An Experimental Study on Mechanical Properties of E-glass Fiber Reinforced AL6061 Alloy MMCs

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Abstract: In this present work an attempt is made to prepare and study the mechanical properties of Al6061-E-Glass fiber composite, in which the length of the E-Glass fiber is 3 mm and the diameter is 17µm.The Al6061 Alloy was reinforced with different wt% of E-glass fiber i.e. 3wt%, 6wt%, 9wt% and 12wt% which were fabricated by using Stir Casting method. The ingots were subjected to heat treatment to optimize the properties, the casted specimens were of 170mm length and 20 mm in diameter .The composite specimens were machined as per ASTM E8M-2009 test standards and were subjected to tensile test in Universal Testing Machine (UTM) at room temperature .The test gives the graphs of Load(KN) vs Displacement(mm) and Stress(N/mm^2) vs Strain(%) and the mechanical properties like tensile strength and Young's modulus (E) of the unreinforced alloy i.e. pure Al6061 specimen and the composites specimens have been measured. After the tensile testing of all the specimens, it has been observed that addition of E-Glass fiber significantly improves ultimate tensile strength and also young's modulus (E) or Modulus of Elasticity as compared with that of unreinforced matrix i.e. pure Al6061.

Keywords: Aluminium Alloy 6061 (Al6061), E-Glass Fiber, Stir Casting, ASTM E8M-2009, Ultimate Tensile Strength (UTS), Young's Modulus.

I. INTRODUCTION

Composites are generally described as those materials which are formed by the combination of two or more materials, they are combined at the macro level and which are insoluble and different from their chemical composition. The composite materials comprise of the two materials out of which one material is called matrix material and another material is called reinforcing material. In composites, the combination of multiple materials allows us to make better use of its virtues while at the same time minimizing the impacts of its defects to a certain extent. Formation of composite improves properties like strength, stiffness, corrosion resistance, wear resistance, weight, fatigue life, and thermal conductivity, etc. At present, composite materials are widely used in automotive frames, sporting goods, watches, shipbuilding industry, and cement industry. Advanced composite materials are widely used in the aerospace industries.

In MMCs Aluminium, Titanium & Magnesium are some of the lighter metals which are used as the matrix metals. The MMCs have reinforcement material such as Boron nitride or metallic systems such as steel, Tungsten or Beryllium. The reinforcing agent can be in different forms such as particulates, whisker or in fiber form. Aluminum alloys are widely used as matrix material such as Al6061 and other series of aluminum alloys because they can be used in engineering structures and components where lightweight or corrosion resistance is required. Aluminum Alloy based MMCs (AMMCs) are especially applicable for sliding wear applications, because they are wear resistant materials. Aluminum Metal Matrix composites (AMMCs), are widely used in many industrial applications. They are extensively used in aircraft, aerospace, automobiles and various other fields. The components such as piston, cylinder, brake disc, pushrods, connecting rod etc use AL/Al alloys based MMCs in their applications. [1]

II. LITERATURE SURVEY

Ranganathaiah C.K et al. used Al6061 as the matrix material and E-Glass fiber as the reinforcing material and they varied the wt% of E-glass fiber i.e. 2, 4 6 8& 10%.They used stir casting method for the casting process. They subjected the ingots for T6 heat treatment to optimize the properties. The machining of specimens was done on the basis of ASTM standards. The specimens were subjected to tensile testing. It was seen that the specimen in which the composition of fiber is more, that specimen has shown the increase in ultimate tensile strength. Finally, they showed that the addition of E-Glass fiber in Al061alloy causes increase in ultimate tensile strength significantly, when they compared it with the unreinforced matrix i.e. only Al 6061 alloy without the reinforcement. Therefore the ultimate tensile strength begins to decrease above 6wt% of E-Glass fiber. [2]

