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SOLUTIONIZATION OF ALUMINIUM 6063 MATRIX WITH 5% HDPE FOR IMPROVED HARDNESS AND TENSILE PROPERTIES

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Abstract: Evolved microstructure, hardness and tensile properties from the addition of 5 % high density polyethylene (HDPE) into aluminium 6063 alloy was studied in this research. Two categories of aluminium melts were considered, one containing addition of 5 % high density polyethylene (HDPE) and the second one as control sample. The ingot was melted with lift out crucible furnace using propane gas as fuel. At a temperature of 700 ^{0}C the control sample was cast into prepared green sand mould and allowed to solidify in the mould. The second melt attained the temperature of 720 ^{0}C and 5 % by weight of HDPE was introduced, stirred mechanically and simultaneously cast into green sand mould. Metallographic sample was taken from each casting and photomicrographs were obtained with Zeiss metallurgical microscope. Hardness and tensile tests were carried out on the casting samples. Sample with 5 % HDPE increased in hardness relative to control sample by 17.82 %, it also has improved tensile strength relative to control sample by 5.40 %. The Microstructural geometry shows an elongated needlelike structure of the HDPE in the interstices of the grain boundaries with different orientations from the control sample.
Keywords: Aluminium 6063, HDPE, tensile test, hardness, polymer

1. INTRODUCTION

Aluminium alloy having wide range of properties are used in engineering structural works. The suitability of this alloy for structural use is enhanced by the elements added into the metal [1]. The silicon in aluminium 6063 has affinity for any addition in the form of alloying or composite in other to enhance the overall mechanical properties of the aluminium alloy [2, 3]. However, this makes aluminium composite also finds its usefulness in structural works. Before now, limitation of knowledge in this aspect has led to non–utilization of aluminium alloys maximally in building structures. Aluminium is used as a result of the following characteristics: – high strength to weight ratio, light in weight, high corrosion resistance and it is affordable [2, 4]. In accordance with Rathod and Menghani,[5] the most established route of composite production is by casting and powder metallurgy with addition of reinforcements. Also, in accordance with Alaneme et al. [6] aluminium composite development is aimed at reduction in cost of production and optimize increased properties, due to reduced cost of reinforcement which can be obtained from agricultural wastes sometimes. The advantages derived from the use of reinforcement having low density, good wettability with the matrix, means of processing the material and metallurgical characteristics have been reviewed [7].
High density polyethylene (HDPE) is so defined, as a result of having density greater or equal to 0.941 g/cm^3 [8]. It has low degree of branching and thus stronger intermolecular forces, and tensile strength [9]. They are used in products and packaging for consumables, domestic use and toiletries. Polymer are now required for use in different applications, so they are subjected to different modifications for improved usage by the addition of additives, blends and fillers [10]. HDPE has higher strength over other polymeric materials because it has a linear structure with few short sides branching, which leads to a more crystalline structure and high density [11]. They are thermoplastic made from petroleum; this is an indication that it can be melted unlike thermosetting materials. Polyethylene materials have low melting temperature in comparison to conventional metallic materials [12].
As a result of this phenomenon, they are perceived not to be suitable for use as a reinforcement with metal matrix due to their low melting temperature. This is because little or no appreciable work had been seen with combination of polymeric material with metallic material in alloying or for reinforcements. An attempt was made by Lofty et al. [13] to integrate aluminium powder metal into polymer matrix which was not done by melting processing route, but by mechanical stirring at high speed to integrate the two materials together. Success of inclusion of polyethylene material into metallic materials will assist in recycling most of the polymeric materials waste, as in accordance to Babafemi et al. [14] only about 25% of waste polymers are recycled for use. The aim of this research is to add HDPE into aluminium alloy through liquid metal processing and evaluate its influence on the structure and properties of the product. This is motivated by the prospect in utilizing waste HDPE (that needs recycling) in achieving improve properties in aluminium alloy. Therefore, the resulting product can be considered for use in structural work. It can also be used as a bio material such as implant in human body due to the low–density property of HDPE when compared to metals. It will further solve the problem of utilizing waste polymers materials.

2. MATERIALS AND METHOD

— Materials

Aluminium alloy utilized for this work is Al – Mg – Si known as aluminium 6063. The composition of the alloy is shown in Table 1. Master batch high density polyethylene (HDPE) was the reinforcing material added into the aluminium alloy after melting. Cylindrical pattern of dimension 20 mm diameter by 150 mm length was used for preparing green sand mould.

