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Microstructural and Mechanical Characterization of Reinforced Aluminum Composite (MMC)

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Abstract

The never-ending desire to produce high performance and quality materials which are light weight and a relatively low cost has made metal matrix composite (MMCs) undergo major transitions over the years. In this study, the microstructural and mechanical characteristic of Zinc-Aluminum composite reinforced with coconut shell ash (CSA) and silicon carbide was examined. Five samples were prepared with compositions 0wt% SiC particles added with 0,1,2,3,4, and 5wt% CSA were utilized to prepare 10wt% of the reinforcing phase with Zinc-Aluminum matrix composite using two-step stir casting method. The agro waste material was preheated to a temperature of 250^{0}C before being introduced into the Zinc-Aluminum composite in molten state. Mechanical properties were used to characterize the composites produced. The result shows that decrease in the percentage of SiC resulted to a corresponding decrease in hardness and wear resistance while increase in CSA led to increase in shear strength and torsion. The microstructure shows that SiC and CSA were well dispersed in the alloy matrix. In conclusion, the hardness and wear characteristics of the composite improved with increased in SiC reinforcement.

Keywords: *Mechanical behavior, Microstructure, Coconut shell ash, Aluminum composite.*

1.0 INTRODUCTION

Metal matrix composite (MMCs) is a composite material with at least two constituent parts, one being a metal and the other being a different material entirely such as ceramic or organic compound ("*Tribology in Industry*"). When at least three materials are present it is referred to as a HYBRID. In this context (MMCs) according to "Bobic et al, (2009) are combinations of metals or an alloy with finite fraction by volume or weight of second phase, generally ceramic that is deliberately introduced into the metal in order to improve and infer certain properties in It". Zinc-Aluminum (Zn-Al) falls under this category of MMCs, another example is aluminum-silicon carbide (Al/SiC). Metals commonly used as alloy in MMCs are Zinc-Aluminium based alloy, aluminium based alloys and magnesium alloys. Metal matrix composite is an environmental friendly technology which is welcomed development in tribological industry due to its numerous advantages.

Zinc–Aluminum alloys as competed effectively against copper, aluminum, manganese and other iron based foundry alloys. Bobic et al., (2009), further reported that at elevated temperature (<100^0C) its properties are undesired and unsatisfactory; wear behavior of this material is also of optimum concern". Mitrovic, et al, (2011), revealed that "they are also important bearing materials, low weight, excellent foundry castability, good fluidity, good machinability, improved hardness and tensile strength with good wear resistance are properties to be enjoyed of this product". Hence, it seems probable that metal matrix composites will replace conventional materials in many commercial and industrial applications in the near future (Puthvirag, 2011). Zinc-Aluminum alloys are very good materials with desire able qualities, however the product of this MMCs can be widely used in verity of engineering applications, construction, automobiles, aerospace, high load and low speed applications. This study presents an environmental friendly technology of reinforcing Zn–Al alloys with other materials.

Aluminum alloys have a specific gravity of approximately 2.7g/cc thereby placing it among the light weight structural metal. Six major elements constitute the aluminum alloy system, they include; silicon, copper, magnesium, iron, manganese and zinc. Each of this elements affect they alloy interdependently and interactively ("*NADCA Product Specification Standards for Die Casting"*). Most of the commercial works on MMCs has focused on aluminum as the metal matrix. The combination of light weight environmental resistance and favorable mechanical properties has made aluminum alloy very popular for use as metal matrix" (Bobic et al., 2009). The application areas of Al based composites is expected to continue growing, this is possible by virtue of the attractive property spectrum possessed by AMCs and the low cost of production in comparison with other competing MMCs (such as Magnesium, Copper, Titanium and Zinc) similar applications (Fatile et al., 2014).

Generation of agro-wastes in most developing countries have grossly increased over the years as a result of the increase in population and the most widely used method of managing these agro-wastes is open air burning which had led to environmental pollution. Due to the adverse effect associated with open air burning, there is a need to explore other available options where agro-waste can productively utilized with little or no harmful environmental effect. This research work is to buttress the current effort tailored towards harnessing the potentials of different agro waste ashes for the development of low-cost high-performance Aluminium based hybrid composites. Madakso et al., (2012), reported that coconut shell ash has the characteristic for potential utilization in metal matrix composite for automotive applications. In this paper, the processing, microstructural features, and mechanical behavior of an Zinc-Aluminum matrix composite which are reinforced with varied weight ratios of Coconut shell ash and silicon carbide are reported.

