International Journal of Current Science, Engineering & Technology
ISSN : 2581-4311
Original Research Article | Open Access | AMCT 2017 Malaysia | *Special Issue*

Effect of Single Walled Carbon Nanotube Addition to thePhysical Properties of Monolithic Alumina

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ABSTRACT. The effect of single-wall carbon nanotube (SWCNT) addition on the physical properties of alumina (Al_2O_3) ceramic composite were studied in this paper. The SWCNT and Al_2O_3 nanocomposite samples were prepared using wet mixing with 5 different compositions of SWCNT. The nanocomposite samples were confined inside alumina sagger with high purity graphite packing powder and were sintered using pressureless sintering at 1600°C. The hardness shows an optimum values at 0.1 wt% of SWCNT, 20.13 GPa. However, further addition of SWCNT then reduced the properties values of the Al_2O_3.

Keyword: *Al_2O_3, Hardness, SWCNT, Density;*

Received: 15.10.2017, Revised: 15.12.2017, Accepted: 30.02.2018, and Online: 20.03.2018;

DOI: *10.30967/ijcrset.1.S1.2018.585-590*

Selection and/or Peer-review under responsibility of Advanced Materials Characterization Techniques (AMCT 2017), Malaysia.

1. INTRODUCTION

Al_2O_3 is a well-known ceramic because of its exceptional properties which makes it suitable for wide range of application[1-9]. Al_2O_3 has magnificent hardness around 15-22 GPa[10], good flexibility [11] high melting point where the value is 2000°C [12] and also has great wear resistance material with high electrical resistivity and corrosion resistance [10]. Al_2O_3 suitable for cutting tool application because it more stable when operating at high temperature condition, which it resistant to chemical reaction when operated at high working temperature [13]. However, Al_2O_3 experiences the characteristic of low toughness, around 3-4 MPa.m$^{1/2}$[14], which may lead to premature failure in applications that are related to load-stress. So, in order to increase the toughness, Al_2O_3can be reinforced with many type of material either metal like Fe, Ni and Mo or ceramics such as SiC, ZrO and MgO [15]. Recently, nanotechnology industrials have emerged along with some new nanomaterials that have extraordinary properties. It is suggested that the composite may be able to be integrated with these nanomaterial as it can improve the properties of ceramics. Nanomaterials are materials that have particles size smaller than 100 nm in at least one dimension [16]. Carbon nanotubes (CNT) are widely used as they exhibit excellent mechanical properties such as stiffness up to 1.5 TPa and tensile strength above 100 GPa [17]. Types of CNTs can be categorized into two classes, which are Single-

Walled Carbon Nanotubes (SWCNT) and Multi-Walled Carbon Nanotubes (MWCNTs). In this study, SWCNT is preferred because are more malleable than MWCNT and also capable of generally self-assemble into bundles as in order to minimize surface energy [18]. The SWCNT are described by strongly bonded by covalent bond, unique one-dimensional (1D) structure and also nanometer size which give astonishing properties, such as magnificent tensile strength more tha 100 GPa [17] good resilience,Young Modulus of up to 1 TPa [19], great electrical conductivity [20] and excellent thermal conductivity, almost 3500 $Wm^{-1}K^{-1}$ with length and diameter of 2.6 μm 1.7 nm, repectively [21]. Al_2O_3 ceramics were fabricated and studied to ascertain the effect of a mixture of SWCNT on the fracture behavior, hardness, densityand microstructure.

Many studies had been done to test the effect of reinforced Al_2O_3 with SWCNT. For example, from researched that was conducted by Zhan [10], it has been reported that a fracture toughness of 10 vol% SWCNT/Al_2O_3 fabricated by spark-plasma sintering technique is 9.7 $MPa.m^{1/2}$ compared to pure Al_2O_3 which is only 3.7 $MPa.m^{1/2}$. Thomson et al. [22] have questioned the effectiveness of the Vickers method to evaluate the hardness in 10 vol.% SWCNT/Al_2O_3 composites that was fabricated by Wang et al. [23] as the surface finishing was not acceptable. He disagreed with Wang and said that the presence of large pores impedes indentation measuring. The aim of this study is to investigate the effect SWCNT addition to the physical properties of Al_2O_3.

