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INFLUENCE OF MILD STEEL PARTICLES ON THE PHYSICAL AND MECHANICAL CHARACTERISTICS OF CERAMIC MATRIX COMPOSITES

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ABSTRACT

Micro particles of mild steel, silicon carbide, magnesia and bentonite were employed as input materials in the development of ceramic composites by powder metallurgy method. Varied formulations were used in producing the samples and they were characterised. The microstructure of the composites were examined using a scanning electron microscope (SEM) equipped with an energy dispersive spectroscope (EDS). Furthermore, the physical (density and water absorption) and mechanical properties (hardness, compressive strength, and impact energy) of the composites were evaluated at room temperature. The samples demonstrated desirable characteristics. Sample D containing 12 wt. % of mild steel particles exhibited density of 1.78 g/cm3, water absorption of 0.3 %, hardness of 137.15 BHN, compressive strength of 146.38 MPa, and impact energy of 6.64 J, which are better when compared with other samples. Proper blending of constituent materials and strong bonding enhanced the characteristics of the composites. The results indicated the suitability of the composite for use in fields that require high compressive strength and hardness.

1. INTRODUCTION

The application of ceramics has increased in various fields because of the desirable characteristics exhibited by ceramics. Some desirable attributes of ceramics are low density, high hardness and compressive strength, rigidity, thermal and abrasive resistance [1]. Despite these desirable attributes, they are confronted with the problem of brittleness and low impact energy, which have limited their application. Silicon carbide, magnesia, bentonite, zirconia, alumina, etc are examples of ceramics. In solving these problems of ceramics, ceramic matrix composites were introduced.

Composites are produced when two or more materials that are different are combined to produce materials that demonstrate superlative characteristics, which cannot be obtained in the original materials. Matrix and filler are the two phases in a composite with the matrix phase enclosing the composite and giving it its bulk form [2]. The filler (particles, fibers, flakes, laminas) strengthens the composite. The characteristics of composites depend on the properties of their constituents, compatibility of the components, concentration, shape, size, and dispersion of filler into the matrix [3].

To produce ceramic composites, filler, which could be a ceramic or metal, combines with ceramic matrix to form composites with improved characteristics [4]. Particles disperse the energy of cracks propagation thereby enhancing the impact energy of ceramic matrix composites [5]. Particles are economical to use as fillers in producing composites and conventional methods (press moulding, pultrusion moulding, casting, continuous casting, and slip forming) can be adopted to produce composites [3].

Studies have been conducted on the development and characterisation of ceramic matrix composites. For example, effect of Al-6%Si alloy particles on tin tailings ceramics matrix composites was investigated. The alloy particles increased linear shrinkage, yield strength, tensile strength, and impact energy but a reduction in density, porosity and hardness was exhibited. The increase in strength and impact energy was because the alloy particles were well dispersed in the tin tailings and strong bond between the two materials [6]. Alumina was blended with particles of zirconia (ZrO2) and strontia (SrO) to produce ceramic composites which were characterised. The alumina that contained ZrO2 developed grains with phase change, which enhanced toughness of the composite. Alumina that contained SrO formed long grains, which enhanced the

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toughness. However, blending both SrO and ZrO2 with alumina did not improve the hardness, but could enhance fracture toughness [7]. Mild steel is a widely used material due to its desirable characteristics such as high melting point, mechanical strength, ductility, etc [8]. Blending particulates of mild steel with ceramics to develop particulate ceramic matrix composites (PCMCs) with enhanced characteristics is a welcome development. Hence, the aim of this study is to investigate the influence of mild steel particles on the physical and mechanical characteristics of ceramic composites for possible properties enhancement.

2. METHODS

2.1. Preparation of Materials

Silicon carbide, mild steel particles, bentonite and magnesia are the input materials. Mild steel chips obtained from the Engineering workshop of the University of Lagos were ground and sieved to the desired particles size using British standardised sieves (BSS). As-received particles of silicon carbide, magnesia and bentonite were obtained in Lagos. Fig. 1 shows the materials used.