Previous research work indicated there is little knowledge available on Zinc-Aluminium based composite, thus this research will add to the existing body of knowledge on Zn-Al composite alloy matrix, produce a high performance materials which is of light-weight and a relatively low cost, making use of organic reinforcement (CSA) and SiC in varying proportions. In most hybrid composites agro waste materials that are commonly used include; coconut shell ash, fly ash, rice husk ash, palm oil fuel ash, sugar cane bagasse, maize stalk ash, bamboo leaf ash and ground nut shell ash. The use of these Agro waste materials would help address and mitigate the adverse effect of environmental pollution considering them as organic contaminants. This study takes into special consideration the manufacturing of a test piece of Zinc-Aluminum (Zn-Al) based composite reinforced with coconut shell ash (CSA) and silicon carbide (SiC).

2.0 METHODOLOGY

2.1. Materials

Pure Zinc ingot and aluminum 6063 were used in preparation of ZA-27 (Zamak 27) alloy metal matrix. Chemically pure silicon carbide (SiC) with coarse particle size and coconut shell ash (CSA) derived from burning and sieving of dry coconut shell was used as reinforcement. Eight Test samples with varying proportions of reinforcement according to charge calculation were produced.

Table 1.0 Elemental composition of zinc ingot

ELEMENTS	%
Zn	84.70
Fe	11.89
Cu	3.38

Table 1.1 Chemical composition of Zinc aluminum alloy.

COMPOSITION(ELEMENT)	%
Al	25-27
Cu	2.06

Fe	0.065
Mg	0.012
Si	0.02
Zn	Balance

2.2. Preparation of the Agro Waste Material

The agro waste material (coconut shell) were obtained from a nearby local market at Badagry in Lagos Nigeria. The already dried solid shells were poured on a steel plate outside in open air and set on fire with the use of a match stick and diesel fuel. It burned vigorously for ten minutes after which it was left to continue burning in open air for about two hours. The volume reduced drastically during burning, the remains were gathered into a crucible and left to continue burning for a whole day. The ash obtained in the drum was allowed to cool in the steel plate before removal. In accordance with K. K. Alaneme et al (2013) recommendation, the ash obtained was then conditioned in a furnace at the temperature of 6500C for 180 minutes so as to reduce the carbonaceous and volatile constituents of the ash. Table 1.2 shows chemical composition of CSA.

Table 1.2 Elemental composition of CSA

ELEMENT	%
Al_2O_3	5.45
CaO	0.57
Fe_2O_3	12.4
K_2O	0.52
MgO	16.2
Na_2O	0.45
SiO_2	45.05

2.3. Preparation of the Zinc Ingot

The Zinc ingot (28kg) was marked and sub-divided into 21 pieces with the aid of a chalk. The ingot was then drilled along the marked area to enhance cutting. A drill bit of size 10 was used on the pillar drilling machine for the drilling operation. After drilling, the ingot was then cut manually with a hack saw, 21 pieces were obtained as earlier marked. Eight pieces weighing approximately 1kg were selected for the melting process.

2.4 Preparation of the Aluminium

The aluminum 6063 (window profile) were cut into pieces and it was weighed on a digital scale. Eight samples weighing approximately 365g were selected for the melting process.

Table 1.3 Chemical composition of Al 6063

ELEMENT	%
Si	0.2-0.6
Fe	0.35
Cu	0.10
Mg	0.10
M	0.45
Cr	0.10
Zn	0.10
Al	Balanced
Others	0.15

2.5. Preparation of Mould

This started with selection of pattern and molding box (cope and drag). All pattern used were single piece pattern both wooden and plastic. Circular patterns were selected for the wear specimen while cylindrical patterns were selected for the torsion, microstructural and hardness specimen. After selection of pattern, the mould was then prepared. This started with collapsing of the previously made mould with d use of a shovel and hammer, the moulding sand was then conditioned with water and mixed, sieving of the facing sand inside the head pan. The drag was prepared, facing coming first, ramming after. Parting line was created along the side of the patterns to facilitate allowance for easy removal of pattern. Parting sand was applied on the face of the drag. The cope was after then prepared creating cavity in it with the sprue pins. The materials used in preparation of the mould are; cope and drag, shovel, sieve, head pan, pattern, parting sand, moulding sand, water, bellow, hand trowel, rammer, and moulding board.

