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MODELING AND CHARACTERIZATION OF METAL MATRIX COMPOSITES: ALUMINIUM-GRAPHITE COMPOSITE

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ABSTRACT

The emergence of metal matrix composites is partly a consequence of an improved understanding of their potentials and limitations based on their science of process, principles of physical metallurgy and interfacial chemistry. They can be produced by conventional casting techniques. The reinforcing material such as particulates of graphite can be added into the melt of any metal during its stirring. The resultant mixture is then cast into a permanent mould. This technique was used to produce aluminum-graphite composite containing different percentage concentrations of graphite ranging from zero to twenty (0-20%wt). To solve the problem of making the molten aluminum alloy wetting the graphite, a special chemical activation was carried out. The accent is on mechanical performance, describing how the presence of reinforcement in a metallic matrix influences its mechanical and physical properties. This composite shows a decrease in wear rate due to the presence of graphite in the composite.

KEYWORDS: *Metal, Matrix, Composites, Aluminum, Graphite and Concentration.*

INTRODUCTION

1.1 Background of the Study

Composite materials are divided into three groups Polymers matrix composite (PMC). These materials use a polymer-based resin as the matrix and fibres such as glass, carbon and aramids as reinforcement. We also have the ceramics matrix composites (CMC) used in very high temperature environments. These materials use a ceramic in the matrix and reinforced with fibres, whiskers from silicon carbide and boron carbide. Then the metal matrix composites (MMC) inversely found in automobile industries these materials use a metal such as aluminum as the matrix and reinforced with fibres such as silicon carbide (11). Amongst the various matrix materials available, aluminum and its alloys are widely used in the fabrication of MMCS and have reached the industrial production stage.

In this research, discussion will be based on the characterization of engineered materials (metal matrix composites) and would be narrowed down to aluminum-graphite matrix composite. The bevhaviour centers on the structure and characteristics of the engineering materials while the processing involves the procedural steps taken in the manufacturing of this material with a view to studying and producing a property of high quality microstructures characterized by a uniform distribution of reinforcement through the whole sample and uniform load bearing mechanical properties of the final product.

Graphite in the form of fibres or particulate has long been recognized as a high-strength, low-density material. Aluminum graphite particles MMCs produced by solidification techniques represent class inexpensive tailor-made materials for variety of engineering applications such as automotive components, bushes and bearings. Their uses are being explored in view of their superior technological properties such as the low coefficient of friction, low wear rate, superior gall resistance, high seizure resistance, high damping capacity and good machinability.

Several processes involving the incorporation of graphite particles in aluminum-base alloy to produce particulate composite have been developed. While powder metallurgy is a powerful method to produce such composites in mass scale production of small components, the liquid metallurgy techniques are now attracting much attention because of their inherent production advantages.[8] The most economical production of such composite is by stir casting; nevertheless, this is associated with some problem arising mainly from the apparent now-wet ability of graphite by liquid aluminum alloys and density differences between the two materials. As a result, introduction and retention of graphite particles in molten aluminum is extremely difficult.

Several investigations have been documented to improve the wetability between the two components by special treatment of both, the particulates and melt. A considerable amount of studies have been carried out in the area of development of processes, the characterization of the structure and properties of these materials. [10]

In view of the above-mentioned problems, this study was undertaken to produce an aluminum/graphite composites with high-quality microstructures characterized by a uniform distribution of the reinforcement throughout the whole sample and good mechanical properties of the final product. The key idea is to apply sufficient shear stress (T) on particle clusters embedded in the liquid metal to overcome the average cohesive force or the tensile strength of the cluster.

A new rheo process has been developed at Brunel centre for advanced solidification Technology (BCAST), Brunel university, by utilizing the melt conditioning by advanced shear Technology (MCAST) process in which the liquid undergoes a high shear stress and a high intensity of turbulence inside a specially designed twin screw machine. The effects of processing parameters on the reinforcement distribution have also been examined with the purpose of optimizing the process parameters to yield components of high integrity. [15]

The experimental results of novel melt-conditioned high-pressure die cast (Mc-HPDC). Aluminum composites are compared with conventional high-pressure die-casting (HPDC) samples. The adopted technique or process clearly demonstrates a significant improvement in the distribution of the reinforcement in the matrix with a good combination of improved ultimate tensile strength (UTS) and tensile elongation (E), which is the stir mixing and casting method.

1.2 Statement of Problem

In the world of technology, especially in high speed transmissions such as automobiles, aerospace, and spinning- weaving light weight and high strength are paramount, there is this need to source for materials that maintain these qualities. This motioned the inquisitiveness to embark into this type of composite design (Aluminum –Graphite). Components running at high speeds tend to change their morphology due to heat generation and as such resistance to heat is considered in the design.

Early attempts to produce particulate composites by the stirring technique have not been successful. It has been postulated that the major difficulty with such an approach is that most graphite particles are not wetted by most of the molten alloys. However, the basic problem associated with the production of aluminum –graphite composite is that the graphite particle is not wetted by the aluminum melt. This technique also has the drawbacks of high cost and/or extensive reaction between the particles and the melt, which degrades the properties of the composites.

Secondly, the problem of the wetted graphite rising to the surface of the melt due to the density difference between the graphite particles and aluminum melt, accumulating at the top forming a thick layer (pushing effect) was also encountered.

1.3 Aim and Objectives

- To enhance stiffness of Aluminum components where there is need for avoidance of excessive elastic deflection.

- To enhance the strength of the material by addition of reinforcement fiber there by increasing the fatigue resistance
- To increase creep resistance, achieved mostly by addition of long fibres especially to Ti alloys.
- To produce material with reduced density and high strength for ultra modern engineering use.
- To increase the wear resistance of the material (matrix); introduction of reinforcement reduces wear rate by factor of up to ten.
- To make a component that operates under high temperature conditions.

1.4 Significance of the Study

The behaviour of a manufactured part during its expected service life is an important consideration. It is important to determine what could occur on a product that would be damaging and questions of failure of parts that are made of these composite materials. This work gives an idea of the properties of aluminum graphite composite material to aid in bringing to existence the knowledge its strength, hardness and other mechanical properties so as to know the maximum load that can be exerted on parts made of these material also from the knowledge of its physical properties which provides its strength to weight ratio, density presented from the view point of material selection and manufacturing and its relevance to the service life of the component.

1.5 Scope and Limitation

The study uses aluminum as the matrix and graphite as the particulate fibre and the two materials are mixed to form a homogenous mix. Standard samples were made from them and to be used for mechanical properties tests to determine relative properties with fiber concentration addition. The major problem in this work is difficulty in mixing to form a homogenous mixture.

LITERATURE REVIEW

Among the major developments in materials in recent years are composite materials. In fact, composite are now one of the most important classes of engineered materials, because they offer several outstanding properties as compared to other conventional materials. Composite materials have found increasingly wide applications in aircraft, space vehicles, offshore structures, piping, electronics, automobiles, boats and sporting goods. [15] The oldest example of composites is the addition of straw to clay in the making of mud huts and of bricks for structural use; this combination dates back to 4000B.C. [14]. In that application, the straws are the reinforcing fibers, and the clay is the matrix. Another example of a composite material is the reinforcement of masonry and concrete with rods, which was begun in the 1800s.

Examples of metal matrix composites stretch back to the ancient civilization. [8] Among the first composite materials to attract scientific as well as practical attention were the dispersion hardened metal systems. These developed from work (Schmidt 17, 1924) on consolidated mixtures of aluminum/alumina powders and led to the extensive research in the 1950s and 1960s.

Despite their highly promising mechanical and thermal properties, metal matrix composites (MMCs) have, for a long time, been afforded only limited use in very specific applications. [18] Shortcomings such as complex processing requirements and the high cost of the final product have presented the greatest barriers to their proliferation. Improvements in the reinforcement fabrication and composite processing techniques are therefore pivotal for increasing their commercial applicability. [12] Significant efforts have been and continue to be, devoted to this end with encouraging result; reinforced metals have begun to show their presence in large-scale commercial applications. Notable examples includes the alumina fiber-reinforced aluminum alloy pistons for diesel engines introduced

by Toyota Motor Corporation in 1982 and, more recently, the aluminum and carbon fiber-reinforced cylinder liners of the Honda Prelude Clyne (5, 1993).
(Early Lotus Elise Models in 2000) used aluminum metal matrix composites rotors, but have less than optimal heat properties due to the wrong choice of reinforcement agent and Lotus has since switched back to cast iron usage. Honda has used aluminum MMC cylinder liners in some of their engines, including the B21A1, H22A and H23A, F2oC and F22C. Porsche also used MMC in reinforcing the engine's cylinder sleeves in the Boxster and 911. Specialized Bicycles has used aluminum MMC compounds for its top of the range bicycle frame for several years Callister (2001).

