A Study on Mechanical properties of Basalt Fiber Reinforced Aluminium alloy (LM25) Composite.

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Abstract: *The aim of the study was to investigate the tensile strength properties of short basalt fiber reinforced Al alloy (LM25) composites. The LM25/short basalt fiber metal matrix composite consists of a 3mm length and 15 to 20 microns diameter of basalt fiber and the volume fractions ranging from 1 % to 5 % in step of 1% and fabricated using stir casting technique. The tensile properties of LM25/short basalt fiber composite samples and the unreinforced alloy samples were experimentally evaluated. The tensile test was carried out as per the ASTM E8M:2009 standards at room temperature in UTM machine. The theoretical strength values were calculated by Halpin Tsai and Pan's Equations and then compared with experimentally found values. The results show that as the short basalt fibers content was increased from 1% to 5% by volume %, an improvement of Ultimate tensile strength (UTS) and Young's modulus values have been observed.*

Key words: *Aluminum alloy (LM25), Short Basalt fiber, Stir casting, ASTM E8M:2009, Ultimate Tensile strength (UTS) and Young's modulus.*

I. INTRODUCTION

In recent years, there has been an increasing demand from automobile, space and aerospace industries for materials possessing high specific strength, better wear resistance, and stability at high temperatures. The process of improving the properties of conventional engineering materials has led to the technique of reinforcing polymers, ceramics, and metals with particles, fibers, and whiskers, thus leading to the production of composites [1]. The Composite material can be described as the material consists of 2 or more materials together at macroscopic level produces single material of desirable properties that cannot be achieved with any of the material alone. One material is termed the reinforcement and the one in which reinforcement material is mixed is termed the matrix [2]. The reinforcing material is in fiber-type, particulate-type, or in flake type. The matrix materials are typically in uninterrupted form. For examples, epoxy strengthened with carbon fibers, concrete strengthened with steel, and aluminium and its alloy reinforced with Silicon Carbide and many more.

Before making the Aluminium alloy MMC, many papers are studied in which the addition of Silicon carbide, Red mud, E-glass fiber, Basalt fiber, fly ash, alumina, and Graphite etc. has been created and Tribological and mechanical properties were studied[5]-[9]. Some of them are as follows.

The two most typically used metal matrices area unit supported aluminium alloy and titanium alloy. Each of those metals has relatively fewer densities and is available in a variety of alloy forms [4]. Aluminium and its alloy have attracted the foremost attention as matrix material in metal matrix composites. Commercially, pure aluminium has been used for its smart corrosion resistance. Aluminium alloys, like 6061, 7075, LM6, and LM25 are used for their higher tensile strength-weight ratios.

Tensile and impact properties of alumina and fly ash reinforced aluminium alloy LM25 composite with alumina 3% weight fraction and fly ash varying from 5% to 15 % were studied [5]. The results found that by the addition of alumina, tensile strength and the hardness were increased and due to poor wettability and reinforcing high amount of fly ash reduces tensile strength.

MMCs reinforced with ceramic materials and short fibers give higher tensile strength, ductility, impact strength and hardness up to certain proportion after that ductility of the composite have been decreases gradually [6].

EzhilVannan and S. Paul Vizhian [7] studied Al 7075/Basalt Metal-Matrix Composites (MMCs) contains short basalt fiber from 2.5 percentages to 10 percentages in step size of 2.5 wt. percentages and manufactured using squeeze infiltration technology. They made the comparison of theoretical results by Mori and Tanaka equation, shear-lag, computational model, Nielsen-Chen equation and Miwa's equation with experimental results.

R. Karthigeyan et al [8] studied Aluminium alloy 7075 reinforced with short basalt fiber with a volume fraction of 2% to 6% and got improvement in tensile strength and tensile ductility values. They got the maximum tensile strength of Aluminium alloy 7075/Basalt fiber composite when reinforced with 6 vol. % was increased by 65.51%.

Short fibers composites are the foremost commonly used reinforcements to boost mechanical properties of ceramics, metals, and polymers. When put next to continuous fibers bolstered composites, short fibers bolstered composites can be simply processed with affordable cost. The foremost necessary factors within the short fibers reinforcement are fiber dispersion and aspect ratio [9].

However, there is no study of the effect of short Basalt fiber volume fraction mixed with Al LM25 alloy. Hence in this work, different volume fraction of short Basalt fibers are mixed with Al and its properties were studied. 5 different volume fractions i.e., 1%, 2%, 3%, 4%, and 5% are chosen for the study.

