International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12, pp: 550-559 www.ijaem.net ISSN: 2395-5252

The Mechanical Properties of Boro-Silicate Reinforced Aluminium Composite

Engr. Prof. Jim E.O. Ovri[1], Nwakiri Ekele C.[2]
[1]-Materials And Metallurgical Engineering Department, Federal University Of Technology, Owerri, (F.U.T.O), Nigeria.
[2]- Corresponding Author And Research Scholar, Materials And Metallurgical Engineering Department, Federal University Of Technology, Owerri, (F.U.T.O.), Nigeria

----
Date of Submission: 25-11-2021 Date of Acceptance: 11-12-2021

ABSTRACT : This research work studies the mechanical properties of Aluminium alloy Al6063 reinforced with boro-silicate material. It is aimed at harnessing high hardness, low coefficient of thermal expansion and the impact strength, and tensile qualities of the combination of the matrix and also reinforcement material.

In this study aluminum alloy, Al-6063/boro-silicate reinforced particles metal-matrix composites (MMCs) were fabricated by stir casting process. The MMCs bars and circular plates are prepared with varying the reinforced particles by weight fraction ranging from 5%, 10%, 15%, 20% and 25%. The average reinforced particles size of boro-silicate particles was 100µm. The stirring process was carried out at 120 rev/min rotating speed by graphite impeller for 15 min.

Mechanical properties of hardness strength (RH_B), impact strength (KJ/m^2), ductility (% elongation and % area reduction) and tensile strengths (engineering/true stress, KN/m^2), physical property (specific weight), and micro-structures were investigated on prepared specimens of MMCs. It was observed that the hardness and the impact strength of the composite increased with increasing of reinforced particle weight fraction. The tensile strength also increased with raising of reinforced weight fraction. The specific weight reduced with increasing boro-silicate particle reinforcement. It was observed that the best mechanical and physical property of the specimen evolved at 25% boro-silicate particle reinforcement.

Metallographic analysis of specimens by Optical microscopic process, shows that fabrication route was responsible for even particle distribution.

KEYWORDS: Stir casting process**,** aluminium alloy Al6063, boro-silicate particles, hardness strength, impact strength.

I. INTRODUCTION

Metal Matrix Composites (MMC's) have evoked a keen interest in recent times for potential applications. Advance composite materials like Aluminium based metal matrix composite is gradually becoming very important materials in the manufacturing and transportation industries e.g. aerospace and aviation, automotive, maritime, food processing, industries etc, due to their superior properties such as light weight (low density), high strength to weight ratio, high hardness, high temperature and thermal shock resistance, superior wear and corrosive resistance, high specific modulus, high fatigue strength etc. [16].

These properties are not achievable with light weight monolithic titanium, magnesium, and aluminium alloys. Particulate metal matrix composites have nearly isotropic properties when compared to long fibre reinforced composite. But the mechanical behaviour of the composite depends on the matrix material composition, size, and weight fraction of the reinforcement and method utilized to manufacture the composite [11]. The distribution of the reinforcement particles in the matrix alloy is influenced by several factors such as rheological behaviour of the matrix melt, the particle incorporation method, interaction of particles and the matrix before, during, and after mixing [1]. Non homogeneous particle distribution is one of the greatest problems in casting of metal matrix composites [2].

A wide and growing variety of methods is available for producing MMCs, either as components or as feedstock for further processing (e.g. billets for extrusion, rolling, forging). Many of these methods are still on a laboratory or developmental scale. In general terms, they usually involve either melting of the matrix metal, powder blending or vapour/electro-deposition.

Particle reinforced aluminium matrix composites can be produced by:

i. pressing and sintering blends of pre-alloyed powder and reinforcement particles (powder blending),
ii. mechanical alloying (M.A),
iii. mixing particles with molten metal (melt-stirring),
iv. compo-casting (rheo-casting) and,
v. spray co-deposition

Amongst various processing routes stir casting is one of the promising liquid metallurgy technique utilized to fabricate the composites. The process is simple, flexible, and applicable for large quantity production. The liquid metallurgy technique is the most economical of all the available technique in the production of MMC [7].

From past review, it is found that the number of research work on wear behaviour of MMCs have been published, but only few work related to the influence of weight fraction on mechanical properties like tensile strength, hardness, impact strength, percentage of elongation etc. have been reported.