Fig. 1. Input materials (a) mild steel chips (b) 105-µm mild steel particles (c) 53-µm Silicon carbide particles (d) 90-µm bentonite (e) 90-µm magnesia

2.2. Production of the Composites

105-µm mild steel particles were manually blended with 53-µm silicon carbide, 90-µm magnesia and 90-µm bentonite. Varied formulations were used in producing the samples as illustrated in Table 1. Phenolic resin and water were mixed with each of the formulations. The mixtures were fed into metal moulds rubbed with oil and pressed at 0.35 MPa to enhance their surface smoothness. The samples were removed from the moulds and sun-dried for 12 hrs. They were oven dried at 110 0C for 12 hrs to avoid cracking during sintering. They were sintered at 1100 0C using a muffle furnace and soaked for 1 hr after which they were taken out of the furnace and allowed to cool. Some of the samples are presented in Fig. 2. These processes were repeated twelve times to produce twelve samples of each formulation making a total number of sixty samples out of which thirty were used for the various characterisations.

Table 1. Proportion of used materials (wt. %).

Sample	Mild steel particles	Silicon carbide	Magnesia	Bentonite	Phenolic resin	Total
A	0	30	40	25	5	100
B	4	35	31	25	5	100
C	8	40	22	25	5	100
D	12	45	13	25	5	100
E	16	50	4	25	5	100

Fig. 2. Some of the produced samples

3. EXPERIMENTAL

3.1. Characterisation of the Composites

A scanning electron microscope was employed to reveal the microstructure of the samples. The density of the samples was determined by recording their weights in air. They were dipped in water and the volume of water displaced was recorded. Eq. (1) [9] was used to calculate the density of the samples.

$$\text{Density } (\rho) = \frac{\text{Mass (g)}}{\text{Volume (cm)}^3} \quad (1)$$

Water absorption (WA) of samples was determined by recording their weights (W1) in air. They were dipped in water for 48 hrs as shown in Figure 3. Thereafter, they were removed, weighed (W2) and Eq. (2) [10] was used to calculate WA.

