A Comparative Study of the Effect of AL_2O_3 and SiC on the Mechanical Properties of 6061 Aluminium Alloy

[1]Datau, S. G., [1]Datau Nicodemus; [2] Nnadozie, A. C., [2] Obina Charles, [1]P. M. Kamtu; [1]Adesanmi Adegoke

[1] *Dept of Mechanical Engineering, University of Jos, Jos.*

[2]*Dept. of Mechanical Engineering Tech. Federal Polytechnic, Bauchi*

Abstract: *The effect of Al_2O_3 and SiC reinforcements on the mechanical properties of 6061 aluminium alloy was investigated and compared. The 6061 aluminium alloy was prepared by alloying the recycled pure aluminium scraps to attain its standard chemical specification: Al = 97.9%, Si = 0.60%, Cr = 0.20%, Cu = 0.28%, Mg = 1.0%, Mn = 0.15%. Al_2O_3 and SiC particles in the range 15% to 22% respectively were added to 6061 aluminium alloy to produce the composites. Stir casting was used to produce the composites. A hollow metal pipe, 30mm in diameter and 100mm long was used as casting moulds and 24 specimens were produced for the study. Ultimate strength, impact strength and hardness properties of the produced alloy and composites were determined, and the results showed significant improvement in the mechanical properties. By varying the volume fraction of SiC and Al_2O_3 from 15% to 22%, ultimate strength increased from 75Nmm^{-2} to 87Nmm^{-2}, hardness decreased from 39RHN to 36.33RHN and percentage elongation increased from 3% to 5.5%; and ultimate strength increased from 70Nmm^{-2}–112Nmm^{-2}, hardness decreased from 38.67RHN to 37.50RHN, and percentage elongation increased from 3% to 4.5% respectively. Based on these results, the composites can be used for the structural applications such vehicle parts, aircraft parts, aerospace parts, etc.*

Keywords: *Mechanical properties, reinforcements, 6061 aluminium alloy, and stir casting*

1. Introduction

Different engineering materials are used for the manufacturing of machines and structural materials. The use of these engineering materials as structural materials is influenced by their properties (i.e. physical and mechanical), cost, environment stability, availability, etc. Among the non-ferrous metallic materials, aluminium and its alloys are in common use as structural materials. Aircrafts, space crafts, ships, electronics component, vehicle components, cooking utensils, communication masks, etc, are produced using aluminium alloy based material. This is because Aluminium based materials have good environmental stability (i.e. high resistance to corrosion), physical properties (i.e. low density, and high thermal conductivity), ease of recycling (i.e. recycling scraps through casting), ease of heat treatment, bright colour, etc [1, 2, 3]

However, aluminium alloy components have some limitations – low thermal tensile strength, fatigue strength, and fracture toughness use numbering system [4, 5].

To eliminate some of these limitations, so many efforts have been made and are being made to improve the services performance of the alloy by improving their mechanical properties. Some of the methods that have been used to improve the mechanical properties of aluminium alloys include: alloying with other elements, heat treatment, controlled deformation and addition of ceramics materials to aluminium alloys. Adding metallic elements (i.e. alloying) to pure aluminium has significantly improved its properties (i.e. physical and mechanical). Many aluminium alloys have been developed [1, 6, 7].

Aluminium alloy composites (AMCs) are produced by adding ceramic materials to aluminium alloy. The aluminium alloy serve as matrix while the ceramic materials are the reinforcements. The reinforcements have properties that are different from that of the matrix and are usually added in small quantity. Literatures have reported that composites of aluminium alloys possess unique combination of properties such as high stiffness, strength, hardness, thermal conductivity, corrosion resistance, temperature performance, and low density. Many AMCs have been and are being developed due to the many aluminium alloys and reinforcing materials that exist [8, 9, 10]. Although there are many reinforcements and aluminium alloy matrices, the flexibility of tailoring the properties of the composites to a specific need depends on the ability of the aluminium matrices to combine with the reinforcements in a wide range of volume fractions, sizes and shapes [11, 12].