In this study, different weight fractions of boro-silicate particulates were added with aluminium matrix to fabricate the Al-B_4Si_3 metal matrix composites. Different samples have been fabricated by stir casting and their hardness, impact strength, ductility and tensile strength, has been studied. The influences of the reinforced particulate size and weight fractions (5%, 10%,15%, 20% and 25%) on the mechanical properties, physical property and micro-structure have been investigated.

ADVANTAGES OF COMPOSITES

The advantages of composites over their conventional counterparts are the ability to meet diverse design requirements with significant weight savings as well as strength-to-weight ratio.

Some advantages of composite materials over conventional ones are as follows:

i. Tensile strength of composites is four to six times greater than that of steel or aluminum (depending on the reinforcements).
i. Improved torsional stiffness and impact properties.
ii. Higher fatigue endurance limit (up to 60% of ultimate tensile strength).
iii. 30% - 40% lighter for example any particular aluminium structures designed to the same functional requirements.
iv. Lower embedded energy compared to other structural metallic materials like steel, aluminium etc.
v. Composites are less noisy while in operation and provide lower vibration transmissions than metals.
vi. Composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements.
vii. Long life offer excellent fatigue, impact, environmental resistance and reduce maintenance.
viii. Composites enjoy reduced life cycle cost compared to metals.
ix. Composites exhibit excellent corrosion resistance and fire retardancy.
x. Improved appearance with smooth surfaces and readily incorporable integral decorative melamine are other characteristics of composites.
xi. Composite parts can eliminate joints / fasteners, providing part simplification and Integrated design compared to conventional metallic parts.

FUNCTIONS OF MATRIX,

Although fibres are a striking feature of a composite, it is initially helpful to examine the functions of the matrix.

Ideally, it should be able to;

i. Infiltrate the fibres and solidify rapidly at a reasonable temperature and pressure.
ii. Form a coherent bond, usually chemical in nature, at all matrix/fibre interfaces.
iii. Envelop the fibres, which are usually very notch sensitive, protecting them from mutual damage by abrasion and from the environment (chemical attack, moisture).
iv. Transfer working stresses to the fibres.
v. Separate fibres so that failure of individual fibres remains localized and does not jeopardize the integrity of the whole component.
vi. Debond from individual fibres, with absorption of significant amounts of strain energy, whenever a propagating crack in the matrix chances to impinge upon them, and remain physically and chemically stable after manufacture.

II. STATEMENT OF PROBLEM

Considerable amount of work has been carried out by previous investigators to ascertain the mechanical and physical properties of Aluminium based composites, at different fractions of particle reinforcement using stir casting and other methods. But up till now very little effort has been made by publishers on Boro-silicate materials as a particle reinforcement material for aluminium metal matrix composites, either in an attempt to study the mechanical, physical, micro-structural or any other property of the resultant material, in spite of the large applications and properties of borosilicate material.

III. OBJECTIVES OF THE STUDY

The AIM of this study is to harness the fabrication of engineering materials by stir casting process, properties combination of high hardness, high impact strength, high tensile strength, low specific weights, and low thermal expansion coefficients. That can be applicable to conditions of high temperatures, high mechanical pressures, strong acidic conditions etc, and also not susceptible to crack propagation and abrasion under mechanical pressures and acidic environments respectively.

Therefore, the MAIN objectives in accomplishing of this work includes the follows:

1. To synthesize boro-silicate particle material reinforced aluminum metal matrix composite specimen using stir casing method.
2. To study the effect of weight fractions of boro-silicate material particles on the hardness properties of aluminum metal matrix composites.
3. To study the impact strength of aluminum metal matrix composites at different compositions of boro-silicate material particles reinforcement.
4. To study the effect of weight fractions of boro-silicate material particles on the tensile strength and ductile behaviour of aluminum metal matrix composites.
5. To study the effect of boro-silicate material particles reinforcement on the specific weight (density) of aluminum metal matrix composites.
6. To study the effect of microstructures on the mechanical and physical properties of aluminum metal matrix composites at different compositions of boro-silicate materials particle reinforcement.

IV. MATERIALS AND METHODS

A. MATERIALS:

The materials for this research work is tailored to combine high strength to weight ratios, high temperature resistance alongside alignment and dimensional operations stability. Thus, the material constituents are;

- Aluminium Alloy, (Al6063), -Matrix,
- Boro-Silicate Material Particles, -Reinforcement,

Table 1.0: Properties Of Composite Sample Constituent Materials, (Meena, Banwalt and Jaswanti, 2013).