Aluminum was first produced in 1825. Aluminum, Alumina/ graphite and its alloys are extensively used in large number of industrial applications due to their excellent combination of properties like high strength-to-weight ratio, good corrosion resistance, better thermal conductivity, easy to deform, etc. Because of high strength-to-weight ratio that automobiles and aircrafts components and its alloys are made in order to make the moving vehicle lighter, which results in the saving of fuel consumptions.

Using composite materials can yield terrific benefits in most industries. One example is the decreased fuel consumption in the new Boeing 787 Dream liner, which was designed with a lightweight, composite fuselage and wings Pamela (15, 2007).

In 2007, alliminum/graphite-composite military High Mobility Multi-Purpose Wheeled Vehicle (HMMWV in Hummvee) was introduced by TPI composites Inc. and armor Holdings Inc; the first all aluminum/graphite-composite military vehicle and in 2008 also, an all aluminum/graphite-composite recreational vehicle (RV) was introduced by Pilgrin International Inc. the shell is composed of cosmolite, a thermoplastic fiber-reinforced composite and the exterior surface sepctralite which incorporates Dupont surlyn, an impact resistant coating found on golf balls.

The principles of precipitation hardening in metals date from the 1930s and were developed in the following decade. Recent collected papers celebrating such landmarks in the use of metals, give a fascinating insight into the major metallurgical advances during this period. For both dispersion hardening and precipitation hardening, the basis of the strengthening mechanism is to impede dislocation motion with small particles. [1] This is achieved by the incorporation of either fine oxide particles or non-shearable precipitates within a metallic matrix. Of prime importance is the minimization of the spacing between the inclusions.

Most recent developments have brought the concept of metal matrix composite closer to engineering practice. An interesting example is provided by the so-called "dual phase" steels, which evolved in the 1970s. These are produced by annealing fairly low carbon steel and then quenching. This result is a product very close to what is now referred to as a particulate MMC, with about 70% of very hard, relatively coarse particles distributed in a soft matrix. This is a strong-tough and formable material, now used extensively in important applications such as car bodywork. Interest in fibrous metal matrix composites mushroomed in the 1960s, with effort directed mainly at aluminum and copper matrix systems reinforced with tungsten and boron fibres. In such composites the primary role of the matrix is to transmit and distribute the applied load to the fibres. Researcher on continuously reinforced composites waned during the 1970s, largely for reason of high cost and production limitations. The continuing need for high temperature, high performance materials for various components in turbine engines have trigged a resurgence of interest, mainly directed towards titanium materials.

Discontinuously reinforced composites fall somewhere between the dispersion strengthened and fiber strengthened extremes, in that both matrix and reinforcement bear substantial properties of the load.

[4) They have been rapidly developed during the 1980s, with attention focused on aluminum-based composites reinforced with Sic particles, Al_2O_3 particles, short fibres or graphite particles. [7]
Metal materials have advantage of higher elastic modules over polymer matrix, matrix material in these components usually aluminum, Lithium, magnesium, copper titanium and super alloys. The elastic modulus of nonmetallic fibre ranges between 200Gpa and 400Gpa with tensile strength beings in the ranges from 20000Mpa to 3000Mpa.

Table 2.1: Metal matrix composite materials and Application.

Fibre	**Matrix**	**Application**
Graphite	Aluminum	Satellites, missile and helicopter structures
	Magnesium	Space and satellite structure
	Lead	Storage-battery plates
	Copper	Electrical contacts and bearings
Boron	Aluminum	Compressor blades and structure supports
	Magnesium	Antenna structures
	Titanium	Jet engine fan blades
Alumina	Aluminum	Super conductor restraints in fission power reactors
	Lead	Storage battery plates
	Magnesium	Helicopter transmission structures
Silicon carbide	Aluminum, titanium	High temperature structures [
	Super alloy (co-base)	High temperature engine components

2.1 Fabrication Processes

Varieties of processes have been and are being developed for the manufacture of MMCs. These may be divided into primary liquid processing and secondary processing. A further important distinction can be drawn for the primary liquid processing depending on whether the matrix becomes liquid at any stage. Each technique has its own limitations in terms of component size and shape, and imposes certain micro structural features on the product. Table 2.2 lists of different processing routes which is discussed in this chapter as well as their applicability to the production of different composite materials.

Table 2.2: MMC Fabrication Processes

	Types of reinforcements				
	Continuous		Discontinuous		
Processing Routes	**Mono-filament**	**Multi-filament**	**Staple fibre**	**Whisker**	**Particulate**
Squeeze infiltrate perform	(√)	√	√	√	(√)
Spray coat or co-deposit	√	√	X	X	√
Powder premix/extrude	X	X	√	√	√
Slurry coat/hot press	(√)	√	X	X	X
Interleave/diffusion bond	√	X	X	X	X
Stir mixing and casting	X	X	(√)	(√)	√

X = Not practicable

(√) = Not common
√ = Current practice

As can be seen in table 2.2 above, many fabrication routes are now available by which reinforcements can be incorporated into a metal matrix. It is important to note from the outset that making the right choice of fabrication procedure is just as important as terms of the microstructure and performance of a component, as it is for its commercial viability.

However, before looking in detail at the various processing options, it is worthwhile dwelling for a moment on selection of the reinforcement clearly, the size, shape and strength of the reinforcing particles is of central importance. Often, the choice between the continuous and discontinuous options is relatively straight forward, both in terms of performance and processing cost. However, within each category, there exist wider variations in reinforcement size and morphology.

As an example, consider particulate reinforcement. The most convenient form is graphite particle of about 30-90μm diameter, which is cheap (largely because of the mature market for its use as a solid lubricant) and relatively easy to handle.

2.2 Primary Liquid Processing

Various techniques have been developed which involves the matrix becoming at least partially molten as it is brought in contact with the reinforcement fibre.

2.2.1 Squeeze Casting and Squeeze Infiltration

The term squeeze casting has come to be applied to various processes in which pressure is imposed on a solidifying system, usually via a single hydraulically activated ram. The technique has certain general characteristics such as a tendency towards fine microstructures and low porosity levels encouraged by efficient liquid feeding. After smelting of the charge, it is allowed to fall into the die cavity by withdrawing the sliding base of the crucible, after which the ram is brought down as to pressurize the melt and force it into the perform. Air escape paths are provided here in the form of a suitable clearance between the die and its base.

Infiltration is usually carried out with equipment of the type although, the molten charge is often introduced from the side rather than along axis of the ram travel, the performs are commonly fabricated by sedimentation of short fibres from liquid suspension. It is common to compress the perform while the liquid is being drained off, sometimes with simultaneous gentle heating.

A typical experimental procedure would involve decanting the liquid with fibres in suspension, into an open-topped cylindrical die having fine drainage holes around the base. The liquid is removed by suction while the residue is compressed by a ram.

The mixing of graphite particulate and liquid metal is a convenient and versatile technique for MMC production. The blending can be carried out dry or in liquid suspension. This is usually followed by cold compaction, canning evacuation (degassing) and a high temperature consolidation stage. It can be difficult to achieve a homogenous mixture during blending particularly with fibres (and especially whistlers), which tend to persist in the form of tangled agglomerates with spaces for too small for the penetration of reinforcement particles. Another notable feature of much powder route material is the presence of fine oxide particles usually present in Al-MMCs.

2.3 Secondary Processing

2.3.1 Extrusion and Drawing

Extrusion may be carried out on discontinuous MMCs produced in various ways commonly by squeeze infiltration or by powder blending. There is scope for alignment of fibres parallel to the extrusion axis, but at the expense of progressive fibre fragmentation.

