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Research Article

Production and evaluation of ceramic and metal matrix composite by powder metallurgy

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Abstract

The quest to looking for new materials with improved performance in service is on the increase these days. This is one of the reasons why materials development is essential to reduce the cost of material procurement as well as having better results/performance. It is also what necessitated this research work. Sample of a natural clay deposit was milled in a ball mill to obtain -150 microns and its composition was determined using atomic absorption spectroscopy. -212 microns of iron filing was mixed with the clay in different proportions and compacted to produce 9 samples as follows: sample A 10 % clay with 90 % iron filing, B, 20 % clay 80 % iron filing, C, 30 % clay 70 % iron filing, D, 40 % clay 60 % iron filing, E, 50 % clay 50 % iron filing, F, 60 % clay 40 % iron filing, G, 70 % clay 30 % iron filing, H, 80 % clay 20 % iron filing and sample I, 90 % clay 10 % iron filing. The Compressed samples were sintered in a muffle furnace at a temperature of 10000 C and was held for 2 hours. Each sample was analysed for hardness, porosity, compressive strength and abrasive strength. The optimum results for the above test were obtained when the clay content was not more than 60 %.

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1. Introduction

As a result of technological progress, natural materials have now become insufficient to meet increasing demands on product capabilities and functions [1]. The quest to seek for diverse engineering materials of many purposes had therefore been on the increase these days. Many new classes of materials have been devised to satisfy various new applications. Essence of forming composites is to obtain properties that cannot be obtained from a monolithic metal or clay [2] [3]. Energy needed for melting metal such as ferrous metal is significantly expensive and represents about one-quarter of the production cost for cast iron foundries [4]. One major factor in choosing the combination of materials for composites production is lower cost of production in comparison with other composites [5]. A cermet is a composite material composed of ceramic (cer) and metallic (met) materials. A cermet is ideally designed to have the optimal properties of both a ceramic such as high temperature resistance and hardness, and those of a metal, such as the ability to undergo plastic deformation. Depending on the physical structure of the material, cermets can also be metal matrix composites, but cermets are usually less than 20% metal by volume [6]. The properties of ceramic materials, like all materials, are dictated by the types of atoms present, the types of bonding between the atoms, and the way the atoms are packed together. The type of bonding and structure helps determine what type of

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properties a material will have. Ceramics usually have combination of stronger bonds called ionic (occurs between a metal and non-metal and involves the attraction of opposite charges when electrons are transferred from the metal to the nonmetal); and covalent (occurs between two non-metals and involves sharing of atoms). The strength of an ionic bond depends on the size of the charge on each ion and on the radius of each ion [7]. Clay / ceramic is mostly referred to as refractory material due to their ability to withstand the action of abrasive and corrosive solid, liquid or gases at high temperature. They also withstand sudden changes in temperature and have low coefficient of thermal expansion, which means they can endure high temperature. [8] [9]. The aim of this research work is to investigate the properties of ceramic combined with iron filing in order to explore the usefulness of the resulting products. The resulting composite will be expected to find applications in area where high wear and abrasive resistance is required.

2. Methodology

2.1 Preparation of the Clay and Iron Filing Material

Clay deposit having the chemical composition shown in Table 1 was pulverized and milled after drying, in a ball mill. Chemical composition of the clay was determined using atomic absorption spectroscopy. The milled product was sieved in a set of sieves and -150 microns size of the clay was collected for the work. Iron filing used was grinded from medium carbon steel having 0.42 % C. It was also sieved using a set of iso-sieves and -212 microns size was collected for use in this work. Having obtain -150 microns and -212 microns sizes respectively does not mean the entire used particle sizes was that values, but the maximum size was able to pass through -150 and -212 microns and lesser sizes are embedded in the bulk of collected sizes.