	Aluminium Alloy, Al6063	Boro-Silicate Material, B_4Si_3
Melting Temperature, (^oC)	650	1,500
Density, (g/cm^3)	2.70	2.23
Modulus Of Elasticity, (Gpa)	70	70
Tensile Strength, (Mpa)	185	280
Thermal Expansion Coefficient, ($x10^{-6}/^oC$)	23	3.3

The metal matrix material used is Aluminium Alloy, 6063. Al6063 is a precipitation hardened alloy, containing magnesium and silicon as major alloys. It has good tensile strength, flexural and impact strengths, combined with good corrosion resistance, ease of formability and excellent anodization ability.

Typical alloys in this group includes Al6061, Al6063, and Al6082, used for building structures applications, land and sea transport applications, etc.

Borosilicate material is a type of glass production material with the main forming constituents silica and boron trioxide. Borosilicates are known for having very low coefficients of thermal expansion (~3 × 10−6 /°C at 20 °C), making them resistant to thermal shock, more so than any other common glass material. Such material is less subject to thermal stress and is commonly used for the construction of reagent bottles.

In addition to the quartz, sodium carbonate, and aluminium oxide traditionally used in glass making, boron is used in the manufacture of borosilicate glass. The composition of low expansion borosilicate material is approximately 80% silica, 13% boric oxide, 4% sodium oxide, and 2-3% aluminum oxide. It's superior

durability, chemical and heat resistance finds excellent use in chemical laboratory equipment, cookware, lighting and, in certain cases, windows.

The common type of borosilicate material used for laboratory glassware has a very low thermal expansion coefficient (3.3 x 10−6/^{o}C), about one-third that of ordinary soda-lime glass material. This reduces material stresses caused by temperature gradients which makes borosilicate a more suitable type of material for certain applications.

Table 2.0: Chemical Composition Of Aluminium Alloy, Al6063, (Aluminium Rolling Mills,(A.R.M.), Otta,Ogun State, Nig. 2016).

Constituents	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
Percentage (%)	0.45	0.22	0.02	0.03	0.05	0.02	0.03	0.02	98.71

Table 3.0: Chemical Composition Of Boro-silicate Material, (Schott Borofloat, Wolfsburg, Germany, 2016).

Constituents	SiO_2	Coke(C)	Al_2O_3	ZrO_2	Y_2O_3	B_2O_3
Percentages(%)	56.0	36.0	1.0	3.0	2.5	1.5

B**. FABRICATION OF SAMPLES, [STIR CASTING PROCESS],**

The fabrication of the composite samples of Al-B_4Si_3, follows the stir casting process route adopted due to it´s simple set-up, and cost.

For each composite sample, the aluminium scrap was initially melted, at 650°C temperature, the molten metal and reinforcement mixture (powder) was poured in and stirred in order to effectively distribute the reinforcement in the matrix metal. Hence, the reinforcement is added as powder into the molten metal, while Al6063 alloy is held, in the furnace.

With the addition of particle reinforcement, the molten metal is vigorously mechanically stirred.

Then, the admixed melt is poured/casted in a sand mold with standard dimension. The molten composite mixture is allowed to solidify for 24 hours, before the machining process.

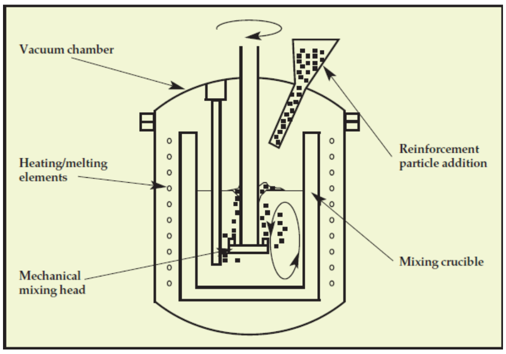

Figure 1.0: Stir Casting Process, For Making Aluminium Metal matrix Composites, (AMMC) (Neelima and Surowska, 2000)

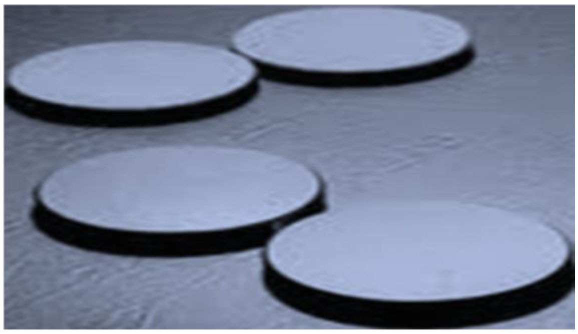

Figure 2.0: Hardness Test Samples Before Indentation ø40mm, 15mm Thick Gauge, (Material Lab, FUTO , Owerri).