2.6. Production of the MMCs

Two step stir casting process was used in accordance with alaneme and Aluko (2012), for production of the composite material, this was adopted to allow homogeneity and even distribution of particles. The CSA particles were pre heated to a temperature of about 250^{0}C for 2 hours, this was done in order to improve wettability and harmonize the temperature in conformity with Aku et al., (2013). It was then sieved to obtain a finer ash grain of size 150µm and remove impurities. The aluminum was fired into the furnace and heated to a temperature around 670^{0}C till it melts completely. Zinc was then charged into the furnace and allowed to melt completely. After melting the melt was taken out of the furnace and stirred. The melt was returned to the furnace and heated for 7 minutes, the pre heated CSA particles were charge into the furnace followed by the silicon carbide particle and stirred again was heated for 5minutes. A gas fired crucible furnace was used for the operation. The whole process lasted for 25minutes. The slurry was then casted into the moulds. This sequence was repeated for the rest of the sample.

Table 1.0 Charge calculation

SAMPLE	ZINC(g)	ALUMINUM(g)	SiC(wt%)	CSA(wt%)
A	985.5	364.5		
B	985.5	364.5	10	
C	985.5	364.5	9	1
D	985.5	364.5	8	2
E	985.5	364.5	7	3
F	985.5	364.5	6	4
G	985.5	364.5	5	5

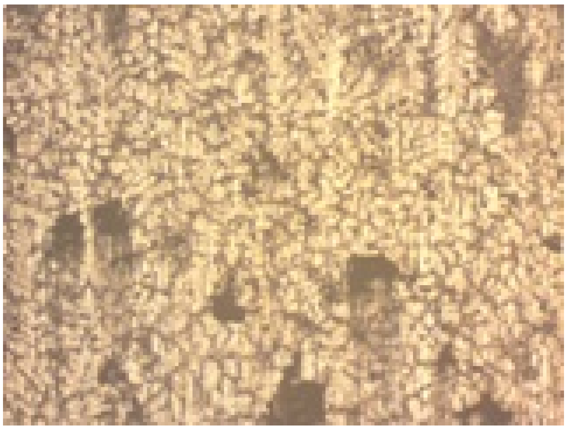
2.7 Microstructural Analysis

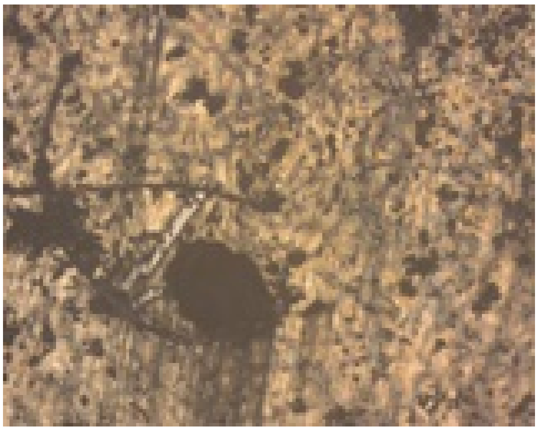
The micro-structure was determined using metallurgical microscope in line with STN 42 setting procedures. The microscope is equipped with a CCD camera connected to a computer for image capturing. The test specimens were cut with a cutting disk. Polishing began with 180-grit emery paper revolving at 150rpm for one minute under the flow of water. This step was repeated for emery paper 220, 400, 600, 800 grit papers. The seven specimens were etched with natal (nitric acid and ethyl alcohol), dried with hand drier then micro structural examination was carried out.

3.0 RESULT AND DISCUSSION

3.1 Microstructural Analysis

Fig 1.1a shows a photomicrograph of the Zn-Al composite 10wt% of SiC (sample B) with the SiC well dispersed in the Zn-Al with the black pores indicating defects. It was observed from fig 2.2b that there is high volume of particulate dispersed in the Zn-Al matrix for 5wt% CSA reinforced composite with larger pores compared to the single reinforced Zn-Al 10wt% SiC composite.



