Saudi Journal of Engineering and Technology (SJEAT)
Scholars Middle East Publishers
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

ISSN 2415-6272 (Print)
ISSN 2415-6264 (Online)

Investigation of Mechanical Properties of Alumina Reinforced Eposand Composites

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Original Research Article

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Article History
Received: 12.08.2018
Accepted: 25.08.2018
Published: 30.08.2018

DOI:
10.21276/sjeat.2018.3.8.8

Abstract: This paper investigates the mechanical properties of an aluminium oxide reinforced Eposand composites. The matrix a brand of epoxy was obtained from Shell Petroleum Development Company (SPDC) and reinforced with particulates of alumina in micro-scale. The resin and hardener were mixed and compounded in the ratio of 2:1 and through the application of centrifugal force was thoroughly compounded with the fillers. Two main mechanical tests of tensile and compression where carried out to obtain tensile, compressive, and yield strength of the composites. Four samples of 10%, 20%, 30%, and 40% by weight of alumina with five replications each were prepared and subjected the tests in accordance with ASTM D3039 and ASTM D3401M for tensile and compressive tests respectively. Maximum compressive strength of 133.3 MPa was recorded for 30% of filler, while maximum tensile strength of 7.9 MPa was obtained 10% of filler. An optimal yield strength of 3.4 MPa was recorded at 20% weight of filler. The analysis showed that the compressive strength increases with increase in percentage weight of alumina.

Keywords: Tensile Strength, Yield Strength, Compressive Strength, Alumina Filler.

INTRODUCTION

Composite materials are materials formed from two or more dissimilar materials, each of which contributes to the final mechanical properties of the formed material [1]. A structural composite is a material that consists of two or more phases on a macroscopic scale, whose mechanical performance and properties are designed to be superior to those of the constituent's materials acting independently [2].

Polymer matrix composites (PMCs) are the workhorse of the composites industries. They have excellent room – temperature properties at a comparatively low cost.

There are two major classes of polymers used as matrix materials, thermoplastic and thermosetting polymers. Thermoplastics soften when heated and harden when cooled-processes that are totally reversible and may be repeated whereas thermosetting polymer having cured (or hardened) by a chemical reaction; will not soften or melt when subsequently heated. Epoxies are one type of thermosetting polymer that are more expensive and have better mechanical properties and resistant to moisture than the polyester and vinyl resin [3]. Most composites consist of a reinforcement component in the form of small – diameter fibers, whiskers, particles, and flakes. Particulate filled polymers are used in very large quantities in all kinds of applications and despite the overwhelming interest in advanced composite materials, considerable research and development is done on particulate filled polymers even today. Fillers increase stiffness, fracture toughness, and high temperature load-bearing capability, decrease shrinkage and improve the appearance of composites. The major parameters that influence the mechanical properties of the particulate composite are: volume fraction or filler concentration, kind of the particles reinforcement, and particle size, shape of the particles and the interfacial adhesion between the matrix and the particles Ibitihal, Ahmed and Manal, 2011.

Epoxy resins (ER) are one of the most important classes of thermosetting polymers which are widely used as matrices for fiber-reinforced composite materials and as structural adhesives. They are amorphous, highly cross-linked polymers and this structure results in these materials possessing various desirable properties such as high tensile strength and modulus, uncomplicated processing, good thermal and chemical resistance, and dimensional stability. However, it also leads to low toughness and poor crack resistance, which should be upgraded before they can be considered for many end-use applications [4].

An epoxy resin is a thermosetting material that requires a cure treatment to attain suitable physical and mechanical properties for industrial applications. Modification of epoxy resin is still necessary since some applications in engineering area require higher mechanical and thermal properties [5]. In this research work, a brand of Epoxy known as Eposand (resin and hardener) is compounded with micro-particles of aluminum-oxide (Al_2O_3) at varying volume fractions, and the effect of the reinforcement and variation on the mechanical properties (tensile and compression) of the composites were determined.

