FORMATION OF MECHANICAL AND TRIBOLOGICAL PROPERTIES OF AL-6061 BASED METAL MATRIX COMPOSITES WITH WATER QUENCHING

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Abstract— Aluminum matrix composites (AMCs) reinforced with AL_2O_3 Powder particles are being used for high performance applications such as automotive, aerospace, military and electrical industries because of their improved physical and mechanical properties. In this research, Al2o3 and E-glass fibers particles are synthesized by Solution Combustion Synthesis process. The Al-6061 Aluminum alloy weight was constant at 1.5kg. Reinforcements are 1.0, 2.0 and 3.0weight percentages of the synthesized particles, through Stir Casting Technique. The composites were then characterized by three tests tensile wear and hardness. The tests were carried out for varying weight percentage ratios of the reinforcement at varying Solution Heat Treatment temperatures of T6 and T86 conditions. The T6 is 480ºC and 3hour heating all specimens. After heating, we quench the specimens for 5sec, using water. The T86 is for ageing of each 10 specimens using woven in that 175 º C heat they left in 6hours.The hardness and tensile were tests carried out for varying weight percentage ratios of the reinforcements with different ageing. Wear tests were carried out for varying weight percentage ratios of the reinforcements with constant Conditions of Speed, Load and Time. The proto type of tensile specimen created with the suitable dimensions using CATIA V5 R17 software. The geometrical of model specimens and its components are converted from physical domain into computational domain using discretizing the model using HYPERMESH 10 software. To create a different cell zones to apply boundary condition. The results reveal that the Hybrid Metal Matrix Composite (HMMC)'s containing 2.0 weight percentage particle reinforcement has improved mechanical properties.

Index Terms— Al-6061, Al2O3, Analysis, E-glass, Hardness, T6, T86 (conditions), Tensile, & wear.

I. INTRODUCTION

Aluminum is a relatively soft, durable, light weight, ductile and malleable metal with appearance ranging from silverative dull gray depending on the surface roughness. It makes up about 8% by weight of the earth's solid surfaces. It is a silvery white member of the boron group of chemical elements. It as the symbol Al and its atomic number is 13. It's not soluble in water under normal circumstances. Aluminium is the third most abundant element in the Earth's crust and constitutes 7.3% by mass. In nature however it only exists in very stable combinations with other materials (Particularly as silicates and oxides) and it was not until1808 that its existence was first established. It took many years of painstaking research to "unlock" the metal from its ore and many more to produce a viable, commercial production process.

Fig 1: Aluminium Metal

Fig 1 shows Pure aluminium is a silvery-white metal with many desirable characteristics. It is light, nontoxic (as the metal), nonmagnetic and no sparking Aluminium is the third most abundant element in the earth's crust, which contains 8% aluminium. It is a constituent of most rocks and in the form of aluminium silicate it is an important source of clays commercially, the most important source of the metal is bauxite which contains 52% Al_2o_3, 27.5% Fe_20_3 and 20.5% H_20. Bauxite is treated with caustic soda and claimed at 1200° produce high purity alumina. The alumina is then smelted electrolytic cell to produce pure aluminium. It is decorative and it is easily formed, machined, and cast. Alloys with small amounts of copper, magnesium, silicon, manganese, and other elements have very useful properties.

2. MATERIAL SELECTION

1.ALUMINUM ALLOY AL-6061, 2.AL_2O_3 POWDER, 3.E-GLASS FIBER

BASE MATRIX MATERIAL (AL6061)

Fig 2: Al-6061 Ingots

Fig 2 shows Base matrix material constitutes major part of the composite material. Matrix phase supports the fibers (reinforcing material) and keep them in their position, transfers the load to strong fibers, protects the fibers from damage and prevents cracks initiated at fiber from propagating. Electrical properties, chemical properties and elevated temp behavior of the composite depend on the matrix material in table 1and table 2.