2. MATERIALS AND METHODS

The raw materials (SWCNT and Al_2O_3) were weighed using AND EK 300-I according to different composition of SWCNT which are 0, 0.05, 0.1, 0.3, and 0.5 wt.% of SWCNT. The compositions of SWCNT were varied between 0-0.5 wt.%. The total weigh for each composition is 15g. Table 3.2 illustrates the composition of the raw materials used.

Table 1 The composition of raw materials used

Composition	SWCNT (wt.%)	Al_2O_3 (g)	SWCNT (g)	Total (g)
1	0	15.0000	0	15
2	0.05	14.9925	0.0075	15
3	0.1	14.9850	0.0150	15
4	0.3	14.9550	0.0450	15
5	0.5	14.9250	0.0750	15

After the weighing process was done, then, continued with mixing process. Each of the mixture ofAl_2O_3 with SWCNT were put into a beaker and carefully dispersed with 40ml ethanol with ultrasonic agitation for 2 hours. The ethanol here acts as a binder for the mixtures. Then, the mixtures were dried in an oven with temperature of 100°C for 24 hours. Then, the dried mixtures were then grounded using agitate mortar. Samples powder then were sieved using 75 micron size siever. The mixtures were uniaxially pressed at pressure of 17.93 MPa in a disk (steel die) using hydraulic hand press (Carver) and then hold for 5 minutes which then produced green compact samples with diameter of 11mm. The compacted samples were confined into alumina sagger with high purity graphite packing powder, and then sintered at 1600°C for 1 hour.

There are three of characterization to be observed in this study, density, firing shrinkage and Vickers hardness. For density observation, each composition was tested 10 times using electronic densitometer. For Vickers hardness, samples were first prepared by grinding and polishing until the surface was able to be seen under optical microscope and no scratches on the polished surfaces. Grinding machine used was Mecapol P 260. The hardness of the samples was determined using Micro-Hardness Tester 401 MVA and Buehler

Omnimet software. Load used was 10 kgf to produce the indentation on the sample for 15 s. Measurement of bulk density was done according to Archimedesmethod.

3. RESULTS AND DISCUSSION

From Fig. 5, it is shows that the percentage of shrinkage for the ceramics is increase from 8.95% of 0 wt.% SWCNT to 9.29% and 10.03% at composition of 0.05 and 0.1 wt.%, respectively. However, with further addition of SWCNT, the value of shrinkage dropped to 9.7% at 0.3 wt% of SWCNT and 8.6% at 0.5 SWCNT wt.%. Generally, the addition of SWCNT will affect the shrinkage of Al_2O_3 during sintering. Good dispersion of SWCNT inside Al_2O_3 will be resulting high shrinkage percentage values, and vice versa. High shrinkage percentage means that the density of the ceramic is also high, which related to the densification.

During sintering, the particle become close to each other. As the sample shrink, the grain size become smaller. Small grain size will result in porosity reduction. Thus, results in denser ceramics. However, from the graph, we can see that the trend drop at the composition of 0.3 and 0.5 wt.% SWCNT. This is because of the SWCNT agglomerations. At 0.01wt.% SWCNT, although the amount of SWCNT inside the Al_2O_3 is small, the decrease in the shrinkage percentage may due to the poor dispersion of the SWCNT, which lead to agglomeration. At 0.3 and 0.5 wt.% SWCNT, the drop on shrinkage percentage value is because the amount of SWCNT is exceeding optimum, because it tends to agglomerate more.