LITERATURE REVIEW

Polymers have made significant advances in the markets of metals, wood, glass, paper, leather, and vulcanized rubber that were conventionally used in most household goods and industrial components as well as creating new markets of their own. The main reason behind the widespread use of polymers is their unique set of properties such as toughness, light weight, low cost, and ease of processing and fabrication. The evolution of composite material has replaced most of the conventional material of construction in automobile, aviation industry etc.

In the literature, many works devoted to the mechanical properties of synthetic fibers and fillers from micro to nano scale are available. Yamamoto *et al.*, [6] reported that the structural shape of silica (SiO_2) particle have significant effects on the mechanical properties such as fatigue resistance, tensile and fracture properties of their epoxy based composites.

Weizhou *et al*., [7], studied the mechanical properties of epoxy composites filled with grafting alumina particles by poly-glycidyl methacrylate (PGMA). The epoxy resin composites filled with the particulates of PGMA/AL_2O_3 which were prepared by incorporating and curing the resin containing the particulates. The mechanical properties of the resulting resin composites Epoxy/PGMA/Al_2O_3 can be significantly increased due to higher bonding strength and bonding modulus between them, therefore, the properties of the composites are improved largely. And the higher the PGMA, the greater the impact strength and yield strength of the resin composites are, which primarily depends on the structure properties relationship of the composites.

Yamamoto *et al*., [6], reported that the structure and shape of silica particle have significant effects on the mechanical properties such as fatigue resistance, tensile and fracture properties. Nakamura et al. discussed the effects of size and shape of silica particles on the strength and fracture toughness based on particle-matrix adhesion and also found an increase of the flexural and tensile strength as specific surface area of particles increased. Pattnaik *et al*., reported the existence of a possible correlation between thermal conductivity and wear resistance of particulate filled composites. Nayak *et al*., [8] have reported on the modified thermal conductivity of pine wood dust filled epoxy based composites.

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is commonly called alumina, and may also be called aloxide, aloxite, oralundum depending on particular forms or applications. Alumina contributes 15% of the earth's crust and is amphoteric in nature. It has strong ionic inter-atomic bonding. It commonly occurs in its crystalline polymorphic phase α- Al_2O_3, in which it comprises the mineral corundum, varieties of which form the precious gems ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point. Al_2O_3 is an electrical insulator and has a relatively high thermal conductivity (35 W/m-K). The key properties include high strength and hardness, high temperature stability, high corrosion resistance, high wear resistance.

Experience on the use of aluminium oxide as a filler of epoxy matrices is very limited. In the best case, investigations have been performed with micro sized particles, because the filler has been added to the resin in the form of a powder [9]. The reinforcement of the epoxy matrix by aluminium oxide particles is especially attractive, because these fillers increase the strength and impact resistance to corrosive media, except for strongly alkaline medium. In an attempt to develop a rapid and economical method for making tools with low volume production, some particulate reinforced epoxy composites were investigated by Ma *et al*., [10]. The tools built up using this method are suitable for wax and polymer materials injection moulding applications. Biswas, and Satapathy [11] described the development of alumina filled glass fiber- reinforced epoxy matrix composites and compared the experimental results obtained from Taguchi experimental design with the theoretical erosion model. These composites find applications in highly erosive environments.

Ihueze and Obuka [5] studied the creep properties of a hybridized epoxy-alumina-calcium silicate nanocomposite materials operating at high temperatures. This composite material they found out can be applied in high temperature operations like the oil and gas pipelines due to the presence of alumina particulates which has very high heat conductivity. Patnaik, *et al*., [12] studied an abrasive wear behaviour of randomly oriented glass fiber reinforced with epoxy resin filled Al_2O_3, SiC and pine bark dust. Recently, Sabeel Ahmed *et al*., [13] studied the effect of ceramic fillers like SiC and Al_2O_3 on wear behaviour of jute/epoxy composites and observed that Al_2O_3 filled composites has better wear resistant than SiC filled composites. An experimental study is carried out to investigate bearing strength behaviour of pinned joints of glass fiber reinforced composites by Osman [14] and hence concluded that bearing strength first increased with 15wt% Al_2O_3 filler content and then decreased with further increase in Al_2O_3 content due to low void content in the previous concentration. Wang *et al*., [15] studied the tribological and electrochemical corrosion properties of Al_2O_3 /polymer nano-composites coatings and showed improvement in scratch and abrasive resistance for 20 wt% Al_2O_3 compared with that of polymer coating. Dudkin *et al.*, [16] studied that filling Al_2O_3 nanoparticles in matrices increases the mechanical strength of the composite to a larger extent whereas filling of the matrices with Al_2O_3 nanofibers favours an increase in the Young modulus.