— Production

Melting of the aluminium alloy was done with lift out crucible furnace using propane gas as fuel in other to obtain melt that is comparatively free of impurities. The first melt without any addition was cast as sample A at a temperature of 700 ^{0}C into prepared green sand mould, after the removal of dross on the melt. The second melt of the same alloy composition was allowed to attain a temperature of 720 ^{0}C, and 5 % w/w of master batch high density polyethylene (HDPE) was added into the melt, stirred mechanically at moderately low speed of 150 rpm in accordance with Alaneme and Sanusi [4]. It was simultaneously cast into green sand mould as sample B as stirring was taking place.

— Mechanical Properties (hardness and tensile)

The hardness measurement of the two samples were assessed using digital Vickers hardness machine in accordance with ASTM E–92 [15] standard. The sample surfaces were prepared by grinding with 400 grit emery paper in other to obtain flat surfaces on each sample so as to obtain reliable reading. Four hardness indents were made on each sample and the readings within the range of ± 3 % was used to compute the average hardness of each sample.

The tensile behaviour of the two samples were evaluated using Instron universal testing machine in accordance with ASTM E8M [16] standard. Samples for the test were machined to gauge length of 30 mm and diameter of 5 mm. The samples were mounted on the machine test platform and pulled by the machine at a strain rate of 10^{-3}/s until fracture. All the test was conducted at room temperature in compliance with the recommendation of the standard used. Three tests were carried out on each sample and the average reading was obtained and used for the reliability of the results. Some of the properties evaluated from the test are ultimate tensile strength, peak load, break load and peak displacements.

— Microstructural Characterization

Representative sample of sample A and B was cut from the castings, grinded through series of emery paper from 60 grits to 600 grits before polishing operation. Buehler Polisher was used for polishing starting from 800 grits and 1200 grits of emery paper, final polishing was done with polishing cloth of 3 micron until mirror surface was obtained.

Etching was done with application of 0.5 M hydrofluoric acid, using cotton wool with etching time of 10 seconds. Etching helps in revealing the structures when view under the microscope. Zeiss metallurgical microscope was then used to obtain the photo micrographs of the specimens.

Table 1. Composition of used Aluminium 6063

Element	wt %
Magnesium	0.452
Silicon	0.580
Copper	0.055
Zinc	0.131
Manganese	0.072
Iron	0,057
Titanium	0.016
Sodium	0.003
Aluminium	Balance

3. RESULTS AND DISCUSSION

— Microstructures

The microstructures of the two samples of aluminium products produced are presented in Figure 1. In sample A the microstructure consists of network of grain boundaries with the alloying constituents perceived to be finely dispersed in the structure, while sample B that contains 5 % HDPE is seen to show elongated structures formed round the finely dispersed ones, this gives a unique and "bogus" orientation along the grain boundaries, having discontinuous orientation from the control sample. This elongated HDPE structure produces a needle–like arm formation in the entire microstructural features with non–uniform sizes. The difference in sizes might be as a result of preferential cooling in different regions of the casting, this is because there would be low freezing range, bearing in mind the low melting temperature of HDPE as compared to aluminium alloy.

The improvement in hardness and tensile properties is not unconnected to the ability of the HDPE to form in the interstices of the grains and grain boundaries of the metal matrix. This is shown in the microstructure to form solid solution. Peradventure, this result was achieved due to the melting temperature (about 660 °C) of aluminium matrix. It is perceived that using high temperature metallic materials such as ferrous material and copper alloys, there will be every likelihood for the greater volume of the HDPE to vapourize before final solidification. Therefore, this materials combination will be feasible using metallic materials of relatively low melting temperature and their alloys such as zinc, magnesium. The products will then be suitable for application as a biomaterial due to the resulting final density.