II. MATERIALS

Aluminium Alloy LM25

The Aluminium alloys are alloyed in which Al is the predominant metal. The LM25 material conforms to British Standards 1490-1988.The main constituents of Al alloy LM25 are Silicon, Magnesium, and Iron. This alloy available in four heat treatment conditions in both chill and sand cast. In this research work as cast LM25-M standard was used.

Table 2.1 Chemical Composition of aluminium alloy LM25 [11].

Element	Mg	Cu	Si	Fe	Mn	Ni	Zn	Sn	Tin	Al
% Weight (Max)	0.2-0.6	0.1	6.5-7.5	0.5	0.3	0.1	0.1	0.1	0.05	Balance

Table 2.2 Mechanical Properties of aluminium alloy LM25 [11].

LM25	**SAND CAST**	**CHILL CAST**
0.2 % Proof Stress (MPa)	80-100	80-100
Tensile Strength (MPa)	130-150	160-200
Elongation (%)	2	3
Brinell hardness No.	55-65	55-65
Young's Modulus (GPa)	71	71
Density (g/cm^3)	2.68	2.68

BasaltFiber

Basalt fiber is a new reinforcement material to MMCs and it is a type of lava rock available on the surface of a planet. Manufacturing of basalt fiber uses crushed basalt rock as a raw material and produced in continuous fiber form through igneous basalt rock melt drawing process at high temperature (1500^{0}C) [12].Chopped Basalt fiber (3mm × 20 micron Ø) was purchased from Go Green Products, Chennai, India.

Table 2.3 Chemical composition of basalt fiber

Element	Al_2O_3	SiO_2	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO
%	14.18	69.51	3.92	2.41	5.62	2.74	1.01	0.55	0.04

Table 2.4 Mechanical Properties of Basalt Fiber

Specific Gravity (g/cm^3)	2.7
Young's Modulus (GPa)	86-90
Tensile strength (MPa)	2800-4800
Strain at Break (mm/mm)	0.0315

Volume fractions of composite

The Aluminium alloy (LM25)/basalt fiber composite contains 5 volume fractions ranging from 1 percent to 5 percent in a step size of 1 percentage are shown in table 2.5.

Table 2.5 Volume fractions of composite.

Volume fraction	**Al alloy (LM25)**	**Basalt fiber**
Unreinforced	100 %	0 %
VF1	99%	1 %
VF2	98 %	2 %
VF3	97 %	3 %
VF4	96 %	4 %
VF5	95 %	5 %

Figure 2.1 Al alloy LM25 Ingots and Short basalt fibers.

III. EXPERIMENTAL SETUP AND PROCEDURE

Specimen Preparation

Stir casting technique is used for the preparation of Al/basalt fiber composite. It is a low-cost process for the fabrication of discontinuous metal matrix composites. An Induction furnace is used to melt the matrix material. Required amount aluminium alloy LM25 taken in a graphite crucible and kept it in an Induction furnace for melting. As the matrix material starts melting and reaches a temperature of 600^0C, at that temperature the preheated reinforcement (short basalt fiber) was added in molten metal. At another side, the cast iron dies of size 170mm in length and 20mm in diameter was preheated up to 100^0C and clamped properly using C-clamp. After adding reinforcement the temperature in the furnace is raised to 800^0C to have the self-stirring process. And also the stirring was done with the help of stirring mechanism at 300 RPM for 2 to 3 minutes.

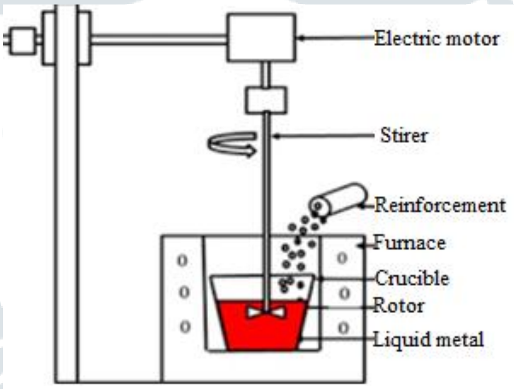
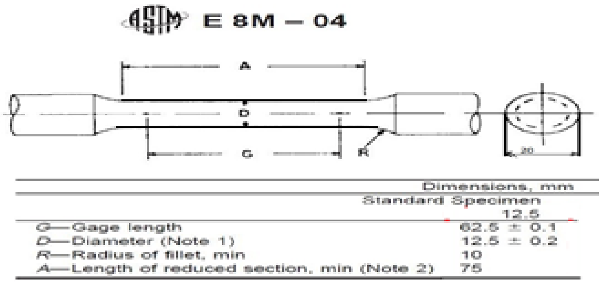


Figure 3.1 Stir casting setup

The hot molten composite in the crucible now poured into the cast iron die. After solidifying, the casted parts were removed from the die and kept for further cooling. Inspect the cylindrical cast ingots visually, if it cast properly then mark the respective volume fraction on it

Figure 3.2 casted cylindrical composite ingot

The casted composite ingots were machined with the help of Lathe machine as per ASTM E8/E8M:2009 standard.



