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Development of Aluminium Matrix Composites Reinforced with Carbonised Coconut Shell and Silicon Carbide Particle for the Production of Automobile Piston

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KeyWords

KeyWords: Al6061 Alloy, Carbonized Coconut Shell particle, Mechanical Properties, Metal Matrix Composite, Powder metallurgy, SiC particles, Sintering

ABSTRACT

In the present work, an effort has been made to develop a hybrid aluminium matrix composite for automobile piston production. Aluminium is widely used as a structural material especially in the aerospace industry because of its light weight, but its low strength and melting temperature however were always its big challenges. An easy method of solving this problem is the use of reinforcing elements such as SiO_2, SiC particles and whiskers or other compounds. Al6061 alloy was selected as the matrix material while carbonized coconut shell particles ($CCNS_p$) and silicon carbide particles (SiC_p) as reinforcement. Composites were prepared using powder metallurgy technique with 0, 2, 4, 6, 8, and 10 wt % of reinforcement. The requisite mixtures were obtained using high energy mixer and loaded into a steel mould and compressed using a Compac hydraulic press of 500kN capacity to obtain the green compacts. The green compacts were carefully ejected and sintered in a muffle furnace at 527^oC for 1hour. Physical and mechanical properties were investigated. For green compacts, a range of 2.3478-2.4510g/cm^3 and 7.041-11.230%, were obtained for density and porosity respectively while for sintered compacts, 2.3496-2.5173g/cm^3,5.045-9.118%, and 197.2-255.9MN/m^2 were obtained for density, porosity and compressive strength respectively. Microstructural examination of the developed composite materials revealed that the reinforcement particles were uniformly distributed in the base matrix and that bonding took place between the base matrix and reinforcements on sintering.

I. INTRODUCTION

Metal matrix composite (MMCs) reinforced with ceramic particles and whiskers are very promising materials for structural applications due to their excellent combinations of properties [1]. With properties of metallic alloys (ductility and toughness) and the ceramic reinforcements (high strength and high modulus) combine together form a superior profile of characteristics [1-3]. There has been an increasing interest in composite containing low density and low-cost reinforcements. Among various discontinuous dispersion used are fly ash, red mud, rice husk ground shell ash is some of the most inexpensive and low-density reinforcement available in large quantities as solid waste by-product [4]. Coconut shell due to its outstanding natural structure and low ash content are appropriate for preparation of carbon black [4]. Therefore, the objective of this current work is to develop and characterize Aluminium alloy-based Composites Reinforced with Nano Carbonised Coconut Shell and Silicon Carbide Particle fabricated using Powder Metallurgy Technique. Powder metallurgy is the process of making components with required properties and shape by mixing metal and non-metal powder [5]. The process consists of various steps which include powder manufacturing, compaction, sintering, finishing and sizing.

In their research, [6] studied the properties of Al-SiC_p metal matrix composites fabricated through powder metallurgy route. Investigation reveals that density, porosity, hardness, compressive strength and indirect tensile strength of Al-SiC_p composites increase with increase in weight percentage of SiC_p from 5 to 30 wt % for both ball-milled and un-ball milled powder. The research carried out by [4] on the effect of coconut shell ash and SiC particles on mechanical properties of Aluminium based composite. The composites were prepared using stir casting process with bottom pouring at a pre-set melting temperature and stirring speed. Their results reveal hardness increases with increase in wt% of coconut shell ash, but impact strength and density decreased with increase in wt% of coconut shell ash.

II. MATERIALS AND METHOD

2.1 Materials

Aluminium alloy 6061 is used as base material; silicon carbide and nano carbonized coconut shell are used as the reinforcements.

