EXPLOITATION OF QUARTZITE AS REINFORCEMENT IN ALUMINIUM BASED METAL MATRIX COMPOSITE (AMMCS)

[1]BALOGUN, B. T., [1]MURIANA, R. A., [1]ESSIEN, U. A., & [2]ASUKE, F.
[1]Department of Materials and Metallurgical Engineering,
School of Infrastructure, Process Engineering and Technology,
Federal University of Technology, Minna, Nigeria.
[2]Department of Metallurgical and Materials Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
E-mails: balogun.tope@futminna.edu.ng, asukef@gmail.com, u.essien@futminna.edu.ng
Phone No: +234-706-836-4092

Abstract
The production of lightweight materials that are strong and durable, and ensuring human health safety has been a global challenge that researchers seek to surmount. The use of quartzite ore as reinforcement in aluminium based metal matrix composites (AMMCs) was investigated in this research. The aim of this work was to improve the properties of Al-Si alloy by the use of quartzite as reinforcement. Ingots of alloy and the composite cast were machined to the dimensions of 60 mm by 100 mm, and finally to 5 mm by 10 mm. Identification, optical, and ultimate tensile test were carried out. The microstructural analysis of the alloy and composite produced were carried out using Scanning Electron Microscope (SEM). The result of the identification and optical test confirmed the presence of Quartzite as the principal metallic mineral present in the ore, trailed by the presence of feldspar and kaolite. Al-Si alloy had a density of 2.6g/cm^2 and a specific strength of 22.92, while the Al-Si/quartzite composite had a density of 2.7 g/cm^2 and a specific strength of 24.50.The microstructural analysis revealed that the Al-Si/quartzite composite has better physical and mechanical properties over the Al-Si alloy.

Keywords: Alloy, Aluminium, Composite, Exploitation, Microstructure, Quartzite ore

Introduction
Aluminium based metal matrix composites (AMMCs) remained as the most vibrant engineering material which attracts keen interest of quality research (Dasgupta, 2012). Long time ago, producing a light-weight, low-cost processing route, non-corrosive, high strength with low density, durable and human health safety material for human use has being a challenge globally in the areas of exploitation of materials in the field of science and engineering applications. In a recent time, a light material such as AMMCs was widely used in most engineering applications such as: air craft, marine travels, robotics, cars, and machine spare parts.

However, shortcomings were observed, most of the materials used were expensive and the processing routes were costly. Some are not human health friendly and not commonly found in domestic homes.

Developing a composite material with quartzite can overcome these challenges in the field of science and engineering technology. Babu *et al.* (2018) developed a disc brake in automobile vehicle using coconut ash as reinforcement in AMMCs, it was affirmed that brakes operate most effectively if safety limits are not exceeded by the users. Kostoglou *et al.*(2018) revealeda novel combustion synthesis of carbon foam-aluminium fluoride nanocomposite materials, a carbon foam-aluminium fluoride composite (C-AlF3) was developed by adopting a combustion synthesis approach, which was an attractive alternative to wet chemical methods usually employed for such purposes. Lathe (2017) also used magnesium as a reinforcement when they developed a material that is made up of AZ91 Mg alloy to an improved mechanical property of AZ91 nano zirconia composites. In another recent development, study revealed that polymeric and metal oxide structured nanofibrous composites fabricated by electrospinning as highly efficient hydrogen evolution catalyst. It was concluded that: nanofibrous metal oxide structured Co3O4/Nfs-1 composite provides the best catalytic activity in terms of hydrogen production rate with 2.54 l H2 min1 gcat1 and good repeatability (Figen *et al.,* 2019).AMMCs was produced but went through a long and expensive processing route method (Dasgupta, 2012).

Study has shown that some heavy metals used in a composite development are dangerous and hazardous to human health. Luo *et al.* (2011) studied heavy metal contamination in soils and vegetables near an e-waste processing site in South China, in their findings, heavy metals such as canadium (Cd), and lead (Pb), were confirmed to be hazardous to human life. Gowd *et al,* (2010), also revealed the assessment of heavy metal contamination in soils at Jajman and Unnao industrial areas of the Ganga plain in India, they considered chromium (Cr) and zinc (Zn) as toxic substance which pose a threat to human health. Soltani *et al.* (2015), also studied: ecological and human health hazards of heavy metals and polycyclic hydrocarbons in road dust of Ishafan metropolis and discovered that heavy metals were harmful to human. Dasgupta (2012)also produced AMMCs and reported that Zn, Cr and Cu may be harmful to human health. Apart from heavy metals, some ores and minerals reported to be dangerous and hazardous to human health. Govindarao *et al.* (2018) affirmed that chalcopyrite causes disease due to exploitation of iron-rich sphalerites material. Similarly, Jaishankar *et al.* (2014) studied toxicity, mechanism and health effects of some heavy metals which confirmed the negative effects that most heavy metals have on human health during the mineral exploitations.