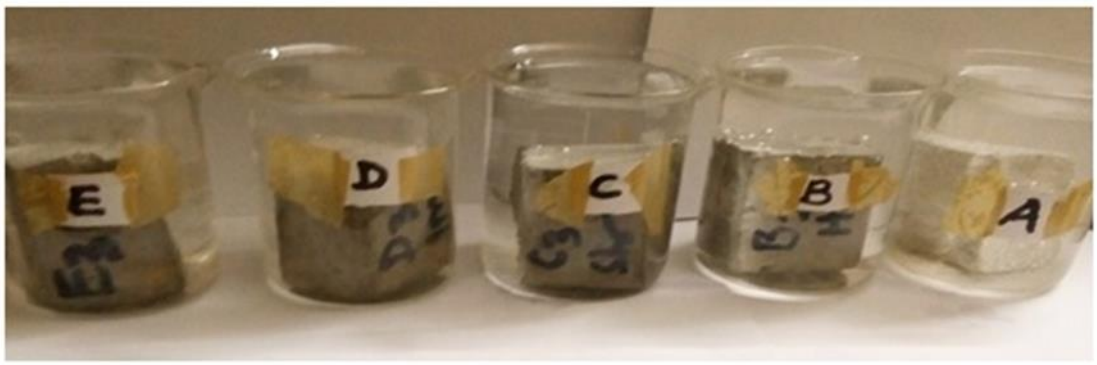


Fig. 3. Photograph of some of the samples immersed in water

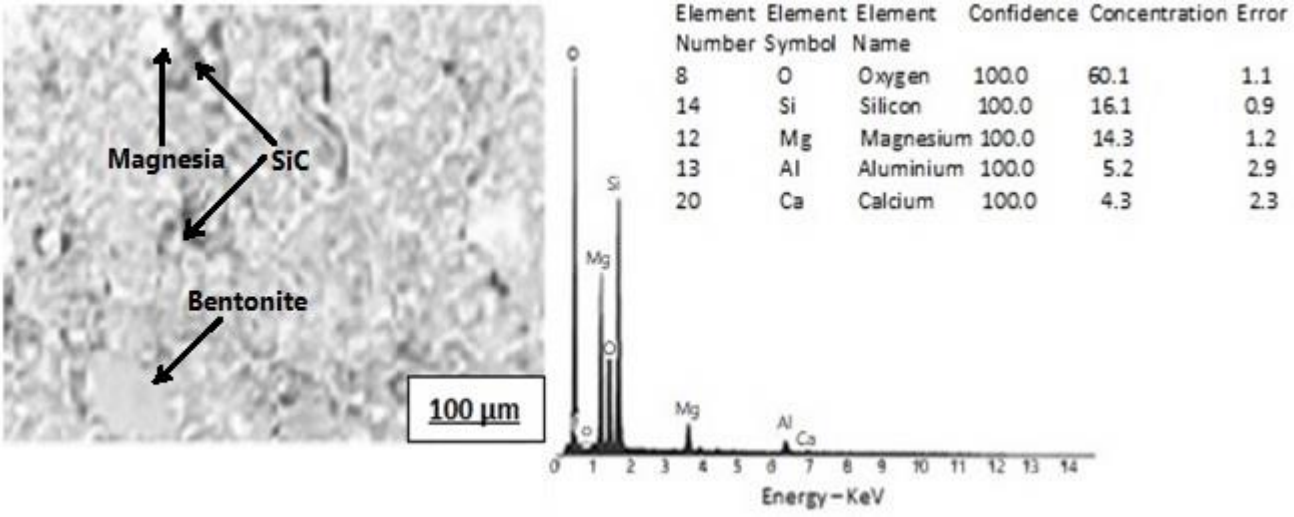
$$W_A(\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad (2)$$

A Brinell hardness tester was used for the hardness test of the samples in accordance with ASTM E10 standard. The compression test was done on the test samples by using an Instron universal testing machine in accordance with ASTM D695 standard. The compressive force needed to crush each of the samples was recorded. Impact energy test was done using an Izod impact tester according to ASTM D256 standard. The pendulum swang downward and hit the samples having a 2 mm deep V-notch in their middle breaking them. A resettable drag pointer indicated the impact energy used.

