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Investigating the Physical and Mechanical Properties of Al-Si-5mg Alloy Reinforced with Al_2O_3 Fibre

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ABSTRACT: *This paper studies physical and some mechanical properties of Al-Si-5Mg alloy reinforced with Al_2O_3 fibres. Aluminumscraps were sourced locally and recycled using stir casting. Composition of the recycled alloy was analyzed at the Defense Industry Cooperation of Nigeria (D. I. C.), Kaduna to determine the percentage concentration of Magnesium and silicon elements respectively. The concentration of magnesium in the alloy was increased to 5% while that silicon element increased to 4%, 6% and 8% respectively. Using stir casting, their composites were produced by adding 30% of Al_2O_3 fibre toAl-Si-5Mg alloy containing 4%, 6% & 8% respectively. The density, yield strength, ultimate strength, flexural strength and hardness of the prepared composites were determined. The results showed a decrease in the density and an increase in the mechanical properties when the silicon concentration was increased. These composites can be used for the production of vehiclesparts as well as structural materials.*

Keywords: *Mechanical properties, reinforcements, Al-Si-5Mg alloy and stir casting.*

I. INTRODUCTION

Composite materials are materials made by combining two or more materials with significantly different physical, chemical or mechanical properties. One of materials of high concentration serves as the matrix while the other one of law concentration serves as reinforcement. The use of composites is dated back to 1907. Different types of composites have been produced by using different matrix and reinforcement materials, reinforcement size and processing methods depending on the service requirement. Some of the composites include: Polymer matrix composite (PMC), Ceramic matrix composite (CMC), Carbon-carbon composite (CCC), Hybrid composite (HC), Laminar composite (LC), Metal matrix composite (MMC), etc [1]. Aluminium matrix composite (AMC) is a MMC in which Al matrix is reinforced with reinforcement such as: Tin-oxide (TiO_2), Silicon-oxide (SiO_2), Aluminium-oxide (Al_2O_3), etc.

The use of Al alloy as matrix has attracted much interest because of its advantagessuch as low cost, low energy consumption, low density, high-specific mechanical properties, nonabrasive and high resistance to corrosion[2, 3]. AMCs widely used in applications such as aerospace, aircraft, cooking, electricity, and vehicle parts, just to mention but a few.

Manufacturing of aluminum alloy composite by stir casting is the most economical method of processing Aluminium matrix composites (AMC) [4]. Recently, materials research and development has shifted from monolithic to composite materials, because of the global need for reduced CO_2 emission, fuel consumption and high performance. The key benefits of AMCs in transportation sector are lower fuel consumption, less noise and lower airborne emissions. Different techniques exist for the processing of AMCs. Some of the techniques include ultrasonic assisted casting, powder metallurgy, high energy ball milling, friction stir casting

II. EXPERIMENTAL METHODOLOGY

2.1 Materials and Equipment

2.1.1 Materials

Aluminium scraps, Silicon (Si) element, Magnesium (Mg) element, Aluminium Oxide (Al_2O_3) fiber, Foundry sand, Wax for pattern, Mould, Coal, etc.

2.1.2 Equipments

Weighing scale, Open hearth furnace, Micrometer screw gauge, Vanier caliper, Lathe machine, Milling machine, Universal testing machine, Industrial hardness tester

2.2 Experimental procedure

2.2.1 Preparation of the specimen

Three patterns for test specimens were made from wax. The patterns were made according to the specimen specification for tensile, hardness and flexural test as shown below.
Tensile test specimen, the pattern dimensions were; diameter 12mm a gauge length 60mm,shoulder diameter 25mm and shoulder length 10mm.