Arun Kumar M.B et al. used Aluminum alloy 6061 as the matrix material and fly ash, E-glass fiber as the reinforcing materials. Aluminum alloy 6061 was reinforced with fly ash and E-glass fiber by varying the weight % i.e. they took fly ash of 2, 4, 6& 8% wt and E-glass fiber of wt 2, 4, 6&8%. The liquid metallurgy technique was carried out for casting to prepare the composite specimens. The liquid metallurgy technique was carried out for casting to prepare the composite specimens and then they were machined by using specific ASTM standards. They observed that ultimate tensile strength, hardness properties & compressive strength increased significantly due to the addition of fly ash, when they compared with an unreinforced matrix. [3]

From the literature survey, it can be said E-Glass fiber is commonly used reinforcement material because its cost is less, strength is high, stiffness is high, density is low, resistance to heat and chemical resistance is good, insensitive to moisture. Aluminum 6061 alloy (AL 6061) has a high degree of corrosion resistance and excellent performance. AL 6061 alloy has various uses such as it exhibits formability weldability and low cost.

In this present work, an effort has made to study the influence of E-Glass fiber reinforced Al 6061 composites to study the mechanical properties, by varying the reinforcements from 3%,6%,9% &12% E-Glass fiber in the Al6061 alloy, tensile properties were studied as per the ASTM standards.[4]

III. MATERIALS

Aluminium Alloy 6061 (Al6061) as Matrix

Aluminum alloy 6061 is one of the extensively used matrix material in preparation of composite materials. It is the most used alloy in 600 series in aluminum alloys. The elastic modulus of the aluminum alloy 6061 is 68.9 GPa. Its density is 2.70 gm/cc, high ductility, good machinability when compared to other alloys. This alloy is readily available and it cost is low. It can be prepared easily and can be mixed with two other different materials with the clear interface.

Figure 3.1 Al6061Alloy Ingots

E-Glass Fiber as Reinforcement

E-Glass fiber is commonly used reinforcement, because of its low cost. It is also known as fiberglass. The E-Glass fiber used in this project is 3 mm and 17µm.There are some properties which make E-Glass fiber so popular that they are used widely as reinforcing material i.e. they have relatively low density, heat resistance, high production rates, high strength, high stiffness and good electrical insulation.

Figure 3. 2 E-Glass fiber

Table 3.1 Average properties of E-glass fiber

Sl.No	Properties	E-Glass
1	Specific Gravity	2.54
2	Tensile Strength (MPa)	2000
3	Young Modulus (GPa)	80
4	Diameter range (microns)	3 to 20
5	Density(g/cm^3)	5

IV. EXPERIMENTAL PROCEDURE

According to the calculations, a known quantity of Al6061 alloy is made to pour into the clay graphite and then it is placed into the casting Induction furnace, where the furnace is connected with the electric motor. Aluminum alloy 6061 (Al6061) which is placed inside the crucible will get melted under the temperature condition of 770^0C. Then the melt in the furnace was made to stir by using a mild steel stirrer, which is used for the stirring process. After it reaches the melting point, it is taken out of the clay graphite crucible of the Induction furnace and then it is poured into the die. The casting die is made by high stainless steel as per the required dimensions (170mm length, 20mm diameter), after pouring the obtained mold into the die we will get the desired specimens of required length and diameter of aluminum alloy 6061 (Al6061) specimens. Now we have to consider the E-Glass fiber with different volume fractions (0%, 3%, 6%, 9% &12%) and they are mixed with the matrix material i.e. Al6061.In order to carry out the first volume fraction, the required materials are measured by the weighing machine and appropriate calculations were made for all the volume fractions. For example, the initial volume fraction is carried out by the mixture of matrix material and (3%) E-glass fiber is put in the furnace and then it is heated to required temperature. After reaching its melting point, the melt was stirred using a mild steel stirrer and then it was poured into the die. We then get the composite specimens for first volume fraction which is a composite of E-Glass fiber as the reinforcing material and Al 6061 as matrix material. The experimental procedure is repeated for second third and fourth volume fractions, by varying the volume fractions.