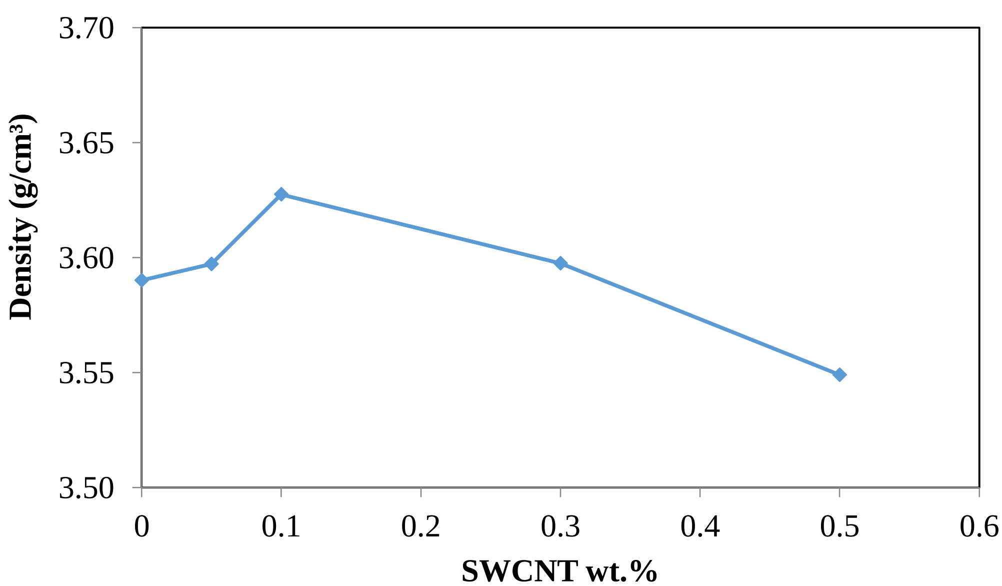

Fig.4. Density of Al_2O_3 with different different composition of SWCNT

Hardness is defines as the resistance of a solid material toward plastic deformation due to compression. Vickers Hardness is chose as a test method because it is preferable for hard materials. Fig. 6 shows the Al_2O_3 of alumina with addition of SWCNT, varies from 0 to 0.5 wt% of SWCNT addition. From the graph, it can be seen that the hardness of the Al_2O_3-SWCNT composite increase from 16.07 GPa to 17.09 and 20.13 GPa with the addition of 0.05 and 0.1 wt% SWCNT, respectively. However, the trend dropped with further addition of SWCNT, to 18.08 GPa at 0.3 wt% and 11.97 GPa at 0.5 wt% of SWCNT.