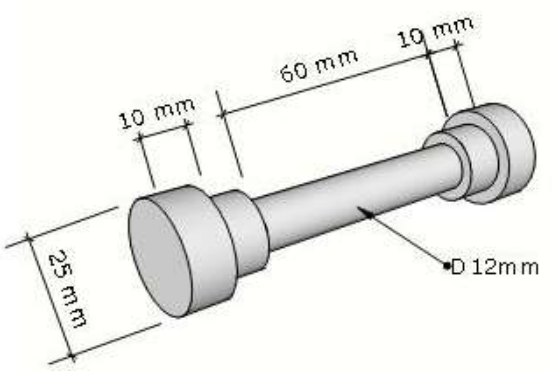

Fig 1.0 Specimen for tensile test

Flexural test specimen, pattern is made 10mm by 10mm cross section and 80mm long

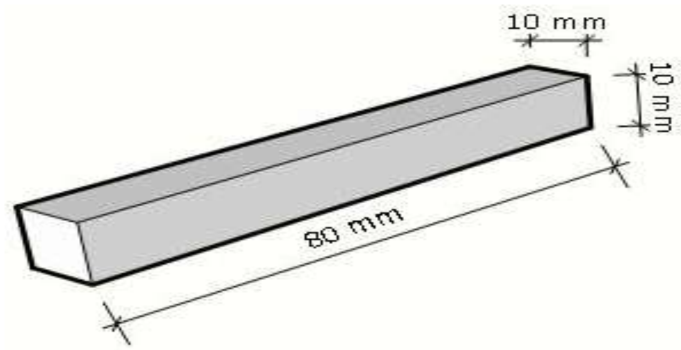

Fig 2.0 Specimen for flexural test

Hardness test specimen, patternis 30mmby 30mm wide and 10mm thick

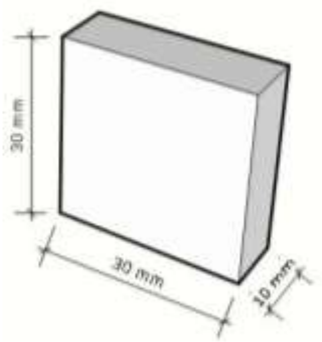

Fig 3.0 Specimen for Hardness test

These patterns were placed in sand mould and the cavities, ingots and risers were prepared into which the molten metal was poured and allowed to solidify and then the castings were extracted.

2.2.2 Preparation of the Al-Si-5Mg alloy

The Aluminium (Al) scraps were sourced locally at the scrap market and recycled by casting [5]. Composition of recycled Al was analyzed at the Defense Industry Corporation of Nigeria in Kaduna.

2.2.3 Micro-Analysis

Surface analyses, chemical analysis and imaging on a variety of materials are performed using a Scanning Electron Microscope (SEM). The Scanning Electron Microscope is equipped with an Energy Dispersive Spectrometer (EDS). SEM/EDS provide chemical analysis of the field of view or spot analyses of minute particles.

Table 1. Chemical analysis results for the recycled scraps

Element	Al	Si	Mg
Concentration (W %)	96.19	0.81	3

2.2.4 Preparation of Al-Si-5Mg alloy composites

The Al-Si-5Mg alloy was reheated to its molten state using an open hearth furnace. While at the molten state,30% [6]of Al_2O_3 fibre was added and stirred continually. The stirring of the melt with the Al_2O_3 fibre lasted for about 4mins andthen the mixture was added into the prepared mould and allowed to solidify. The procedure was repeated for alloy containing 4%Si, 6%Si, and 8%Si (i.e. specimens A, B and C respectively) and Mg kept at 5% [4, 8] as shown in the tables 2, 3 and 4 below.

Table 2. Composition for specimen A

Element	Al	Si	Mg
Concentration (W %)	91	4	5

Table 3. Composition for specimen B

Element	Al	Si	Mg
Concentration (W %)	89	6	5

Table 4. Composition for specimen C

Element	Al	Si	Mg
Concentration (W %)	87	8	5

2.2.5 Tests for Tensile Strength, Flexural Strength and Hardness of Specimens.

Tensile Test Specimens

The equipment used for the ultimate tensile test is a universal material testing machine model SSR25 14, digital indicating system having a capacity of 1000KN (10 tones) and is hydraulically operated. The test piece was held at both ends and was made to be tensioned slightly and the meter set to zero with the pump handle in the down position and locked. The load was increased uniformly and the corresponding extension was noted. Again the force was gradually increased at equal intervals until the specimen finally failed and the corresponding extensions were recorded [7].This process was repeated for other specimens prepared for tensile test.