As this experiment is carried using mild steel stirrer it is named as stir casting process. In this experiment, we make use of the Induction furnace which is made by high stainless steel and the stirrer is made of mild steel, whereas the melting point of steel is high when compared to that of aluminum.

Table 4.1 Chemical composition of Al6061 by weight %

Sl.No	Composition	Wt%
1	Mg	0.920
2	Si	0.750
3	Fe	0.280
4	Cu	0.220
5	Ti	0.100
6	Cr	0.070
7	Zn	0.060
8	Mn	0.040
9	Be	0.003
10	V	0.010
11	Al	Balance

Table 4.2 Chemical compositions of E-glass fiber by wt %

Sl. No	Chemicals	Compositions (%)
1	SiO_2	54.3%
2	Al_2O_3	15.2%
3	CaO	17.2%
4	MgO	0.6%
5	B_2O_3	0.8%

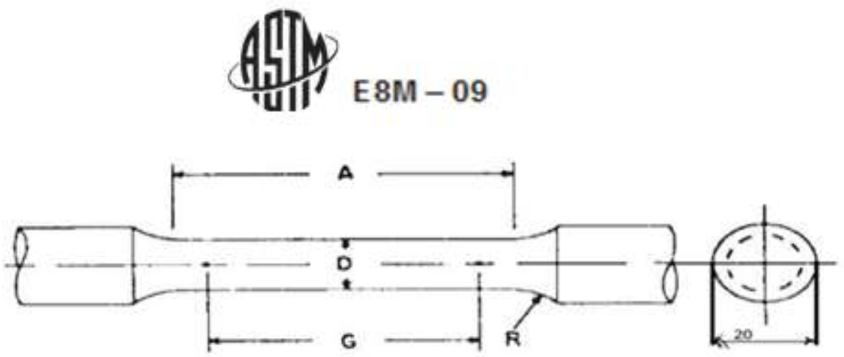
V. SPECIMEN PREPARATION AND TESTING

The machining operation was carried out by using lathe according to ASTM standards. The casting specimens are subjected to machining operation as per ASTM standards. The casted specimens were machined with the help of Lathe machine as per ASTM E8M-09 standard.

Tensile Test

The tensile test is carried out using a Universal testing machine of 40-ton capacity and as per the ASTM E8M-04 standard. An extensometer is used for 0.2 % proof stress reading. it measures the parameters such as Ultimate Tensile load, ultimate tensile strength and the graph of tensile load vs displacement and Stress vs Strain is obtained from the tensile strength testing from this Graph we can obtain the modulus of elasticity.

The tensile testing for these specimens is tested by using UTM which gives the digital reading results by which we can obtain Load(KN) vs Displacement(mm) graph and Stress vs Strain graph, as for varied composition of reinforcing material E-glass fibers and the Al6061 matrix the. Results of the specimens can also vary like peak load, yield stress, and tensile strength, Elongation in %. The tensile strength increases for the different volume fraction (0%, 3%6%, 9%, &12%) of E-glass fibers.



	Dimensions, mm
	Standard Specimen
G—Gage length	62.5 ± 0.1
D—Diameter (Note 1)	12.5 ± 0.2
R—Radius of fillet, min	10
A—Length of reduced section, min (Note 2)	75

Figure 5.1 Dimensions of specimen as per ASTM E8M-04standard. [4]