Mechanical strength of various composites has been investigated by many researchers in other to determine their mechanical properties and in most cases addition of reinforcements have an exceptional effect on the mechanical properties of the composite, the efficiency of these materials improves significantly on addition of suitable reinforcement, this is evident in the research work on the mechanical properties of epoxy/Al_2O_3 nanocomposites by Kadhim. Abdullah, AL-Ajaj and Khalil [17], with varying weight percentage of Al_2O_3 nanoparticles three-point bending test was used to determine the mechanical properties and they observed that Al_2O_3 nanoparticles enhanced mechanical properties (young modulus and flexural strength) of epoxy matrix with increasing weight percentage of Al_2O_3 nanoparticles and reaches maximum at 4wt.%.

MATERIALS AND METHODS

This research work adopted a mix-methodology approach which includes information and data extraction (web-surfing), compounding of specimens (samples) and laboratory tests. In the process of the work, it was found that the formation of these composites will depend a lot on the properties of the epoxy (resins and hardener), hence different types of epoxy products were tried out before obtaining the one with required properties. The characterization of the prepared samples is based on the fibre volume fraction of the novel composites materials, which in this case is the Alumina filler volume fraction. These composites were prepared through compounding (mixing and casting into moulds). Raw materials for manufacturing or formation of these composites namely epoxy (eposand) and alumina were procured or sourced from the local market. Beside these, other necessary instruments were made available and set up at Louis Carter Industries laboratory, Nnewi.

Eposand brand of epoxy (both eposand resin and eposand hardener) from shell was used to compound sets of samples. Eposand is a trademark product of Shell Petroleum Development Corporation (SPDC), which is used in the offshore well-cementing process. The resin and hardener are mixed at the combination ratio of 2:1 respectively. Table-1 below shows the Alumina micro-particulate volume fraction and the mould dimensions in accordance with the SON and ASTM standards specifications. Each of the sample A (10A), sample B (20A), sample C (30A) and sample D (40A) was replicated five times for more accurate testing result (for each mechanical test). The designations of 10A etcetera signifies 10%, 20%, 30%, and 40% volume content by percentage weight of alumina in the composites.

Table-1: Sample Specification According to ASTM Standards

Samples	Alumina micro-particulate weigth fraction (%)	Mechanical tests	Dimensions (mm)	Standards
Sample a	10	Tensile	$400\times 20 \times 20$	ASTM D3039
	10	Compressive	$50 \times 40 \times 40$	ASTM D3410M-03
Sample b	20	Tensile	$400 \times 20 \times 20$	ASTM D3039
	20	Compressive	$50 \times 40 \times 40$	ASTM D3410M-03
Sample c	30	Tensile	$400 \times 20 \times 20$	ASTM D3039
	30	Compressive	$50 \times 40 \times 40$	ASTM D3410M-03
Sample d	40	Tensile	$400 \times 20 \times 20$	ASTM D3039
	40	Compressive	$50 \times 40 \times 40$	ASTM D3410M-03

Specimens' (Sample) Production Procedures

Many steps or procedures were followed while producing these composite samples. The first was measuring out each raw material (resin, hardener, and micro-particulate fillers) according to the required percentage (%) fractions. This is made possible by the use of an electric scale model LD-1000 by Napco precision company China. After measuring each constituent of the composite, it is poured into a mixer or container inside which these constituents are mixed to form the composite. With the aid of an electric drilling machine upon which a spring rod with blades is attached to its spindle rotating at a speed of 2800rpm. The composite is cast into the moulds and allowed to cure for about 48 hours since the matrix (Eposand) has a very slow curing rate but produces excellent material with good mechanical properties after curing. During curing, the composite develops a temperature up to 180℃ .