Table 1: Chemical Composition Of Al-6061

SL	Silicon	Iron	Copper	Manganese	Magnesium	Chromium	Zinc	Titanium
Max	0.8%	0.7%	0.40%	0.15%	1.2%	0.35%	0.25%	0.15%
Mini	0.4%	NO	0.15%	NO	0.8%	0.04%	NO	NO

Table 2: Physical Properties

Density (g/cc)	Poisson's Ratio	Elastic Modulus (GPa)	Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation	Hardness (HB 500)	Shear Strength (MPa)	Fatigue Strength (MPa)
2.70	0.33	70 – 80	125	55	25-30%	47	125	90

REINFORCEING MATERIAL

The Foreign matter in the form of particulate fiber or ceramids which are introduced into base matrices material, to obtain a new material with improved strength and hardness. These foreign matters are known as Reinforcing Materials. Example: Mica, E-glass, Fly ash, AL_2O_3 ………etc.

AL_2O_3 powder

Fig 3: AL_2O_3 Powder

Fig 3 shows AL_2O_3 is widely distributed and occurs in igneous, metamorphic and sedimentary regimes. Large crystals of AL_2O_3 used for various applications are typically mined from granitic pegmatite's.AL_2O_3 is a clear transparent material (Aluminosilicate) with a high dielectric strength, can withstand a constant temperature of 550°C, and a melting point of approximately 2250°C.

COMPOSITIONS

AL_2O_3 IS the typical nominal composition of Ca -1.6%,Co-0.8%,Fe-0.2%,Na<300&Si-3.5%. the melting points is 2200^0C and density 3.6g/cc . It is soluble at water$\leq$.2%,PH value (10%aqueous suspension) =6.8-7.8.

PROPERTIES AND USES

AL_2O_3 has a high dielectric strength and excellent chemical stability, making it a favored material for manufacturing capacitors for radio frequency applications. It has also been used as an insulator in high voltage electrical equipment. It is also birefringent and is commonly used to make quarter and half wave plates. Because Al_2O_3 is resistant to heat it is used instead of glass in windows for stoves and kerosene heaters. The idea is to keep the metal conductors from fusing in order to prevent a short-circuit so that the cables remain operational during a fire, which can be important for applications such as emergency lighting.

Illites or clay AL_2O_3s have a low caution exchange capacity for 2:1 clays. K+ ions between layers of AL_2O_3 prevent swelling by blocking water molecules. Because AL_2O_3 can be pressed into a thin film, it is often used on Geiger-Müller tubes to detect low penetrating Alpha particles.

E-GLASS

Fig 4: Shows E-Glass Short Fibers

Fig 4 shows E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiberglass.

COMPOSITION

E-Glass is a low alkali glass with a typical nominal composition of SiO_2 54wt%, AL_2O_3 14wt%, CaO+MgO 22wt%, B_2O_3 10wt% and Na_2O+K_2O less than 2wt%. Some other materials may also be present at impurity levels.

3. EXPERIMENTAL PROCEDURE

An Electric Arc Furnace is a furnace (fig 5) that heats charged material by means of an electric arc. Arc furnaces range in size from small units of approximately one ton capacity up to about 400 ton units used for secondary steel making. Arc furnaces used in research laboratories and by dentist may have a capacity of only a few dozen grounds. Ingots of Al-6061 are pre-heated so as to remove the oil content and other contents which are slicked to the surface of the ingots. After pre-heating the ingots are added into the furnace for melting. The ingots are heated in the furnace up to their melting point about750 C. Reinforcing materials Al_2O_3 and e-glass of required composition are added to the molten metal to obtain a required composite. Degasser (fig 6) is added at the right time and temperature before reinforcement is added.

Fig 5: Mechanical Stirring

Fig 6: De-Gasser

Two halves of a mold is joined, and liquid metal is poured into the mold through a hole in the top. The metal is allowed to cool, and casting is struck by separating the two halves of the mold. Table 3 shows ratio of reinforcement and matrix material is added in the furnace.

