately after the quenching, before precipitation starts and material becomes harder. (Before 6 Hrs)

**Aging:**

*Single aging:* This step is carried out at a temperature of 120 ±5°C for a period of 16- 24 hrs.

*Double aging:* After the first step aging, second step aging is carried out at 170 ±5°C for period of 16-18 hrs.

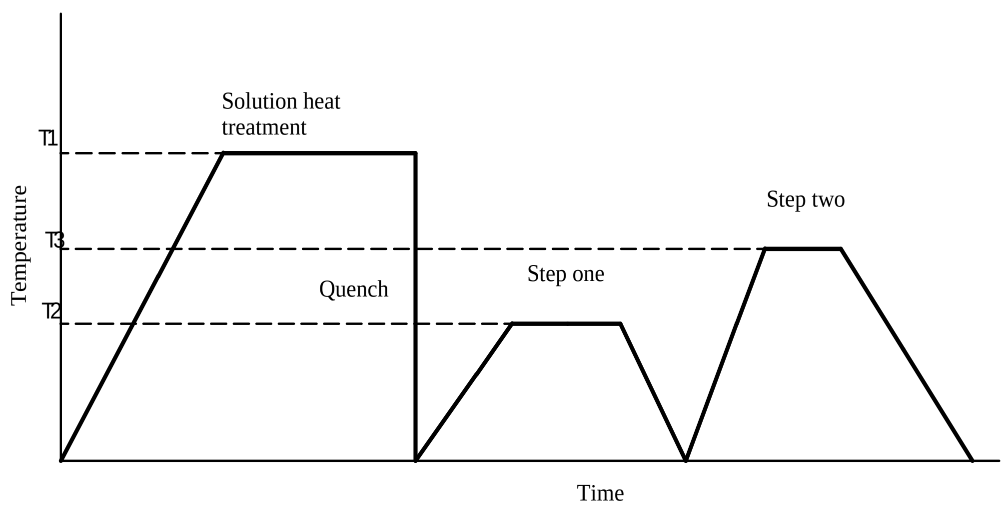



**Fig. 1: Schematic representation of temperature Vs time plot showing both solution and precipitation heat treatments (artificial ageing).**

## III. RESULTS AND FINDINGS

**Microstructure analysis**

Figures below- shows the microstructure of As- cast Al6061 composite. Precipitations were evident both along and across grains. Figure-2to 5 shows typical microstructure of the Al 6061 Hybrid Composites containing 2% Mica and 2 % e-glass fiber. Micrograph clearly reveals minimal micro porosities in the casting. No clustering of reinforcements was observed in the matrix, and the dispersion of Mica particles and e-glass short fibers is seen to be almost uniform. Figure 4 and 5 shows there is good bonding between matrix material and the reinforcements. Also it is clearly evidenced that the particulates are concentrated in the boundary region which is clearly visible and it indicates good bonding strength. The grain structure in Double aged with strain (Figure 5) is denser than other conditions; hence this gives better mechanical and tribological properties. It clearly indicates that no gap is observed between the particle and matrix and between the fiber and the matrix, and reinforcing materials are seen well bonded with the matrix.

There are numbers of software available which can mimic the process involved in your research work and can produce the possible result. One of such type of software is Matlab. You can readily find Mfiles related to your research work on internet or in some cases these can require few modifications. Once these Mfiles are uploaded in software, you can get the simulated results of your paper and it easies the process of paper writing.

As by adopting the above practices all major constructs of a research paper can be written and together compiled to form a complete research ready for Peer review.