4. RESULTS AND DISCUSSION

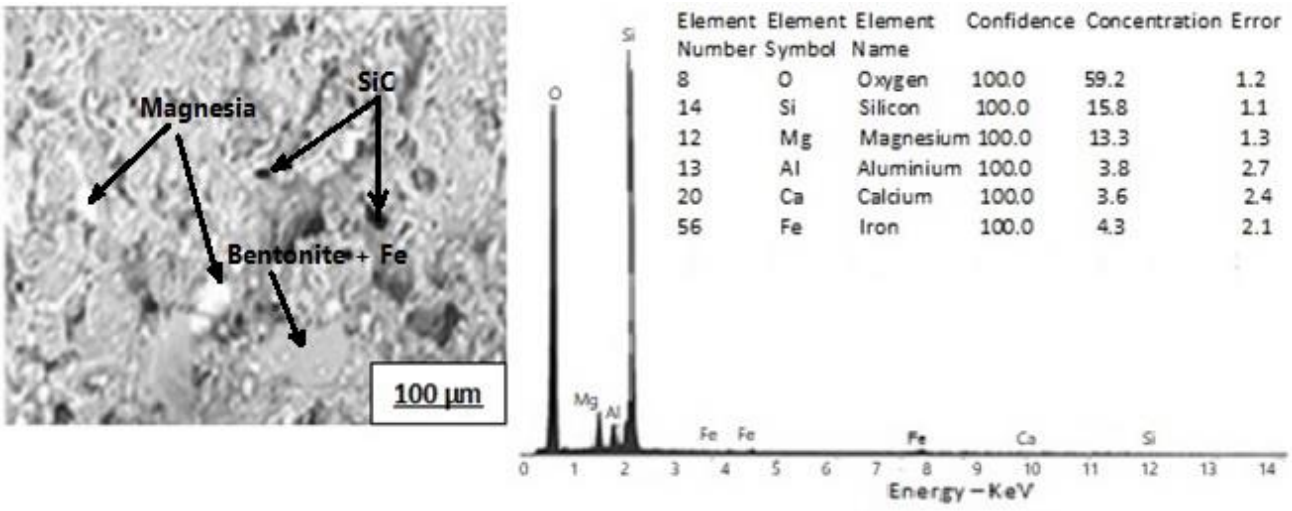
4.1. Microstructure

Microstructures show that the samples contain different phases with different shapes. Some are globular while some are needle-like as revealed in the micrographs. The elemental composition as revealed by the energy-dispersive spectroscopy (EDS) spectra show that sample A contains O, Si, Al, Mg, Ca. Other samples also contain these elements plus Fe (iron) from the added mild steel particles shown in Fig. 4 – 8. In all the samples, there are some indistinguishable peaks in the spectrographs indicating the presence of other elements in very small amount (traces). The whitish areas in the micrographs are magnesia (MgO) phases while the dark areas are silicon carbide phases and gray areas are combinations of Fe and bentonite phases.



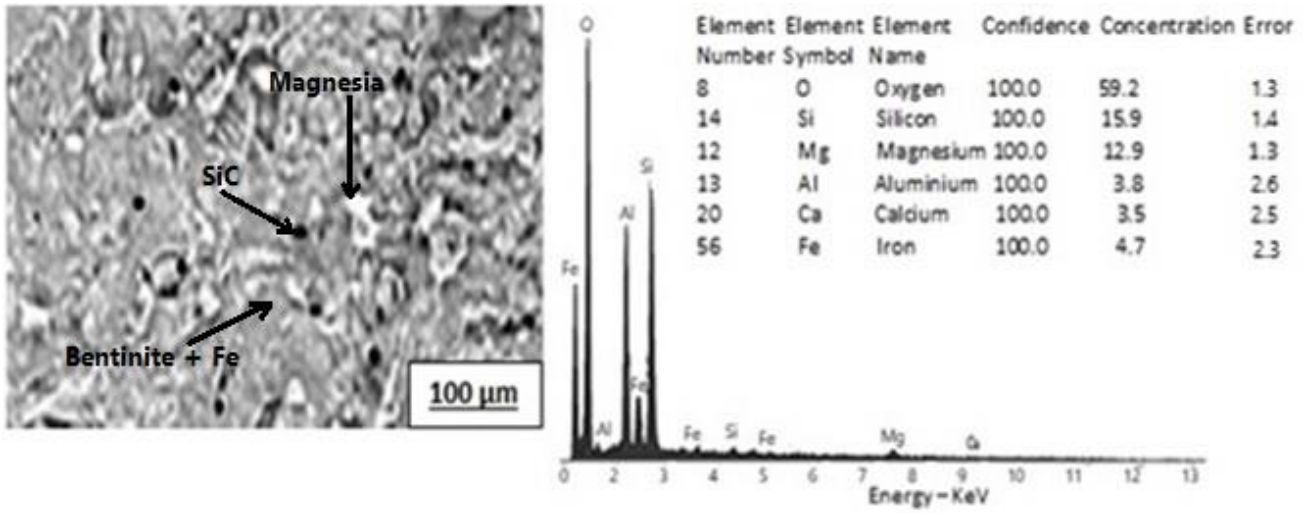
Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
8	O	Oxygen	100.0	60.1	1.1
14	Si	Silicon	100.0	16.1	0.9
12	Mg	Magnesium	100.0	14.3	1.2
13	Al	Aluminium	100.0	5.2	2.9
20	Ca	Calcium	100.0	4.3	2.3