2. Motivation of the Study

Although commercial aluminium alloy composites have been produced using SiC and Al_2O_3 particles/fibres as reinforcing agents, the high cost of the AMCs limited their wide spread use. This is due to the high cost of the aluminium matrix, synthetic reinforcements (i.e., SiC and Al_2O_3) and machining of the AMCs [13, 14]. Also, 6061 aluminium alloy has been considered to have good properties for structural application and its properties can be influenced by heat treatment [15, 16].

The aim of this paper is to compare the mechanical properties of recycled 6061 aluminium alloy reinforced with the same volume fraction of SiC and AL_2O_3 particle. The 6061 aluminum alloy was produced by upgrading the composition of recycled aluminium scraps to that standard 6061 aluminium alloy by adding the required chemical elements.

3. Materials and Methods

3.1 Materials/Equipments

Pure aluminium scrap (97.9% Al) sourced from Northern Cable Company (NOCACO) in Kaduna state was used to produce the 6061 Aluminium alloy. The metal elements: Silicon (Si), Chromium (Cr), Copper (Cu), Magnesium (Mg), and Manganese (Mn) were sourced locally from the market and were added to the recycled aluminium scrap for the purpose of developing the 6061 aluminium alloy. Azare foundry sand was used as moulding sand for the preparation of the 6061 aluminium alloy specimens. Sand mixing machine was used to prepare the moulding sand, while the metal pipe, 30mm in diameter and 100mm long was used as pattern. Metal box was used as mould box for producing the casting. Appropriate quantity of aluminium scraps and alloying the elements were measured using a weighing scale. Electric furnace and crucible were used for preparing the scraps and composites melts. Rammer and tong were used for preparing the mould and pouring of the molten metal during the casting of the alloy and the composites. SiC and AL_2O_3 particles were used as reinforcements for the production of the composites. All specimens for property test were prepared using a lathe machine. Universal tensile testing machine (model SSR2514), impact tester (Wolpert), Rockwell hardness tester were used to test tensile strength, impact strength and hardness of the aluminium alloys and composites.

3.2 Methods

3.2.1 Preparation of 6061 aluminium alloy

Scraps of pure aluminium (97.9% Al) sourced locally from NOCACO in Kaduna was alloyed by adding the following elements: Silicon (0.60%), Chromium (0.20%), Copper (0.28%), Magnesium (1.0%), Manganese (0.15%) to form the 6061 aluminium alloy. The mixture of the scrap and the required concentrations of the elements were placed in a crucible. The crucible containing the mixture was then kept in a furnace of heating capacity of 1200^{o}C. The furnace was switched on and set to a temperature of 780^{o}C to melt the mixture. The complete melting of the mixture was attained when the furnace produced a sound, tripped off and came up again. The crucible containing molten alloy (6061 aluminium alloy) was taken from the furnace, and the molten alloy poured into the prepared sand moulds, 30mm in diameter and 100mm in length. After about 25 minutes, the solidified alloy specimens were removed from the mould and cleaned using a wire brush.

3.2.2 Preparation of 6061 Aluminium Alloy Composites

850g of the prepared 6061 aluminium alloy was weighed and placed in a crucible. The crucible was kept in the furnace and the furnace was switched on. When the alloy was fully melted, 150g of Silicon Carbide particles (SiC) was weighed and introduced into the molten 6061 aluminium alloy and stirred vigorously using a stirrer. The molten composite was poured into the prepared cylindrical sand mould (30mm in diameter and 100mm in length), and was allowed to cool for about 20 minutes. The cast composites specimens were the removed and thoroughly cleaned using a wire brush. The amount of 6061 aluminium alloy was reduced to 800g while that of SiCp was increased to 200g and the process was repeated.

Again this process was repeated using 150g and 200g of aluminium oxide particles (Al_2O_3) for reinforcement.

Twenty four specimens were produced. The specimens for tensile, impact, and hardness test respectively were produced to specification as shown in Fig.1a, b and c using a lathe machine.