Flexural Test Specimens

Flexural test was carried out on all the specimens prepared for the test. The test was also conducted using a universal material testing machine. The specimen (A_2) was fixed on the machine as a simply supported beam with a length of 60mm between supports and the meter set to zero. A load of 0.5KN was applied and the deflection was found to be 0.15mm. This load was gradually increased to 1KN and the deflection increased to 0.30mm. The load was further increased at this interval of 0.5KN until the specimen finally failed and the corresponding deflections were noted and recorded. The procedure was repeated for each of the test specimen at room temperature and the results recorded.

Hardness Test Specimens

AMC castings were machined to the required shape for hardness test. Hardness test was carried out on allprepared specimens.The hardness test was conducted using the Rockwell Hardness Testing Machine. The hardness was determined in terms of the depth of an indent produced by a diamond cone. The correct indenter was selected, pre-load stop of 288N at 14.4N were inserted, and the test specimen was placed on the test table. A hand wheel was used manually to raise the spindle towards the indenter until the small needle has reached the red mark and the big needle has made three (3) full turns which signals the application of the pre-load.

The exact zero setting of the big needle was made by turning the scale ring of the dial gauge. The application of the test load and the release were effected by means of a motor driven eccentric. The motor stopped automatically after the test is completed. The procedure was repeated for each of the specimen at room temperature and the results were recorded.

Table 5. Yield strength, Ultimate strength, Elongation and Reduction in area

Specimen	Yield strength	Ultimate strength	Elongation	Reduction in area
	δ_y	δ_u	Σ	γ
	(N/mm^2)	(N/mm^2)	%	%
X	20.3	39.8	8.3	16.0
A	25.6	48.6	14.3	47.8
B	26.5	49.4	15.5	45.8
C	28.3	53.3	16.7	43.8

Table 6. Young's modulus, Modulus of rupture, Hardness and Density

Specimen	Young's modulus	Modulus of rupture	Hardness	Density
	E	M_R	H_S	ρ
	(KN/mm^2)	(N/mm^2)	(HRF)	Kg/m^3
X	68	138	40.30	2.5
A	110	216	64.25	1.97
B	114	252	65.50	1.95
C	116	306	66.73	1.94

III. RESULTS AND DISCUSSION

From the laboratory tests carried out, the results obtained were used to calculate for the mechanical properties and density of the composites. The change in composition of Si and keeping constant the Mg in the AMC influences the physical and mechanical properties [9].

The results of the various tests are presented in tables 5 and 6.

3.1 Tensile Test

Effect of Al_2O_3 fibre and Si concentration on yield strength of Al-Si-5Mg alloy is represented in the tensile test results shown in table 5 and 6.It was observed that the yield strength of the unreinforced alloy X (i.e. control specimen) is 20.3N/mm^2 and that of specimen A (i.e. the Al-Si-5Mg alloy reinforced with Al_2O_3 fibre) is 25.6N/mm^2 which indicates that the reinforced alloy (composite) has higher yield strength than the ordinary alloy.This shows that increasing the Si concentration enhances better mechanical properties. It can also be seen that specimen B has higher yield strength than specimen A. In this case, reducing the Al and increasing the Si concentration by the same amount say; 91-89%Al and 4-6%Si keeping the amount of Magnesium Mg constant at 5%Mg in the AMC to have 89%Al-6%Si-5%Mg instead of 91%Al-4%Si-5Mg increased the yield strength from 25.6N/mm^2 to 26.5N/mm^2 respectively even though the reinforcement remained the same at 30%Vol. This is in line with the works of [10-12]. The results of the different Si concentrations are represented in figure 1.