Table 1 Chemical composition of clay used for the production

Silica (SiO ₂) %	Alumina (Al ₂ O ₃) %	Iron oxide (Fe ₂ O ₃) %	Calcium oxide (CaO) %	Magnesium oxide (MgO) %	Alkalis (Na ₂ O+ K ₂ O) %
47.50	30.99	4.77	2.65	1.32	3.81

2.2 Mixing and Compression

Clay and iron filing were mixed together with the aid of a mechanical mixer that rotates at the rate of 250 revolutions per minute (rpm) for 5 minutes on different mixing proportion. The mixing proportion to produce different sample are denoted with percentage clay first then that of iron filing as follows: Sample A (10, 90), sample B (20, 80) sample C (30, 70) sample D (40, 60) sample E (50, 50) sample F (60, 40) sample G (70, 30) sample H (80, 20) and sample I (90, 10). During mixing, each mix was moistened with water of only 5 % of the total mix weight; this is to aid the bindability of the mix during compression. The prepared mix was compressed in a compression machine to a pressure of 5 bars. The machine has a plunger which is raised against the upper screwable plate during compression. The prepared mix was in between the plunger and the plate where it was compressed. A cylindrical sample of diameter 33.0 mm was produced and the height of the sample depends on the quantity of the prepared mix poured into the compression machine.

2.3 Sintering

The produced samples were put in a muffle furnace which heated gradually at 4^o C per minutes to 1000^oC. On attainment of 1000^o C they were held in the furnace for 2 hours for homogenization and then allowed to cool in the furnace.

2.4 Hardness Test

Each sample was tested on Rockwell hardness testing machine with a B scale (HRB). Force was applied to press hardened steel ball indenter into the surface of the material. The calibrated scale on the machine measured the depth of indentation on the material and converts it to hardness measurement. The average results of the hardness values taken for three consecutive readings are shown in Table 2.

2.5 Porosity Test

The samples were initially weighed before immersion in water. The immersion was done for 24 hours before removal. They were cleaned and the new weight of the samples was taken again. The difference in weight was recorded, and the porosity was calculated as the difference in weight divided by the initial weight multiplies by 100. This forms the estimation of the percentage of pores available on which it can absorb and retain water in Result of porosity test is shown in Table 2.

2.6 Compression Test

Each sample was fixed on a compression testing machine. The machine exerts a compressive force into the samples. The magnitude of the force in kiloNewton (kN) needed to break or fracture the sample was read on the machine. Result of the compression test is shown in Table 2.

2.7 Abrasion Test

The rate of wear was studied on the composite samples produced. This was carried out in a ball mill as follows; Weight of each samples were taken before putting one sample at a time in ball mill. 6 pieces of grinding balls weighing 0.5 kg which act as grinding media was added into the sample. This was done similar to K. Narasimha Murthy et al [10] who used 13 Kg load for 6000 revolution according to ASTM G-65 guideline. The mill was switched on and it rotates at a speed of 60 revolutions per minute. It was rotated for 180 seconds (3 minutes). The effects of collision forces with the introduced weight help in bringing about abrasive/ wear effects. The introduced weight from the grinding ball was estimated according to the weight of the sample. Final weight was taken and the difference in weight was expressed over the initial weight multiplies by 100, as the wear rate as a result of abrasive movement with the balls in the mill. The result is shown in Table 2.

2.8 Microstructure Test

Each sample produced and sintered were grinded on emery paper of 800 and 1000 grits then polished with 3 microns polishing cloth using carborundum (SiC) powder. They were rinsed with water and dried, then viewed un-etched under a Zeiss high resolution metallurgical microscope of X1000 magnification. The viewed structures were snapped to obtain its photomicrograph. The photomicrographs are shown in plate 1 – 9.

3. Results

Table 2: Result of tests conducted on the produced composite

		Average Hardness (HRB)	% Wear	Required force to Fracture (KN) (Compressive Strength)	% Porosity
A	10 - 90	44.7	2.72	25	8.29
B	20 - 80	46.1	2.28	25	8.23
C	30 - 70	45.2	2.12	30	8.64
D	40 - 60	45.7	1.85	35	9.16
E	50 - 50	42.9	1.81	45	8.94
F	60 - 40	44.9	1.896	50	9.58
G	70 - 30	33.2	3.93	30	11.10
H	80 - 20	27.5	4.3	25	13.54
I	90 - 10	27.0	4.09	20	16.18

