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Original Research Article

Effect of B_4C Particulate on the Mechanical Properties of ZA-27 Alloy Composite

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ABSTRACT

An investigation was carried out to study the effect of boron carbide (B_4C) on the mechanical properties of ZA-27 alloy composites. The base alloy was reinforced with B_4C particles of 30 µm and the composite was produced by stir casting method. The as-cast samples consisting of varied weight percentage of 0, 2.5, 5, 7.5, and 10% amount of B_4C were tested for various mechanical properties such as hardness, tensile, impact tests and the results were compared with the unreinforced sample under the same conditions. It was observed that the addition of B_4C particles increased the mechanical properties of the alloy. The tensile test result showed the 7.5wt% B_4C composite having maximum tensile strength of 305.53 N/mm^2 and 10wt% B_4C the least value of 127.3 N/mm^2 as compared with the unreinforced (0wt% B_4C) which was 229.15 N/mm^2. The hardness was found to be maximum for the 10wt% B_4C composite with a value of 93.5 HRB and least with a value of 67.4 HRB for the 0wt% B_4C. The impact test result revealed that the impact strength for 10wt% B_4C composite was the highest with a value of 0.1298 J/mm^2 and the strength is least for 0wt% B_4C with 0.0267 J/mm^2. The composites produced has light weight combine with good strength and can be used as bearings for combustion engines.

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1. INTRODUCTION

Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications (Seah *et al*., 1996).

Zinc-aluminum (ZA) alloy is one of the attractive materials for matrix phase due to properties such as high tensile strength, resistance to corrosion, good castability and good tribological properties (Babic *et al*., 2004, 2009). Commercially available ZA-27 alloys have become the alternative material primarily for aluminum cast alloys and bearings, due to good castability and unique combination of properties (Bobic *et al*., 2014). These alloys are relatively affordable and can be processed efficiently with low energy consumption without endangering the environment (Babic *et al.*, 2005). ZA-27 alloy, in particular, has been used in bearings and bushing applications, as a replacement for bronze bearings because of its low cost and equivalent or superior bearing performance (Babic and Ritrovic, 2005).Moreover, ZA-27 is classified as a high strength alloy with a tensile strength substantially higher than that of ordinary cast aluminium alloys (Sharma *et al.*, 2008). ZA-27 alloy has the highest strength and the least density of the ZA alloys and provides the highest design stress capability at elevated temperatures of all the commercially available zinc-based alloys (Seah *et al.,* 1996).

Attempts have been made by different researchers in the field of materials engineering to develop ZA-27 alloy with different reinforcement in order to address the issue of decrease in strength at elevated temperatures (Choudhury *et al.*, 2002). The use of different reinforcements such as silicon carbide SiC, alumina Al_2O_3, fly ash, and agro wastes for developing ZA-27 alloy has been reported in literatures (Shanta *et al.,* 2001; Alaname and Aluko 2012; Fatile *et al.,*2017). In comparison with the already studied reinforcements, boron carbide (B_4C) particulates possess a superior and unique combination of hardness, specific strength, low density, elastic modulus, chemical and thermal stability (Auradi *et al*, 2014).

Limited research work has been reported on the use of B_4C as a promising reinforcement of particulate reinforced metal matrix composites (PRMMCs). B_4C received little attentions over its counterparts such as SiC and Al_2O_3 due to high raw material cost and poor wetting. In order to enhance the wettability of ceramics and improve their incorporation behaviour into Al melts, particles are often heat treated or coated (Kennedy and Brampton, 2001). However, B_4C is known to possess excellent chemical and thermal stability, high hardness (HV=30GPa) and low density (2.52g/cm^3) (Auradi *et al*, 2014). It is therefore envisaged that encouraging results may be achieved as it is being used in Zn-Al matrix composites with its low cost casting route. In the light of this, the current research is focused on using B_4C particulate as reinforcement in ZA-27 alloy with the hope of producing materials with improved properties. This study will contribute in the development of a composite material which can be used in engineering applications where light weight combined with good wear resistance and strength at high temperatures are required such as in bearings for combustion engines.