Figure 3.0: Impact Test Specimens Before Fracture (PTE Lab. FUTO, Owerri).

Figure 4.0: Impact Test Specimens After Fracture, (PTE Lab. FUTO, Owerri).

Figure 5.0: Tensile Test Specimens Before Fracture (Materials Lab. ESUT, Enugu).

Figure 6.0: Tensile Test Specimens After Fracture, (Materials Lab., ESUT, Enugu).

V. RESULTS AND DISCUSSIONS,

A. HARDNESS TEST RESULTS,

The hardness values of the composites were evaluated from the average penetration diameters of three readings and equivalent hardness as computed below.

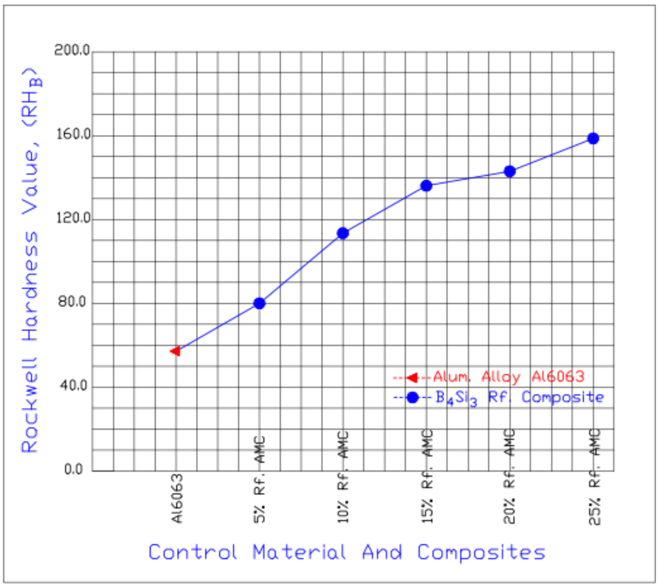

Figure 7.0: Hardness Values Of Composites, Using Al6063 As Control,

B. IMPACT TEST RESULTS,

The values of the Impact Strength of the composites were evaluated from the values of the Impact energy and the area under notch, and evaluated as follows;
Impact Strength (I.S) = Impact Energy, E (KJ)/Area Under Notch, A(b x d).

I.S(KJ/m^2) = E/bd.

where, b = composite length, (m),
d = width below material notch, (m),

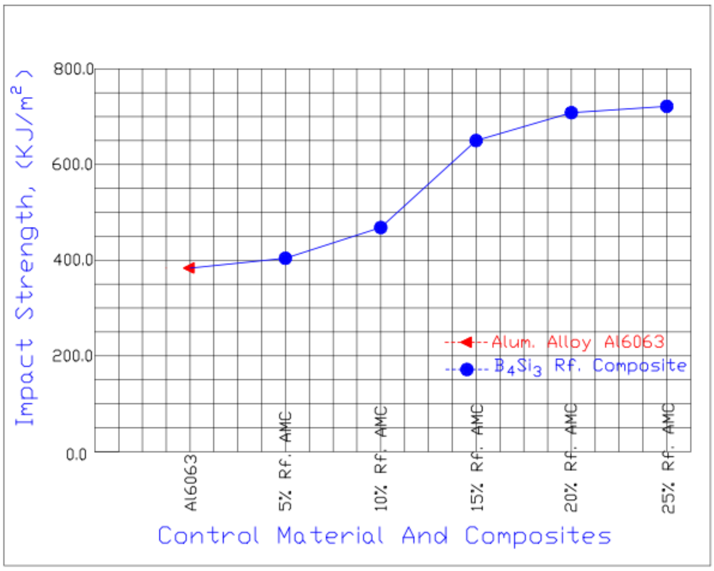

Figure 8.0: Impact Strength (KJ/m^2) Of Composites, Using Al6063 (398.8 KJ/m^2) As Control,

C. DUCTILITY OF THE COMPOSITES, (PERCENTAGE,% ELONGATION),

The percentage (%) elongation of the composites were evaluation and results shown below,
The composites were destructively tested and the various properties were determined using the following equations.
1.Percentage(%) Elongation = Increase In Length/Original Length x 100.

% El. = $\Delta L/L_o$ X 100.