Nevertheless, some ore materials are safe in exploitation but are expensive in processing route, this was established by Igami *et al.* (2018)in their recent development when using sillimanite ore in determining Al/Si order of temperature using high angular resolution mechanism by X-ray spectrometry.

It is highly commendable that researchers of recent time have been exploiting ores and minerals in aluminium based metal matrix composites. Asif*et al.* (2017) improved the hardness and tensile strength of automobile clutch hub when used graphite mineral as reinforcement in the matrix of aluminiumA356 hybrid composites. Ceramic mineral silicon dicarbide (SiC) was also used with flyash in aluminium metal matrix composite as reinforcement by Peyyala *et al.* (2017), in their development, an improved hardness and compressive strength as well as tensile strength was achieved.

In another recent development, Lokesh *et al.* (2018) used red clay in AMMCs. It was concluded that the inclusion of the clay mineral actually increased the hardness factor of the composites and as well the malleability of the composite material developed was tremendously improved.

Bashman (2010) affirmed that quartz and feldspar can be associated minerals, also Zuo *et al.* (2016) established that: raw powder of quartzite ore contains 85% of quartz and 15% of kaolite and illite clay with traces amount of feldsper. It was also concluded in their findings that colour of quartz was predominantly white.

In order to overcome afore mentioned challenges, we therefore research in to the exploitation of quartzite in aluminium based metal matrix composite to see the degree of its effectiveness in a composite development.

Some aluminium based alloy were meant for high temperature studies therefore, alloy material that was used for high temperature was basically required, as stir casting technique was employed for the method of production of alloy and composite to be produced, which was casted at high temperature(Zamani, 2017).

Chemical compositions of the alloy used for high temperature studies were presented in Table 1.

Table 1: Chemical compositions of the aluminium alloy used for high temperature studies (wt. % except for Sr ppm) (Zamani, 2017)

Si	Cu	Mg	Fe	Zn	Mn	Sr	Al
10.0	2.6	0.24	0.8	0.8	0.26	0 – 48	Balance

Based on the chemical composition in Table 1, the material used for this research belongs to series A4XXX (Higgin, 1993).

Materials and Method

Materials and Equipment that were used in this research are: quartzite ore, aluminium alloy scraps (as-received), deionized water, A crucible furnace, sand, graphite (plumbago), digital weighing machine, analogue weighing balance, explorative ball mill locally made by using mild steel., crucible furnace, (as-received) sieve, a set of standard BBS sieves, graphite crucible, Metallurgical Trinocular Microscope (model: MM039B00M), Fourier Transformation Infrared Spectrophotometer (model: L-785-BIS), Scanning Electrons Microscope (SEM) (model: MEL 30000, SN: MEL-0351), universal testing machine (model: AIE-M, SN: 161) and Hounsfield Tensometer.

Characterization of Quartzite Ore

Quartzite ore was subjected to the following processes before used:

Thorough washing of the ore- The crystal of quartzite was thoroughly washed by using deionized water and allows it to dry in a natural air condition at room temperature.

Weighing of the ore- The weight of the ore was known by the use of analogue weighing machine and 7.5kg of weight was recorded.

Commmunition process- This is the crushing and grinding of the ore in to powdery form. The crushing was done by the use of universal testing machine and it was grinded manually by the use of explorative ball mill locally made by using mild steel.

Weighing of the ore powder- The ore powder was weighed so as to have the precision and accuracy of the quantity of powder that was taken for sieve analysis process and 100g of powder was biasedly taken.

The sieve analysis of the particles- The particle size analysis of quartzite powder was carried out in accordance with BS1377: 1990 (Chike *et al.*, 2014) by using British Standard Sieve (BSS). 100g of grinded Particles of quartzite ore was placed in to a set of sieves arranged in descending order of fineness and shaken for 15 minutes which was the recommended time to achieve complete Classification (Chike *et al.*, 2014). The particles that were retained in the BS 0.05 μm were used in this study.