2.2 Methods

2.2.1 Production of carbonized coconut shell particle ($CCNS_p$)

The collected coconut shell was washed with water to remove impurities and dried in an oven at 110^oC to reduce its moisture content. It was then crushed and grinded to form coconut shell powder. The powder was packed in a graphite crucible and fired in an electric furnace in the absence of air to a temperature of 400^oC and held for 10 hrs to form carbonized coconut shell particle. In order to further reduce the particle size, the carbonized coconut shell ash was ball milled for 16hrs in accordance with [8]. After-ball milling the carbonized coconut shells particle was sized using a set of sieves.

2.2.2 Characterization of carbonized coconut shell particle

The carbonized coconut shell particle was characterized based on particle size and its constituents. This was carried out in accordance with [9]. About 100g of the carbonized coconut shell particle was placed unto a set of sieves and shaken for 15 minutes to achieve classification in accordance with [10]. A mini pal compact energy dispersive X-ray spectrometer (XRF) was used for the elemental analysis of the carbonized coconut shell particle.

2.2.1 Experimental Plan for Formulation of Composite Materials

In formulating the composite materials, capital English alphabets were used to denote type of composite based on variation in percentage reinforcement while Arabic numerals represents the variation in relative weight within the reinforcing components. Thus, letters A, B, C, D, E and F respectively represent 0, 2, 4, 6, 8 and 10%wt composition of the hybrid reinforcement. 1, 2 and 3 represent composites with 25, 50, and 75%wt content of SiC_p relative to $CCNS_p$ content in the respective composites.

3.2.3 Experimental Plan for Formulation of Composite Materials

Table 2: Experimental Plan for Formulation of Composite materials

%compositionof Reinforcement	% composition of Reinforcing component (Label)	25% $CCNS_p$ / 75% SiC_p	50% $CCNS_p$ / 50% SiC_p	75% $CCNS_p$ / 25% SiC_p
0	**A**			
2	**B**	**B1**	**B2**	**B3**
4	**C**	**C1**	**C2**	**C3**
6	**D**	**D1**	**D2**	**D3**
8	**E**	**E1**	**E2**	**E3**
10	**F**	**F1**	**F2**	**F3**

2.3 Preparation of Composite materials

During the sample preparation, Al 6061 powder and silicon carbide powder were first heated separately to a temperature close to that of the main process temperature 520^{o}C for 5 hours so as to remove water vapour and other contaminants present in the powders.

2.3.1 Mould Specification

The specification of mould used for compaction is a cylindrical die of internal diameter of 25mm, thickness of 10mm and heights of 70mm respectively, made of steel with hardness 65HRC.

2.3.2 Mixing of Powders

After the various powders were measured according to the various compositions, the mixing of the powder was performed using a high energy mixer. To ensure a proper homogenous mixture of the powers, the mixing process was carried out for 30minutes for each sample.

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2.3.3 Powder Compaction

The conventional compaction method is pressing, in which opposing punches squeeze the powders contained in a die in accordance to [11]. Green compacts of the powder blend were prepared using a 500kN capacity compact hydraulic press with punch and die assembly. Here the measured powder mixture was carefully poured into the die with one end temporarily closed. A manually operated pressure of 450kN was applied for powder compaction. After compaction the sample is brought out through one end of the die by applying pressure on the punch to allow it pass through the die therefore ejecting the green compact.

2.3.4 Sintering

After compaction, some of the specimens were sintered in a muffle furnace to improve its bonding as well as its mechanical properties. During sintering the power particles are bonded together by diffusion and other atomic transport mechanisms, and the resulting somewhat porous body acquires a certain mechanical strength. In order to protect the green compact from oxidation and reduce residual surface oxides during sintering, sintering was carried out in argon atmosphere in a muffle furnace with sintering temperature starting form room temperature to 527^oC (90% of the base matrix melting temperature, 585^oC). The sintered sample was then held for 1hour at 527^oC after which it was allowed to slowly cool down in the furnace.

2.3.5 Tests

The various test conducted on the composite include density and porosity for both green and sintered compact, compressive strength for sintered compacts.