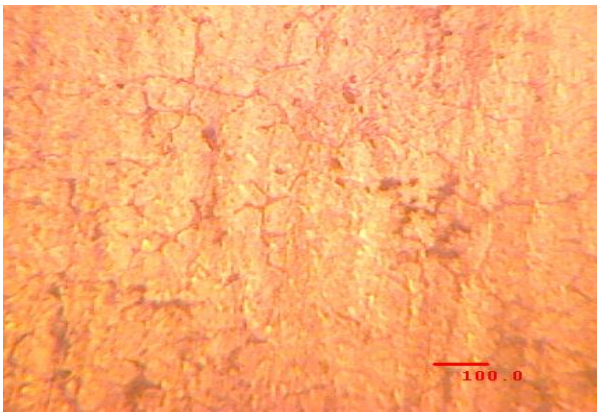



**Fig2: Microstructure of As-Cast Al6061 Composite (2wt% mica, 2wt% E-glass fiber)**

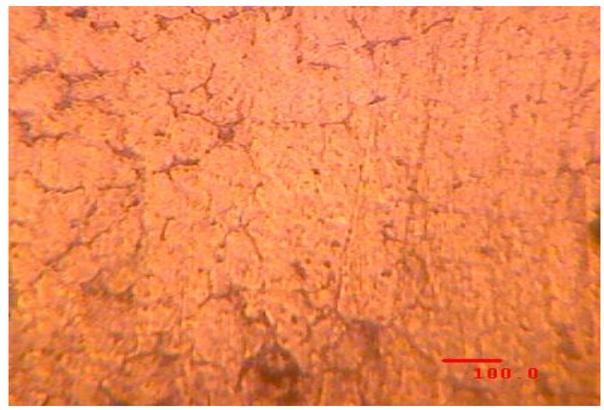



**Fig3: Microstructure of Single aged Al6061 Composite (2wt% mica, 2wt% E-glass