Drawing involves a rather similar strain field to extrusion, but the stress state in the process zone has a similar compressive hydrostatic component. In addition, it is normally carried out a lower temperature. One consequence of this is that there is a much greater risk of internal cavitations during drawing, particularly if the interfacial bond strength is low. Surface finish, on the other hand, is often superior.

MATERIALS AND METHODS

3.1 Materials

3.1.1 Equipment and Tools Required

The proposed method of production is the stir mixing and casting method. A coal furnace was used for the melting process. In carrying out this, series of apparatus were made used of which are:

- Melting crucible for melting of aluminum
- Stirring pot-it looks like the melting crucible, which has a stirrer, attached to the lid for stirring the measured quantities of graphite and aluminum to obtain the desired result.
- Measuring cups- They are of four sizes 80g, 85g, 90g and 95g respectively with insulated handle used in measuring the exact proportion of aluminum melt to be introduced into the stirring crucible.
- Mould made of two layers with sand, binded with bentolite. It has an upper (male) layer and a lower (female) layer with half cylindrical impression on both cavities/layers where the already agitated melt is being poured into and allowed to cool.
- Graphite pre-heating crucible for heating of the measured quantities of graphite particles.
- Dipper- A spoon shaped object, which contains the already heated graphite particles, which is to be dipped into molten silicon to improve its wettabilty.
- Digital scale-used for weighing graphite particles.
- Sieves, arranged in decreasing order (90μm to 30μm) to get the desired graphite particle sizes.

3.1.2 Materials Selection

In the course of selecting materials for the manufacture of the composite material, so many factors were considered amongst which are: mechanical properties, availability, cost, machinability, resistance to corrosion, resistance to wear, resistance to heat, high strength, and density, etc.

The stir mixing and casting method was due to the fact that it can easily be worked with and its setup components were cheap compared to other processing methods.

The required component that make up the composite material are the matrix which is aluminum, reinforcement which is graphite and some flux additives.

3.2 Methods

The proposed method of production is the stirring mix and casting method. A coal furnace was used for the melting process

3.2.1 Coating

The coating was done by dip plating technique which is aimed at promoting the wettability of the graphite on the final fabricating composite so that there is less concern about the integrity and microstructure of the coating.

It involves the use of a spoon-shaped dipper to help dip the particulate reinforcement into the molten silicon so as to get the adequate coating required. The graphite is first heated to a temperature of about 900^{0}C, then dipped into molten silicon for 5 seconds and allowed to cool slowly.

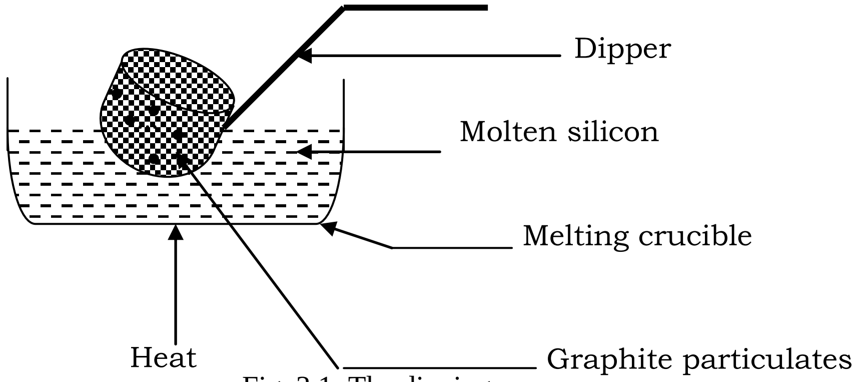


Fig. 3.1: The dipping process.

3.2.2 Mechanics of Coating

The avoidance of mechanical damage is the most important objective of coating for example large differential thermal contraction stresses can be generated during fabrication.

A better wetting property of the reinforcement reduces pushing effect of matrix on the reinforcement and thus improves even particle distribution. The degradation in mechanical properties as a result of non-uniform distribution of Si-C particulate can be attributed to the tendency of early crack nucleation in the matrix at the cluster or agglomeration sites.

Poor interfacial integrity prevents the effective load transfer a cross the Al/Si-C interfaces, thus reducing the role of Si-C particulate as load carriers in the metallic matrix.

Table 3.1: Percentage Weights and Quantities of Matrix and Reinforcement

S/N	Specimen	Reinforcement	Matrix	Total
	%	% gr, Si (g)	Qty. Al_1Mg (g)	
1	0	0	100	100
2	5	5	95	100
3	10	10	90	100
4	15	15	85	100
5	20	20	80	100

3.2.3 Melting and Stirring

According, the present invention provides a process for the manufacture of aluminum-graphite particles composite using coated graphite particles which comprises melting aluminum alloy in a coal furnace, adding a flux (magnesium) to cover the melt to remove slag and impurities (coke and pitch) and to prevent absorption of moisture, treating the melt with the reactive metal to increase the wettability of the alloy and the graphite particles and mixing the melt thoroughly for proper distribution of the reactive metal, gradually adding the surface activated graphite powder to the bath and stirring at a temperature of about 300^{0}C to about 400^{0}C.

It is essential that these two prominent impurities are removed before graphite is introduced into the melt. To achieve this, sieved graphite is heated up to 900^{0}C and maintained for an hour before dispersing in the melt.

To start with, the main crucible for melting aluminum alloy is placed in the furnace and the small crucibles for preheating graphite powder are arranged on its side. Weighed amount of graphite powder is placed in the crucible and covered with a lid. The graphite particles were of sizes ranging from 30μm to 90μm and of weights 5g, 10g, 15g and 20g respectively.

As soon as the melting crucible is heated up, a weighed amount of aluminum alloy (where ranges are 80g, 85g, 90g, 95g and 100g) is charged and crucible is covered. Magnesium to the extent of 10% of the melt is recommended to achieve wetting. The graphite powder is, now added then, agitated with the help of a small spoon to achieve uniform heating and to release the volatile matter (pitch) from the powder. The lid of the graphite crucible is then removed and addition of graphite particles is started with the help of a spoon and the addition has to be slow.

If for any reason graphite is not wetted by aluminum, it will be rejected and will float to the surface. In that case the rejected graphite is skimmed off and fresh addition of pre-heated graphite is made in that manner. To take care of such eventuality, two lots of graphite are heated side by side in separate crucibles in the furnace.

A spoon is used to take out the composite melt for pouring into the moulds. Every time, before the metal is spooned out, it is agitated by the spoon itself to ensure uniform distribution of wetted graphite.

The mixer (mixing device) consists of a manually operated handle which is attached directly to the shaft and a bearing to the lid of the melting crucible having two low carbon steel stirring blades coated with China clay. The mixture poured into the mould and cooled quickly to prevent the pushing effect of the matrix on the reinforcement as it causes agglomeration of the graphite particles. Addition of graphite does adversely affect the mechanical properties of the base alloy but the desired properties can be achieved in the composite by adjusting the percentage of graphite and proper selection of the base alloy. It however improves the tri biological behavior of the composite. It should be noted that a higher rotation speed of the stirrer will introduce gases into the melt which will increase the porosity.

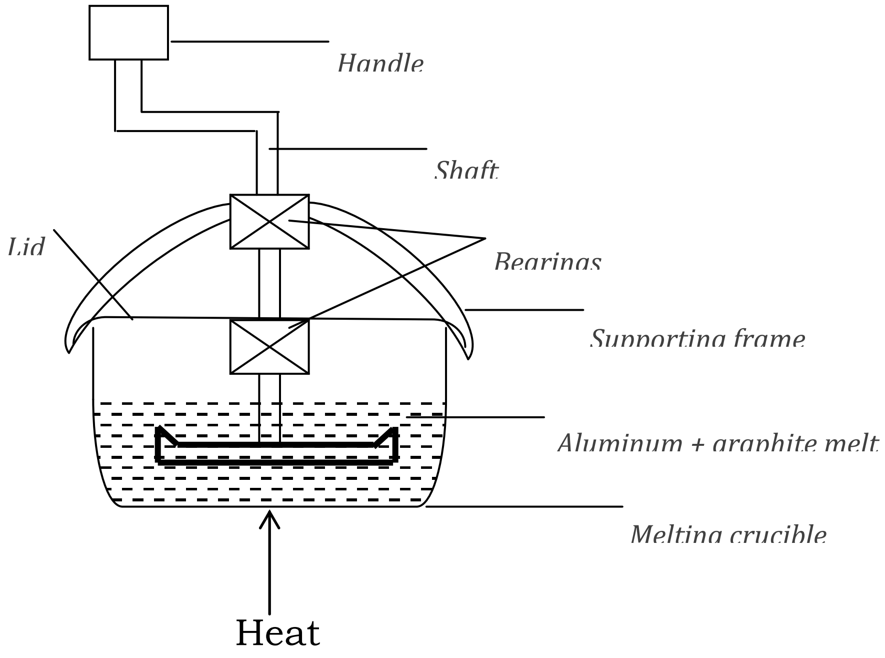


Figure 3.2: Melting Furnace with Stirring Device

3.2.4 Machining and Smoothening of Samples

The samples were machined to required shapes and sizes at the mechanical workshop of the center for composite research and development, Nsukka, Enugu State, Nigeria. The desired dimensions of length = 120mm and diameter = 15mm were adequately and correctly obtained.