III. RESULTS AND DISCUSSION

3.1 Chemical Composition of Carbonized Coconut Shell Particle.

The results obtained from the XRF chemical composition of the carbonized coconut shell particle ($CCNS_p$) is shown in Table 3. The Analysis of the result reveals that SiO_2, MgO, Al_2O_3 and Fe_2O_3 were the major constituents of the particle. SiO_2, Fe_2O_3 and Al_2O_3 are known to be the hardest substances. Other oxides found to be present in traces include CaO, K_2O, Na_2O and MnO. The presence of hard substances like SiO_2, Al_2O_3 and Fe_2O_3 indicate that the carbonized coconut shell particle can be used as particulate reinforcement in various metal matrix composites [10]. After ball milling for about 16hrs, the particles sizes were found to be in the range of 90-120nm.

Table 3: Chemical Composition of carbonized coconut shell particle

Element	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	MnO	ZnO
%	16.6	0.57	14.5	0.50	16.4	0.45	46.5	0.22	0.3

3.2 Compressive Strength

The variation of average compressive strength of sintered specimen for each composition of $6061Al/SiC_p/CCNS_p$ is shown in Figure 1 for reinforcement varied from 2-10 weight percentage in step of 2, with percentage of SiC_p been varied from 75-25% and nano $CCNS_p$ varied from 25-75% for each weight percentage of reinforcement. It was observed that there is a significant improvement in compressive strength for all composites compare to that base matrix which has a compressive strength of 189.4MN/m^2, as measured values of compressive strength of composite ranges approximately from 197 MN/m^2 to 255MN/m^2. This phenomenon could be

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attributed to the presence of hard compound such as SiO_2, MgO, and MnO in $CCNS_p$ with SiO_2 being the major element and a very hard ceramic particle of its own accord improves compressive strength of the composites [4], while SiC_p owing to it higher density and hardness than $CCNS_p$, carries the load acting on it and could be the reason behind each composites with higher weight percentage of SiC_p having higher compressive strength than those with either equal weight percentage of reinforcement (i.e $CCNS_p$ and SiC_p) and higher weight percentage $CCNS_p$ in the various group.