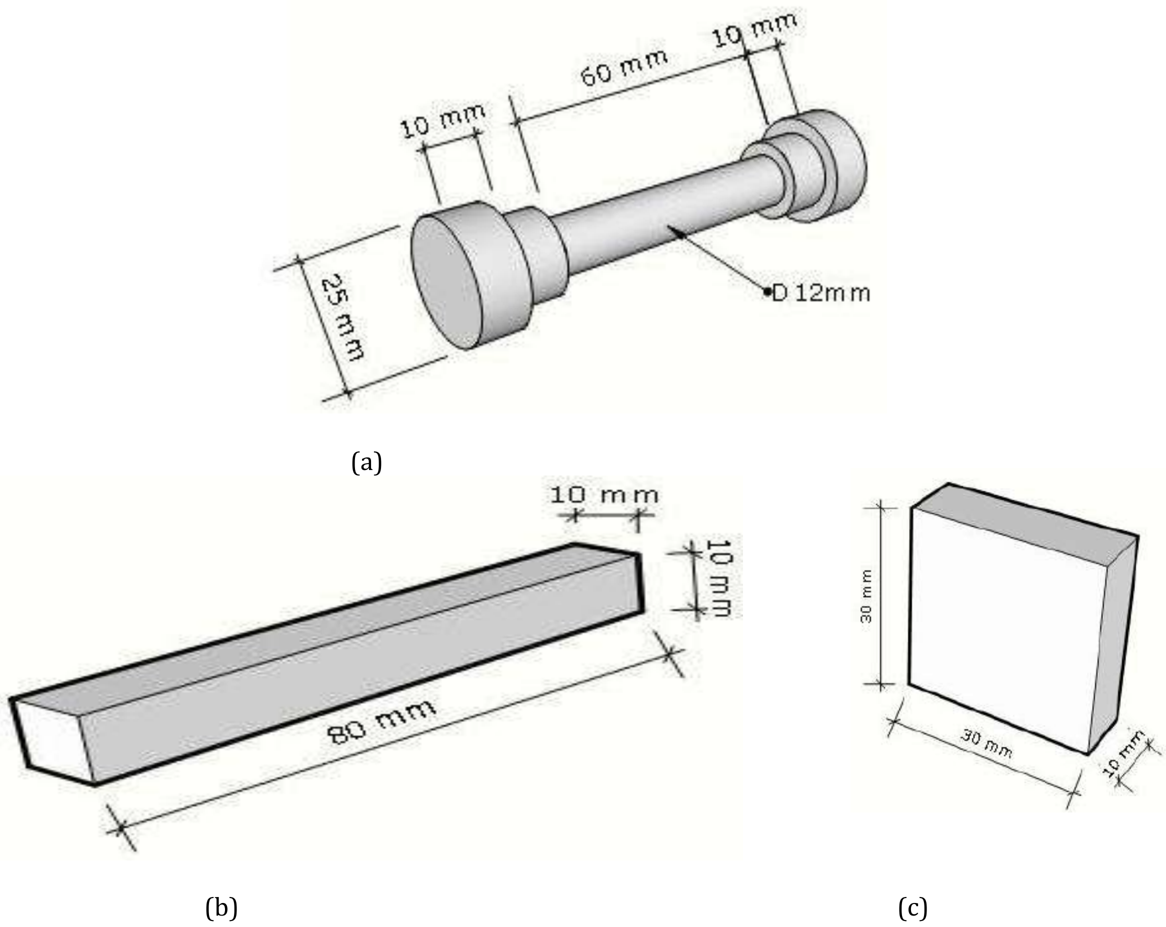

Fig. 1 Specimen for: (a) tensile test (b) impact test (c) hardness test

For the three tests, total of twenty four (24) specimens were used, 8 specimens in each case. The tensile test, impact test and hard test were carried out to determine tensile strength, percentage elongation, impact strength and hardness of the produced alloy and composites respectively.