Effect of Al_2O_3 Fibre and Si Concentration on Ultimate Strength of Al-Si-5Mg Alloy was obtained from the calculated values shown in tables 5 and 6.It can be seen that the ultimate strength of material changes with reinforcement as well as variation in the Si concentration. Specimen X has an ultimate strength of 39.8N/mm^2 which is lower than that of B and that of lower than that of C as the specimens A, B and C has the Si concentration at 4, 6 and 8%Si respectively. From this; it can be said that increasing the Si concentration increases the ultimate tensile strength of the material. This increase in Si can be continued until an optimum value is obtained. The results of the different Si concentrations are represented in figure 2.

Effect of Al_2O_3 fibre and Si Concentration on Elongation and Cross-Sectional Area of Al-Si-5Mg Alloy was obtained from the results of tensile test, it can be seen in tables 5 and 6, that the percentage elongation for specimen X is 8.3% and for specimen A is 14.3%. This indicates that the material has been improved on the mechanical properties as the specimen A has been reinforced and X is kept unreinforced. Comparing the elongation of A and that of B which are 14.3 and 15.5 respectively, we also discover that the decrease in the Al and increase in the Si concentration makes the material more ductile. The results of the different concentrations are represented in figure 3.

Also, for the reduction in cross-sectional area of the material when subjected to load depends on the ductility of the material and this is also indicated in the calculated values for percentage reduction in area of the material.The results of the influence of the different concentrations are represented in figure 4.Figure 5 shows that there is increase in modulus of elasticity of the different Si concentration values of 4%, 6% and 8%.

3.2 Flexural test

The results obtained from the flexural strength are recorded in tables 5 and 6 as well as in figure 6 From these results, the effect of Al_2O_3 fibre and Si concentration on the flexural strength of Al-Si-5Mg alloy is shown in tables 5 and 6. It can be seen that the flexural strength increases with the reinforcement as well as the increase in Si concentration.It is interesting to note that flexural strength increases with increase in Si concentration in the AMC.

3.3 Hardness Test

Effect of Al_2O_3 fibre and Si Concentration on the Surface Hardness Al-Si-5Mg Alloywas determined. The measured hardness values of the alloy of all the composites are presented in table 6 and also in figure 7. It can be seen that the hardness is increasing with the increase in Si concentration. However further increase in the Si concentration can increase the surface hardness value of the composite as discussed in the work of [13]
Effects of Al_2O_3 Fibre and Si Concentration on the Density of Al-Si-5Mg Alloy was determined.

From table 6, it was observed that the density of the material reduced drastically by reinforcing the alloy. Also, the decrease in Al and increase in Si concentration in the AMC influences the density of the composite which implies that the material becomes lighter. This reduction in the weight of the material makes it suitable for many purposes even though more of this can be achieved by subsequent increase in the reinforcement of the Al-Si-5Mg alloy.It is interesting to note that density decreases with increase in Si concentration in the AMC.