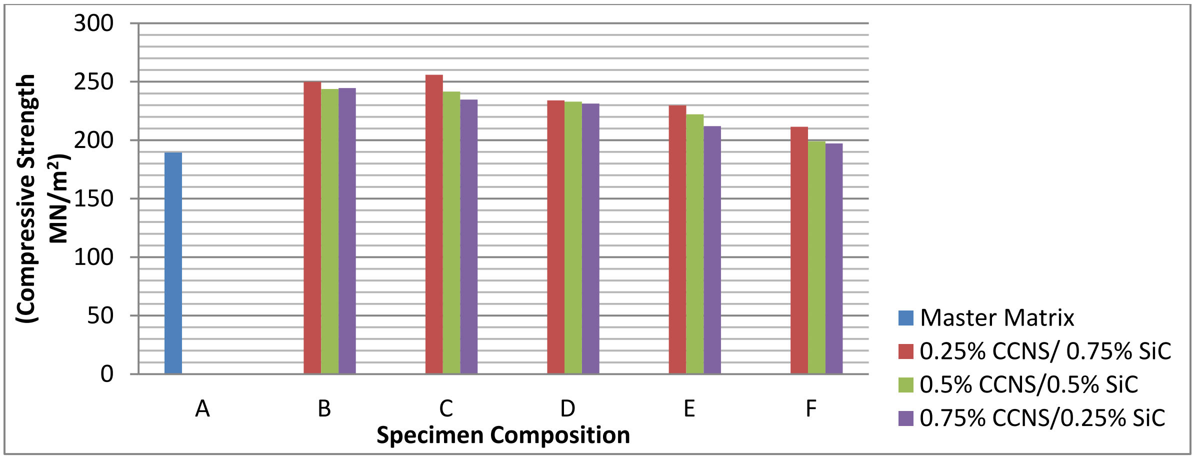

Figure1. Variation of compressive strength with specimen compositions

4.2.3 Density

The variation of theoretical densities and the average densities of uniaxial pressed compacts in green and sintered condition are shown in Figure 2. The theoretical densities of 6061Al-SiC_p-$CCNS_p$ decrease with increase in weight % of reinforcement from 2 to 10 % weight because of the low density of $CCNS_p$. The measured density for the base alloy is 2.4561g/cm^3 and 2.5333g/cm^3 for both the green and sintered specimen respectively indicating an increase in density of 3.1% on sintering. It was observed that the green specimens generally have density values less than that of sintered specimen. This could be attributed to the higher level of porosity (air entrapment) being present in the green specimen compared to the sintered specimen and the insufficient compaction pressure which is limited to the available hydraulic press.

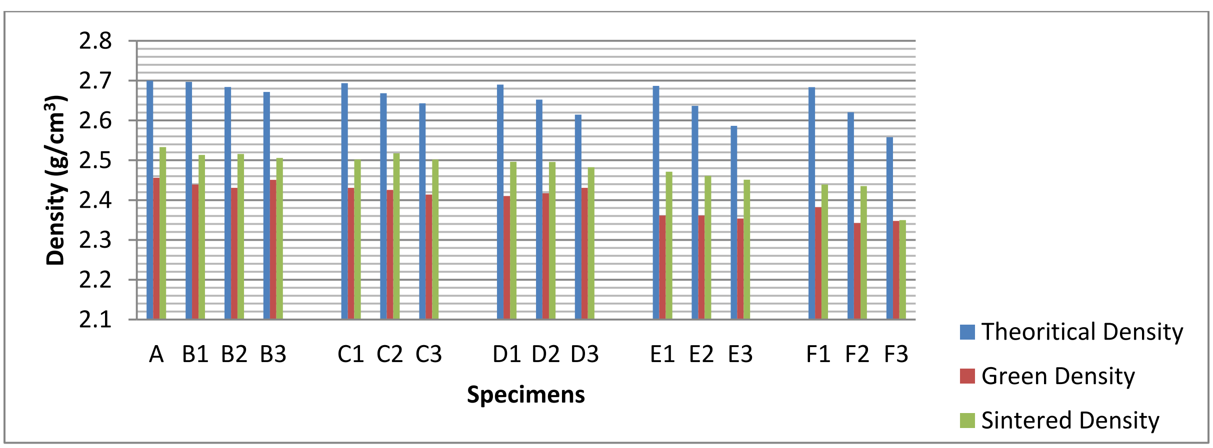

Figure 3 Density variations of specimens

4.2.4 Porosity

Figure 4(a) and 4(b) shows the respective variations of porosity for green and sintered compacts for all specimens. The base matrix has a porosity of 9.033% and 6.174% for green and sintered compact respectively indicating a decrease in porosity of 31.65% after sintering. Generally the level of porosity in green and sintered compact is observed to decrease down each group with increase in weight percentage of reinforcement which could be as a result of nano particle of $CCNS_p$ and melted Al 6061 alloy diffusing into pores during sintering thereby reducing the number of pores present in the composite specimen across each group and enhancing its mechanical properties [7].