The tensile test was carried out using the Universal testing machine (model SSR25 14). The specimens for the tensile tests (as shown in Fig.1(a)) were machined from the cast specimen (30mm in diameter and 100mm in length) using a lathe machine. The specimen is prepared according to standard specification. The specimen was fixed in the upper and lower work holder of the Universal testing machine and the load was applied until the specimen failed. The ultimate strength and percentage elongation were recorded. This process was carried out on the specimens of 6061 alloys and the composites. The tests were carried out at room temperatures.

The impact tests were carried on the impact testing machine (Wolpert). The specimens for the tests (shown in Fig.1 (b)) were machined from the cast specimens of size 30mm in diameter and 100mm in length using a Lathe machine. The specimen was placed on the anvil of the machine and then impact load applied by the pendulum which caused the specimens to fracture. The Charpy scale was used to measure the energy at the fracture of the specimen. The process was repeated for all the specimens. The tests were carried out at room temperature and the impact strength for each specimen was determined

Rockwell hardness test method was used to measure the hardness of the 6061 aluminium alloy and the produced composites. The specimens for the hardness test (i.e. shown in Fig.1(c)) were machined using a Lathe machine. The specimen was then placed on the hardness tester and the hardness of the specimen was measured at three different positions on the surface of the specimen and the average determined.

4. Results and Discussion

4.1 Results

The results of the analysis and mechanical tests carried on the recycled 6061 aluminum alloy and the produced 6061 aluminium alloy composites are presented in Tables 1, 2, 3 and 4. Table 1 showed the chemical composition of the recycled 6061 aluminum alloy while Tables 2, 3 and 4 are the mechanical properties of the recycled 6061 aluminum alloy, 6061 aluminum alloy reinforced with 15% SiC and 15% Al_2O_3; and 6061 aluminium alloy reinforced with 22% SiC and 22% Al_2O_3 respectively.

Table 1: Chemical composition of 6061 aluminium alloy

Element	Al	Si	Cr	Cu	Mg	Mn
Weight percentage (wt%)	97.9	0.60	0.20	0.28	1.00	0.15

Table 2: Mechanical properties of the as cast 6061 aluminium alloy (control specimen)

Alloy	Ultimate strength (N/mm^2)	Impact strength (J/mm^2)	Hardness (RHN)	Elongation (%)
6061 Aluminium alloy	75	0.059	33.67	6

4.2 Discussion of Results

Effect of 15% SiC and Al_2O_3 reinforcement on the Hardness of 6061 aluminium alloy

The results of the effect of SiC and Al_2O_3 particles on the hardness of recycled 6061 aluminium alloy (shown in Table 3 and Fig. 2) showed that for the 6061 aluminium alloy reinforced with 15% SiC, the hardness increased from 33.7RHN to 39RHN; and for the alloy reinforced with 15% Al_2O_3, the hardness increased from 33.7RHN to 38.67RHN. However, when the percentage concentrations of both reinforcements increased to 22%, the hardness increased from 33.7RHN to 36.33RHN for SiC and 37.50RHN for Al_2O_3. This shows that the change in percentage concentration of both reinforcements resulted to the decreased in the hardness of the composite. Changing the percentage concentration of SiC affects the hardness of the alloy more than Al_2O_3. For 5% increased in concentration of both SiC and Al_2O_3, the hardness decreased by 2.77RHN in the case of SiC and 1.17RHN in the case of Al_2O_3. It can be inferred from this results that at higher concentration, reinforcing 6061 aluminium alloy with SiC gives higher hardness as shown in Fig.2. The higher hardness of all the developed composites compared to that of the recycled 6061 aluminium alloy was attributed to the hard nature of SiC and Al_2O_3 particles. However, slightly drop in the hardness at 22% SiC and Al_2O_3 additions might be due to the agglomeration and non-uniform distribution of the particles in the aluminium matrix [20, 21].