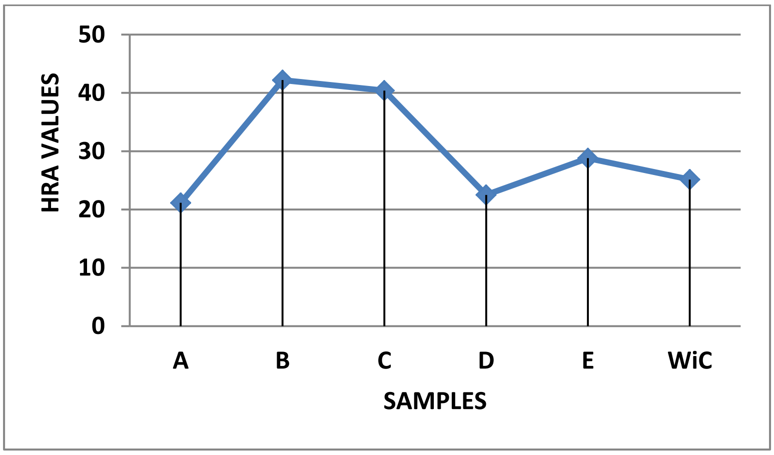


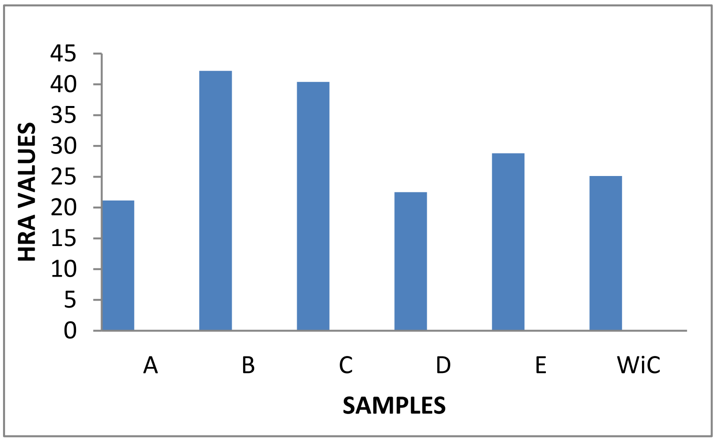
(a) photomicrograph of the Zn-Al composite 10wt% (b)photomicrograph of the Zn-Al/5wt% SiC-5% of CSA of SiC

Fig 1.1 Microstructural characteristic of the composite showing SiC and CSAparticles dispersed in Zn-Al matrix

3.2 Mechanical Behaviour

Figure 1.3 shows the hardness test results. The HRA (Rockwell hardness) value reads maximum at sample B containing 10wt%SiC-0wt% CSA. It was observed that an increase in hardness was as a result of increase in SiC particle and this is in conformity with Pruthviraj, 2011. The ductility of the composite material however increased with addition of CSA as a result of SiO_2 which is less hard compared to SiC according to Courtney (2006). At 2wt%CSA-8wt%SiC (sample D) the Zn-Al composite material however showed a rapid decline in hardness, after which it gradually picked up and continued in an undulating form. The reinforced composite materials however exhibited better hardness values than the Zn-27 alloy material.





WEAR TEST

Figure 1.4 and 1.5 bellow describes the wear test values of the composite material. The value was at the least at 10wt%SiC-0wt%CSA variation (sample B). It was observed that the reinforced particle had better wear resistance compared to the ZA-27 alloy. In line with pruthviraj, (2011) wear properties were best at the 10wt%SiC. The result followed a undulating form just like that of the hardness for the first four values before just hitting a peak value at variation 7wt% of SiC by 3wt% of CSA, this may be due to the minimum quantity (wt%) of reinforcing particle needed to improve property. Contrary to Madakson etal., (2012) it was observed that wear rate increased with an increase in weight percentage of coconut shell ash.