Nevertheless, before casting into the moulds, they were coated with mould releaser. After trying different mould releasers such as paraffin wax, petroleum jelly and diesel gas none could actually release or help in recovery of the produced samples. Finally, ordinary engine-oil was applied and the product (sample) was recovered. The produced specimens were then cut to shapes and dimensions according to specified standards given by the Standard Organization of Nigeria and ready for testing.

Fig 1: Specimens after Tensile Test

Fig-2: Specimen after Final Collapse on Compressive Test

RESULTS AND DISCUSSION

Tensile Tests

Tinus Olsen universal testing machine was the tensile testing machine used at SON for conducting test on the material, the tensile strength of the samples were automatically calculated by the machine. The tensile testing machine displayed the tensile strength, yield strength, the elongation and plotted the tensile stress strain graph for each sample. The information were then subjected to further analysis using bar charts and graphs. Note that for each test and type of composite three replicate samples were tested and their average value were reported

Compression

Determination of the compressive strength of the material was also performed in the SON laboratory. The samples were properly prepared to ASTM D3410M-03 standard prior to conduction of the test. Readings were taken at initial crack but it was discovered that the material absorbed more compressive force even after initial crack therefore force (kN) at final collapse was also noted. The machine displayed compressive force (kN) at first crack and compressive force (kN) at final collapse, the area of the specimen was measured with the aid of a meter rule and the compressive strength in (MPa) obtained by dividing the force with the area of the specimen.

$$compressive\ strength\ at\ first\ crack(MPa) = \frac{F_1}{A} \quad (1)$$

$$compressive\ strength\ at\ final\ collapse = \frac{F_2}{A} \quad (2)$$

Where,

$F_1 = compressive\ force\ at\ first\ crack$

$F_2 = compressive\ force\ at\ final\ collapse$

Note that for each test and type of composite three replicate samples were tested and their average value were reported and analysed further using charts and graphs. Also note that in the experiment sample 10A represents sample A, 20A represents sample B, 30A represents sample C and 40A represents sample D.

Analysis of Compressive Test Result

Table-1: Average Compressive Strength at First Crack

Sample ID	**10A**	**20A**	**30A**	**40A**
Average Compressive Strength (Mpa)	29.5	33.4	46.7	63.7