2. MATERIALS AND METHODS

2.1. Materials

The matrix material for the present study is ZA27 Alloy; the reinforcing material selected is B_4C of particle size 30 μm. Zinc and Aluminum ingots were sourced from Towers Aluminium, Lagos State, Nigeria while boron carbide was procured from china

2.2. Methods

2.2.1. Production of composite

The ZA-27 alloy matrix composites reinforced with B_4C particles was produced using stir casting method (Fatile *et al.,* 2017). The quantitative amount of B_4C required to produce 2.5, 5, 7.5 and 10 wt % reinforcement was determined by charge calculations. The B_4C particles were preheated in an oven separately at a temperature of 250 ^{o}C for an hour in order to eliminate moisture/ volatile matter and improve wettability with the molten ZA-27 alloy. An electric arc furnace crucible was used to completely melt the alloy by firing to a temperature of 690±30 ^{o}C (above the melting temperature of the ZA-27 alloy). Manual stirring was performed at this temperature before charging the preheated B_4C particles into the vortex and the stirring was continued for about 2 minutes to ensure homogeneity in the composites. After removing the slag, the molten composite was poured into the permanent mould and allowed to cool and solidify. Finally, the castings were removed from the mould and machined into the desired shapes and size. The same procedure was followed to produce composites of different weight percentages of reinforcement by adding the required amount of B_4C particles. The cast samples were machined to appropriate shape, size and dimension so as to meet up with the specification for the mechanical test such as tensile, hardness and impact tests.

2.2.2. Density

The density measurements were carried in order to study the effects of the wt % proportions of the boron carbide on the densities of the produced composites. Samples were machined to 10 mm thickness x 16 mm diameter and weighed using a digital balance and then suspended in water in a calibrated measuring cylinder. The volume of the samples was determined by displacement method. The densities of the samples were then calculated using Equation 1.

$$Density = \frac{mass}{volume} \tag{1}$$

Where:
mass is the quantity of matter the sample contains
volume is the amount of space the sample occupies

2.2.3. Tensile test

Tensile tests were performed and evaluated on each composite test sample produced in accordance with ASTM D6-38 (Madheswaran *et al.*, 2015) standard specifications. The samples for the test were machined to specimen configurations with 8 mm diameter and 37 mm gauge length. The tensile test was performed at room temperature (25 ^{o}C) using Mosanto Tensometer ASTM E8M standard operated at a strain rate of 10^{-3}/s. Tensile test standard specimen as per ASTM D6-38 is shown in Figure 1.

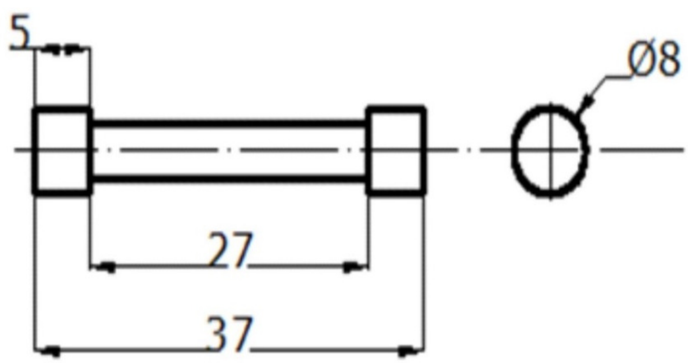

Figure 1: Tensile specimen (All dimension in mm)

2.2.4. Hardness test

The hardness values of the produced composites were evaluated using Rockwell Hardness Tester (Identec, ((Model: 8187.5 LKV(B)) with hardness scale of HRB. The sample preparation and testing procedure was performed in accordance with ASTM E-92 standard (Owoeye and Folorunsho, 2018). The samples were exposed to a direct load of 10 kgf for 10 seconds on the mounted transverse sections to determine the hardness profile through the depth. Three indentation points hardness tests were performed on each sample and the average value was noted.

2.2.5. Impact test

The izod specimen (10 mm x 55 mm) was machined and notched and was subjected to izod impact test. According to ASTM E23 standard (Madheswaran *et al.*, 2015), test specimen was prepared and subjected to izod impact test, which is shown in Figure 2.