fiber)**

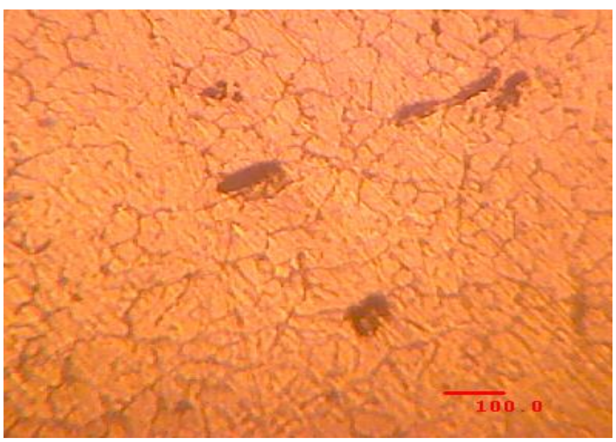



**Fig4: Microstructure of Double aged without strain Al6061 Composite (2wt% mica, 2wt% E-glass fiber)**

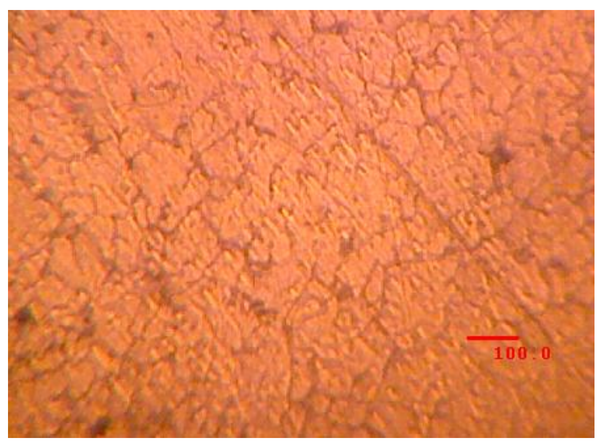
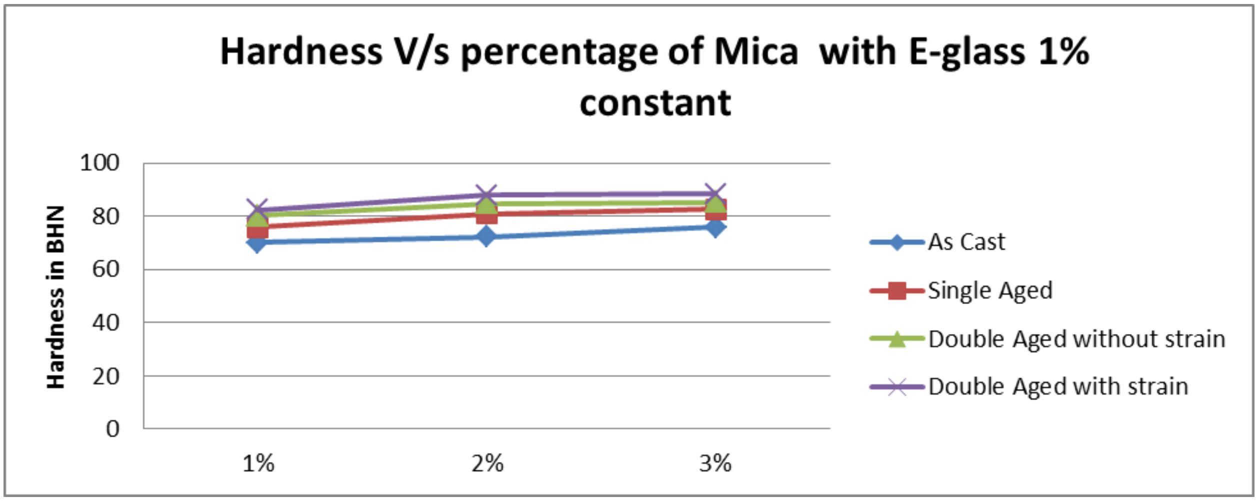