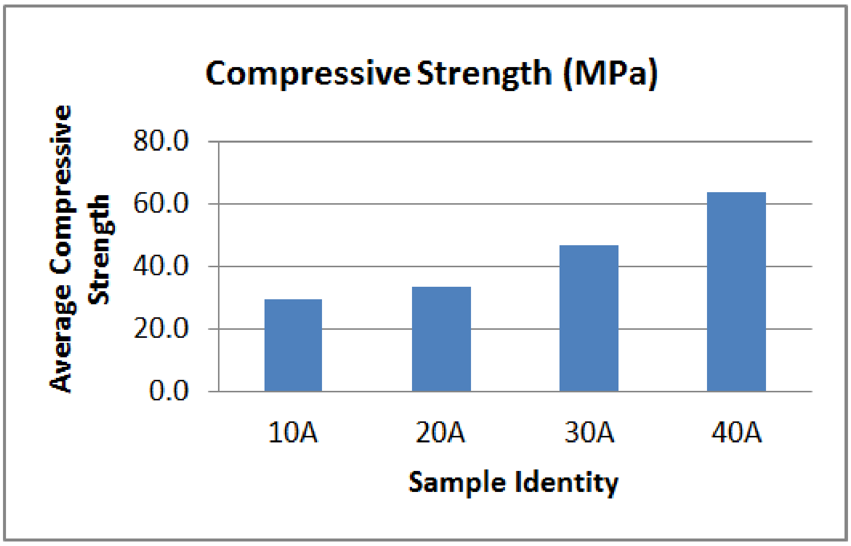

Fig 3: Chart showing Compressive strength of samples at first crack

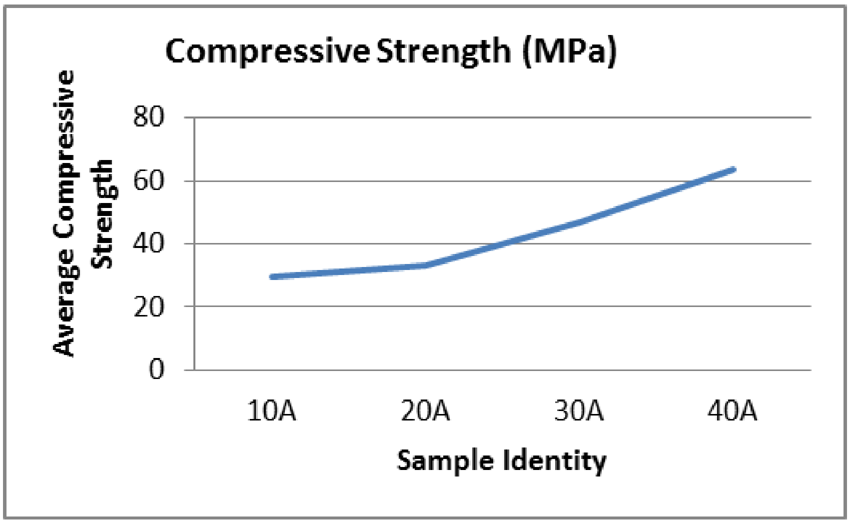

Fig-4: Graph Showing the Compressive Strength at First Crack

From Fig 3 and 4 above, it can be observed that sample 40A has the best compressive strength with a value of 63.7Mpa before the first crack. The compressive strength increases with the increase in percentage weight fraction of the aluminum oxide in the composites.

Table-2: Average Compressive Strength at Final Collapse

Sample ID	**10A**	**20A**	**30A**	**40A**
Average Compressive Strength (Mpa)	57.0	46.8	133.3	130.9