Melting and Casting

The aluminium alloy was cast by stir casting method using sand mould. A 9kg of aluminium alloy scraps (as received) from Pantaker market Minna Niger State, was properly cleansed of dirt and oil by the use of deionized water. A crucible furnace which was locally made by the use of alumina bricks was preheated to about 300^{o}C and a 9kg of aluminium alloy scraps was carefully charged in to the crucible furnace. The charged material was covered with charcoal to prevent hydrogen pick-up which can result to loss of excess heat. The alloy was heated to about 800^{o}C for adequate homogeneity. The melt was poured into a graphite crucible in two places labelled A and B. Each crucible contained a melt of about 1kg. An amount of 0.2wt% of quartzite ore of 0.05μm particle size was added into the crucible B and quickly stirred thoroughly with the use of Stirrer, the stirring took about 60 seconds to ensure proper mixing and homogeneity. The melt from the crucible A and B were quickly poured into sand mould. Gasification was noticed for about 5 minutes in crucible A but takes longer period of about 10 minutes in crucible B. Two casts of 1kg ingots were made. Ingot A was Al-Si alloy cast, while ingot B was Al-Si/Quartzite Composite cast.

Test Procedure

Test samples were taken from ore crystal and powder, alloy and composites produced for the mineralogical, metallurgical and mechanical test according to the recommended standard for each test.

Identification Test

Identification test such as: colour, luster, streak, fracture, tenacity and optical test were carried out on ore in order to confirm the authenticity of the quartzite material used in this study.

Colourtest- The ore was thoroughly washed with deionized water to be freed from dirt and debris. It was then observed by the use of hand lens which gives clear appearance of the physical colour of the ore crystal.

Luster test- The crystal of the ore was visually observed in a bright light during the sunny day at the exploration site.

Streak test- The ore crystal was kept dried after colour and luster test, it was crushed by the use of universal testing machine AIE-M, SN: 161and grinded manually in to powder by the use of explorative ball mill locally made. It was then observed by the use of hand lens which gives clear appearance of the physical colour of the ore powder. The powder of the ore was also touched with index finger and rubbed with the thumb finger.

Fracture test- The ore crystal was put in a compressive chamber of universal testing machine AIE-M, SN: 161 and a load is being applied by pressing the automatic button until it fractured in to failure.

Tenacity test-The same procedures as that of a fracture test was applied. Tenacity of the ore crystal was determined at the same time with fracture test immediately a load was applied. Tenacity test was also determined during streak test when the ore crystal was powdered.

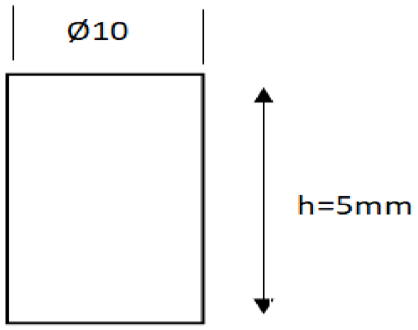
Optical test- Grinding of ore crystal was carried out using paper grit of silicon dicarbide grit of different grades ranges from 220-800 grit.The polishing of ore samples was done by the use of emery clothe with alumina and water which were carried out in a rotating polishing machine disc. The polished ore samples were then rinsed in deionized water and were allowed to dry at room temperature. The polished and dried ore sample was examined under a reflected light by Metallurgical Trinocular Microscope (model: MM039B00M).

Fourier Transformation Infrared Spectrophotometry (FTIR) Analysis
Test analysis was conducted on ore powder and the alloy scrap (as-received) samples so as to determine the chemical compound present in the ore and the alloy. The powder of ore was examined by using FTIR, model: L-785-BIS.

Determination of Density the Alloy and Composite
A 1kg each from two ingots of alloy and composite cast of dimensions 60mm by 100mm obtained by oblique machining operations at a cutting speed and feed rate of 556 rev/min. and 4 min/rev. respectively were further machined to a smaller dimension 5mm by 10mm for determination of density and specific strength of alloy and the composite produced. The mass of each alloy and composite samples were measured by using a digital weighing machine and the mass of each samples were recorded. The density of each sampleswas determined using calculated parameters. The density of alloy and the composite developed was determined using the formula in equation (1).