Table 3: Shows Ratio of Reinforcement and Matrix Material (Weight In %)

Sl no	% Al_2O_3	% E-glass	% Al-6061
A0	0(0gms)	0(0gms)	100(1.5kg)
A1	1(15gms)	1(15gms)	98
A2	1(15gms)	2(30gms)	97
A3	1(15gms)	3(45gms)	96
A4	2(30gms)	1(15gms)	97
A5	2(30gms)	2(30gms)	96
A6	2(30gms)	3(45gms)	95
A7	3(45gms)	1(15gms)	96
A8	3(45gms)	2(30gms)	95
A9	3(45gms)	3(45gms)	94

MACHINING

It is process carried out after the casting process is completed; it is used to remove the excess material from the test bar. Machining(fig 7) is the process of removal of excess of material from the work, which is carried out in order to get down the casted specimen to the required specifications by making use of lathe.

Fig 7: Machining process.

HEAT TREATMENT

The procedure for heat treatment involves the following steps

Solutionizing , Quenching and Two-step aging

1. First step at lower temperature
2. Second step at higher temperature

Solution heat treatment

A treatment in which an alloy is heated to a suitable temperature and held at this temperature for a sufficient length of time to allow a desired constituent to enter into solid solution, followed by rapid cooling to hold the constituent in solution. The material is then in a supersaturated, unstable state, and May subsequently exhibit Age Hardening.

Quenching

Rapid cooling of hot metal by sudden dipping of the metal into selected fluid medium is known as quenching.

Aging

It is the change in the mechanical physical and chemical properties of metals and alloys resulting from the lack of thermodynamic equilibrium in the original state and the gradual approach of the structure to the equilibrium state under conditions that permit a sufficient diffusion rate for the atoms.

Fig 8: The Muffle Furnace

Single aging: This step is carried out at a temperature of 480 ±5°C for a period of 3hrs.

After 3hrs quench the specimens in water, dipped in each 5sec is carried out (fig 8) furnace

Double aging: After the first step aging, second step aging is carried out at 175 ±5°C for period of 6 hrs.

4. RESULTS AND DISCUSSION

BRINELL HARDNESS TESTING

Hardness is the measure of the resistance of a metal to permanent (plastic) deformation. The hardness of a metal is measured by forcing an indenter into its surface. The indenter material, it is usually a ball, pyramid, or cone, is made of a material much harder than the material being tested. After the indentation has been made, the indenter is withdrawn from the surface. An empirical hardness number is then calculated or read off a dial (or digital display), which is based on the cross sectional area or depth of impression.

Table 4: Brinell Hardness Values For Different Composition

Samples	Single aged(BHN)	Double aged (BHN)
Plain	87	86
A1	89	88
A2	91	92
A3	94	95
A4	92	93
A5	89	87
A6	87	85
A7	90	79
A8	82	76
A9	78	74

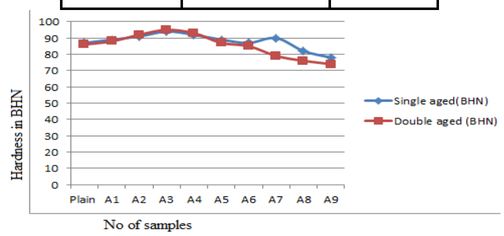

Fig 9: Hardness Number (BHN) V/S Number of Samples Tha table 4 is BHN values fig 9 show that BHN v/s sample numbers for plain (A3) AL-6061 Aluminum alloy is greater value of 95 at double aging. The A4(1% e-glass &2% Al_2O_3) both are the almost same value of 93 single and double ageing at 480^{0}C & 175^{0}C.

WEAR TEST

Wear can also be defined as a process where interaction between two surfaces or bounding faces of solids within the working environment results in dimensional loss of one solid, with or without any actual decoupling and loss of material.