3.2.5. Testing Equipment Descriptions

Having produced, standard and smoothened the samples for tensile, compressive, bending and hardness strength tests, the whole samples were taken to Standard Organization of Nigeria (SON) Emene, Enugu state of Nigeria for the proper testing and analysis

3.2.6 Testing Methods

All the mechanical testing methods that were carried out were based on American Standard Testing Methods (ASTM) there were five tests performed, namely tensile Test (ASTM D638), Bending Test (ASTN D256), Compressive Test (ASTM D346), Hardness Test (ASTM D570) and Impact Test (ASTM D790).

3.2.7 Determination of the Strength and Elastic Modulus of Composite Materials

The strength and elastic modulus of reinforced aluminum can be determined in terms of the strength and modulus of both fibre and matrix. In the following equations, c refers to the composite, f to the fibre and m to matrix the total load (P_c) is shared by fibre (P_t) and matrix (P_m) thus:

$$P_c = P_t + P_m \qquad (3.1)$$

Which we can be written as

$$\sigma_c A_c = \sigma_f A_t + \sigma m \ Am \qquad (3.2)$$

Where Ac = cross sectional area of composite
Af = cross sectional area of fibre
Am = cross sectional area of reinforcement
Denote x as the area fraction of fibre composite

$$\sigma c = x \ \sigma f + (1 - x) \sigma m \qquad (3.3)$$

Calculating the load carried by fibre, first note that, in the composite under tension load, the strains sustained by fibre and matrix the same (that is $e_c = e_f = e_m$)

$$\text{And, } e = \frac{\sigma}{E} = \frac{p}{AE}$$

Consequently

$$P_f = A_f \ X \ E_f$$
$$\mathbf{Pm = Am \ X \ Em} \qquad \mathbf{(3.4)}$$

By using equ (3.1) we can determine the fractional P_t/p_m.
Hence, substituting Es for σ in equ. 3.3 to determine elastic module

$$Ec = x E_f + (1\text{-}x) E_m \qquad (3.5)$$

3.2.8 Tensile Testing

In a broad sense, tensile test is measurement of the ability of a material to withstand forces that tend to pull it apart and to what extent the material stretches before breaking. The stiffness of a material which is represented by tensile modules can be determined from stress-strain diagram.

According to ASTM (D638) a dumbbell shaped specimen is needed for reinforced composite testing. Detailed dimension for these are shown in figure 3.4 and table 4.1

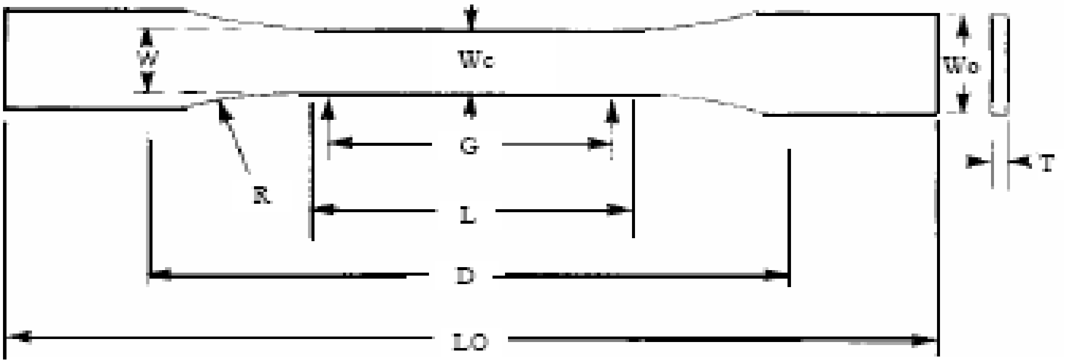


Figure 3.4: Dumbbell Shaped Specimen [ASTM (D638)]

Table 3.2: Dumbbell Shaped Specimen Dimension for Type I in ASTM D638

Dimension Value,	**mm (in)**
Diameter <15mm (0.38in), T	15.00 ± 0.4 (0.23 ± 0.02)
Diameter of narrow selection, W	10 (0.3)
Length of narrow selection, L	90 (2.25)
Diameter overall, WO	19 (0.75)
Length overall, LO	120 (5.5)
Gauge length, G	50 (2.00)
Distance between grips, D	90 (4.5)
Radius of fillet, R	76 (3.00)

Figure 3.5: Photo of Mechanical Properties Testing Rig

The testing were done to standard laboratory atmosphere of 23^{0}c ± 2^{0}c (73.4 ^{0}F± 3.6^{o}f) and 50 ± 5 percent relative humidity. A universal testing machine (Gunt Hambury of Germany, Model 75o41) was used for graphite-aluminum tensile testing. The specimens were positioned vertically in the grips of the machine with maximum calibration of 20KN. The grips were then tightened evenly and firmly to prevent any slippage with gauge length kept at 50mm.

As the tensile test starts, the specimen elongates the resistance of the specimen increases and is detected by a load cell. Instrument software provided along with the equipment will then calculates the tensile properties for instance tensile strength yield strength and elongation at break. Below are the basic relationships to determine these properties.

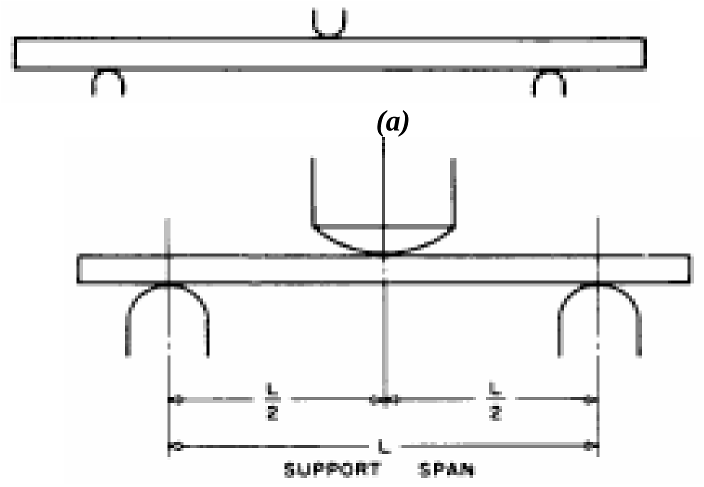
$$\text{Tensile strength} = \frac{\text{force (load}}{\text{cross sectional area}} \qquad 3.6$$

$$\text{Tensile strength at yield} = \frac{.\text{max} - \text{load recorded}}{\text{cross section area}} \qquad 3.7$$

$$\text{Tensile strength at break} = \frac{\text{load recorded at break}}{\text{cro ss section area}} \qquad 3.8$$

3.2.8 Bending Testing

Bending strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. The three point loading system applied on the supported beam was utilized. According to ASTM D790, the specimens of test pieces were prepared with dimension of 127mm x 12.7mm x 3.2mm (5in x ½ in x 1/8 in). The test pieces were tested flat-wise on a support and the load was applied as shown in figure below; the load applied at specified cross-head rate was fixed for a value within the ± 10 % of the calculated R using equation 3.6



(a)

(b)

(a) Minimum radius = 3.2 mm (⅛ in),
(b) Maximum radius support 1.6 times specimen depth;
maximum radius loading nose = 4 times specimen depth

Figure 3.6: Allowable Range of Loading Nose and Support Radii in ASTM D790

$$R = ZL\ 2/6d \qquad 3.9$$

Where R – rate of cross-head motion, mm/min (in/min)
Z – rate of straining of the outer reinforcement, mm/mm/min (in/in min) = 0.01
L – support spar, mm (in)
D – depth of beam, min (in)

3.2.9 Compressive Testing

Compressive test is measurement of the ability of a material to withstand forces that tend to push it together and to what extent the material compresses before rupture. Compressive tests were performed according to ASTM D346 specification. They were carried out using an Italian made automatic compressive machine, model L18/0, whose readings ranged from 0 to 250Kn. The test piece was then compressed at a ram speed of several Kpa/sec using pre-determined force of 10KN intervals. The thickness of the sample was recorded at these various forces, until the sample finally failed using a digital caliper up to the point of failure. The failure of the specimen occurred when the said sample ruptured under an applied load. The effect of particulates on the compressive strength of the aluminum-graphite composite is shown in figure 4.3 below.