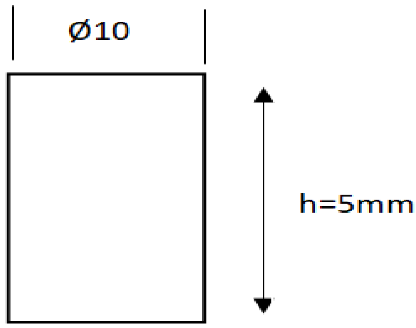
$$\text{Density} = \frac{mass}{volume} \qquad (1)$$

Two samples, each from 1kg of ingots cast were machined to a cylindrical shape of the following parameters:



Alloy Sample
Alloy Sample parameters
$V = \Pi r^2 h$
$M_1 = 1.02g$, r=5mm, h=5mm

$$\text{Density} = \frac{\text{mass}}{\text{Volume}}$$



Composite Sample
Composite Sample parameters
$V = \Pi r^2 h$.
$M_2 = 1.05g$, r=5mm, h=5mm

The density was determined as Al-Si alloy cast is 2.61g/ml, while that of Al-Si/quartzite cast is2.70g/ml**.**
The density of pure aluminium metal in excited state = 2.70g/ml.

Ultimate Tensile Strength Test
The Hounfield Tensometer Testing Machine (HTM) was used for the tensile test. A graph sheet was inserted into the drum and the test specimen was inserted into the chucks and gripped firmly by the crosshead. The wheel was rotated to apply a tensile force to the specimen till it fractures. The head of the pin on a rotating drum bearing was traced on the graph so that the stress strain curve is plotted. Figure 3 shows the Photograph of the Fractured Specimen. The ultimate tensile strength of alloy and the composite produced were determined using equation (2).
Ultimate tensile strength (σ_u):

$$\sigma_u = \frac{p_u}{A_o}(2)$$

Where:

σ_u: The ultimate tensile strength of the samples,
P_u:applied load on the samples,
A_o:thecross-sectional area of the test piece,

Determination of Specific Strength of Alloy and Composite Cast

The basic method of determining the specific strength of alloy and composite cast is by using equation (3).
Specific strength (SS):

$$\mathrm{SS} = \frac{\sigma_u}{\rho}(3)$$

Where:

SS:is the specific strength of the samples,
σ_u:ultimate tensile strength of the samples,
ρ:the density of pure aluminium.

From the result value of ultimate tensile strength obtained from the laboratory experiment, we therefore deduced the specific strength of alloy and composite cast

i. The specific strength of alloy cast.

$$\text{Specific Strength} = \frac{\text{ultimate tensile strength of the alloy cast}}{\text{Density of pure aluminium metal}} = \frac{61.89}{2.70}$$

Specific Strength = 22.92

ii. The specific strength of composite cast

$$\text{Specific Strength} = \frac{\text{ultimate tensile strength of the composite cast}}{\text{Density of pure aluminium metal}} = \frac{66.07}{2.70}$$

Specific Strength = 24.50

Microstructural Test

The SEM MM039B00M was used to identify the surface morphology of the alloy and the composite cast samples. Coarse particles of very tiny proportions of 0.05g from each sample were taken for microstructural viewing and the microstructures were displayed on the screen of the SEM.

Results and Discussion

Identification Test

Colour Test

It was observed that the quartzite crystal has whitish colour of quartz with lateral line of dark colour of kaolite and small amount of brownish colour of feldsper in a visual observation of crystal. This was presented in Figure 1. This test predicts the ore crystal to be quartzite.

Figure 1: Crystal structure of quartzite ore

Luster Test
The crystal was visually observed in a bright light and it reflects light and does not allow light to pass through it even through its thin edges and glassy luster was observed. This test predicted the presence of quartz in the ore.

Streak Test
The quartzite was observed to be pure colourless all through when grinded in to powder which was quite different in colour when it was in crystalline form. It was also observed that the ore leave a trail of powder on the two fingers when rubbed with each other. This test predicts the presence of quart as part of mineral present in the ore as indicated in Figure 2.