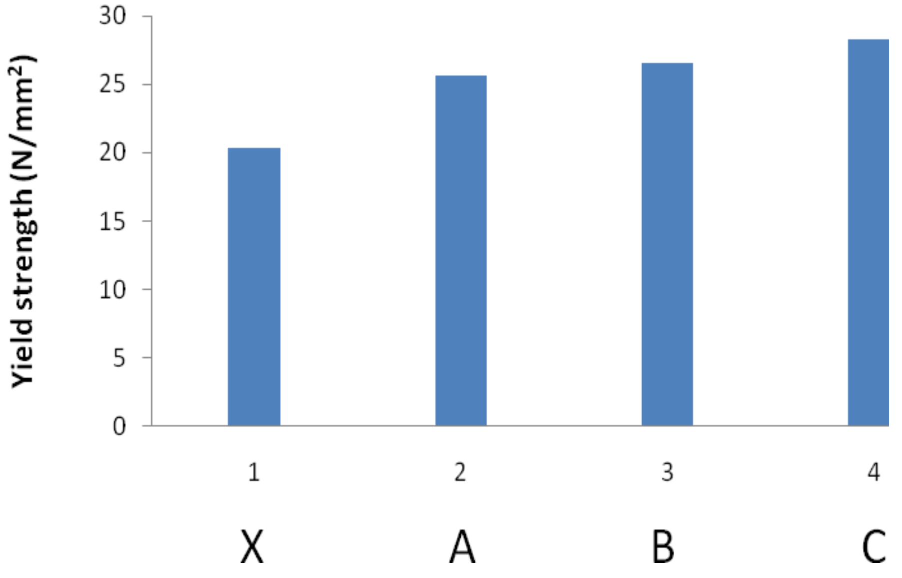

Fig.1 Yield strength of control and composite specimens

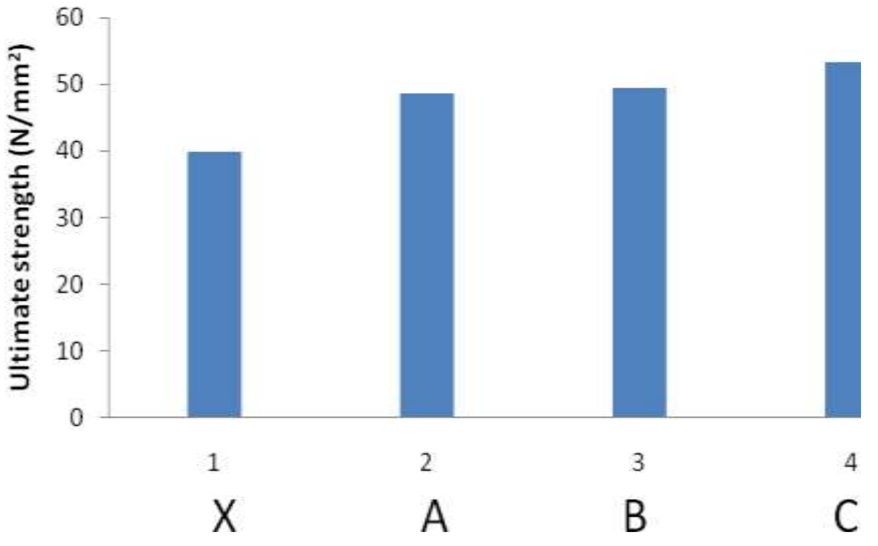

Fig.2 Ultimate strength of control and composite specimens

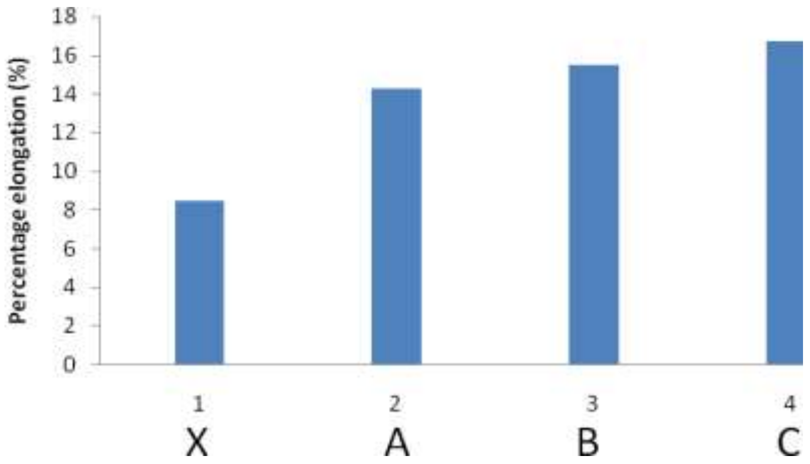

Fig.3 elongation of control and composite specimens

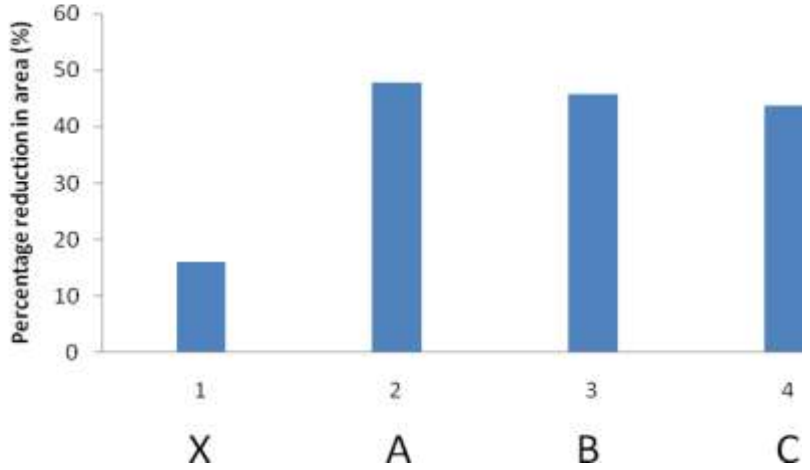

Fig.4 Reduction in area of control and composite specimens

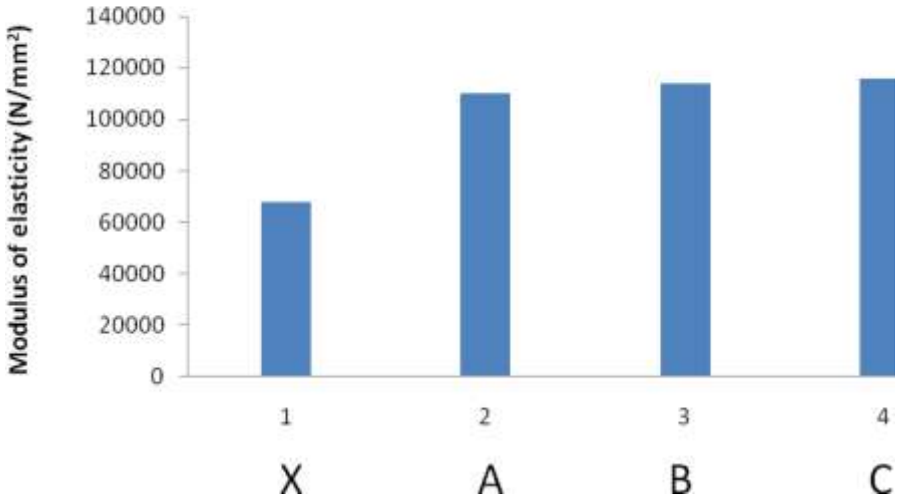