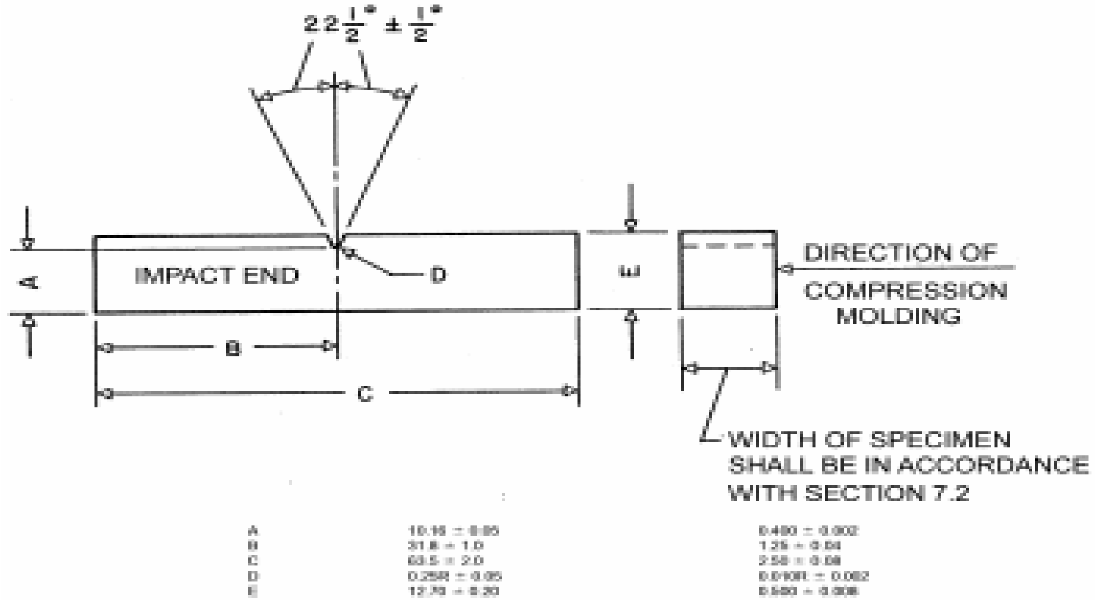
3.2.10 Hardness Testing

Hardness is the property of a material by virtue of which it resists deformation by external forces. Accordingly, in common hardness testing methods, a hand test body is pressed into the sample perpendicular to its surface. Lasting impressions can be achieved in very hand and brittle materials without resulting in cracks. This, however, distinguishes hardness testing from the tensile testing of the sample. The test sample was placed on the supporting surface so that the centre of the test sample was located below the centre of the hardened steel sphere called the indenter. Then a force of about 5Newtons was applied to the selected position of the test sample for a restricted time and after an indentation was made on the sample the load was released.

4.5 3.2.11 Impact Testing

The impact properties of the material are defined as the ability to absorb applied energy. It is a measure of toughness. According to ASTM D256, test method A (Izod type) was used for testing. The apparatus involved was cantilever Beam (Izod type). In this testing, specimens were clamped vertically as a cantilever beam and then stuck by a single swig of the pendulum released from a fixed distance from the specimen's clamp.

In this work of research, RAY-RAN universal Pendulum Impact System for Izod-charpy-Tenson and Puncture was used to measure the work of fracture for graphite –aluminum composite. There are few parameters that are set according to the standard for instances, hammer velocity - 3.46m/s and Hammer weight = 0.905Kg.



A	10.16 ± 0.05	0.400 ± 0.002
B	31.8 ± 1.0	1.25 ± 0.04
C	63.5 ± 2.0	2.50 ± 0.08
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.20	0.500 ± 0.008

Figure 3.7: Dimension of Izod Test Specimen in ASTM D256

3.2.12 Density Properties

Determination of density

Density of a material is mass per unit volume it can also be expressed in relation to that water (specific gravity)

$$\rho = \frac{m}{v} \tag{3.10}$$

ρ = density
m = Mass of specimen
V = Volume, obtained by Archimedes principles

Or using the relationship $\pi d^2 \text{ x } \frac{h}{4}$
in case of cylindrical samples
where π= 3.142
d = diameter of sample
h = height

N.B: Other shapes use respective formulas for the shape.

RESULTS & DISCUSSIONS

4.1 Results

4.1.1 Table 4.1: Effects of graphite particulate concentration on the tensile strength of the aluminum-graphite composite

S/n	**Force (KN)**	**Area ($10^{-3}m^2$)**	**Graphite conc.(%)**	**Extension (10^{-3}m)**	**Strain (10^{-2})**	**Tensile stress ($10^5N/m^2$)**
1	2.00	3.740	0	3.00	20.000	5.348
2	3.50	3.794	5	4.20	20.800	9.220
3	7.60	3.861	10	5.40	30.600	19.614
4	7.00	3.916	15	6.36	40.240	20.815
5	5.40	3.926	20	6.85	40.567	13.755

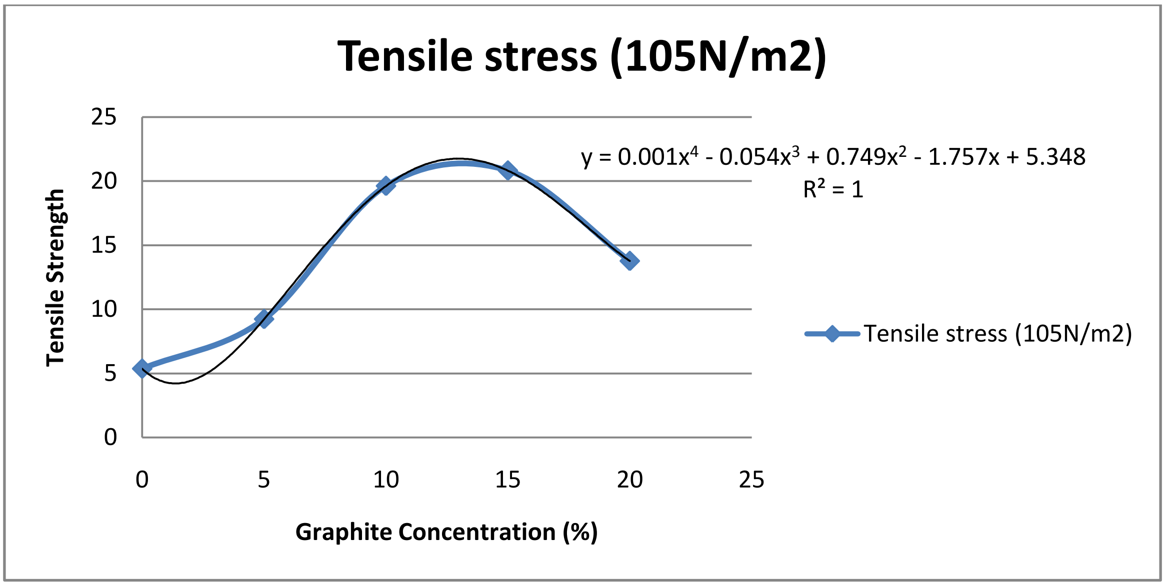


Figure 4.1: Graphs of Stress/Strain Vs Graphite Concentration (%)