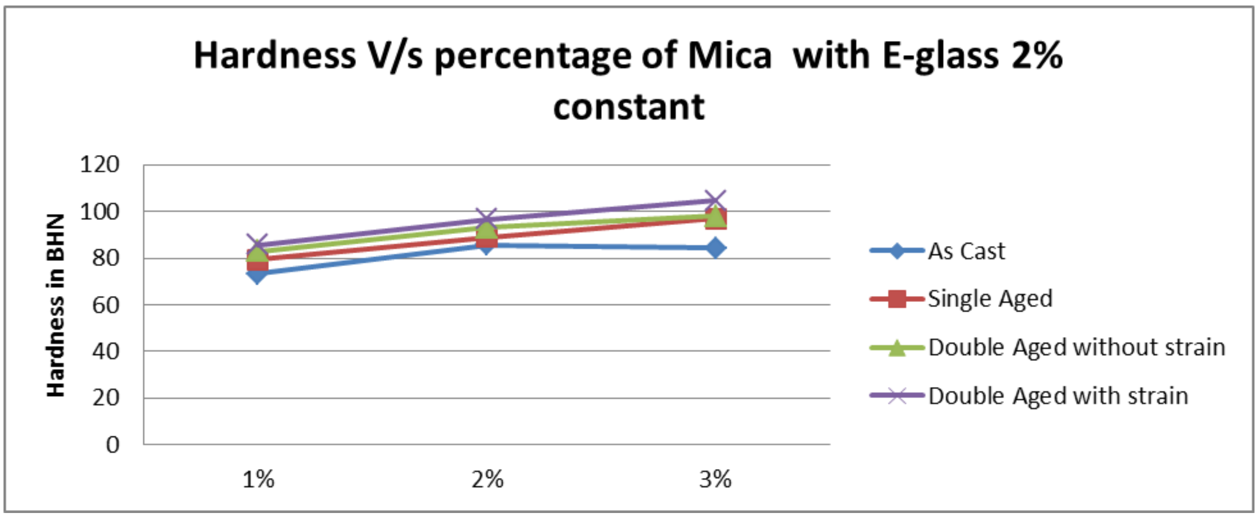

**Fig5: Microstructure of Double aged with strain Al6061Composite (2wt% mica, 2wt% E-glass fiber)**

**Hardness**

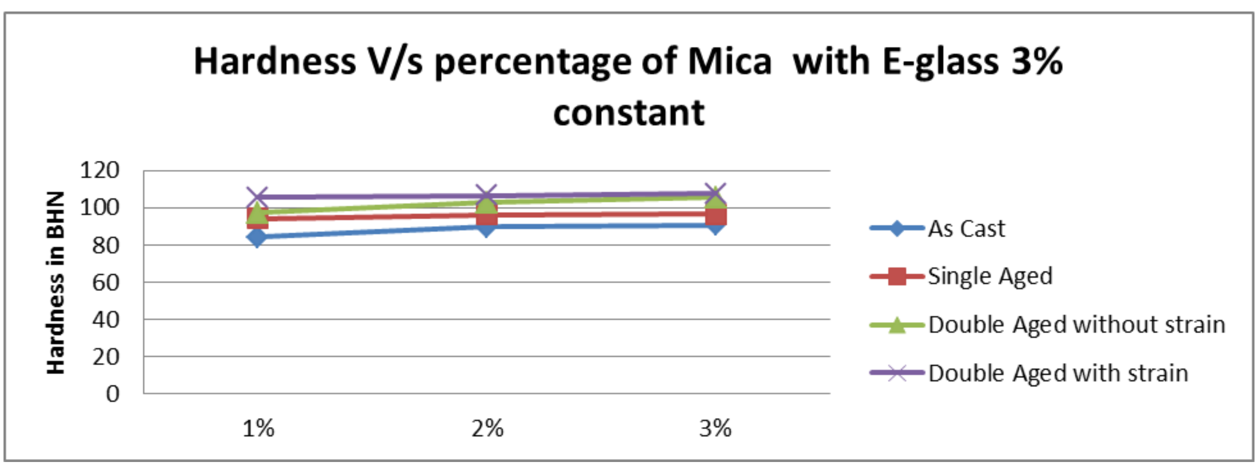
Hardness test was carried out using Brinell hardness tester. Test specimens of 20 mm thickness were machined from as-cast, single aged and double aged with strain and without strain of various compositions mentioned. Steel ball of 2.5 mm diameter and 60 Kgf load was used. The test was carried out at three different locations and the average value was taken as the hardness of the composite specimens.The results are shown as below




**Graph 1. Shows Evaluation of hardness for samples with various Mica Compositions and aging conditions with E-glass 1% constant**




**Graph 2. Shows Evaluation of hardness for samples with various Mica Compositions and aging conditions with E-glass 2% constant**