Figure 5.2 Machined Tensile test specimens as per ASTM Standards

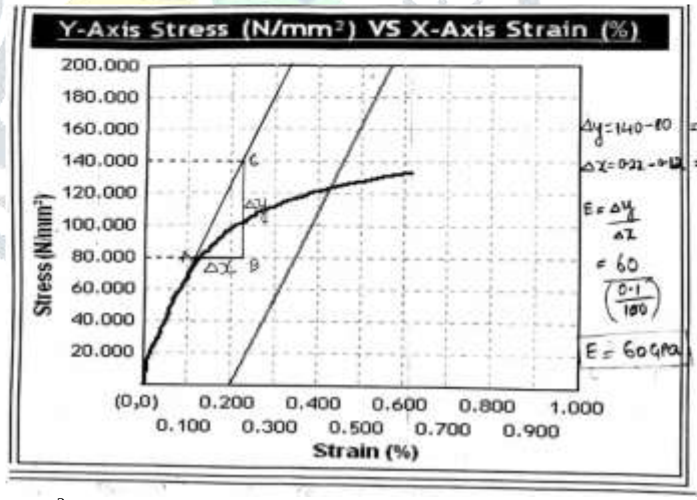
Figure 5.3 Specimens after tensile testing

VI. RESULTS AND DISCUSSION

In this study work tensile test was carried out. For every specimen Load (KN) vs Displacement (mm) graph is shown for each volume fraction. Tensile testing of pure Al6061 specimen and also four volume fractions i.e. 3%, 6%, 9% &12% were carried out. For every specimen Load (KN) vs Displacement (mm) graph is obtained for each volume fraction. Simultaneously the Stress (N/mm^2) strain (%) graph is also obtained for every specimen. From the Stress (N/mm^2) vs Strain (%) graph Young's Modulus is calculated with the help of the slope. The Young's Modulus vs % weight of E-Glass Fiber is plotted and also the Ultimate Tensile Strength vs% weight of E-Glass Fiber is plotted.

Experimental Results

A typical calculation is shown to calculate the young's modulus (E) by using the obtained graphs during tensile testing. The same procedure is applied to all the specimens in order to calculate the young's modulus (E).



Graph 6.1Stress (***N/mm***^{2}) vs Strain (%) for Specimen T_3 of 3% volume fraction

Draw a line tangent to the yield point curve and then draw a right angle triangle ABC on that line as shown in graph 6.16.Measure the distance between BC (stress in N/mm^2) and AB (strain in %).then the measured values use to calculate young's modulus. A typical calculation is shown below

From the above graph the young's modulus will be,

$$E = \frac{Stress}{Strain} = \frac{\Delta y}{\Delta x} = \frac{60}{0.001} = 60{,}000 MPa$$

***E*=60GPa**

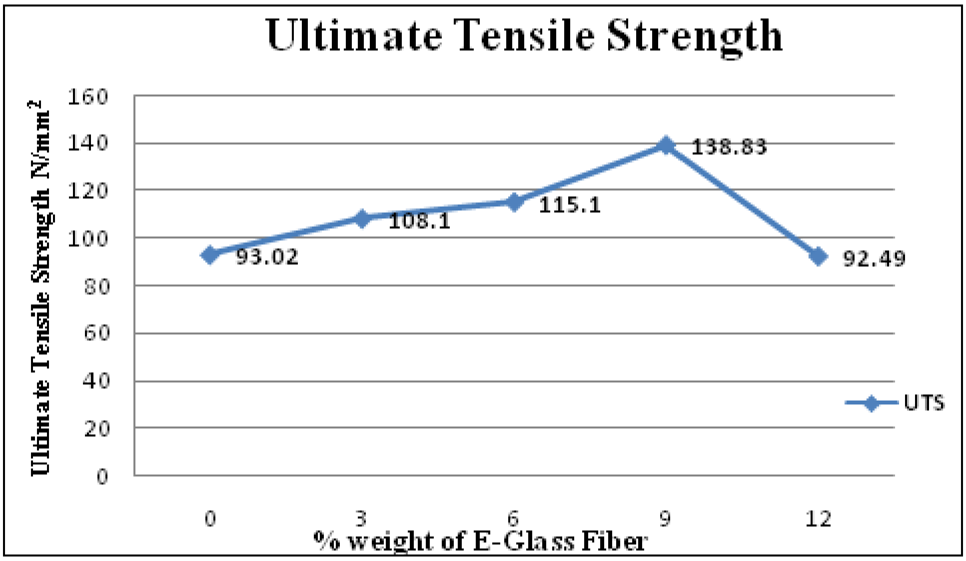
Tensile Test Results

The values of young's modulus are calculated from the graphs and its corresponding ultimate tensile strength is tabulated in the table 4 along with its average values which are obtained during tensile testing.