	Dimensions, mm
	Standard Specimen
	12.5
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 3.3dimensions of specimen as per ASTM E8M standard [10]

Tensile Testing

The Tensile strength test is carried out using the Universal testing machine of 40-ton capacity and as per the ASTM standard E8M-09. An extensometer is used for 0.2 % proof stress reading.

Figure 3.4 Tensile test specimens after testing.

IV. RESULTS AND DISCUSSION

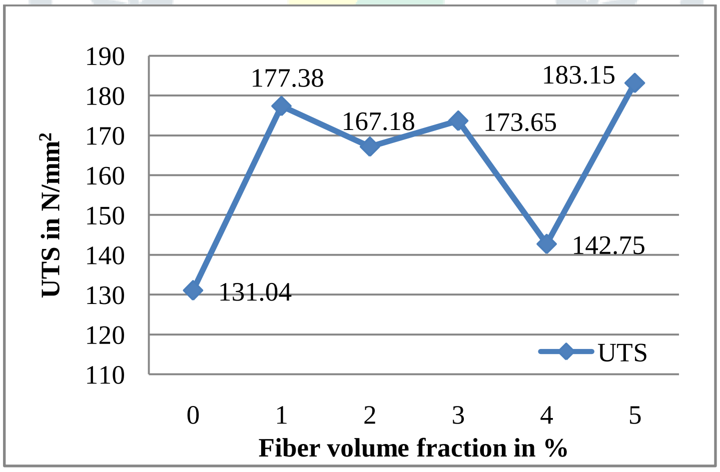
Experimental Results

Tensile Strength

Mean value of three specimen results for all the volume fractions of Al LM25/Basalt fiber composite is shown in table 4.1. The results indicate an improvement in tensile strength with the increase in basalt fiber addition. As compared to the strength of matrix material, there is an increase of 30% strength at 5% fiber volume fraction (Graph 4.1). Generally,the ductility of composite decreases with increase in strength but in this case the ductility or % elongation also increased with increase in the fiber volume fraction.

Table 4.1 Tensile strength results of all volume fraction composites.

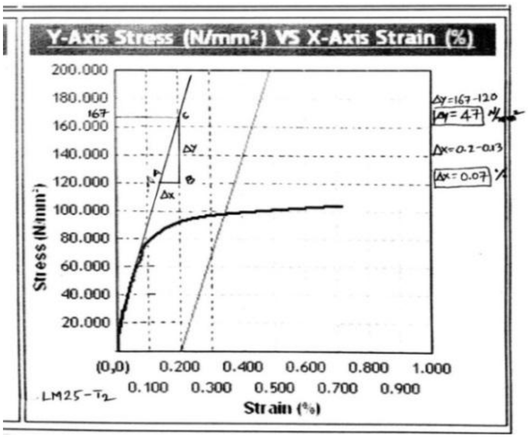
Sl. no.	Volume fraction	Peak Load in KN	Ultimate Tensile Strength in (N/mm^{2}or MPa)	Elongation (%)
1	Unreinforced	15.8	131.04	1.07
2	VF1	21.30	177.38	2.33
3	VF2	20.38	167.18	2.60
4	VF3	20.84	173.65	1.94
5	VF4	16.86	142.75	2.58
6	VF5	22.26	183.155	2.26



Graph 4.1 Line chart of Ultimate Tensile Strength.

Young's Modulus

TheYoung's modulus is calculated by using the slope of stress v/s strain graph. Draw a line tangent to the yield point curve and then draw a right angle triangle ABC on that line as shown in graph 4.2. .Measure distance between BC (stress in N/mm^2) and AB (strain in %).then the measured values used to calculate Young's modulus. A typical calculation is shown below.