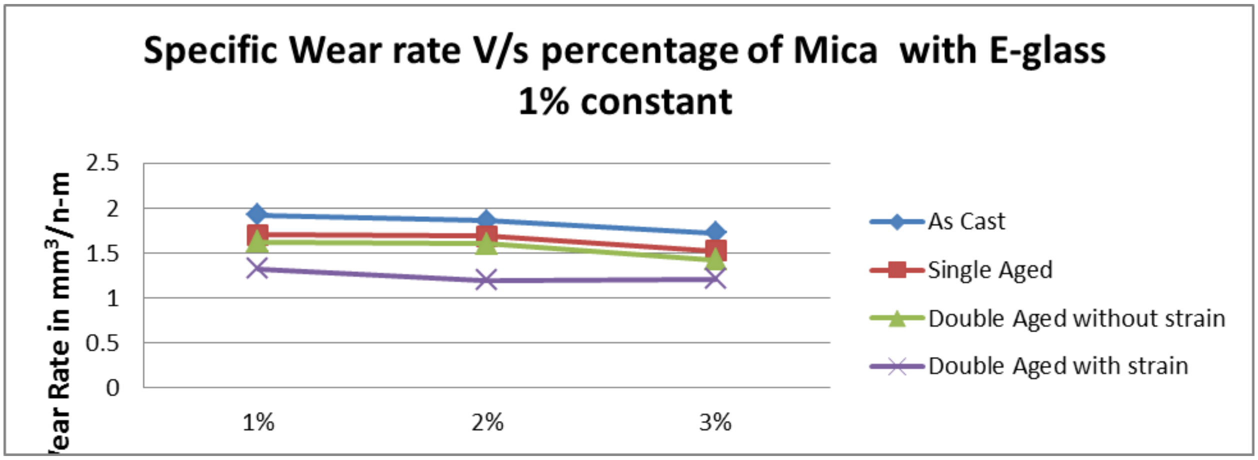

**Graph 3. Shows Evaluation of hardness for samples with various Mica Compositions and aging conditions with E-glass 3% constant**

From the above Figures it is evident that the hardness of the composite material is much higher then that of its parent metal. It is also shown that the hardness of the composite material increases with wt% of Mica and E-glass content. This is because of addition of reinforcement makes the ductile Al6061 alloy into more brittle and hard as silica content increases. And also the heat treatment and aging lead to the formation of intermetallic precipitates. In double aging the amount of precipitate and the size of the precipitates are favorable. When the specimens are subjected to strain the grains are more uniform and closer and this leads to enhanced hardness which is seen in the above graphs.

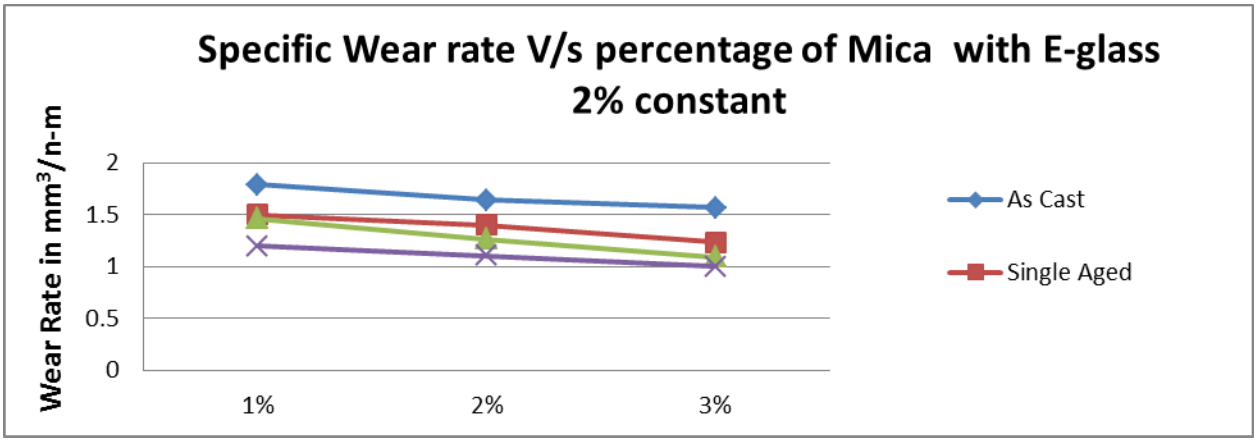
**Wear Resistance**

A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of the composites. Wear specimen of 8 mm in diameter approximately 30 mm long were prepared. Heat treated and aged as per the requirements. Test was conducted for 10 minutes with a load of 1kg and at 600 RPM. All tests were conducted at room temperature and specific wear rear rate was calculated by volume loss method. During the test, the pin was pressed against the counterpart rotating against an EN32 steel disc (hardness 65 HRC) by applying the load. All the specimens followed a single-track, 80 mm in diameter, with a tangential force. A friction-detecting arm connected to a strain gauge held and loaded the pin specimen vertically into the rotating hardened steel disc. The Specific wear rates of the composite specimens were studied as a function of the volume worn out, sliding distance, and applied load