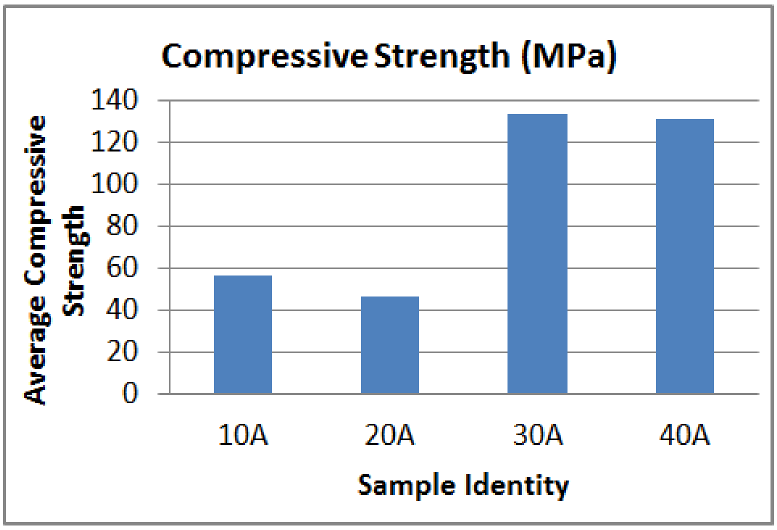

Fig-5: Chart Showing Compressive Strength of Various Samples at Final Collapse

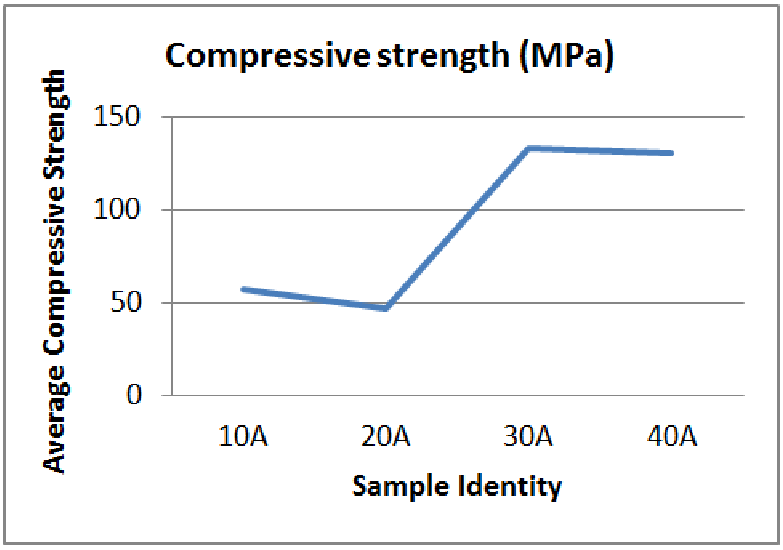

Fig-6: Graph Showing Compressive Strength of Various Samples at Final Collapse

From Fig 5 and 6 above, it can be observed that, sample 30A has the best compressive strength with a value of 133.3Mpa at final collapse. This is closely followed by sample 40A, while sample 20A recorded the least compressive strength of 46.8MPa at final collapse.

Analysis of Tensile Test Result

Table-3: The Average Tensile Strength of Various Samples

Sample ID	**10A**	**20A**	**30A**	**40A**
Average Tensile Strength (MPa)	7.99	4.63	2.39	3.55

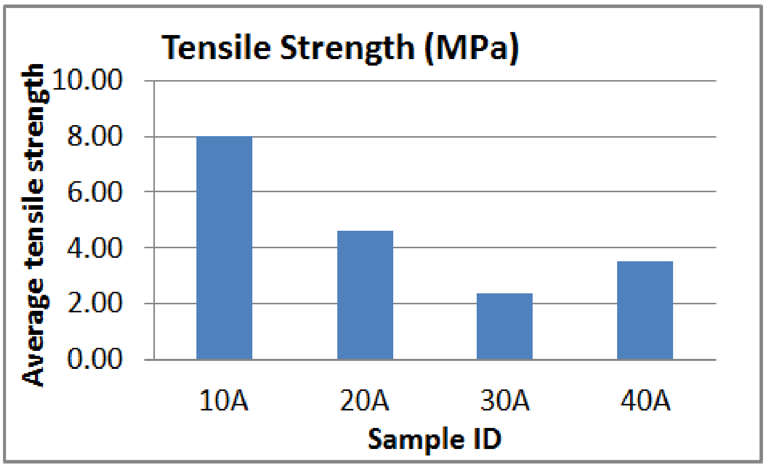

Fig-7: Chart showing tensile strength of various Samples

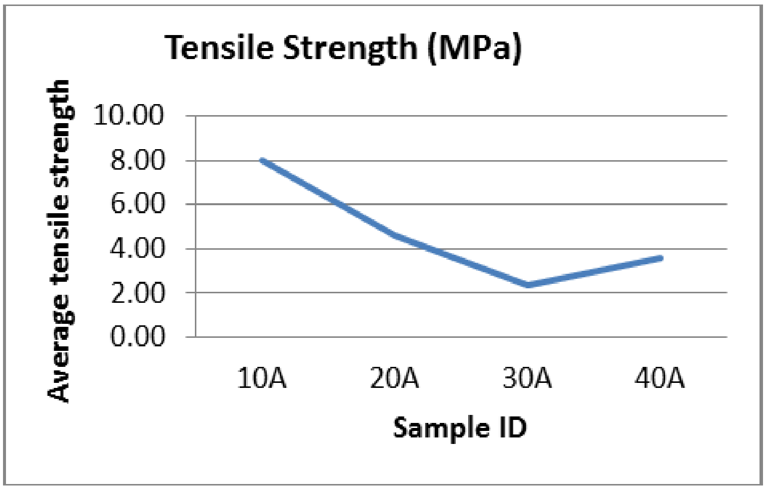

Fig-8: Graph Showing Tensile Strength of Various Samples

From Fig 7 and 8 above, it can be observed that sample 10A has the best tensile strength with a value of 7.99MPa before fracture and the sample 30A with the least tensile strength of 2.39MPa. This is an indication that the tensile strength of the composite decreases with increase in percentage weight fraction of alumina up to 30A but increases again at 40A.