Graph 4.2 shows stress v/s strain for specimen 2 of VF1 volume fraction

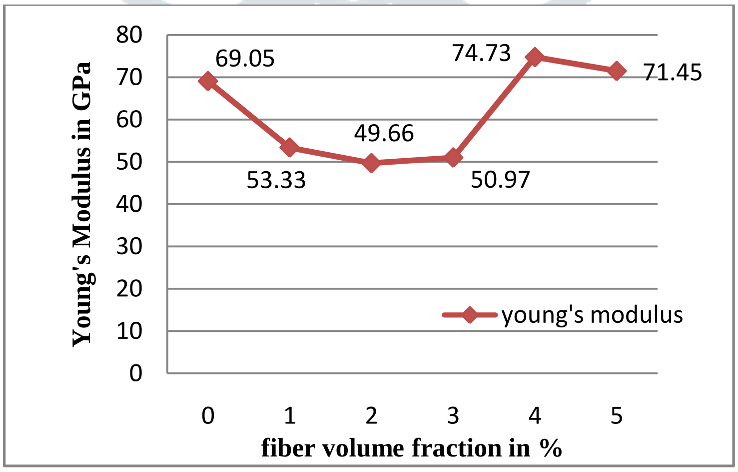
From the graph Young's modulus would be,

$$E = \frac{stress}{strain} = \frac{\Delta y}{\Delta x} = \frac{45.33}{0.085} \times 100 = 53.33 GPa$$

The graphical calculation of Young's Modulus for remaining volume fraction would be same. And results for all volume fractions are shown in following table 4.2. The results indicate that overall improvement in Young's modulus compares to the unreinforced matrix material. The Young's modulus of 1%, 2%, and 3% volume fraction is less than the value of matrix material but at 4% and 5% volume fraction young's modulus values are greater than values of the matrix material (Graph 4.3).

Table4.2 young's modulus from graphical method.

Sl. no.	Volume fraction	Stress(Δy) MPa	Strain(Δx) (%)	Young's Modulus $E = \frac{\Delta y \times 100}{\Delta x}$ (GPa)
1	Unreinforced	43.5	0.063	69.05
2	VF1	45.33	0.085	53.33
3	VF2	46.33	0.0933	49.66
4	VF3	39.5	0.0775	50.97
5	VF4	46.33	0.062	74.73
6	VF5	40	0.056	71.43



Graph 4.3 Line chart of Young's modulus

Theoretical Results

The theoretical calculation for Young's Modulus of short fiber reinforced composites can be computed from two approaches. One is Halpin Tsai model and another is Pan's model.

Halpin Tsai model [13]

Halpin Tsai model is a mathematical formulation used to calculate Young's modulus of random distribution of reinforcement in the matrix material. In this model, both longitudinal and transverse direction of elastic modulus is considered for calculation of elastic modulus of the composite material.

The Halpin Tsai Equation for two-dimensional case of short fiber composite can be written as,

$$E_c = \frac{3}{8}E_{11} + \frac{5}{8}E_{22} \text{ ………………………………. (Eqn. 4.1)}$$

Longitudinal Modulus (E_{11}) of short fiber composites can be written as,

$$E_{11} = \frac{1+2\left[\frac{l_f}{d_f}\right]\left(\eta_L V_f\right)}{1-\left[\eta_L V_f\right]}E_m \text{ …………………….. (Eqn.4.2)}$$

Transverse Modulus (E_{22}) of short fiber composites can be written as,

$$E_{22} = \frac{1+2\left(\eta_L V_f\right)}{1-\left[\eta_L V_f\right]}E_m \text{ ………………………….. (Eqn. 4.3)}$$

Where,

$$\eta_L = \frac{\left[\frac{E_f}{E_m}\right]-1}{\left[\frac{E_f}{E_m}\right]+2\left[\frac{l_f}{d_f}\right]} \text{ …………………………. (Eqn. 4.4)}$$

$$\eta_t = \frac{\left[\frac{E_f}{E_m}\right]-1}{\left[\frac{E_f}{E_m}\right]+2} \text{ ………………………………. (Eqn. 4.5)}$$

Where,

E_{11} = Longitudinal modulus, E_{22} = Transverse modulus, E_c = Tensile Modulus of composite.

l_f = Length of basalt fiber, d_f = Diameter of basalt fiber, E_f =Tensile Modulus of the basalt fiber.

E_m =Tensile Modulus of the matrix material, and V_f =Fiber volume fraction

Table 4.3 Properties of short Basalt fiber and LM25.