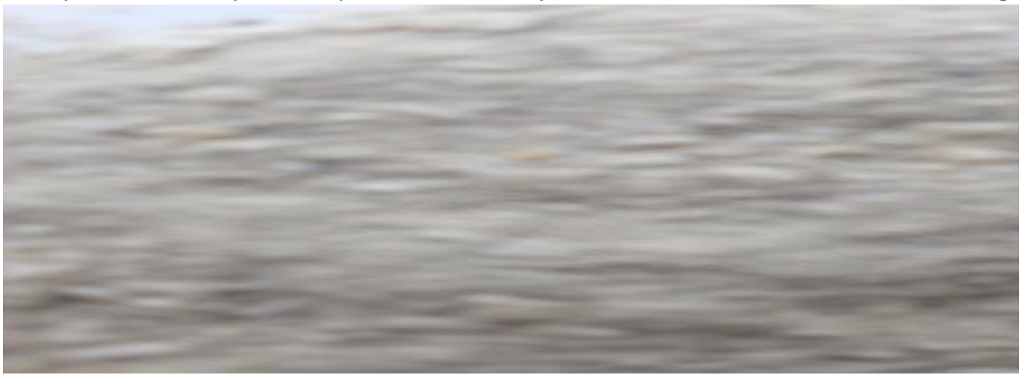


Figure 2: Sreakcolour of quartzite ore powder

Fracture Test
The ore crystal was fractured in to failure by universal testing machine (AIE-M, SN: 161) and it was observed that the crystal was broken in to a flat, smaller fragments of smooth cleavage faces that was plane of structural weakness, instead of splitting in to smaller fragments. It was also observed that the surface of the break shows curves like the rings made by a pebble dropped in to still water. In this type of description, it was being confirmed that the ore gives a conicoidal fracture. It was also observed that the bonding of atoms of the ore crystal structure were uniformly strong in all directions as this was indicated by the machine during the laboratory test as presented in Figure 3. The above test confirmed the predominant presence of quartz in the ore crystal.

Figure 3: Fracture sample of quartzite

Tenacity Test
Tenacity of the ore crystal was quickly observed under a load application during fracture test and also during streak test when it was grinded in to powder. It was observed that the ore was easily powdered during streak test. The reaction of the ore crystal when the load was applied on it and was quickly noted during the fracture test, it was observed that the ore gives a crushing characteristic of failure by broken in to smaller fragment easily which

confirmed the ore to be brittle material and this was justified by fracture test in figure 3 above. The above test suggests the ore tested to have quartz as its constituents.

Optical Test

The crystal was examined in a Metallurgical Trinocular Microscope MM039B00M) under a reflected light by 400X magnification and a predominant brownish colour was observed which confirm the presence of quartz, few amounts of yellowish colour confirmed the presence of feldsper and small amount of dark colour indicates the presence of kaolite as mentioned in the visual observation test. This is presented in plate 1 to 3 below as it was replicated during laboratory experiment.

It was observed that the way quartz and feldsper appeared when viewed in a metallurgical reflected-light microscope in terms of colour was quite different from when viewed with necked eyes under physical observation. In a physical observation, quartz appeared in a whitish (colourless) but it appears brownish under a metallurgical reflected-light microscope. Feldsper appears brownish in a physical appearance but showing yellowish colour when viewed in a metallurgical reflected-light microscope. It was observed that kaolite maintained same dark colour in both necked eyes and microscopic view.

Crystal Structure of Quartz Ore in an Optical Reflected Light Microscope

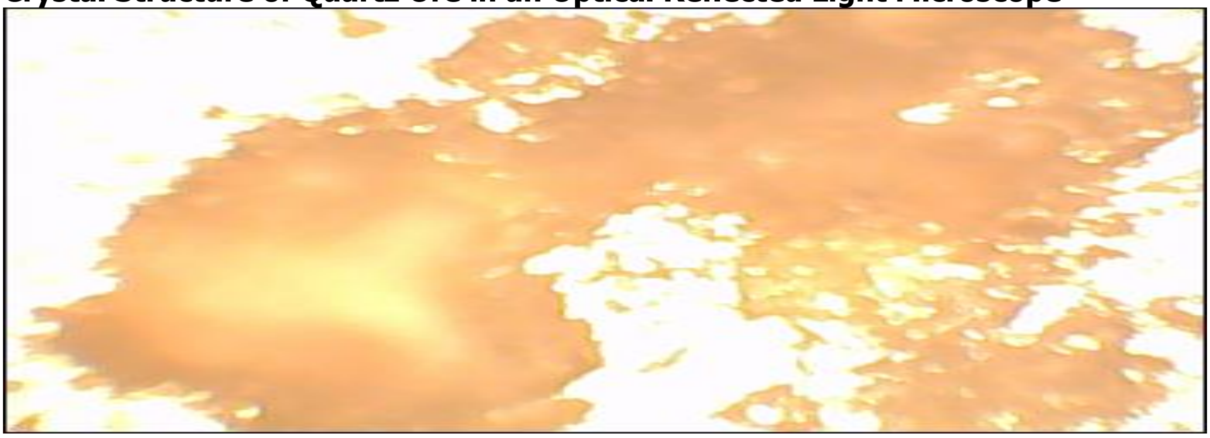


Plate 1: Replicate I under 400X magnification showing quartz as principal non-metallic mineral, associated with feldspar and kaolite