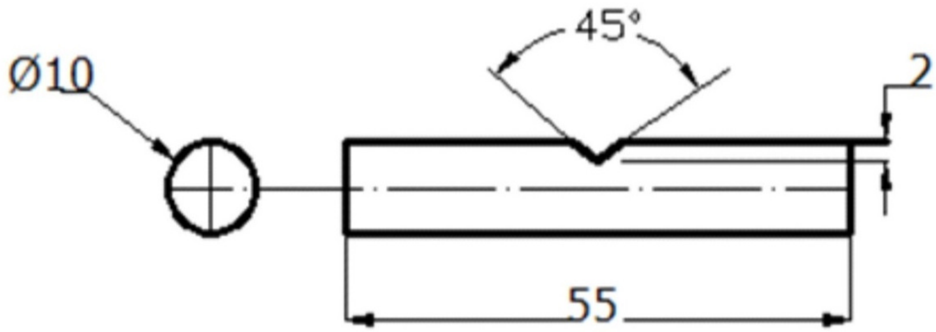

Figure 2: Impact test specimen (All dimension in mm)

As the pendulum was released the potential energy converted to kinetic energy until it strikes the specimen. The izod specimen placed with the V notch facing the specimen was hit above the V notch until fracture occurs. The energy absorbed after fracture was noted from the impact testing machine, and the impact strength is the absorbed energy divided by cross sectional area of the specimen under the notch.

2.2.6. X Ray fluorescence analysis

XRF analysis was used to determine the elemental and oxide composition of the ZA-27/10% B_4C composites. The XRF specimen was machined to 12 mm diameter with thickness of 6 mm and was ground and polished before use, and the elemental and oxide products of the ZA-27/10% B_4C composites were identified through XRF analysis.

2.2.7. X Ray diffraction analysis

The XRD diffraction pattern was recorded by an X-ray diffractometer (EMPYREAN). The machine was operated at 45 KV voltage and 40 mA using Cu Kα radiation (λ = 1.5406 Å) in the angle range of 20-80 ^{o}. The phases and reaction products of the ZA-27/10% B_4C composites were identified through XRD analysis. The XRD test specimen was machined to 10 mm diameter with thickness of 5 mm. The specimen was ground and polished before the XRD test.

3. RESULTS AND DISCUSSION

3.1. Density

The results of the density are presented in Figure 3. Figure 3 shows that the composite with 0wt% B_4C had the highest density of 4.72 g/cm^3 while that with 10wt% B_4C had the least density of 4.28 g/cm^3. The composite with 7.5wt% B_4C had a density of 4.41g/cm^3 while that with 2.5wt% B_4C density was 4.46 g/cm^3. From the Figure 3, it is observed that as the weight percentage of reinforcement increased, density of the composite decreases. It is however expected because the density of the B_4C is less than the ZA-27 alloy, except for 5wt% B_4C which may be as a result of non-uniform distribution of reinforcing particles in the matrix (Siddesh *et al.*, 2014).

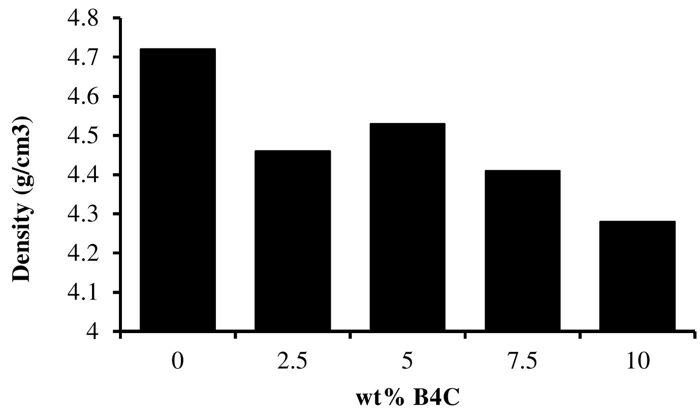

Figure 3: Density of ZA-27 / B_4C particulate composites

3.2. Tensile test

The results of the tensile strength are presented in Figure 4. Figure 4 shows the composite with 7.5wt% B_4C having maximum tensile strength of 305.53 N/mm^2 and 10wt% B_4C least value of 127.3 N/mm^2 which could be as a result of the increase fraction of the reinforcement resulting in low interfacial strength due to poor wettability. For 2.5wt% B_4C composite the tensile strength value is 254.61 N/mm^2, 5wt% B_4C tensile strength is 273.87 N/mm^2 and 0wt% B_4C is 229.15 N/mm^2. The increase in tensile strength was due to alloy strengthening and strain hardening behaviour of boron carbide particles resulting in the reduction of the grain size of the composite matrices (Arslan and Kalemtas 2009; Auradi *et al.,* 2014).