Sl.no.	Properties	Basalt fiber	Al LM25
01	Young's Modulus, E(GPa)	89	71
02	Length of fiber, l_f (m)	$3*10^{-3}$	-
03	Diameter of fiber, d_f (m)	$2*10^{-5}$	-

Table 4.4 shows tensile modulus (E) of composite material.

Sl.no.	Volume fraction of Basalt fiber (V_f)	Longitudinal modulus E_{11}(GPa)	Transverse modulus E_{22} (GPa)	Young's modulus of Composite E_c (GPa)
1	0.01	71.18	71.16	71.17
2	0.02	71.35	71.33	71.33
3	0.03	71.54	71.50	71.51
4	0.04	71.72	71.67	71.69
5	0.05	71.90	71.83	71.86

Pan's model [14]

Ning Pan developed a new approach to predict the Young's Modulus for fiber reinforced composites. He used volume fractions and elastic modulus of the fiber and matrix materials to calculate the elastic modulus of composite for two dimension case.

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

$$E_c = E_f \left[\frac{V_f}{\pi} \right] + E_m \left[1 - \frac{V_f}{\pi} \right] \text{……………………………. (Eqn. 4.6)}$$

By submitting values of volume fraction and young's modulus of matrix and reinforcement in equation 4.6 we get,

Table4.5 Young's modulus of composites by Pan's model

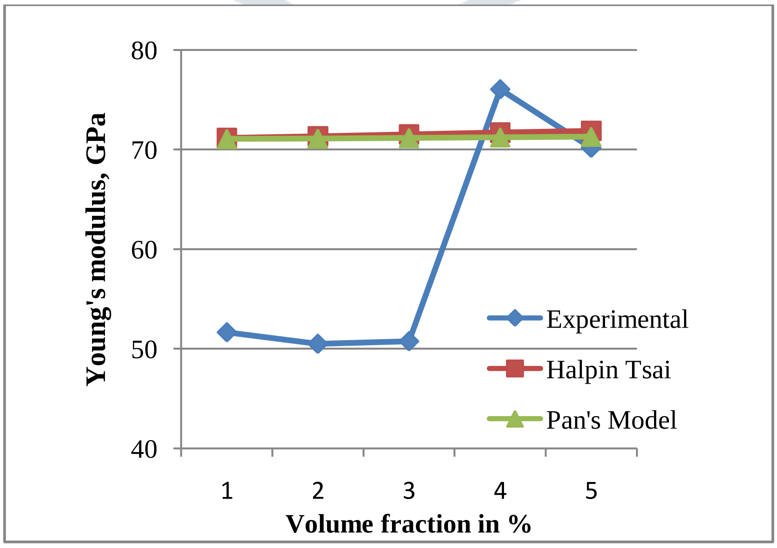
Sl.no.	Volume fraction of Basalt fiber (V_f)	Young's Modulus E (GPa)
1	0.01	71.05
2	0.02	71.11
3	0.03	71.17
4	0.04	71.23
5	0.05	71.29

V. COMPARISON

The following table shows the comparison of Young's modulus for both Experimental and Theoretical values of each volume fraction. From table 5.1 it can be said that the experimental results at 1%, 2%, and 3% volume fractions are less than the Theoretical results. But at 4% and 5%, volume fraction experimental values are close to theoretical values.

Table 5.1 Comparison of theoretical and experimental results

Sl. no.	Volume fraction of short Basalt Fiber in %	Experimental Values E in (GPa)	Theoretical values	
			Halpin Tsai model E (GPa)	Pan's model E(GPa)
1	1	53.33	71.17	71.05
2	2	49.66	71.33	71.11
3	3	50.97	71.51	71.17
4	4	74.73	71.69	71.23
5	5	71.43	71.86	71.29



Graph 5.1 Comparison of experimental and theoretical results.

VI. CONCLUSION

Based on the study done on mechanical properties of short Basalt Fiber/Aluminium alloy LM25 composite, the following conclusions can be made.

- Aluminium alloy LM25 and their composites have successfully manufactured through stir casting with uniform dispersion of Basalt fiber.
- The addition of short basalt fiber improves the yield strength and ultimate tensile strength of aluminium alloy LM25 compare to the unreinforced matrix. The ultimate tensile strength of Al LM25/Basalt fiber composite when reinforce with 5 percentage is increased by 30 %.
- In this case Ductility of composite also increased with the addition of short basalt fiber.
- The experimentally found strength values were compared with various theoretical studies which show that experimental values best suits the theoretical values considering the random distribution of short basalt fiber in Al alloy LM25 matrix.

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