Fig.5 Modulus of elasticity of control and composite specimens

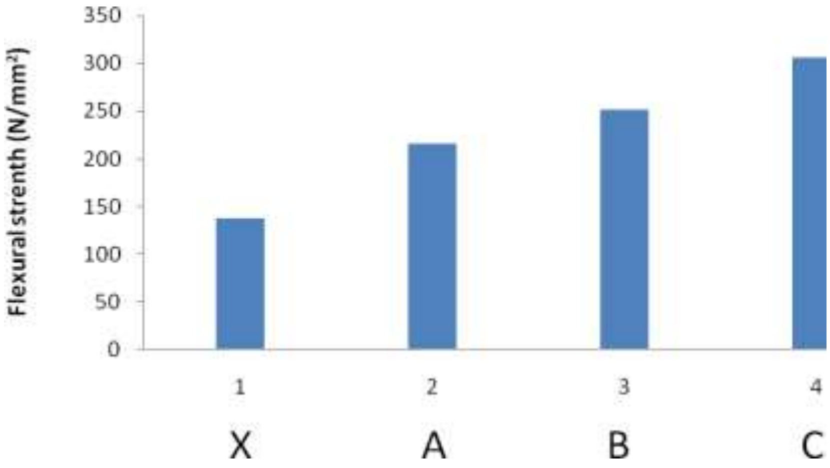

Fig.6 Flexural strength of control and composite specimens

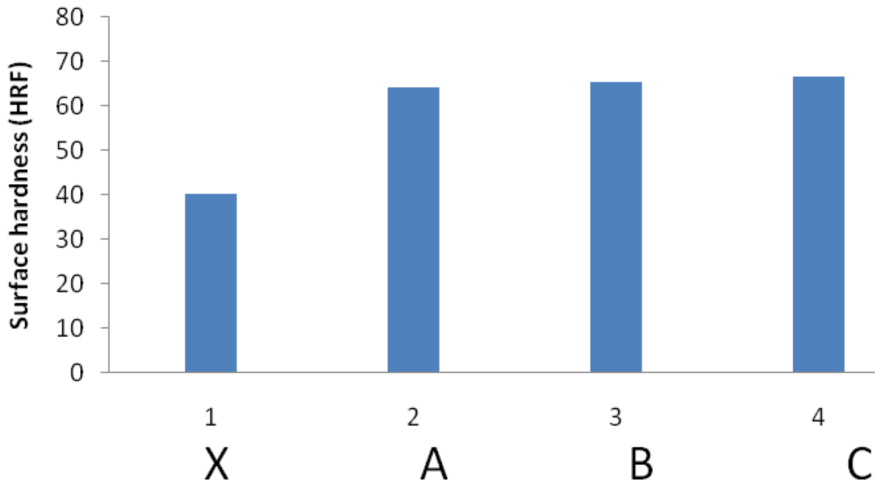

Fig.7 Hardness of control and composite specimens

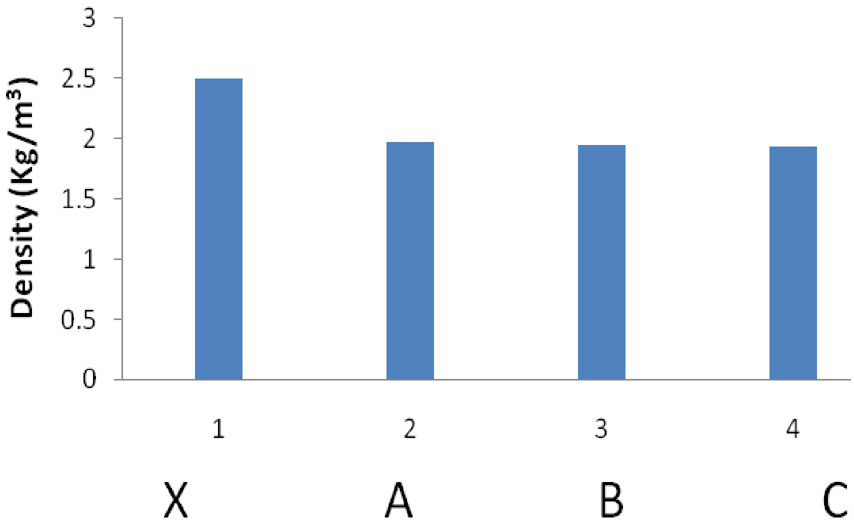

Fig.8 Density of control and composite specimens

IV. CONCLUSION

The following conclusions were made:

- Mechanical properties of the composites are greatly increased by the reinforcement in the Al-Si-5Mg alloy.
- By increasing Si concentration in the Al-Si-5Mg, the physical and mechanical properties are improved.
- Due to the improvement in the ultimate strength, yield strength, flexural strength, hardness and light weight observed from this experiment, AMC can be used for various applications such as aerospace, engine parts, vehicle bodies, structural materials etc.

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