Table 5: Volumetric Wear Rate (µg/m) For Single And Double Ageing

Samples	Single ageing	Double ageing
A0	0.53051	0.59577
A1	0.52046	0.53051
A2	0.51030	0.26525
A3	0.39788	0.25524
A4	0.38781	0.24523
A5	0.26525	0.23521
A6	0.25512	0.22331
A7	0.24509	0.13263
A8	0.23495	0.12252
A9	0.22490	0.11241

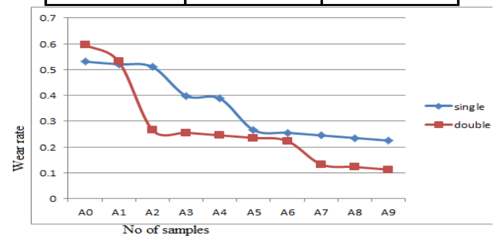

Fig 10: Specific Wear Rate V/S Number of Samples

Table 5 Volumetric Wear Rate, The above fig 10 is clear shows that double aged specimens have lesser wear rate compared to that of single aged specimens. "Composition of, 3%Al_2O_3 and 3% E-glass is better in the lot, gives the minimum volumetric wear rate.

TENSILE TEST

Tensile testing, also known as tension testing is a fundamental materials science test in which a sample is subjected to uniaxial tension until failure. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area.

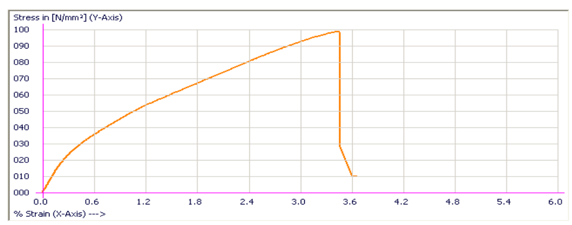

Fig 11: Stress (N/Mm^2) V/S Strain

Fig 11 shows the effect of aging on the ultimate tensile strength of 2% AL2O3 and 1% E-glass fiber metal- matrix composite it has been reported that the addition of reinforcement to aluminium alloys improves the yield strength and the UTS of the composite where as the strain to failure decreases as the weight percentage of reinforcement increase.

Table 6: Ultimate Tensile Strength for Single and Double Ageing

Samples	Single aged(mpa)	Double aged(mpa)
Plain	100.56	95.62
A1	112.87	103.3

A2	133.04	103.72
A3	146.55	121.86
A4	110.78	98.56
A5	106.37	101.61
A6	110.56	103.1
A7	116.29	106.88
A8	126.18	107.58
A9	117.23	105.76

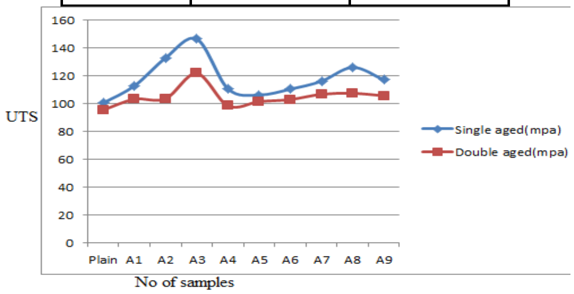

Fig 12: Ultimate Stress V/S Number of Samples

Table 6 is practical results & from the Fig 12.In that increase in percentage of Al_2O_3 composition in aluminum hybrid composite fetches little increase in Ultimate Stress as compared to percentage increase of E-glass composition which gives better Ultimate Stress to the composite.

From the Fig 12 it is very clear shows that single aged specimens have better Ultimate Stress as compared to that of double aged specimens for the A3 composition of single aged specimen gives the maximum value "Composition of 1% Al_2O_3 and 3% E-glass is better in the lot, as it gives the maximum value".

TENSILE ANALYTICAL RESULTS

Table 7: Nodal Solution of Ultimate Tensile Stress for Single and Double Ageing

Samples	Single aged in Mpa	Double aged in Mpa
Plain	102.85	98.14
A1	120.12	100.36
A2	125.12	110.48
A3	139.15	128.34
A4	129.56	117.45
A5	123.57	117.15
A6	123.17	109.19
A7	124.75	114.16
A8	130.73	115.19
A9	119.12	110.42