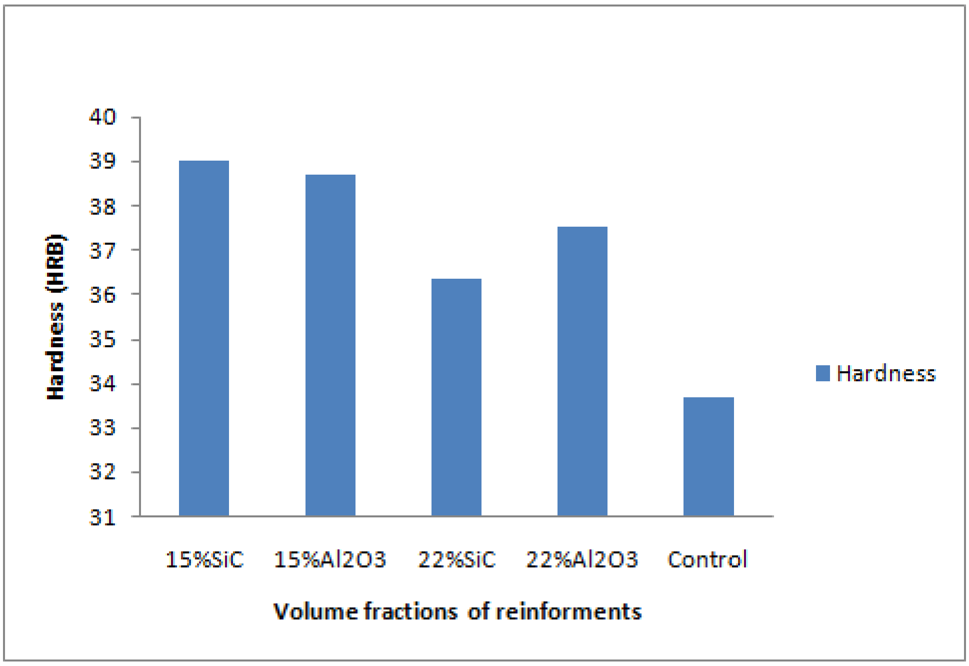

Fig. 2: Hardness of reinforced 6061 aluminium alloy & control specimen

Table 3: Mechanical properties of 6061 Al alloy reinforced with 15%SiC & Al_2O_3

Reinforcement	Ultimate strength (N/mm^2)	Impact strength (J/mm^2)	Hardness (RHN)	Elongation (%)
SiC	75	0.039	39	3
Al_2O_3	70	0.039	38.7	2

Effect of 15% SiC and Al_2O_3 reinforcement on the Ultimate Strength of 6061 Al alloy

From the results shown in Tables 2 and 3, ultimate tensile strength increases with increase in concentration of both SiC and Al_2O_3. Increasing the concentration of both SiC and Al_2O_3 from 15% to 22%, the ultimate strengths of the composites increased from 70N/mm² to 112 N/mm² for the 6061 alloy reinforced with Al_2O_3 and 75N/mm² to 87N/mm² for 6061 alloy reinforced with SiC as shown in Fig.3. This shows that increasing the percentage concentration of Al_2O_3 has more effect on the ultimate strength. At lower percentage concentration, SiC has more effect on the ultimate strength due to the high strength and high elastic modulus characteristics of SiC [16]. However, the slight drop in the ultimate strength of the 6061 aluminium alloy reinforced 22%SiC might be due to inhomogeneous distribution of SiC particles in 6061 aluminium alloy matrix. Similar findings have been reported in literatures of aluminium alloy composites developed using SiC particles as reinforcement [17,18]. The higher strength observed in the 6061 aluminium alloy with 22% Al_2O_3 might be as a result of uniform distribution of the Al_2O_3 particles [18].