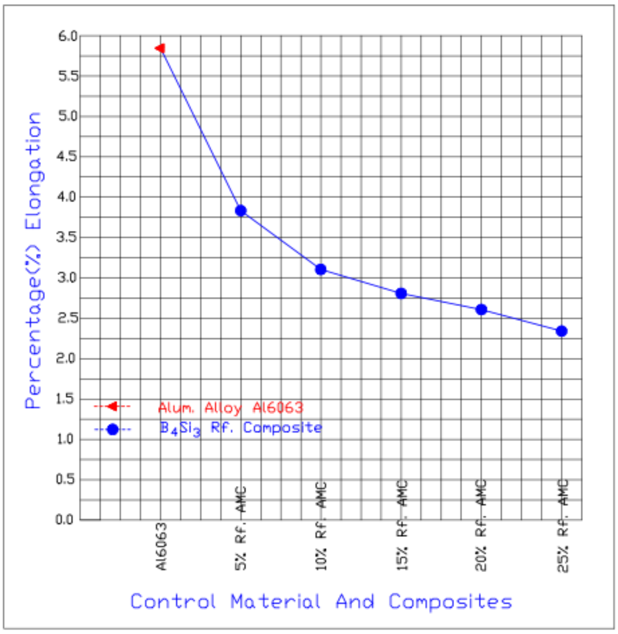

Figure 9.0: Percentage (%) Elongation Of Composites, Using Al6063 (5.83%) As Control,

D. DUCTILITY OF THE COMPOSITES, (PERCENTAGE,% AREA REDUCTION),

The percentage (%) area reduction of the composites were evaluated and the results shown below, using the following;
Percentage(%) Area Reduction = Original CSA. – Fracture CSA./Original CSA x 100.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12, pp: 550-559 www.ijaem.net ISSN: 2395-5252

% AR. = A_o - A_f/A_o x 100.

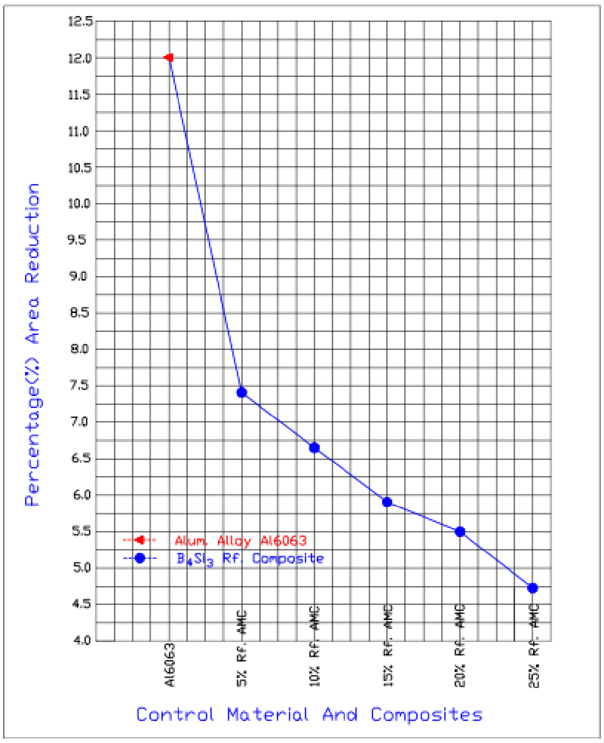

Figure 10.0: Percentage (%) Area Reduction of composites using Al6063, (12.02%) as control.

E. ENGINEERING STRESS/STRAIN AND TRUE STRESS/STRAIN RESULTS FOR Al 6063, AND 25% BORO-SILICATE PARTICLES RF. AMMC'S

The tensile properties of the composites, (standard gauge length of 30mm and diameter of 5mm) were carried out at room temperature, using the testing machine, Hounsfield (Monsanto) tensometer, (W-4404), Cross-head speed of 0.5mm/min. and chart speed of 50mm/min.

The composites were destructively tested and the various properties were determined using the following equations.