Table 6.1 Young's Modulus and UTS from Graphs of all volume fractions

Sl.No	**Composition**	**Specimen**	**Ultimate load (KN)**	**Ultimate Tensile Strength (N/mm^2)**	**Average ultimate tensile strength (N/mm^2) (Best of two)**	**Young's modulus (E) GPa**	**Average (E) GPa(Best Of two)**
1	100% Al 6061	T_1	10.520	90.440	93.02	35.5	30.25
2		T_2	11.360	95.607		25	
3	97%Al6061+3% E-Glass fiber	T_1	9.320	77.428	108.10	53.33	56.66
4		T_2	12.360	101.695		46.15	
5		T_3	16.760	138.788		60	
6	94%Al 6061+6%E-Glass fiber	T_1	12.400	104.694	115.10	40	64.855
7		T_2	13.640	119.607		44	
8		T_3	13.120	110.596		85.71	
9	91%Al 6061+9%E-Glass fiber	T_1	18.360	152.771	138.83	42.22	33.11
10		T_2	17.240	136.522		23.84	
11		T_3	14.720	124.894		24	
12	88%Al6061+12%E-Glass fiber	T_1	10.840	91.377	92.49	28.2	33.3
13		T_2	11.160	93.616		38.4	
14		T_3	10.680	87.305		28.12	

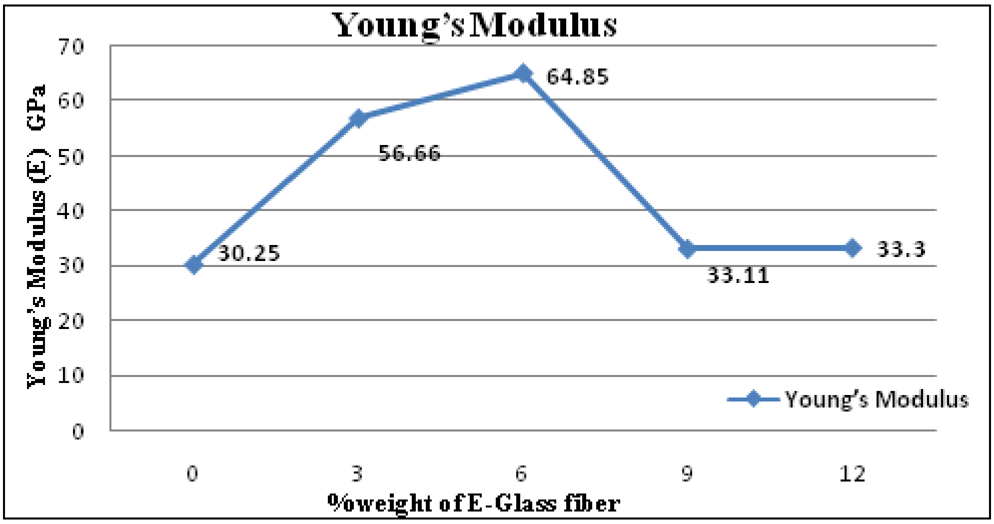
Tensile Strength



Graph 6.2 Ultimate Tensile Strength vs % weight of E-Glass Fiber

The Ultimate Tensile Strength (UTS) for all the specimens are tabulated in the table 4. The graph 3 represents the variation of Ultimate Tensile Strength along with %wt of E-Glass fiber for all the volume fractions i.e. 0, 3, 6, 9& 12% having 3% increase in each volume fraction. It was seen that Ultimate Tensile Strength of Al6061 significantly improved with the addition of E-Glass fiber, when it was compared with the results of unreinforced matrix material i.e. Al6061 alloy.