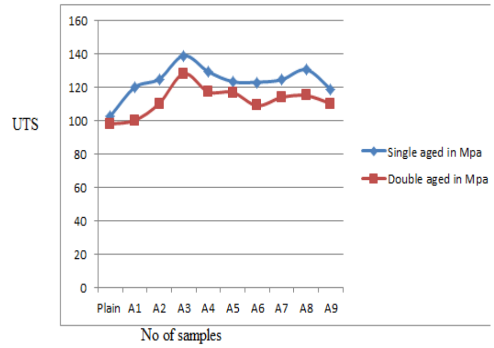

Fig 13: Ultimate Stress V/S Number Of Samples

Table 7 analytical results are plots in Fig 13, initially Ultimate Stress was low for 1% of E-glass composition and as gradually E-glass composition is increased the Ultimate Stress also increased. From the Fig 13 it is very clear that single aged specimens have better Ultimate Stress as compared to that of double aged specimens for the A3 composition of single aged specimen gives the max value

COMPRESSION OF PRACTICAL AND ANALYTICAL RESULTS

Table 8: Nodal Solution of Ultimate Tensile Stresses

Samples	P1 Single aged(mpa)	P2 Double aged(mpa)	a1 Single aged Mpa	a2 Double aged Mpa
Plain	100.56	95.62	102.85	98.14
A1	112.87	103.3	120.12	100.36
A2	133.04	103.72	125.12	110.48
A3	146.55	121.86	139.15	128.34
A4	110.78	98.56	129.56	117.45
A5	106.37	101.61	123.57	117.15
A6	110.56	103.1	123.17	109.19
A7	116.29	106.88	124.75	114.16
A8	126.18	107.58	130.73	115.19
A9	117.23	105.76	119.12	110.42

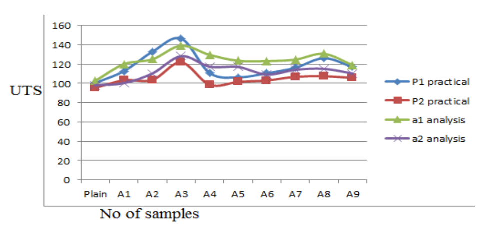

Fig 14: Ultimate Stress V/S Number of Samples

Table 8 is practical and analytical results, & from the Fig 14. It is very clear that analytical results have better Ultimate Stress as compared to that of practical results. Practical results are over laps to the analytical results but analytical results are not over laps. The A3 is the maximum value "Composition of 1% Al_2O_3 and 3% E-glass is better in the lot, as it gives the maximum value".

5. CONCLUSION

- The tests were carried out for varying weight percentage ratios of the reinforcement at varying Solution Heat Treatment temperatures of T6 and T86 conditions. The T6 is 480ºC and 3hour heating all specimens. After heating we quench the specimens each in 5sec, using the water.
- The T86 is ageing of each 10 specimens using woven in that 175 º C heat they left in 6hours.The hardness and tensile tests were carried out for varying weight percentage ratios of the reinforcements with different ageing. Wear tests were carried out for varying weight percentage ratios of the reinforcements with constant Conditions of Speed, Load and Time.
- The harness have concluded that its clear shows double aged specimens have better hardness as compared to that of single aged specimens for the A3 composition of double aged specimen gives the maximum hardness value further addition of reinforcement shows that there is no increase in the hardness and remains stable. "Composition of 1% Al_2O_3 and 3% E-glass is better in the lot, as it gives the maximum hardness value".
- They also tensile results are Ultimate Stress as compared to percentage increase of E-glass composition which gives better Ultimate Stress to the composite. From the Figs it is very clear that single aged specimens have better Ultimate Stress as compared to that of double aged specimens. Same A3 composition of single aged specimen gives the maximum value. And also analytical and practical results are same.
- The Volumetric wear rate of specimens with respect to different E-glass and Al_2O_3 composition in aluminum metal matrix composite, have initially wear rate is high for 1% of E-glass and 1% Al_2O_3 composition and has gradually E-glass composition is increased wear rate also decreases.
- From the Fig it is also clear that double aged specimens have lesser wear rate compared to that of single aged specimens. "Composition of, 3%Al_2O_3 and 3% E-glass is better in the lot, gives the minimum volumetric wear rate.

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