1.Engineering Stress, s = Force(N)/Area(mm^2),

Also, Area, (A) = $\Pi d^2/4$, where d = composite diameter,

2.Engineering Strain, e = Increases in Length(ΔL)/Original Gauge Length(L_o)

$e = \Delta L/L_o$

3.True stress, σ = s(1+e),

s = Engineering stress, (N/mm^2),

e = Engineering strain,

4.True Strain, ε = Ln(1+e),

e = Engineering strain.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12, pp: 550-559 www.ijaem.net ISSN: 2395-5252

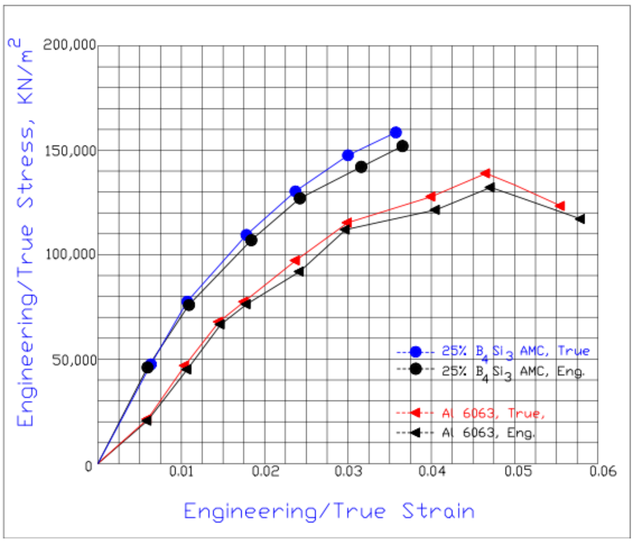

Figure 11.0: Engineering/True Stress Vs Engineering/True Strain For Al6063, And AMC 25% Boro-silicate Particles.

F. DENSITY EVALUATION RESULTS,

The density values of composites were evaluated using the Rule of mixtures , where the volume fraction and specific weights of the constituent materials are combined.
The volume fraction of constituent phases by constituent conventional specific weights for one phase is summed to the values of the next phase. Thus;

$\varrho_c = m_1v_1 + m_2v_2$ - - - - - - - - - - - - - m_nv_n,

where, ϱ_c = Density of composite, (kg/m^3), m_1 and m_2 = specific weights of constituent phases 1and 2, v_1 and v_2 = Volume fractions of constituent phases 1 and 2,
the results are shown below;

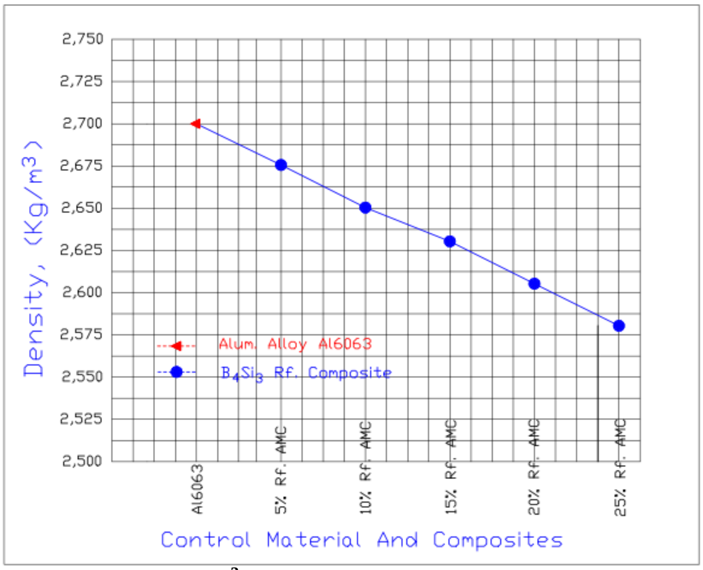

Figure 12.0: Density (Kg/m^3) Of Composites, Using Al6063 As Control,

G. Metallographic Examination Results:

The metallographic test results reveal the micro-graphic composition of Al/B_4Si_3 particles composite material for (5%, 10%. 15%, 20% and 25%) particle reinforcements. Thus:

International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 12, pp: 550-559 www.ijaem.net ISSN: 2395-5252