Young's Modulus



Graph 6.3 Young's Modulus vs % weight of E-Glass Fiber

The young modulus for all the specimens are calculated, and its average values are calculated and tabulated in the table.4. The graph 2 represents the variation of Young's modulus along with %wt of E-Glass fiber for the volume fractions 0, 3, 6, 9 &12 %, having 3% increase in each volume fraction. It was seen that Young's modulus of Al6061 significantly improved with the addition of E-Glass fiber, when it was compared with the results of unreinforced matrix material i.e. Al6061 alloy.

VII. THEORETICAL PROCEDURE

Halpin Tsai model **[5]**

Halpin Tsai model is a mathematical formulation used to calculate young's modulus of random distribution of reinforcement in matrix material. The formulae which are used to calculate young's modulus as follows.

$$E_{11} = \frac{1+2\left[\frac{l_f}{d_f}\right](\eta_L V_f)}{1-[\eta_L V_f]} E_m \text{ .... (Eqn.7.1)}$$

$$E_{22} = \frac{1+2(\eta_L V_f)}{1-[\eta_L V_f]} E_m \text{ .... (Eqn.7.2)}$$

$$\eta_L = \frac{\left[\frac{E_f}{E_m}\right]-1}{\left[\frac{E_f}{E_m}\right]+2\left[\frac{l_f}{d_f}\right]} \text{ .... (Eqn.7. 3)}$$

$$\eta_t = \frac{\left[\frac{E_f}{E_m}\right]-1}{\left[\frac{E_f}{E_m}\right]+2} \text{ .... (Eqn.7. 4)}$$

$$E_c = \frac{3}{8}E_{11} + \frac{5}{8}E_{22} \text{ .... (Eqn.7. 5)}$$

Where,

E_{11} = Modulus of elasticity in longitudinal direction.

E_{22} = Modulus of elasticity in transverse direction.

E_c = Modulus of elasticity of composite.

l_f = Length of E-Glass fiber.

d_f = Diameter of E-Glass fiber.

E_f =Modulus of elasticity of E-Glass fiber.

E_m =Modulus of elasticity of matrix material.

Table 7.1 Properties of fiber and matrix.

Sl.No.	Properties	E glass fiber	Al 6061
01	Young's Modulus, E(GPa)	80	68.9
02	Length of fiber, l_f (m)	3×10^{-3}	-
03	Diameter of fiber, d_f (m)	1.7×10^{-5}	-

Table 7.2 young's modulus of composite material

Sl.No	Volume fraction (V_f)	Longitudinal E E_{11} (GPa)	Transverse E E_{22} (GPa)	E of Composite E_c (GPa)
1	0.03	69.30	69.22	69.25
2	0.06	69.63	69.53	69.56
3	0.09	69.96	69.84	69.88
4	0.12	70.22	70.17	70.18

.

Pan's model **[6]**

Ning Pan developed a new approach to predict the modulus of elasticity for fiber reinforced composites. He used the volume fractions and elastic modulus of the matrix material and E-Glass fiber to calculate the elastic modulus of composite for two dimension case.