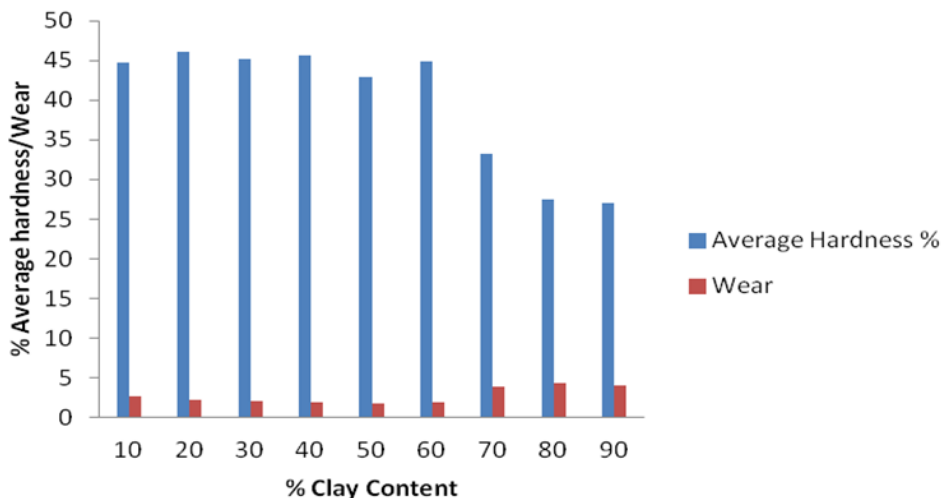


Fig.1. Bar chart showing hardness and wear resistance value of the composite

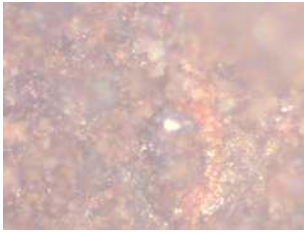


Plate 1: sample A with 10 % clay

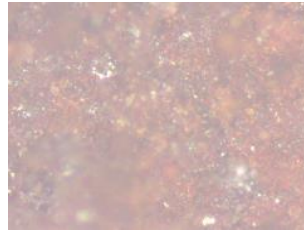


Plate 2: sample B with 20 % clay



Plate 3: sample C with 30 % clay



Plate 4: sample D with 40 % clay



Plate 5: Sample E with 50 % clay

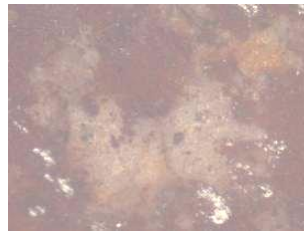


Plate 6: Sample F with 60 % clay



Plate 7: Sample G with 70 % clay



Plate 8: Sample H with 80 % clay



Plate 9: Sample I with 90 % clay

4. Discussion

Production of ceramic / metal matrix composite with iron filing and ceramic clay showed remarkable and improved properties over some alloys and composites. This is another vital area of material processing that is worthy to explore.

Considering the results of the hardness test, it showed an encouraging hardness values which are more than average hardness value for some aluminum and its composite. This was clearly shown by Okafor et al., 2008 [11] where an unreinforced Al-4.5Cu has a hardness of 42.85 HRB. It shows that this composite can favorably compete with this alloy in area of hardness. That implies where hardness of the Al/Cu alloy is of primary requirement, the ceramic metal matrix composite can be of alternative. The microstructures show clearly the distribution of the iron filing and clay within their matrixes as seen on plate 1- 9. The iron filing is seen as dark region distributed within the light brown clay structure.

The percentage wear obtained from the samples is minimal. This can be attributed to significant hardness obtained in the product. Meanwhile, as the percentage clay content increased above 60 % the wear rate and porosity also increased with reduction in hardness. This can be seen in Fig. 1 which shows the hardness and wear behavior of the composite. Porosity obtained in the samples showed increased pores as the clay contents increased higher above 60 %. Porosity results obtained may be due to the interaction of grains of clay and iron filing, and also the force/ pressure exerted during compression. In a possible situation where the exerted pressure during compression is higher than the one used for this work, the porosity is expected to be reduced as a result of higher compression.

5. Conclusion

Optimum performance of products would be obtained when the percentage clay is not more than 60 %. It was discovered from the result of the tests, that the properties obtained is a combination of the emergence of the properties from both clay and iron filing. Above 60 % clay, the properties of the clay dominated the product. This is evidenced as the average hardness reduces down, the wear rate increases and the percentage porosity also increases at more than 60 % clay. This product will be useful in automotive and machinery parts where high hardness and wear resistance is required such as in automotive brake pad and lining.

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