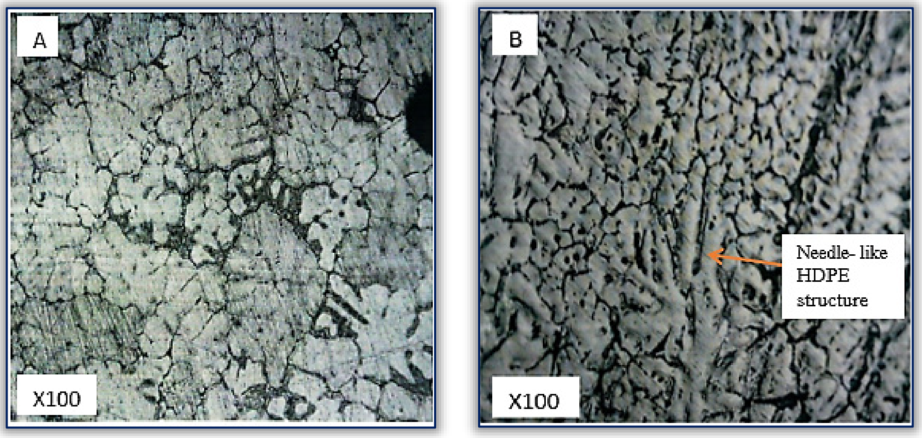

Figure 1: Microstructure of Sample A (control) and B (with 5 % HDPE)

— Hardness Result

Hardness values of the two samples are presented in Table 2. The average hardness of sample B with 5 % HDPE is 120.88 on B scale, while that of control sample is 102.60. This represents an increase in hardness value by 17.82 % in comparison to the control sample. This must be as a result of changes in the structural features in sample B by the effects of the HDPE. This new geometric structure is formed round the original structure of the aluminium matrix to bring about increase in hardness.

Table: 2 Hardness Measurement of the Two Samples

Sample	First Reading (HB)	Second Reading (HB)	Third Reading (HB)	Fourth Reading (HB)	Average Hardness (HB)
A	88.20	100.20	115.60	106.40	102.60
B	119.70	121.40	117.80	124.60	120.88

— Tensile Test Result

Stress – strain curves of the two samples are presented in Figure 2. The ultimate stress of sample A is 70.2 N/mm^2 while that of sample B is 74.0 N/mm^2. This represents an increase of 5.4 % in comparison to control sample A. This is due to the changes in the microstructural features as a result of the HDPE addition. The increase in hardness observed has further brought about increase in the ultimate tensile strength of the material.

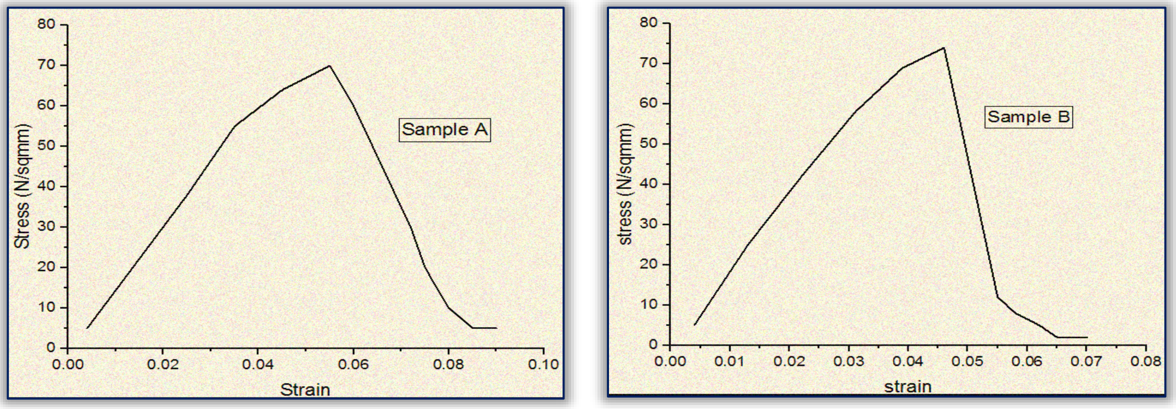

Figure 2. Stress – strain curves of Samples A and B

4. CONCLUSION

Aluminium 6063 matrix was melted, 5 % w/w HDPE was added to the melt and solid solution was formed. Hardness, tensile and microstructural examinations of the product was carried out together with the control sample. From the processing and the tests result obtained it shows that:

- Addition of 5 % HDPE in aluminium 6063 alloy was successful without vapourization of the polymer in the alloy at high temperature before casting and solidification of the casting.
- The HDPE was seen in the structure to be distributed round the phases present in the aluminium matrix. This strengthened and enhanced the evaluated properties.
- The tensile property of the composite was noticed to have increased by 5.40 % relative to the control sample, while the hardness increased by 17.82% relative to the control sample. Definitely addition of HDPE into aluminium enhances the mechanical properties evaluated.