Fig. 4. Microstructure and EDS spectrum of sample A



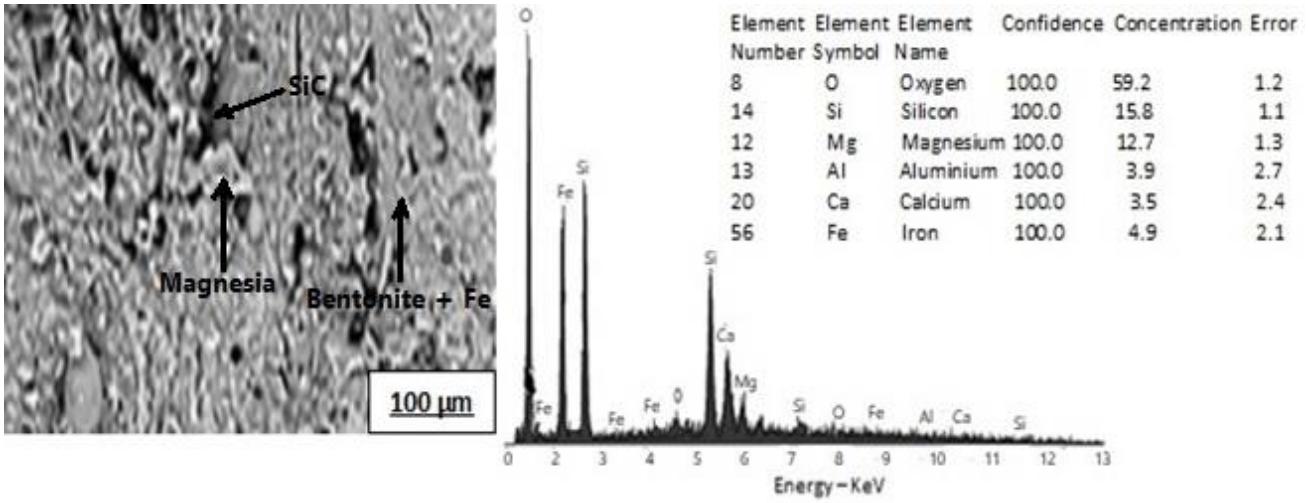
Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
8	O	Oxygen	100.0	59.2	1.2
14	Si	Silicon	100.0	15.8	1.1
12	Mg	Magnesium	100.0	13.3	1.3
13	Al	Aluminium	100.0	3.8	2.7
20	Ca	Calcium	100.0	3.6	2.4
56	Fe	Iron	100.0	4.3	2.1

Fig. 5. Microstructure and EDS spectrum of sample B



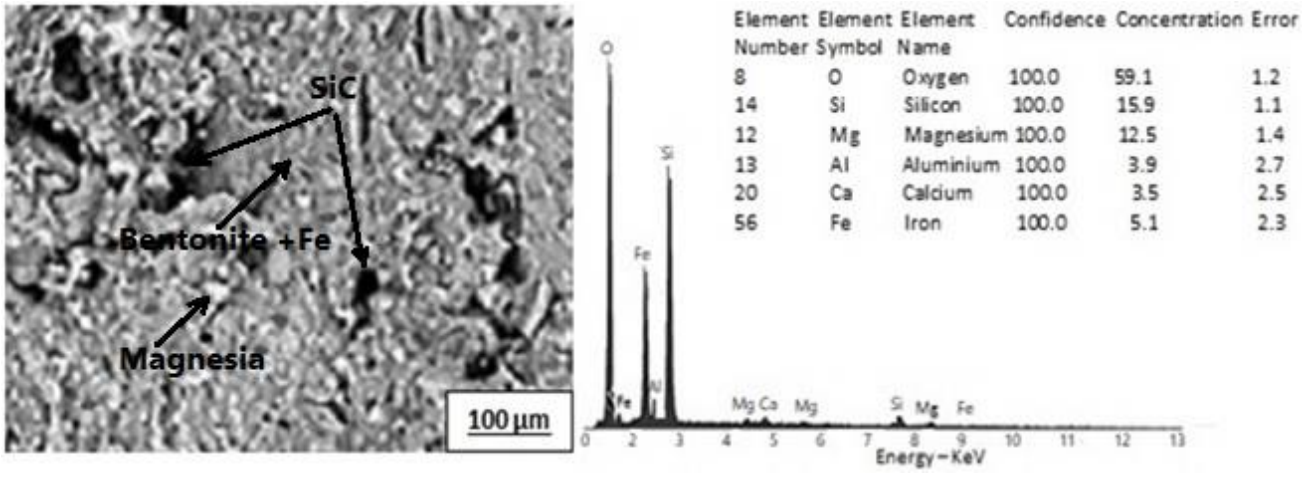
Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
8	O	Oxygen	100.0	59.2	1.3
14	Si	Silicon	100.0	15.9	1.4
12	Mg	Magnesium	100.0	12.9	1.3
13	Al	Aluminium	100.0	3.8	2.6
20	Ca	Calcium	100.0	3.5	2.5
56	Fe	Iron	100.0	4.7	2.3