Analysis of Yield Strength

Table-4: The Average Yield Strength of Various Samples

Sample ID	**10A**	**20A**	**30A**	**40A**
Average Yield Strength (MPa)	3.3	3.4	2.3	2.2

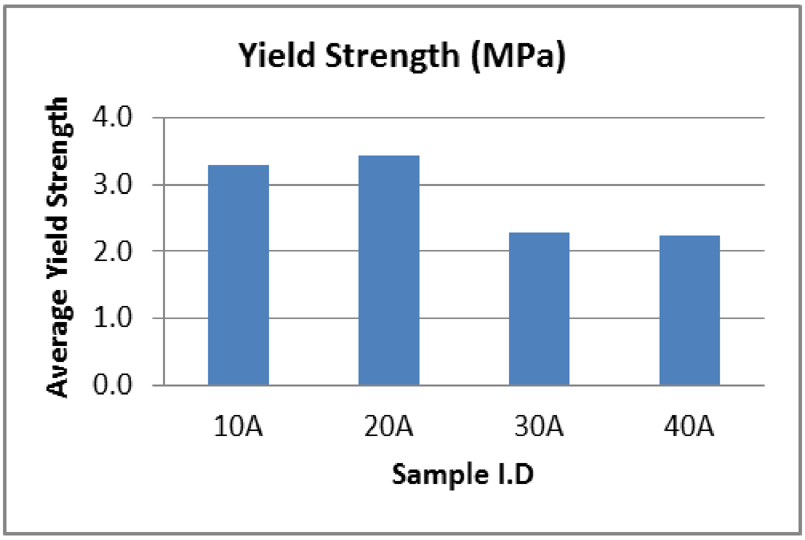

Fig-9: Chart Showing Yield Strength of Various Weight Fractions of Filler

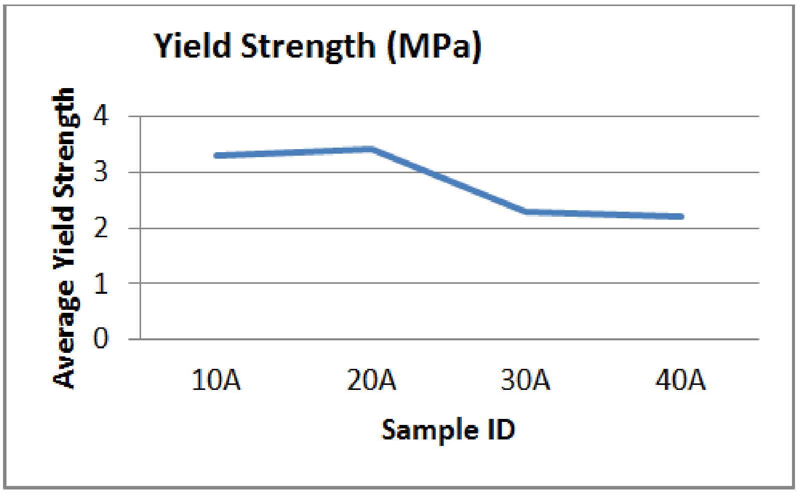

Fig-10: Graph Showing Yield Strength of Various Weight Fractions of Filler

The bar chart and graph of Fig 9 and 10 showed that sample 20A which contains 20% by weight fraction of aluminium oxide filled composites recorded the optimum yield strength of the thermoset composite. This is closely followed by sample 10A with respect to yield.