The authors conclude that as tangible result was obtained from using only 5 % wt volume of HDPE, further works can review the composition between 1 to 4 % and likewise it can be reviewed above 5 % and determine the equilibrium composition where HDPE would be tolerable in the aluminium matrix.

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References

[1] A.A. Adeniran, K. K. Alaneme, I. O. Oladele, E. T. Akinlabi, Microstructural characteristics and mechanical behaviour of aluminium matrix composites reinforced with Si – based refractory compound derived from rice husk. Cogent Engineering.Vol.8 (1), p.1 –16, 2021.

[2] R. J. Immanuel, S. K. Panigrahi, Transformation of cast A356 ingots to wrought sheets with enhanced mechanical and tribological properties by different thermo–mechanical processing

[3] M. L. Rahaman, L. Zhang, An investigation into the friction and wear mechanisms of aluminium high silicon alloy under contact sliding. Wear 376–377, p. 940–946, 2017.

[4] A. A. Agbeleye, D. E. Esezobor, S. A. Balogun, J. O. Agunsoye, J. Solis, A. Neville, Tribological properties of aluminium–clay composites for brake disc rotor applications. Journal of King Saud University – sciences. Vol. 32 (1), p. 21 – 28, 2020.

[5] N. Rathod, J. Menghani, A consequence of reinforcements in aluminum–based metal matrix composites: a literature review. Metall. Mater. Eng. Vol. 25 (3), p. 195 – 208, 2019.

[6] K. K. Alaneme, B. O. Ademilua, M. O. Bodunrin, Mechanical Properties and Corrosion Behaviour of Aluminium Hybrid Composites Reinforced with Silicon Carbide and Bamboo Leaf Ash. Tribology in Industry. Vol. 35 (1), p. 25 – 35, 2013.

[7] K.K. Alaneme, K.O. Sanusi, Microstructural characteristics, mechanical and wear behaviour of aluminium matrix hybrid composites reinforced with alumina, rice husk ash and graphite, Engineering Science and Technology, an International Journal. Vol. 18 (3), p. 416 – 422, 2015.

[8] T. J. Babu, M. K. G. Hussain, A study of mechanical properties of HDPE reinforced with limestone composite materials. International journal of scientific development and research 2(1), p. 49 – 57, 2017

[9] G. Madhu, H. Bhunia, P. K. Bajpai and V. Chaudhary, Mechanical and morphological properties of high–density polyethylene and polylactide blends, Journal of Polymer Engineering. Vol. 34(9), p.813–821, 2014.

[10] P. Scapini, C. A. Figueroa, C. L. G. Amorim, G. Machado, R. S. Mauler, J. S. Crespo, R. V. B. Oliveira; Thermal and morphological properties of high–density polyethylene/ ethylene –vinyl acetate copolymer composites with polyhedral oligomeric silsesquioxane nanostructure. Polymer International Vol. 59, p.175–180, 2010.

[11] O. O. Daramola, A. S. Taiwo, I. O. Oladele, J. L. Olajide, S. A. Adeleke, B. O. Adewuyi, E., Properties of high–density polyethylene matrix composites reinforced with chitosan particles, Materials Today: Proceeding. Article in press, p. 1– 6. 2020.

[12] M. Tasdemir, S. Ersoy, Mechanical, morphological and thermal properties of HDPE polymer composites filled with talc, calcium carbonate and glass spheres. Romanian Journal of Materials Vol. 45(2), p.147 – 154, 2015.

[13] A. Lofty, E. Mohamed, A. K. Handam, B. R. Yu, Investigation of Polymer – Aluminium powder composite. International journal of metallurgy and metal physics. Vol. 5 (051), p.1 – 10, 2020.

[14] A. J. Babafemi, B. Savija, S. C. Paul, V. Anggraini, Engineering Properties of Concrete with Waste Recycled Plastic: A Review, Sustainability, Vol.10. (3875), p.1 – 26, 2018.

[15] ASTM E 92 –82(2003), Standard Test Method for Vickers Hardness of Metallic Materials, ASTM International, West Conshohocken, PA, 2003.www.astm.org.

[16] ASTM E 8M (1991), Standard Test Method for Tension Testing of Metallic Materials (Metric), Annual Book of ASTM Standards, Philadelphia, 1991.

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