Fig. 6. Microstructure and EDS spectrum of sample C



Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
8	O	Oxygen	100.0	59.2	1.2
14	Si	Silicon	100.0	15.8	1.1
12	Mg	Magnesium	100.0	12.7	1.3
13	Al	Aluminium	100.0	3.9	2.7
20	Ca	Calcium	100.0	3.5	2.4
56	Fe	Iron	100.0	4.9	2.1

Fig. 7. Microstructure and EDS spectrum of sample D



Element Number	Element Symbol	Element Name	Confidence	Concentration	Error
8	O	Oxygen	100.0	59.1	1.2
14	Si	Silicon	100.0	15.9	1.1
12	Mg	Magnesium	100.0	12.5	1.4
13	Al	Aluminium	100.0	3.9	2.7
20	Ca	Calcium	100.0	3.5	2.5
56	Fe	Iron	100.0	5.1	2.3

Fig. 8. Microstructure and EDS spectrum of sample E

4.2. Density

The density of the samples increases as shown in Fig. 9 from 1.62 to 1.83 g/cm3. The samples exhibited higher density with increasing mild steel particles content in the sample. It has been reported that iron based materials exhibit increased density [8]. Increase in density could be because of diffusion of iron into the ceramic phase during sintering.

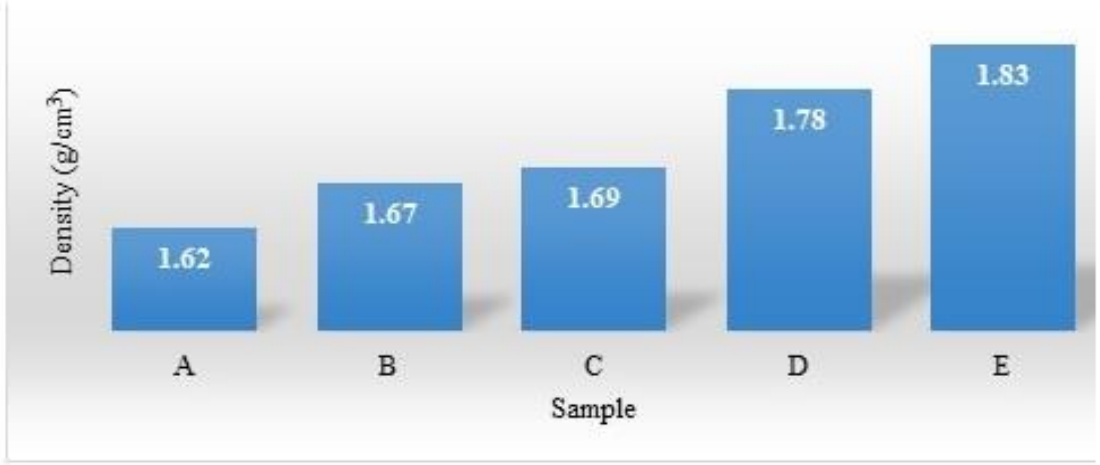


Fig. 9. Density of the composites

4.3. Water Absorption

As illustrated in Fig. 10, water absorption demonstrated by Sample A is higher than that of other samples. The trend decreases from 0.41 % to 0.3 % and rises to 0.32 % in sample E. This shows that the samples contain pores [11]. Water absorption has adverse effect on physical and mechanical characteristics of materials [10]. Generally, the samples demonstrated very low water absorption due to good compaction and bonding of the particles.