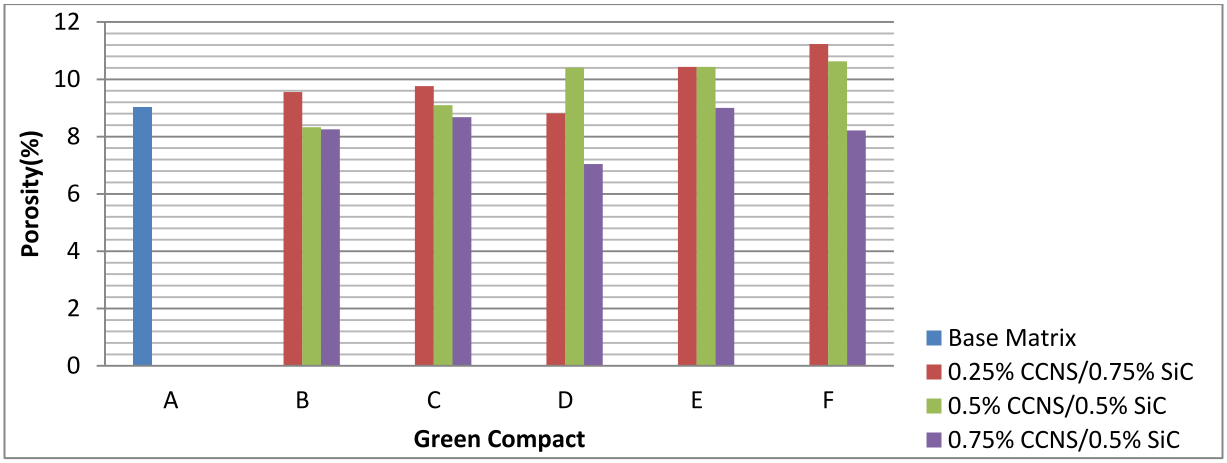

Figure 4(a) Variation of porosity for green compact

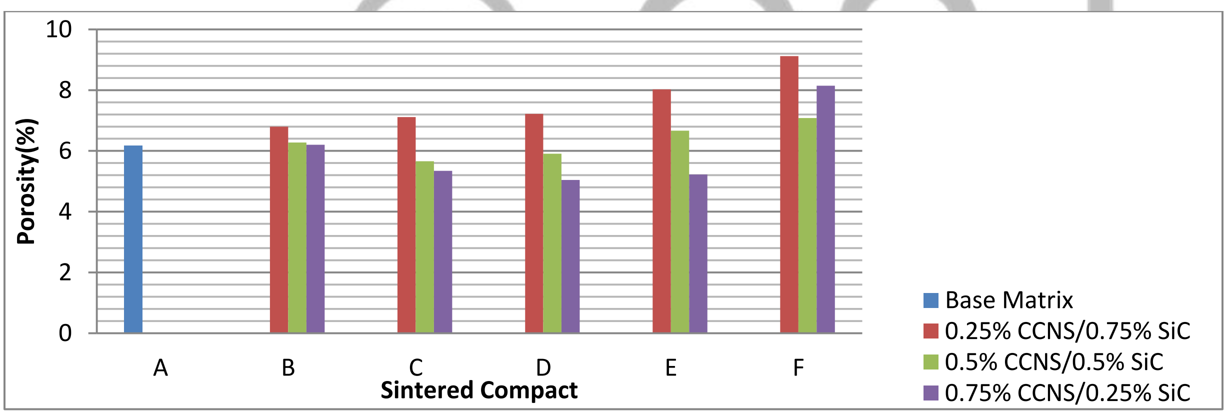

Figure 4(b) Variation of porosity for sintered compact
Figure 4 Variation of porosity with specimen compositions

Conclusions

The primary aim of this research was to evaluate the possibilities of developing aluminium alloy-based composites material for the production of automobile piston from locally available waste material (carbonized coconut shell particle) and silicon carbide particles using powder metallurgy method.

The following conclusion were drawn from the study:

1. Preparation of Al6061-$CCNS_p$-SiC_p composites by powder metallurgy techniques was successful during the research work. Composite were produced by varying the composition of the various constituents. The composition of prepared composites is:
   98%Al6061+2%reinforcement, 96%Al6061+4%reinforcement,
   94%Al6061+6%reinforcement, 92%Al6061+8%reinforcement, and
   90%Al6061+10%reinforcement

2. Compaction of powder was successfully done at 450 kN using a 500 kN Capacity Compact hydraulic press.
3. Sintering of specimen was successfully carried out in a Muffle Furnace at 527^{o}C for 1 hour.
4. Density, porosity and compressive strength showed significant improvement on Sintering.

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