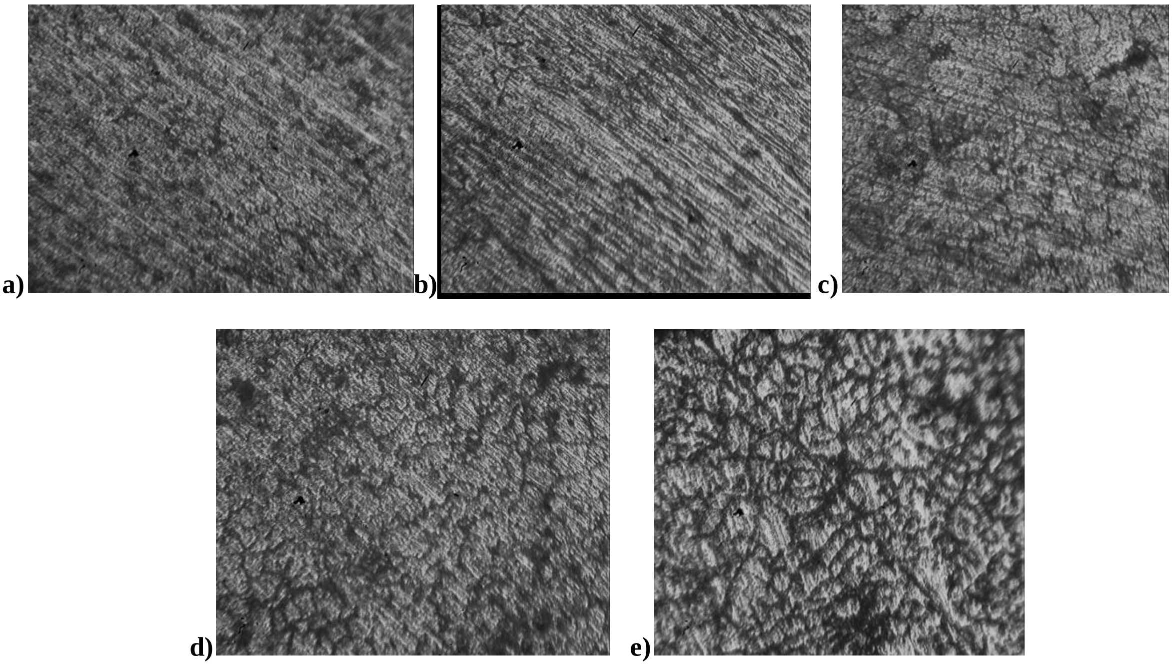

Figure 13.0: Specimen Micro-structures, a) 5% B_4Si_3 Micrograph, 100µm, b) 10% B_4Si_3 Micrograph, 100µm, c)15% B_4Si_3 Micrograph, 100 µm. d) 20% B_4Si_3 Micrograph, 100 µm.) and e) 25% B_4Si_3 Micrograph, 100 µm.) Magnification: x1000).

VI. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION:

This research work reveals the following;

The Optical Micrographic and Metallographic studies shows that stir-casting process of fabrication of composite samples results to reasonable uniform particle distribution of boro-silicate particles in Al-B_4Si_3 material composite because of the isotropic nature of the micro-structural morphology.

The density test of the samples shows that Al/B_4Si_3 with the results, 2,700, 2,676.5, 2,653, 2,629.5, 2,606, and 2,582.5 Kg/m^3 shows a linear decrease from Al6063 to AMMC 25% B_4Si_3 reinforcement, with the best specific weight of 2,582.5 Kg/m^3 for AMMC 25% B_4Si_3.

The hardness test of the samples shows that hardness increased linearly for Al6063 and B_4Si_3 AMC with results of, 57, 80, 112, 135, 142, and 158 RH_B values, with the best penetration resistance of 158 RH_B value for AMC 25% B_4Si_3.

The Impact test results show that Al6063 and B_4Si_3 AMC with values of 358, 400, 470, 650, 705, and 720 KJ/m^3 increased from 5% to 25% B_4Si_3 reinforcement, where 25% B_4Si_3 has the best shock absorption strength of 720 KJ/m^3 and also as a result of fracture not occurring at the notch after several attempts also reveals that 25% boro-silicate reinforcement has zero crack propagation rate.

The ductility (percentage elongation) results for Al6063 and B_4Si_3 AMC with results 5.83, 3.80, 3.17, 2.80, 2.60, and 2.33 shows highest percentage elongation value of 5.83% for Al6063 and lowest percentage elongation of 2.33% for AMC 25% B_4Si_3.

Also, ductility, (Percentage area reduction) of 12.02, 7.43, 6.67, 5.91, 5.50, and 4.47% reveals highest cross-sectional area reduction of 12.02% for Al6063, and lowest cross-sectional area reduction of 4.74% for AMC 25% B_4Si_3.

Stress-strain(Engr.) reveals that Al6063 UTS of 132,280 KN/m^2, fractured at 117,110 KN/m^2 tensile strength, while 25% B_4Si_3 AMC fractured at 152,570 KN/m^2.