The Pan's Equation for composite material is written as,

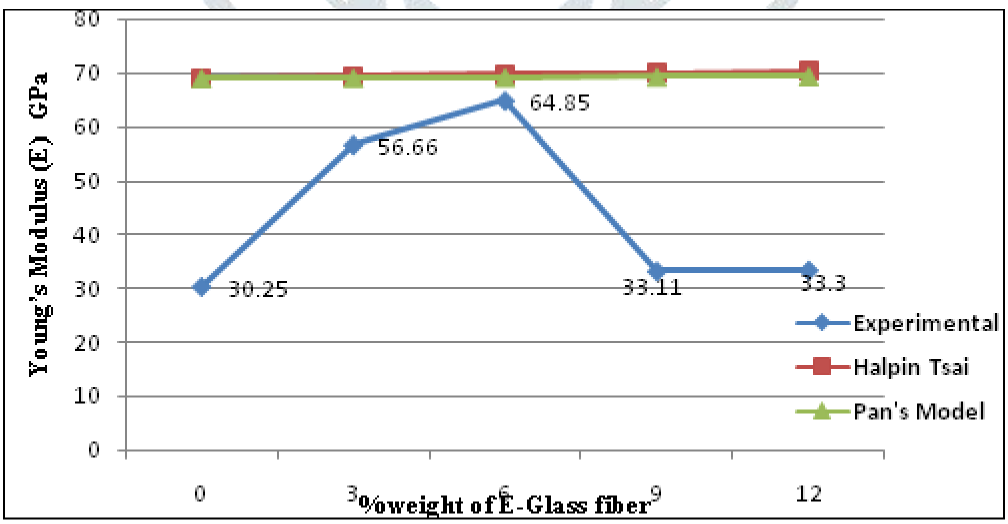
$$E_c = E_f\left[\frac{V_f}{\pi}\right] + E_m\left[1-\frac{V_f}{\pi}\right] \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eqn.7. 6)}$$

VIII. COMPARISON OF EXPERIMENTAL AND THEORETICAL RESULTS

Table 7 shows the comparison of Young's modulus for both Experimental and Theoretical values carried out for each volume fraction

Table 8.1 Comparison of theoretical and experimental results

Sl. No.	Volume fraction	Experimental Values E(GPa)	Theoretical values	
			Halpin Tsai model E (GPa)	Pan's model E(GPa)
1	Al 6061	30.25	68.9	68.9
2	3% E-Glass fiber	56.66	69.25	69
3	6% E-Glass fiber	64.85	69.56	69.11
4	9% E-Glass fiber	33.11	69.88	69.21
5	12% E-Glass fiber	33.3	70.18	69.32



Graph 8.1Comparison of Experimental and Theoretical results

Table 7, shows the comparisons made after obtaining theoretical and experimental results which includes volume fraction, the results of Young's modulus obtained by experimental and theoretical. Halpin Tsai equation and pans model which are used to calculate young modulus theoretically, which is then compared with the experimental results obtained.

From the graph 4, it is shown that value of Young's modulus in experimental results will increase as the % weight of E-Glass fiber increases in Al 6061(matrix material). For 3% volume fraction Young's modulus is 56.66 GPa whereas for 6% the value increases to 64.85 GPa, as the E-Glass fiber weight % increases in Al6061 alloy the value of Young's modulus increases. It is also seen that there is a decrease in value of Young's modulus for 9%, it is because of the cracks and void present in the material and sometimes due to casting process there will be some problems, and after that there were slight increases in the value of Young's modulus for 12%.

IX. CONCLUSION

Based on the study of E-Glass fiber reinforced Al6061 composites, the following Conclusions can be drawn.

- Aluminum alloy (Al6061) with a specific composition along with the E-Glass fiber of length 3mm and diameter 17μm is selected as a matrix material and reinforcement material respectively in this project work.
- The E-Glass fiber was effectively reinforced with Al6061 alloy matrix by the Stir casting method to prepare the composite specimens as per ASTM standards to carry out tensile test.
- The results of this test indicated that there is an increase in tensile strength of the composite specimens was better than the base metal (Al6061 alloy).
- When Al6061 is reinforced with 3%, 6%, 9% &12% of E-Glass fiber, tensile strength of composite specimens was found to be increased.
- Ultimate Tensile Strength & Young's modulus of Al6061 significantly improved with the addition of E-Glass fiber, when it was compared with the results of unreinforced matrix material i.e. Al6061 alloy.

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