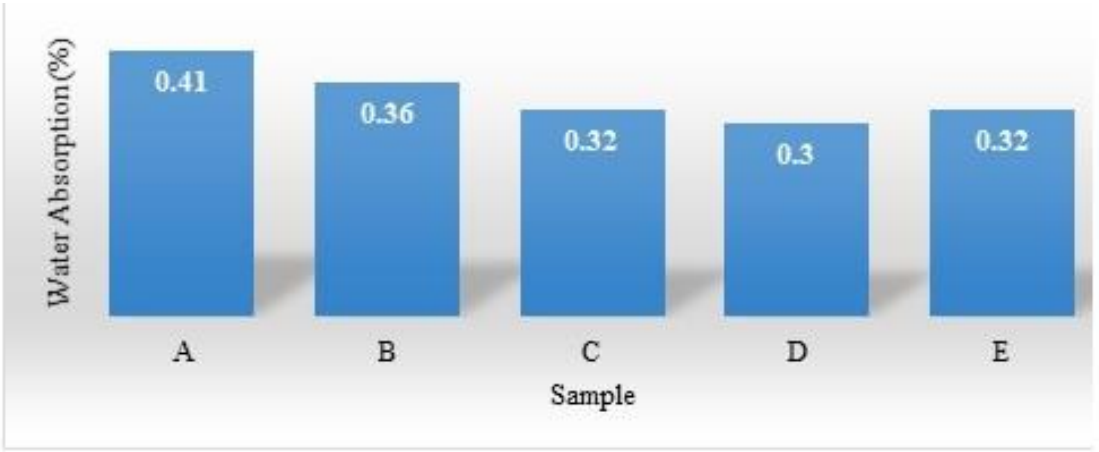


Fig. 10. Water absorption of the composites

4.4. Hardness

A progressive increase in hardness was demonstrated as shown in Fig. 11. Generally, high hardness was demonstrated because of the hard nature of the constituent materials. Silicon carbide and magnesia are very hard materials [12]. Sample A that did not contain mild steel particles demonstrated the least hardness of 121.16 BHN while sample D that contained 12 wt. % mild steel particles exhibited the highest hardness of 137.15 BHN. Strong bonding of the constituents of composites enhances their mechanical characteristics [3, 6]. Weak bond between the phases could cause reduction in hardness of sample E.

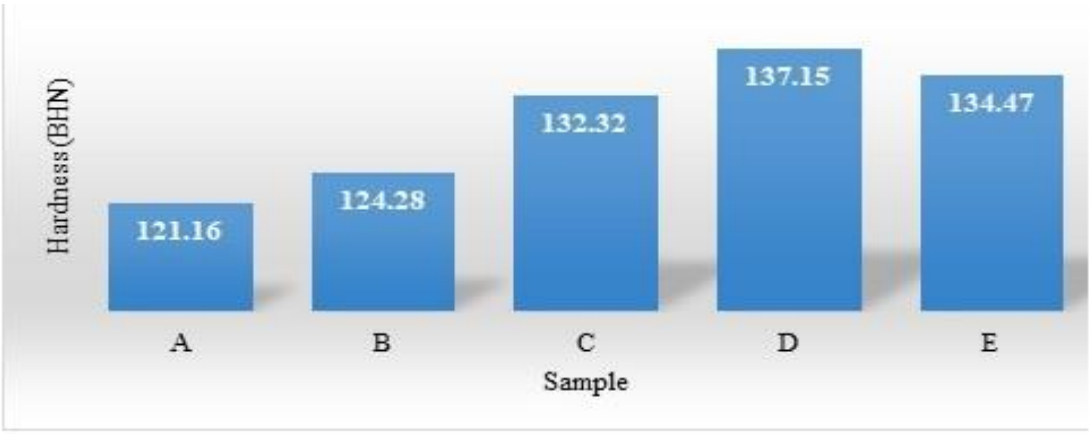


Fig. 11. Hardness of the samples

4.5. Compressive Strength

The samples demonstrated increasing compressive strength as shown in Fig. 12. Sample D that contained 12 wt. % mild steel particles demonstrated compressive strength of 146.38 MPa which is higher than that of others. The strong bond between the particles improved the resistance of the samples to compression, which agrees with the report by [9].