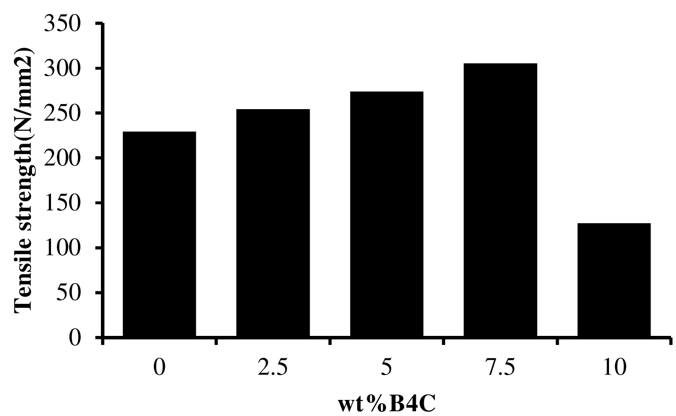

Figure 4: Tensile Strength of ZA-27/ B_4C particulate composites

3.3. Hardness test

The results of the Hardness test are presented in Figure 5. The results show that the hardness of the composite increased with increase in reinforcement content as shown in Figure 5. The Rockwell hardness test of value was found to be maximum for the 10wt%. The hardness test was found to be maximum for the 10wt% B_4C composite with a value of 93.5 HRB and least with a value of 67.4 HRB for the 0wt% B_4C, Composites with

10 wt% reinforcement shows more hardness value which might be as a result of increase in area fraction of reinforcement in the matrix (Mahendra *et al*, 2013).

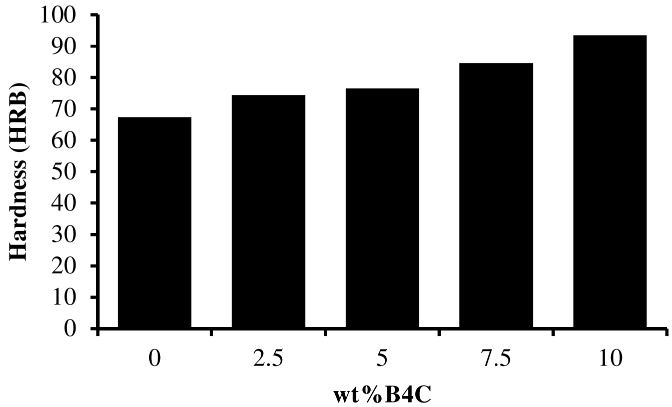

Figure 5: Hardness of ZA-27 / B_4C particulate composites

3.4. Impact test

The results of the impact strength are shown in Figure 6. Impact test result reveals that the impact strength for 10wt% B_4C composite is the highest with the value of 0.1298 J/mm^2 and the strength is least for 0wt% B_4C with 0.0267 J/mm^2. The improved impact toughness may be linked to increase amount of relatively harder B_4C particles in the composites (Madheswaran *et al.,* 2015).

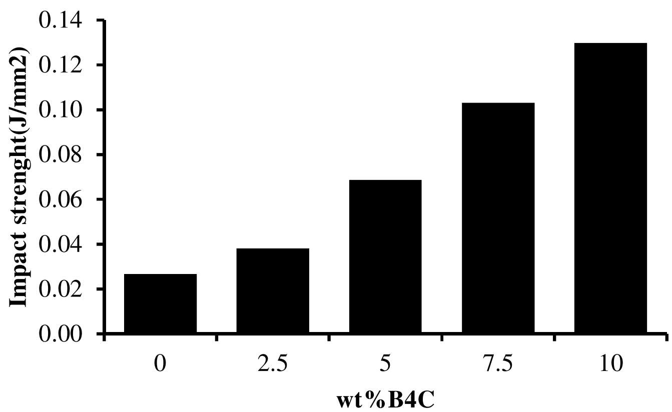

Figure 6: Impact strength of ZA-27 Alloy/ B_4C particulate composites

3.5. X Ray Fluorescence Analysis

The results of the elemental composition shown in Table 1 showed zinc to be the highest in composition with a value of 61.75%, followed by aluminum with a value of 23.227%. Manganese was the least with a value of 0.015%. The results for oxide composition in Table 2 shows ZnO to be the highest in composition with a value of 77.189% followed by Al_2O_3 with a value of 43.9%. TiO_2 was the least with a value of 0.133%. The high temperature oxidation of the molten ZA-27 alloy in the interstices of the B_4C ceramic particulate produces a matrix material composed of a mixture of oxidation reaction products and unreacted metal alloy. By avoiding the potential for inaccuracies caused by incomplete dissolutions and large dilutions, the XRF analysis ensure the reliability and accuracy of results (Pruthviraj and Krupakara, 2008).