Analysis of Elongation (%) Property

Table-5: Average % Elongation of Samples

Sample ID	**10A**	**20A**	**30A**	**40A**
Average % Elongation (%)	6	7.3	5.7	2.3

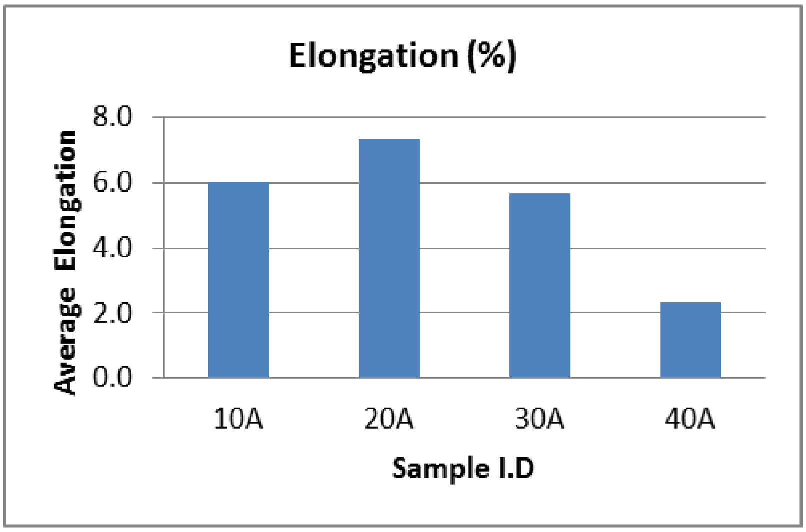

Fig-11: Chart showing Average % Elongation for various samples

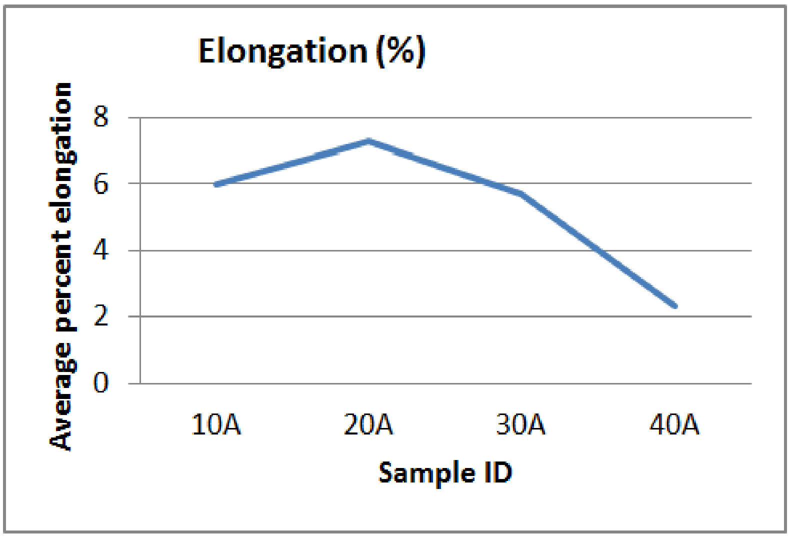

Fig-12: Graph showing Average % Elongation for various samples

From the above chart and graph of Fig 11 and 12 it can be deduced that sample 20A is the most ductile of the composites

CONCLUSION

Mechanical testing is a very important part of engineering as it helps determine the application of engineering materials by giving us definite experimental data on the properties of various engineering materials employed for construction. If it is economical, feasible and convenient. Composites should be subjected to these tests so as to enable engineers to express the mechanical strength theoretically for practical applications.

After producing samples of different volume fractions with Identities 10A, 20A, 30A and 40A using mix-method approach. the specimens were subjected to tensile and compressive tests, the results showed that the material exhibited good tensile and compressive properties and that the tensile strength decreases with increase in alumina particles up to 30A and picks up again at 40A, exhibiting the best tensile strength at 10A with an average tensile strength of 7.99MPa while the compressive strength at first crack increased with increase in filler concentration therefore maximum at 40A with an average compressive strength of 63.7MPa and a maximum average compressive strength (final failure) of 133.3Mpa at 30A. Sample 20A indicated an optimum yield strength and good ductility amongst the composites.

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