4.1.2 Bending Test Results

Table 4.2 Effect of Graphite Concentration on Bending Strength of Aluminum/Graphite Composite

S/N	Applied Force (KN)	Graphite conc. (%)	Deflection (10^{-3}m)	Bending stress (10^5N/m^2)	Bending strain
1	3.2	0	0.750	40.000	37.500
2	4.8	5	1.125	60.000	560.250
3	7.6	10	2.000	90.500	1000.000
4	10.0	15	2.625	120.500	1310.250
5	1.18	20	2.875	140.750	1430.750

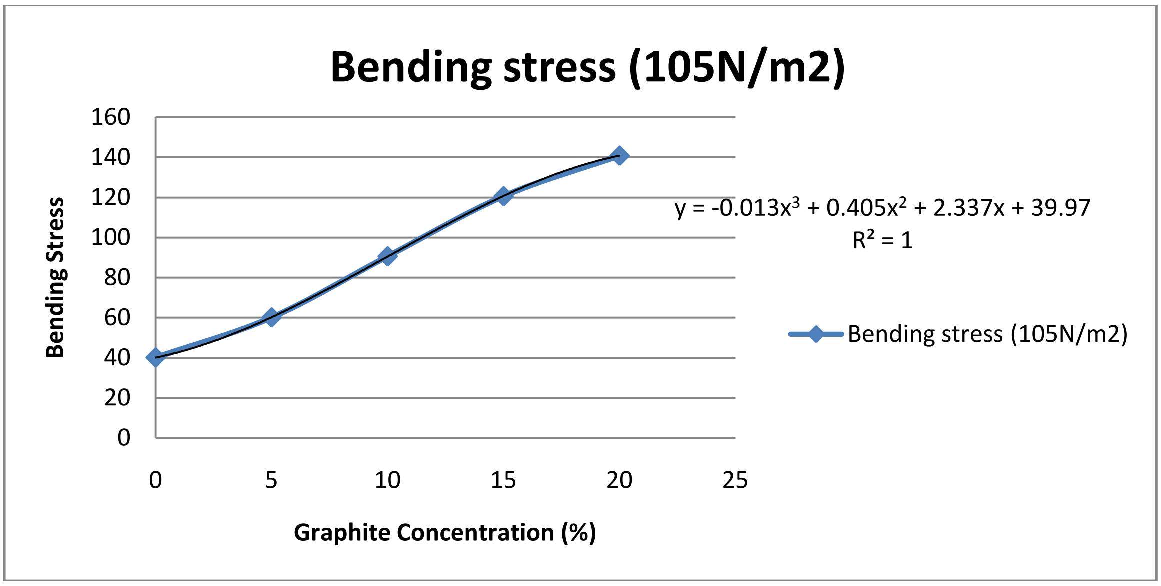


Figure 4.2: Graph Bending Vs Graphite Concentration (%)

4.1.3 Compressive Test Results

Table 4.3: Effect of graphite particulate concentration on the compressive strength of the aluminum –graphite composite

S/N	Applied Force (KN)	Graphite conc. (%)	Compressed thickness (10^{-3}m)	Expanded width (10^{-2}m)	Compressive strength (10^7N/m^2)
1	5.0	0	5.85	2.75	3.108
2	9.0	5	5.60	2.90	5.542
3	15.0	10	4.60	3.60	9.058
4	19.0	15	3.90	3.98	12.241
5	21.0	20	3.40	4.35	14.088

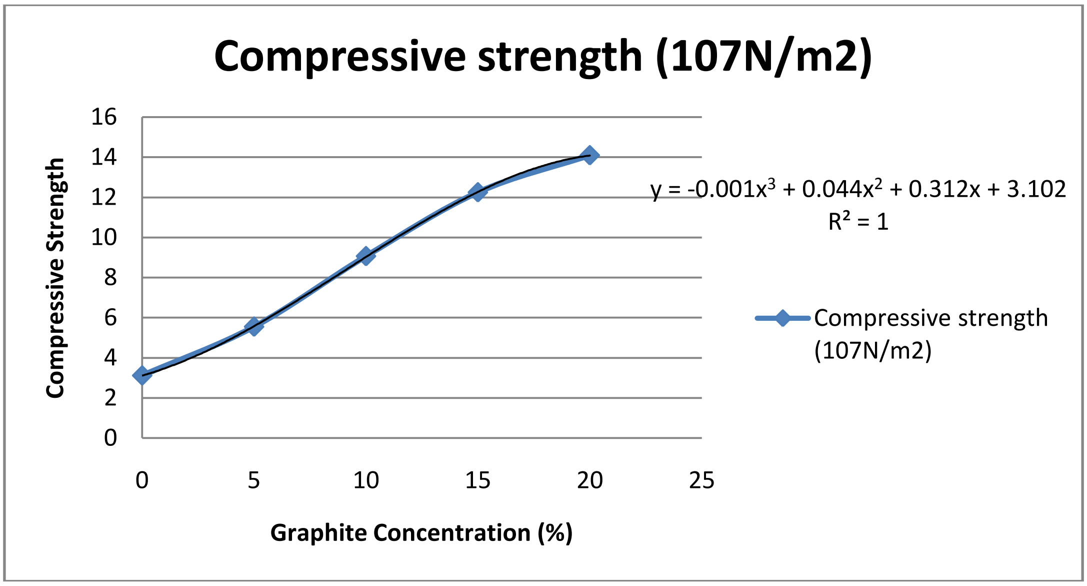


Figure 4.3: Graph of Compressive Strength Vs Graphite Concentration (%)

4.1.4 Hardness Test Results

Table 4.4: Effect of graphite particulate concentration on the hardness of the aluminum-graphite composite

S/N	Applied force (N)	Graphite conc. (%)	Indentation diameter (d) (10^{-3})	Brinell hardness, HB $(10^4 N/m_2)$
1	**5**	**0**	**7.62**	**9.207**
2	**5**	**5**	**7.56**	**9.399**
3	**5**	**10**	**7.46**	**9.720**
4	**5**	**15**	**7.40**	**9.915**
5	**5**	**20**	**7.27**	**10.113**

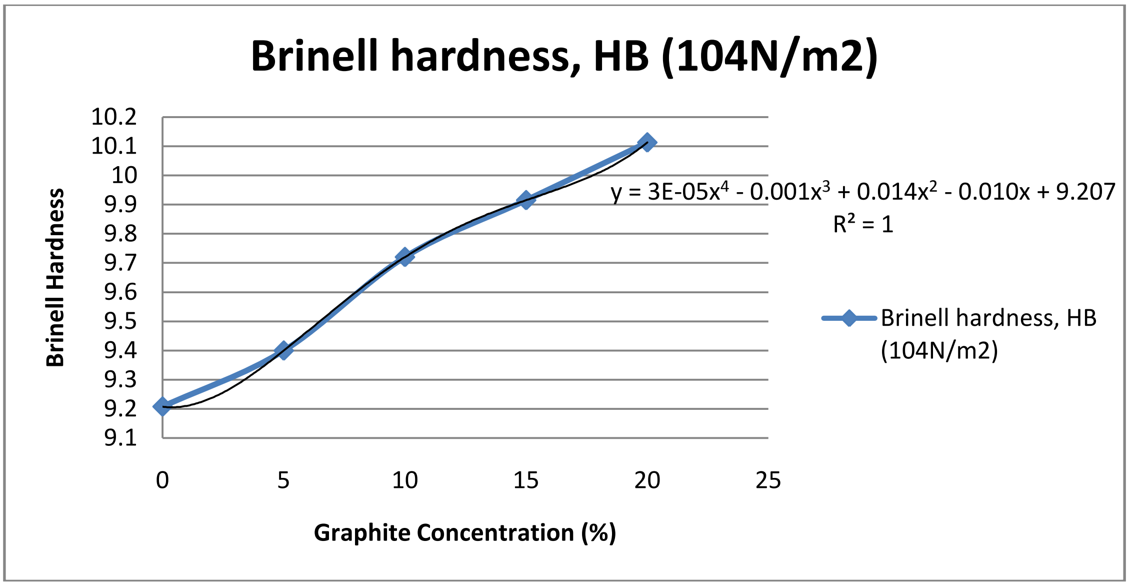


Figure 4.4: Graph of Brinell hardness Vs Graphite Concentration (%)