SAMPLES	A	B	C	D	E
VALUES	0.0178	0.0081	0.0116	0.0103	0.1010

Table 1.5

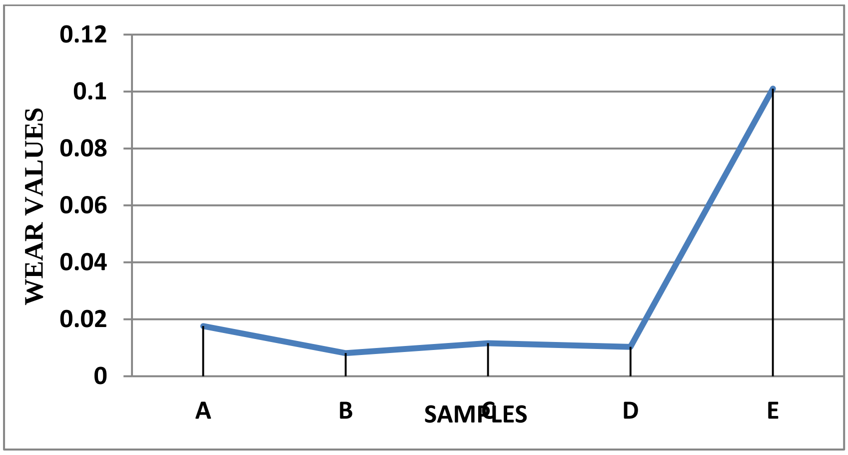


Fig 1.4

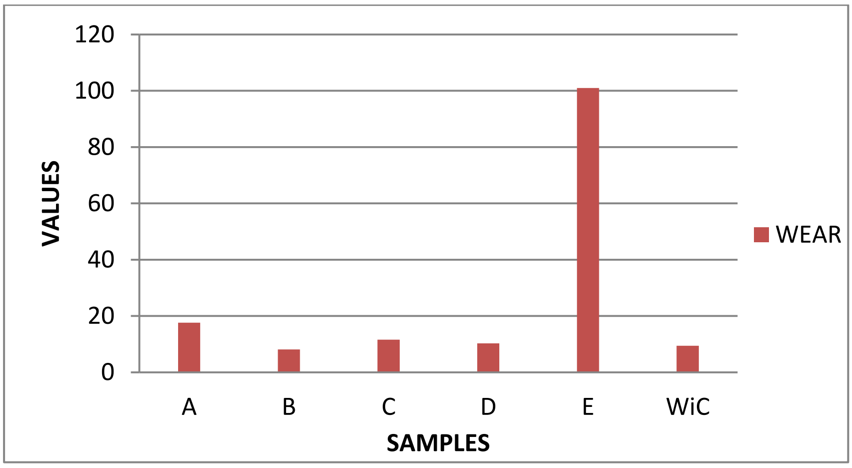


Fig 1.5

TORSION TEST

Fig 1.6 below shows the calculated values for the shear stress

SAMPLES	A	B	C	D	E	Wic
VALUES (MNm^{-2})	199.0	182.3	187.2	183.1	230.1	232.0

Table 1.6

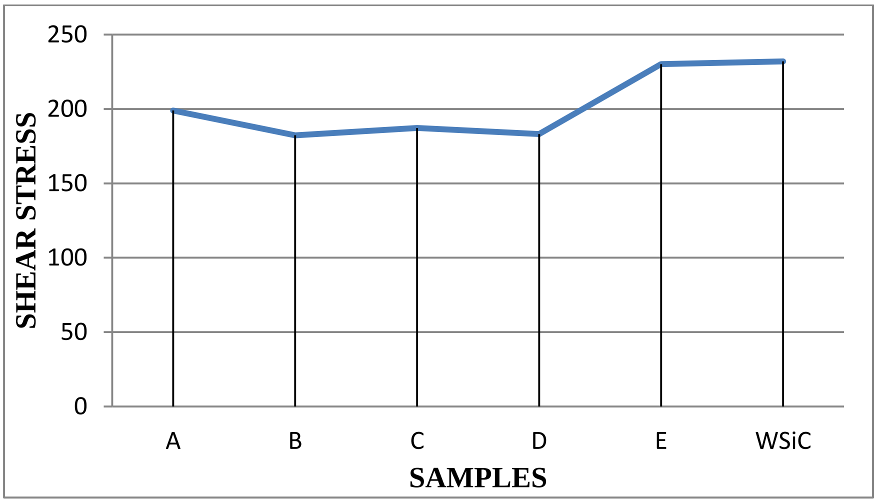


Fig 1.6

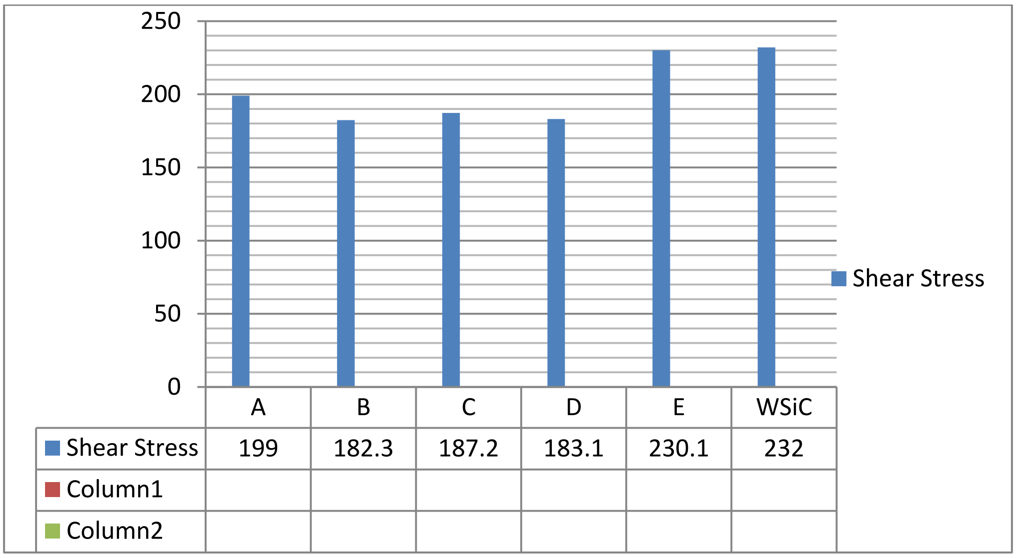


Fig 1.7

Figure1.8 bellow shows a comparative analysis of both the results of the hardness, wear test and shear in a bar chat with sample B having both the highest hardness and the best resistance to abraision. Unlike the hardness test the za-27 alloy did not have the least wear value. SiO_2 has been reported by Lancaster et al., (2013) to be the dominating element in CSA. However this is a softer particle than SiC, Courtney T.W. (2006). There is a relationship between the hardness, torsion and wear.

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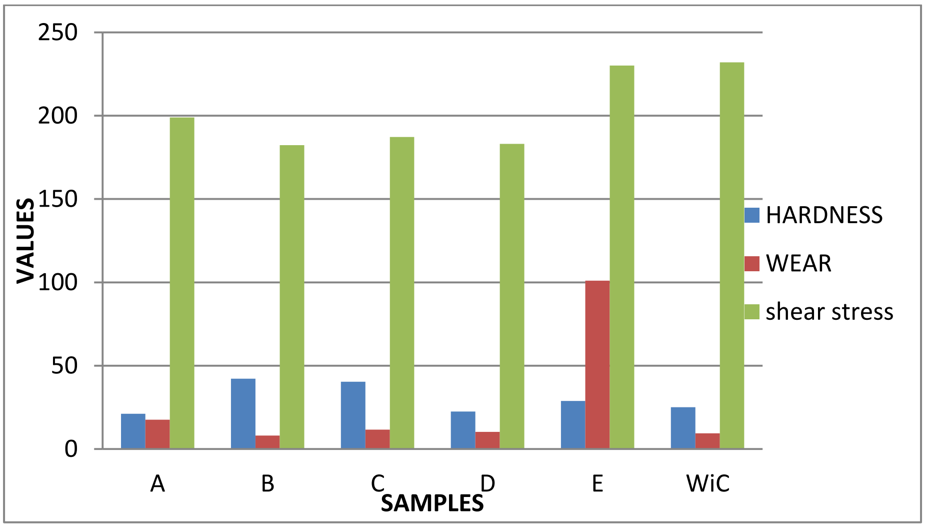

4.0 CONCLUSIONS

The microstructural studies and mechanical properties of Zinc Aluminium alloy metal matrix composite containing silicon carbide and coconut shell ash containing 10:0, 9:1, 8:2, 7:3, 6:4, 5:5 wt % SiC and CSA as reinforced were investigated. The results show that:

The hardness of the hybrid composites was observed to be superior compared to that of the Zn-27 alloy.
The results of the hardness, torsion and wear resistance test followed and undulating pattern
CSA particle has little or no effect on the hardness of the composite material but it had asignificant effect on the maximum shear stress
SiC particles had significant effect on the hardness and wear resistance of the composite material.
The variation of both the SiC and CSA particles is responsible for the undulating pattern of all the test results.
CSA has a great promise to serve as a complementing reinforcement material used alongside with SiC to reduce cost and produce high performance material with better mechanical properties.

4.1 RECOMMENDATION

In other to avoid moulding problems such as outflow it is recommended that the cope and drag should be properly aligned before pouring the molten metal and additional measures such as addition of weight on mould should be implemented to mitigate the effect of metallostatic pressure. While extra charge should be added during the charge calculation to compensate for excesses in the sprue, ingate and runners.

For further studies flexostructural properties of the composite should be studied and impact test may also be carried out for better knowledge on the properties of the composite material.

Due to excellent surface finish this composite it recommended for use in automobiles; alloy wheel, vehicle door handles and some other parts of the vehicle part that in not in contact with extreme heat. It can also be used in food industry for food packaging, electronics, aero space industries, construction, wood work and metal work to complement the final product.

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