FTIR Analysis Result for the Ore Sample

Figure 4: FTIR for Quartzite ore powder

The result of FTIR revealed the presence of quartz (SiO_2) in colourless appearance, feldsper (K, Al, SiO_2) in brownish appearance and kaolite ($Al_2Si_2O_5(OH)_4$) in dark traces as it was being substantiated in identification test. The outcome of FTIR test validates all the result of identification test. It is therefore deduced from FTIR result that the ore sample used in this study is confirmed to be quartzite.

Microstructures of Alloy and Composite

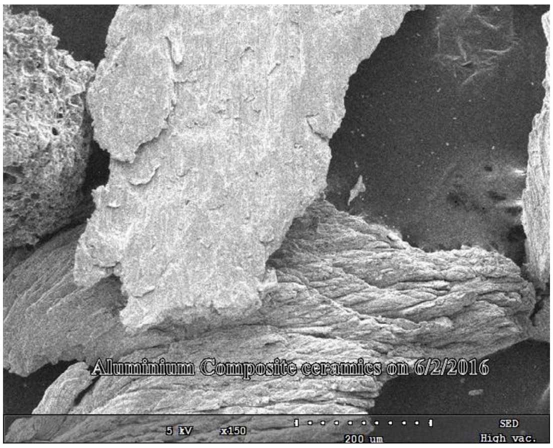


Plate 2a (alloy) x150, 200µm Plate 2b (Composite) x150, 200 µm

Microstructure Analysis
Plate 2a: Alloy Photomicrograph (x150), 200µm.
The photomicrograph reveals the interlocking of grains in edge dislocation. The grains are interlocking, moving in the direction of x-axis, y-axis and z-axis, leaving only the single grain at the centre of the microstructure. The porosity is well pronounced.

Plate 2b: Composite Photomicrograph (x150), 200µm.
There is latice dislocation accommodation into the grain boundary. No transmission of slip but cracking of the grain boundary the grains is covered with well pronounced whitish colour which appears on the surface of the grains as if painted white colour. This is the quartz in the composite added to the matrix of aluminium. The grains appearance reveals a grain that forms a hard substance, showing more plasticity in nature with little of void or cavity at the left side but large void or cavity at the right side of the microstructure.

Physical and Mechanical Properties of Aluminium Alloy and Composite Cast

Table 2: Properties of aluminium alloy and composite cast

S/N	Alloy/composite sample	Density (ρ) g/cm^2	Specific strength (SS)	Ultimate tensile strength (σ_u) N/mm^2
1	Aluminium alloy	2.6	22.92	61.89
2	Composite	2.7	24.50	66.07

During the investigation, the physical and mechanical properties of alloy and the composite developed were determined. These properties wereDensity, Specific Strength (SS), and Ultimate tensile strength.

Physical Properties: alloy cast has a density of 2.6g/cm^2. It has deviated in relative density to that of parent metal of pure Aluminium which is 2.7g/cm^2. The composite developed has maintained the density of 2.7 g/cm^2 which is the same with the parent metal of pure

Aluminium. This means that the composite developed still maintained the light weight of aluminium parent metal, which makes it vibrant in most of engineering applications. Finally, the specific strength of composite developed is 24.50 compared to that of alloy of 22.92.

Mechanical Property**:** From the mechanical properties in Table 2, the composite developed in this research has higher ultimate tensile strength (σ_u) of 66.07 N/mm^2 compared to 61.89 N/mm^2 of alloy.

Conclusion

Development and characterization of Al-Si alloy reinforced with 0.2wt% Quartzite ore of 0.05μm particulate has been studied. The implications of Quartzite ore introduced on the properties of composite developed were investigated. The following conclusions and recommendations are made from the results of the investigations. The microstructure test reveals the superiority of Al-Si/quartzite composite cast over an alloy cast. The composite developed have better physical properties of density and strength. The composite developed was light weight having the same weight with the parent metal of aluminium. Alloy cast has a density of 2.6g/cm^2. The composite developed has maintained the density of 2.7 g/cm^2 which was the same with the parent metal of pure aluminium. Finally, the specific strength of composite developed is 24.50 compared to that of Al-Si alloy of 22.92.

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