4.1.5 Impact Properties

Table 4.5: Effect of graphite particulate concentration on the impact strength of the aluminum – graphite composite

S/N	Applied force (N)	Graphite conc. (%)	Compressed thickness (10^{-3})	Expanded width (10^{-2})	Impact strength (KJm^{-2})
1	9.05	0	5.85	2.75	3.4
2	9.05	5	5.60	2.90	5.0
3	9.05	10	4.60	3.60	6.3
4	9.05	15	3.90	3.98	8.2
5	9.05	20	3.40	4.35	9.7

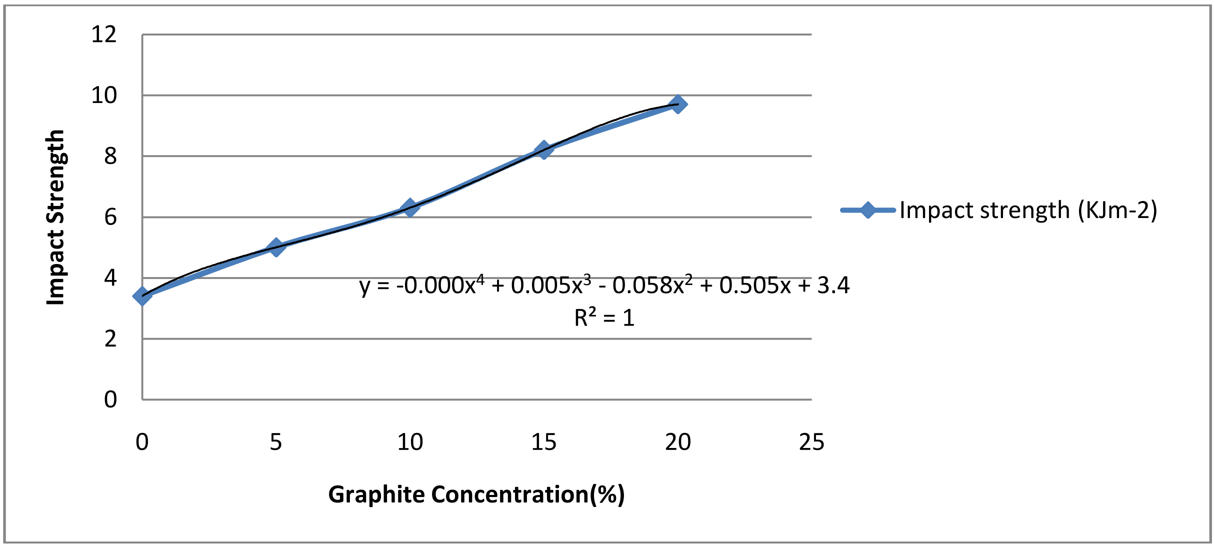


Figure 4.5: Graph of Impact Strength Vs Graphite Concentration (%)

Table 4.7 Effects of graphite particles on composites density

Specimen	Graphite Conc. (%)	Diameter (m)	Length (m)	Volume (m^3)	Mass (Kg)	Density (Kg/m^3)
1	0	0.015	0.12	2.121 x 10^{-5}	0.05708	2691.00
2	5	0.015	0.12	2.121 x 10^{-5}	0.05200	2451.00
3	10	0.015	0.12	2.121 x 10^{-5}	0.05050	2380.95
4	15	0.015	0.12	2.121 x 10^{-5}	0.04916	2317.77
5	20	0.015	0.12	2.121 x 10^{-5}	0.04800	2263.08

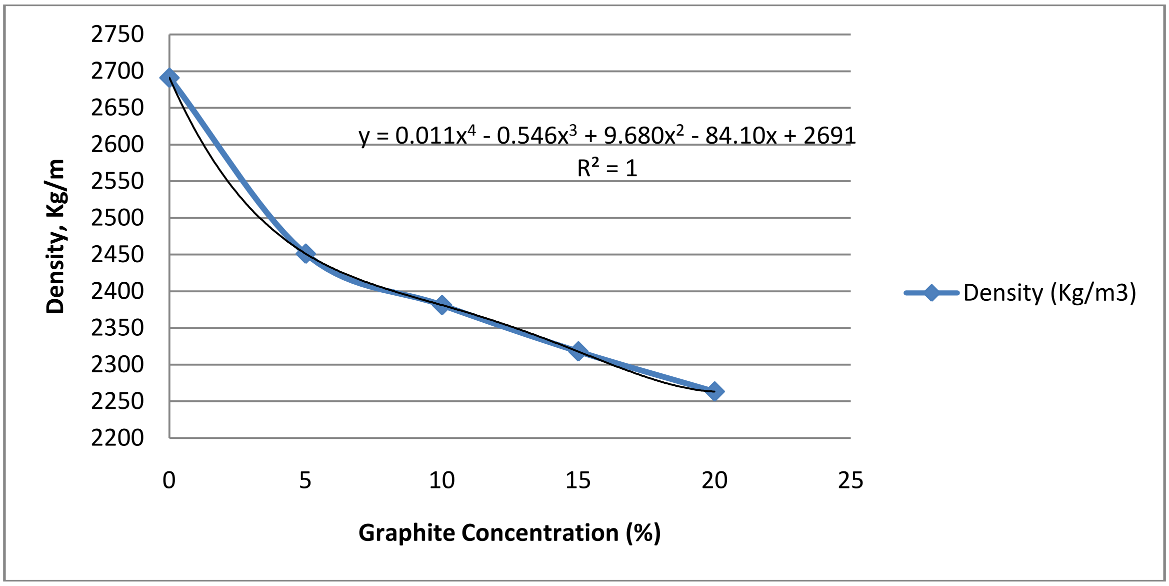


Figure 4.6: Graph of Density Vs Graphite Concentration (%)

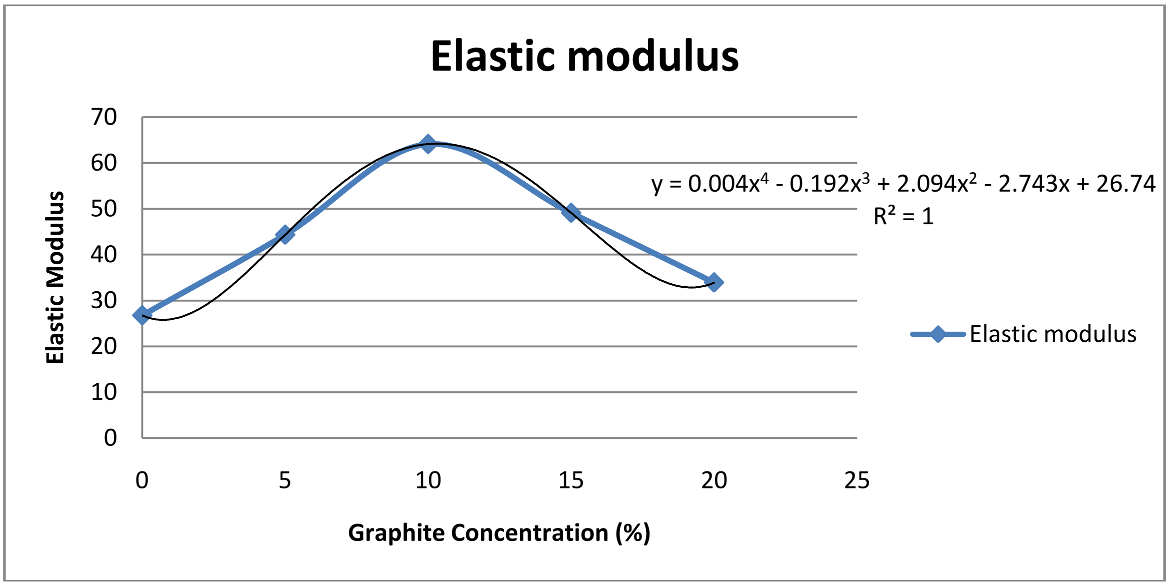


Figure 4.7: Graph of Elastic Modulus Vs Graphite Concentration (%)

4.2 Discussions of Results

4.2.1 Tensile Test Results

Table 4.1 indicates the typical stress-strain results of reinforced aluminum matrix and graphite tested at cross-head speed of 50mm/min. After the initial linear elastic behavior, the curvature of reinforced composite observed was not significant compared to the random graphite particulate has interrupted behavior as they act as foreigners to absorb stress to certain amount.