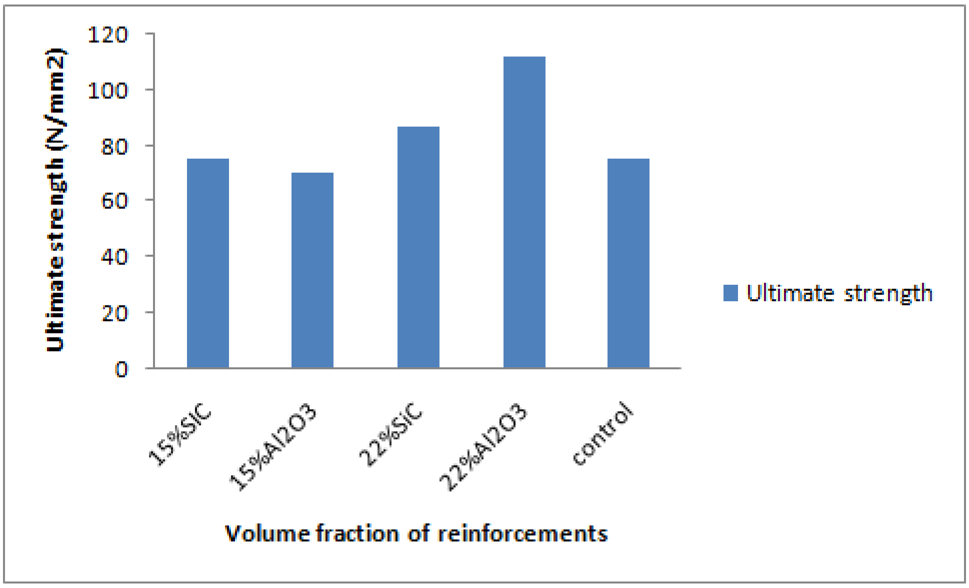

Fig.3: Ultimate strength of reinforced 6061 aluminium alloy

Effect of 15% SiC and Al_2O_3 reinforcement on the percentage elongation of 6061 aluminium alloy

From fig. 4, increasing the percentage concentration of both SiC and Al_2O_3 from 15% to 22% respectively, the percentage elongation increased from 2% to 5.5% for the 6061 aluminium alloy reinforced with Al_2O_3 and 3% to 4.5% for the 6061 aluminium alloy reinforced with SiC. At 15% Al_2O_3, percentage elongation decreased from 6% to 2%, while at 15% SiC, the percentage elongation decreased from 6% to 3%. This shows that introducing both Al2O3 and SiC particles reduces the ductility of the 6061 aluminium alloy. Similar observations have been reported in Literatures [18, 19]. The higher percentage elongation at 15% SiC as compare to 15% Al_2O_3 might be as a result of the homogeneous distribution of SiC particles in the matrix. At 22% Al_2O_3, the percentage elongation is higher than that of 22% SiC. This might be as a result of homogeneous distribution of the Al_2O_3 particles in the matrix. Composites with low percentage elongation will be used as structural materials where high hardness is a requirement while the composites with high percentage elongation are needed in applications that require high fracture toughness [20, 21].