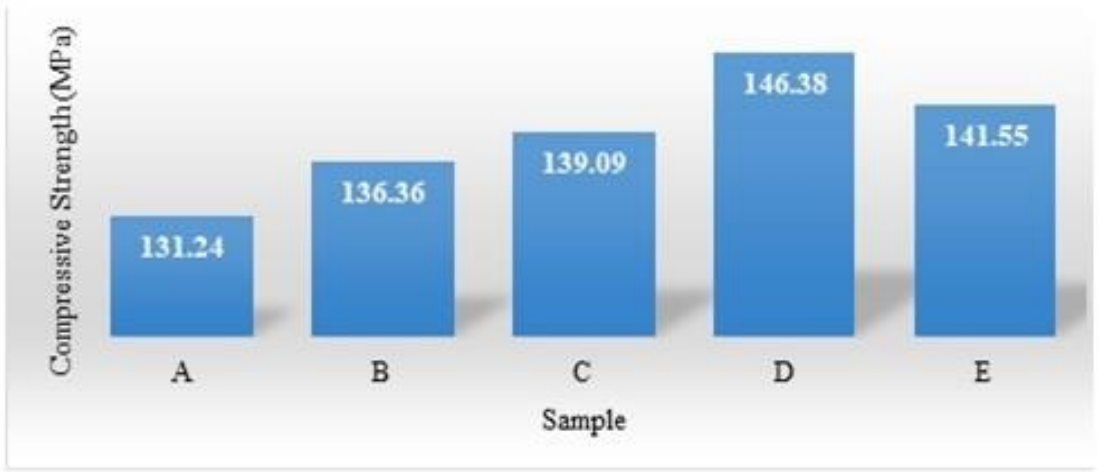


Fig. 12. Compressive strength of the samples

4.6. Impact Energy

The samples demonstrated decreasing impact energy as shown in Fig. 13. Impact energy of Sample A which is 7.03 J is higher than that of others. The decreasing trend in impact energy may be due to the hard nature of the constituents of the samples, which promotes their brittleness.

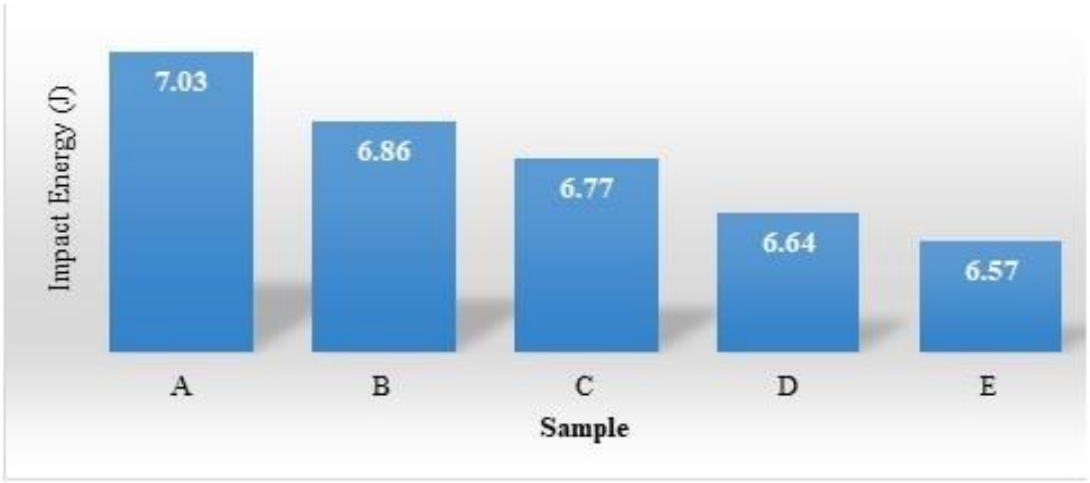


Fig. 13. Impact energy of the samples

5. CONCLUSION

Ceramic matrix composites were developed and characterised. The ceramic composites exhibited desirable physical and mechanical characteristics. Sample D possessed density of 1.78 g/cm3 and exhibited water absorption of 0.3 %, hardness of 137.15 BHN, compressive strength of 146.38 MPa, and impact energy of 6.64 J. The results indicate the suitability of the composite for use in areas that require high compressive strength and hardness.

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