Table 1: Elemental composition of sample using X-Ray fluorescence (XRF)

Element	Pb	Al	Si	Zn	Fe	Mn	Ca	K	S
Composition (%)	0.078	23.227	11.445	61.752	1.573	0.015	0.531	0.339	0.59

Table 2: Oxide composition of sample using X-Ray fluorescence (XRF)

Oxide	ZnO	Al_2O_3	Fe_2O_3	SiO_2	CuO	CaO	MgO	NiO	TiO_2
Composition (%)	77.189	43.9	2.249	24.492	0	0.743	0	0	0.133

3.6. X Ray Diffraction Analysis

The results of the XRD pattern show the intensity peaks of Al, B_4C, Zn, ZnC_2 and Al_3C_4 (Figure 7). The reaction products ZnC_2 and Al_3C_4 (brittle phase) were formed at the interface between the matrix and reinforcement. The ZnC_2 phase is predominant and it is the major reaction product formed. The presence of Al_3C_4 phase is relatively less (Alizadeh *et al*, 2010). The XRD results show homogeneous mixing of reinforcements with respect to ZA27/10%B_4C composites.

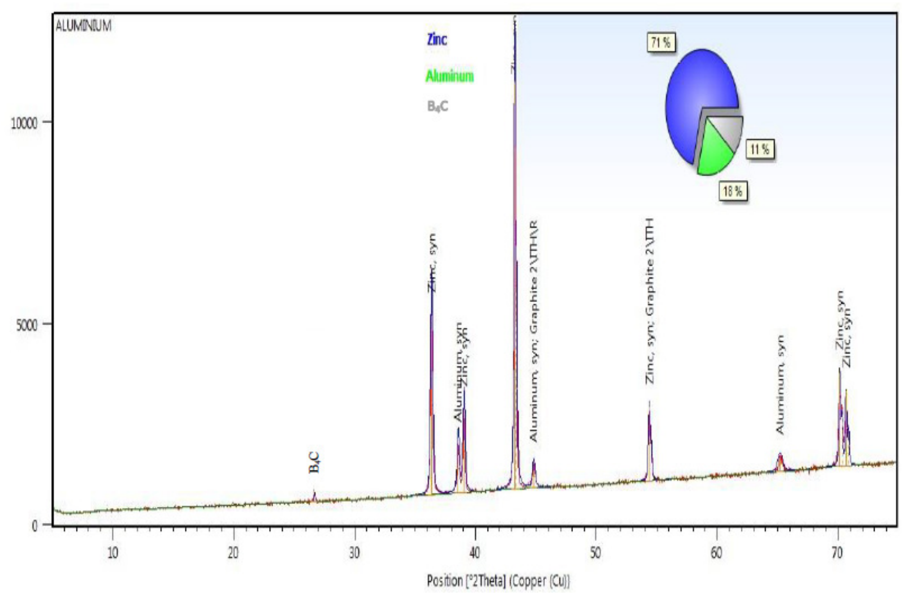

Figure 7: XRD result of ZA27-10% B_4C composites

4. CONCLUSIONS

The following conclusions have been drawn:

- ZA-27/ B_4C composites can be prepared by addition of B_4C particles in molten ZA-27 alloy by stir casting method
- It is possible to introduce only preheated B_4C particles in the melts of ZA-27 alloy to obtain uniform dispersion in the castings
- The density of the composites decreased as the reinforcement content increased

- The hardness and impact strength of the ZA-27/ B_4C composites improves generally over the unreinforced alloy
- The tensile strength of the ZA-27/ B_4C composites show similar trend with hardness justifying correlation between hardness and tensile strength, while tensile strength decreases for 10 wt % reinforcement.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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