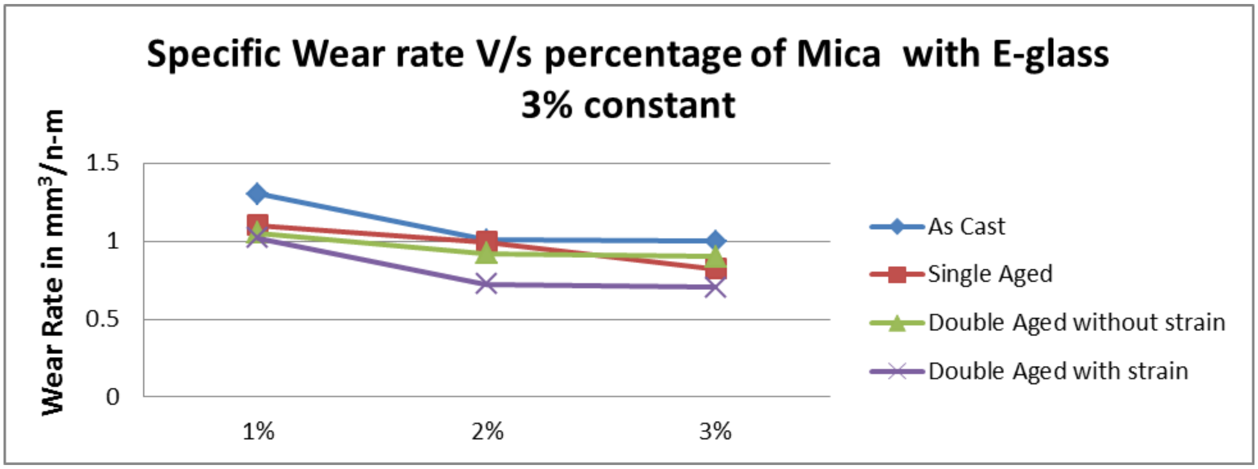
Specific Wear rate is calculated by, $Ksp=\frac{wear\ loss \times cross\ sectional\ area}{normal\ load \times sliding\ distance}$ in $mm^3/Nm$




**Graph 4. Shows Evaluation of Specific wear rate for samples with various Mica Compositions and aging conditions with E-glass 1% constant**




**Graph 5. Shows Evaluation of Specific wear rate for samples with various Mica Compositions and aging conditions with E-glass 2% constant**




**Graph 6. Shows Evaluation of Specific wear rate for samples with various Mica Compositions and aging conditions with E-glass 3% constant**

Wear rate of the composites decreased as the reinforcement increases as there drastic improvement in hardness and good bonding between the matrix and the reinforcement. The wear loss is significantly reduced with aging and lowest wear rate was observed in double aging with strain than single aged or double aged specimens which can be attributed to higher hardness as discussed earlier.

## IV. CONCLUSION

Based on this study conducted on the mica, E-glass containing Al6061 composite material, with different *aging* conditions the following conclusions can be made:

a) Using stir casting method, mica and e-glass fiber can be successfully introduced in the Al6061 alloy matrix to fabricate hybrid composite material.
b) From the microstructure analysis it is evident that the composites fabricated have fairly even distribution of reinforcements in the composite material.
c) Double aged with strain specimens show denser grain structure than other samples.
d) The hardness of the specimens increased with increase in reinforcement content in the composite. Heat treatment and aging has significant effect on hardness and double aged with strain is resulted in the peak values.
e) It is also observed that wear loss decreased with increase in reinforcement in the matrix alloy under specific test condition. Heat treatment has a profound effect on wear behavior of the composite.
f) The results obtained clearly indicate that, the double aged with strain specimens have better hardness and wear resistance compared to the single aged and double aged specimens.
g) It is evidenced that composites with 3% Mica and 3% E-glass has better hardness and wear resistance compared to other combinations

## APPENDIX

Appendixes, if needed, appear before the acknowledgment.

## ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments.

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