Conversely, it is observed that without reinforcement the matrix (Al) maintains a tensile strength of 5.348×10^5 N/m^2, but on addition of the graphite fiber, it continues to increase to the point approximately 22×10^5 N/m^2 at about 12.5 Wt% graphite concentrations, and starts to decrease at further fiber additions. The reason for the fallen in strength is attributed to high concentration of graphite whose strength is low, as all existing fiber cannot serve to the composite as interstices to the Aluminum atoms.

Therefore, the tensile strength of the composite can be evaluated as $Y = -0.001X^4 -0.054X^3 +0.749X^2 -1.757X +5.348$ at $R^2 = 1$, for a given weight % of graphite fiber concentration.

4.2.2 Bending Strength Test Results

From table 4.2 of bending stress and bending strain, they were both increasing gradually with graphite particulate loading. The addition of 20%wt graphite has obviously increased the bending stress and bending strain of unreinforced aluminum as much as 112% and 70%. The bending stress of the composite increased linearly with graphite composition and it was significantly higher than corresponding tensile strength obtained in the experiment. This is to say that graphite reinforced aluminum composites can withstand bending forces better than tensile stress.

The empirical formula for calculating the bending stress at a given graphite weight % is expressed as,

$$Y = -0.013X^3 + 0.405X^2 + 2.337X + 39.97, \text{ at } R^2 =1$$

4.2.3 Compressive Test Results

From the table 4.3, the compressive strength of the graphite-aluminum matrix composites has been found to increase on reinforcement with graphite particles with variable gradient. Compressive strength at any given graphite concentration (%) is given as, $Y = -0.001X^3 + 0.044X^2\ 0.312X + 3.102$ at $R^2 = 1$

4.2.4 Hardness Test Results

From the figure 4.4, the hardness of graphite-aluminum matrix composites has been found to increase on reinforcement with graphite particulate as high as 20%wt. The Brinell hardness is obtained with given equation as,

$$Y = 3E^{-0.05}X^4 -0.029X^3 + 0.014X^2 - 0.010X + 9.207, \text{ at } R^2 = 1.$$

4.2.5 Impact Properties

The figure 4.5 above shows the trend of impact strength with different graphite loadings, the impact strength has risen from $3.4KJm^{-2}$ to $9.7KJm^{-2}$ that is with an increment of 186%. It is generally accepted that the toughness of an Aluminum-graphite matrix composite is mainly dependent on the graphite stress-strain behavior especially graphite particles with high failure strain can actually impact high work to fracture on the composites. It is equally observed that the curves of hardness and impact are mirror image. Therefore, impact strength is evaluated for a given wt % of the graphite concentration with the expression as,

$$Y = -0.00X^4\ 0.005X^3 - 0.058X^2 + 0.505X + 3.4$$

4.2.6 Density Properties

It can be seen from the above graph of figure 4.6, that as the graphite particulate concentration increases, the less dense the composite becomes. Considering also the ranges of thermal conductivity and electrical conductivity of materials at room temperature, both properties of aluminum alloys are higher than that of graphite which means the higher the graphite particulate concentration, the lower the thermal and electrical conductivity.

In the curve of the graph, two major gradients are observed; gradient 1, from 0 up to 5wt % graphite conc. % has high gradient, while gradient 2 is a low gradient from 5 to 25wt. % graphite concentration. The decrease in density is due to the fiber lower density than that of Aluminum.

Therefore, density is evaluated for a given wt % of the graphite concentration with the expression as,

$$Y = 0.011X^4 -0.546X^3 + 9.680X^2 -84.10X\ 2691, \text{ at } R^2 = 1.$$

4.2.7 Elastic Modulus Properties

From figure 4.7, the elastic modulus increases with increase in addition of the graphite concentration (%) in the Aluminum matrix to maximum point of 10wt. (%) graphite of 65N/m^2 elastic modulus. With further addition of the graphite concentration (%), the elastic modulus value began to fall. Therefore, the composite is very sensitive to elastic modulus, and any system that requires materials with high elastic modulus will not select this composite.

Therefore, elastic modulus is evaluated for a given wt % of the graphite concentration with the expression as,

$$Y = 0.004X^4 - 0.192X^3 + 2.094X^2 - 2.743X + 26.74 \text{ at } R^2 = 1$$

From the results in the above tests of properties, the composite was found to be of a good combination of high strength and low density that makes it suitable for most construction works where there is need of its range of strength and reduced density. This will be very useful in mobile parts where energy consumption and power limitation are major concerns.

SUMMARIES OF RESULTS

Table 5.1 showing relative composition of fiber, matrix and physical/mechanical properties

S/N	**Compositions %**		Physical and mechanical properties					
	Fibre	**Matrix**	**Strength**	**Elastic modulus**	**Density**	**Bending test**	**Impact test**	**Hardness**
1	0	100	5.348	26.740	2691.00	40.00	3.4	92.07
2	5	95	9.220	44.327	2451.00	60.000	5.0	93.99
3	10	90	19.614	64.098	2380.95	90.500	6.3	97.20
4	15	85	20.815	49.092	2317.77	120.500	8.2	99.15
5	20	80	13.755	33.907	2263.08	140.750	9.7	101.13

5.2 The Composite (Aluminum- Graphite) Applications

The product, despite its high strength, has an added advantage of low density. This makes it suitable to be applied in numerous areas of modern technology such as

- Aircrafts- Aero plane and helicopters etc can be applied in aerospace
- In making satellites and missiles bodies.
- When coated with graphite to improve its wear and thermal resistance, it is used in automobile industries for making brake pads and driving shafts.
- Other applications because of its appearance include-bicycle \frames, storage racks.

5.3 Conclusion

The results obtained from the research showed that a useful composite with good properties successfully developed using powdered graphite as reinforcing agent in aluminum metal matrix. From this, several conclusions can be drawn regarding to mechanical and physical properties of the composite to the effect of graphite loadings, normally: tensile, compressive, bending, hardness, and impact, and density, electrical and thermal properties.

Conversely, it is found that the bending and impact strengths increased continually as the graphite concentration in composite increased. It is observed that the bending stress increased from 40.0(10^2NHN^2) to 130.725 (10^2 NHN^2) and bending strain increased from 370.5 to 1430 respectively for pure aluminum to 20% wt. graphite. This gradual increase trend has shown that graphite aluminum composite can withstand bending forces to a great extent since their high crystalline fibrils content are strong and can share the load applied in matrix effectively

Finally to summarize everything, grounded graphite particulate has enhanced tensile properties in young’s modulus, bending as well as impact properties of the aluminum metal matrix. The study has demonstrated the optimum graphite loading for peal performance as new processing methods gets developed, and improvement in particulate matrix bonding is attained. These materials will have a place in the future for components that require more resistance to the environment higher operating temperatures and higher strength than those possible by polymer metal matrix composites. Such a composite can be applied in aero-engine components, engine cylinder blocks, bicycle frames and waveguide for space telescope due to the above mentioned properties.

5.4 Recommendations and Future Works

This study may be more applicable and better if the following suggestions are done.

1. Heat treatment of graphite aluminum metal matrix composite can be done. Better performance of graphite aluminum composite is expected as this has been proven in metal alloys,
2. Compounding of graphite particulates or fibres aluminum should be done in an atmospheric controlled condition chamber to give a better mixing effect as it pose greater control of mixing and conveying properties.
3. Solution mixing is suggested to replace meet mixing in metal matrix composite preparation since graphite will be well adhered in aluminum matrix, this enhances the mechanical properties.
4. The results of this study suggested a number of new avenues for research in future. They are

a. The work should be extended to study other properties such as creep, fatigue, shear strength and chemical resistance properties.
b. The usage of different types of graphite particulate sizes and fibre reinforcement can be studied for graphite aluminum composite.
c. Besides aluminum, other metal matrix system can be studied. Also the study should be extended to polymer matrix composites.
d. Hybrid composite composting other reinforcement (such as fibre of loss) besides graphite can be studied, as this will definitely yield better performance of composite systems.

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