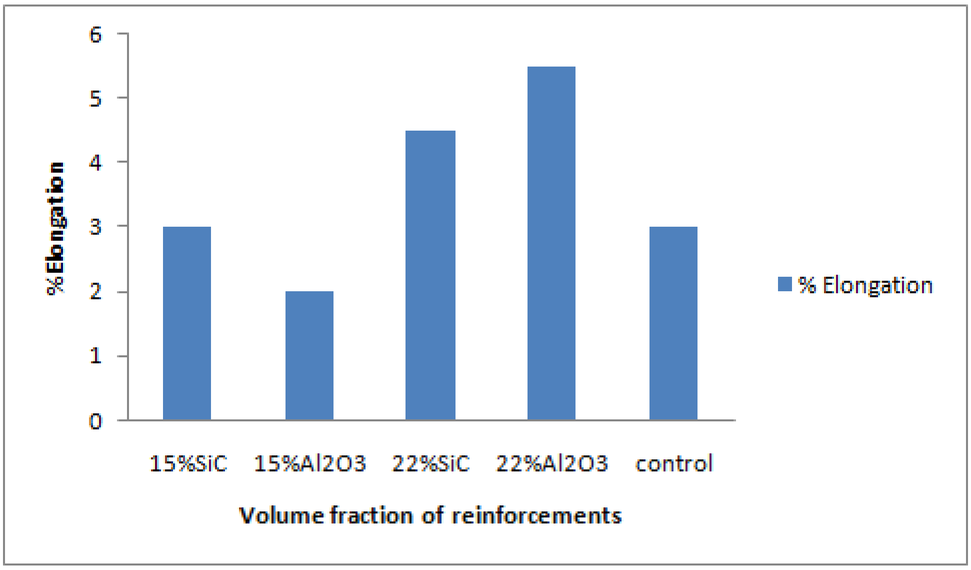

Fig.4: % Elongation of reinforced 6061 aluminium alloy

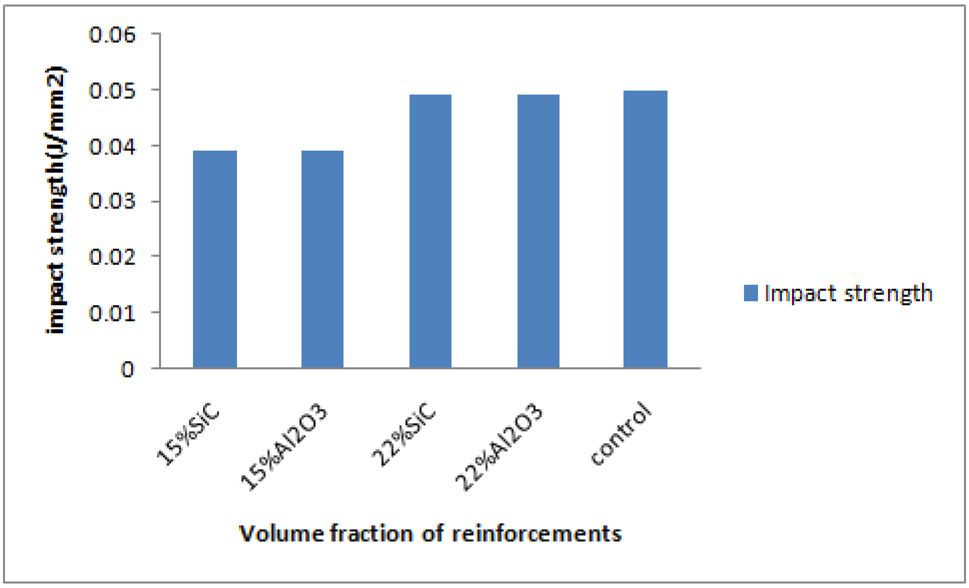

Fig.5: Impact Strength of reinforced 6061 aluminium alloy

Table 4: Mechanical properties of 6061 Al alloy reinforced with 22% SiC & Al_2O_3

Reinforcement	Ultimate strength (N/mm^2)	Impact strength (J/mm^2)	Hardness (RHN)	Elongation (%)
SiC	87.33	0.049	36.33	4.5
Al_2O_3	112.00	0.049	37.50	5.5

5. Conclusion

Reinforcing 6061 aluminium alloy with particulate of Al_2O_3 and SiC increased its hardness and ultimate strength, while its impact strength and elongation decreased. The composites formed by adding SiC and Al_2O_3 particles was of high hardness due to high hardness and high strength of the SiC and Al_2O_3 particles. Due to the increased in the hardness, the percentage elongation and impact strength of the composites decreased.

Increasing the percentage concentration of both Al_2O_3 and SiC resulted to decrease in hardness but increased in impact strength, ultimate strength and percentage elongation. This is due to the interaction between the reinforcing particles and the matrix that led to the formation of refined grains within the composites [18].

At 22% Al_2O_3, 6061 aluminium alloy showed better ultimate strength and percentage elongation than that reinforced with SiC. This might be due homogeneous distribution of Al_2O_3 in the matrix. A similar nature has been observed by some researchers who developed aluminium alloy based composites matrix using some ceramic particles such as TiC, TiO_2, TiB_2, etc [20, 21].

Both composites (6061 aluminium alloy reinforced with Al_2O_3 and SiC) have same impact strength.

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