B. RECOMMENDATIONS:

Stir-casting process should be adopted for the mass production of Boro-Silicate Material reinforced Aluminium matrix composites (AMC) because of the advantage of uniform distribution of particles within the material's micro-structures. 25% Boro-silicate Particles Aluminium metal matrix composites should be adopted as an Engineering material and should be applied to structures where high strength-to-weight, and stiffness-to-weight ratios are required, like the building and construction, Maritime and ship construction, aeronautics and aerospace, food processing industries, etc.

From the properties of 25% boro-silicate particle reinforced aluminium MMC, having properties such as zero crack propagation rate on impact, high tensile strength under tension, high penetration resistance, low specific weight, amongst others, this material should be subjected to further studies whether or not to be consideration as a super engineering material and also to ascertain the possibility of applying it in other fields of study like geology, mining, etc.

C. CONTRIBUTIONS TO KNOWLEDGE:

This research studies contributes to knowledge in the following ways:

We have established that stir-casting process of liquid metallurgy can be harnessed for the mass production of
engineering materials.

Engineering materials of diverse properties ranging from low specific weights, high ductile strengths and corrosion resistance to those of low thermal expansion coefficients, high hardness and stiffness strengths, can be harnessed by casting process to function as a single engineering material.

That, 25% Al6063-B_4Si_3 has lower specific weights of 2.5825g/cm^3 in comparison to a similar material like duralumin with 2.78g/cm^3.

Also, 25% Al6063-B_4Si_3 material is not susceptible to crack propagation and therefore has zero crack propagation rate.

REFERENCES

[1]. Allison, J.E. and Cole, G.S. (1993); Metal matrix composites in automotive industry: Opportunities and challenges, Journal of mechanical science, 19-24.

[2]. Balasivanandha, S., Kaarunamoorthy, L., Kaithiresan, S. and Mohan B. (2006); Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composites, Journal of material processing technology, 268-271.

[3]. Barry C. (2012); Technical properties of synthetic fibres, 1-10.

[4]. Campbell F.C. (2010); Introduction to composite materials, 10-14,

[5]. Carl Z., (1987); Metal matrix composites, 101-103,

[6]. Chandramohan D. and Marimuthu K., (2011); A review of natural fibres, 73-77,

[7]. Chawla, N., (2006); Metal matrix composites in automobile applications, Advanced materials processing, 29-31.

[8]. Chicao G., Xuezheng Z., Tijun C. And Yushi C., (2016); Effects of processing parameters on micro-structure and mechanical properties of powder thixoforged Sic/6061 Al composite, Int'l research journal on materials engineering, 5-8.

[9]. Davis J.R. (2001); Aluminium and aluminium alloys, 362-363.

[10]. Doel T.J.A., Lorretto M.H. and Bowen, P. (1993); Mechanical properties of aluminium based particulate metal matrix composites, Journal of composites, 270-273.

[11]. Eugenio P. and Giampiero D., (2014); Structural composites for aircraft design. Applied science and engineering journal, 10-14,

[12]. Gnjidi, X.., Boi, D. and Mitkov, M. (2001); The influence of SiC particles on compressive properties of metal matrix composites , Materials characterization, 129-137.

[13]. Hashim J., Looney L. and Hashma M.S.J. (2002); Particle distribution in metal matrix composites, journal of materials processing technology, 251-257.

[14]. Ibrahim, I.A., Mohamed F.A., Lavernia E.J, (1991); Metal matrix composites-A review, Journal of materials science, 1137-1145.

[15]. Idenyi N.E. and Nwajagu C.O. (2003); Non-metallic materials technology, 1-6,

[16]. Jamaluddin H.U, Achutha K., and Sharma S.S, (2015); Mechanical characterization of stir cast Al6063 matrix Sic reinforced metal matrix composites. Int'l research journal on mechanical and materials engineering, 63-67.

[17]. James E.O. Ovri, (2019), Fracture Behaviour Of Aluminium Reinforced With Silicon Carbide And Boro-silicate Glass.

[18]. Jaroslaw B. And Barbara S., (2000); Select Micro-structural And Corrosion Aspects Of Aluminium Alloy Metal Matrix Composites, International Journal on Composites, 1-8,

[19]. Neelima D.C, Selvaraj N., and Mahesh V.; (2012); Micro structural Aspects Of Aluminium Silicon Carbide Metal Matrix Composites, Int'l Journal Of Applied Sciences And Engineering Research, 50-56.

[20]. Skibo D.M., Schuster D.M., and Jolla L., (1988); Process for preparation of composite materials containing non-metallic particles in a metallic matrix, 467.