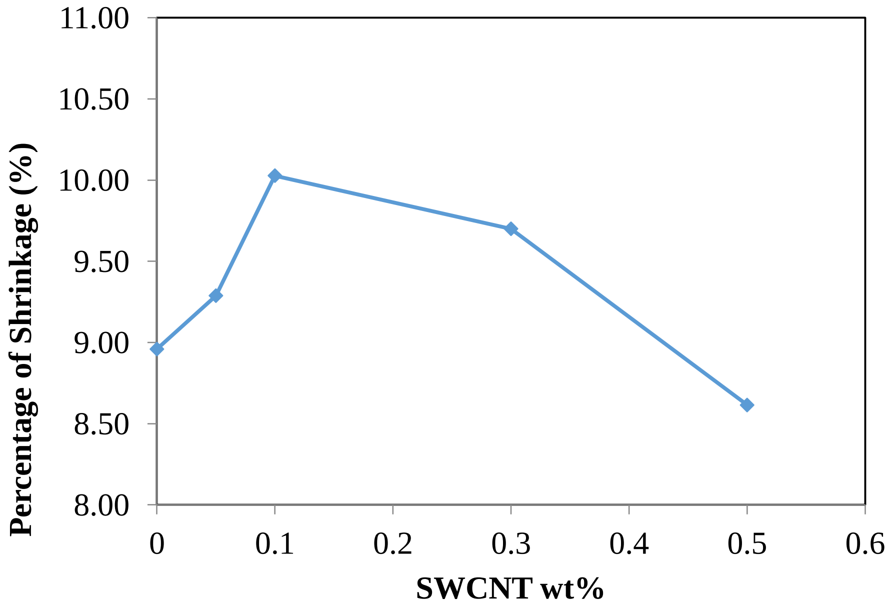

Fig. 5. Percentage of shrinkage of $Al_2O_3$with composition of SWCNT

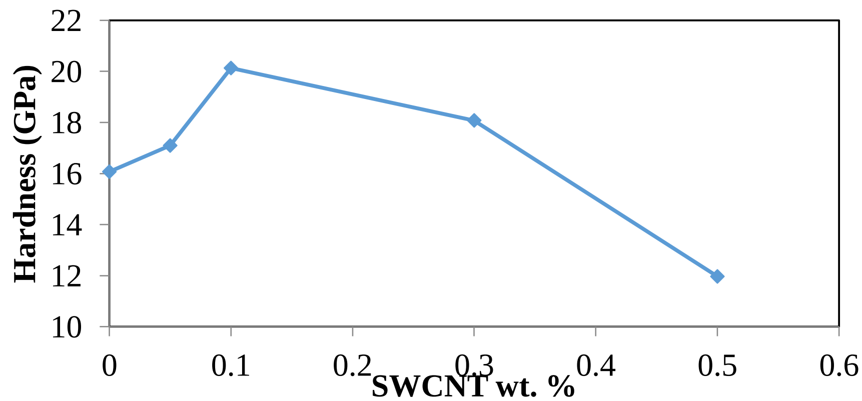

Fig. 6.Hardness of Al_2O_3 with different composition of SWCNT

Based on previous studies by Arseculeratne and Zhang [24] and Lopez et al*.* [25], proved that the addition of SWCNT will reduce the Al_2O_3 hardness. This is because of the poor dispersion of the SWCNT inside the Al_2O_3 matrix. Poor dispersion of SWCNT cause the agglomerated SWCNT, which make the interfacial cohesion of SWCNT with Al_2O_3 matrix is deteriorate. With the inhomogeneous dispersion of SWCNT inside Al_2O_3 matrix, the grains of Al_2O_3 composite are unable to be refined during sintering process. This will cause the cancellation of mechanical improvement at room temperature, as the hardness will only increase with grain refinement. Besides that, the agglomeration of SWCNT will reduce the matric-SWCNT bonding (interfacial), thus the only small amount of load will be transfer from matrix to the SWCNT. However, in this study, the hardness of A Al_2O_3 ceramic increases with the addition of 0.05 and 0.1 wt% of SWCNT, while decrease with other compositions of SWCNT. Increasing in hardness of this ceramic is due to the good dispersion of SWCNT inside the A Al_2O_3 matrix, which caused a strong bonding between SWCNT and A Al_2O_3 [3]. Hence, load will be effectively transfers to the SWCNT from Al_2O_3 matrix, thus increase the hardness of Al_2O_3.

4. SUMMARY

In this paper, the effect of adding SWCNT on Al_2O_3 properties was thoroughly studied. The used of SWCNT as an additive into Al_2O_3 can increase the properties of Al_2O_3. With addition 0.05 and 0.1 wt.% SWCNT, the properties of the composite is increase, meanwhile the further addition of 0.3 and 0.5 wt.% of SWCNT into Al_2O_3 matrix reduced the composite properties.Increase of the Al_2O_3 properties with addition of SWCNT is due to excellent dispersion of SWCNT inside the Al_2O_3 matrix lead to strong interfacial bonding of SWCNT with the Al_2O_3 matrix. However, poor dispersion of SWCNT reduced the properties of the composite, as agglomeration of SWCNT happen which lead to weak interfacial bonding between SWCNT and the Al_2O_3 matrix.In Summary, all properties achieved highest value at composition of 0.1 wt.% of SWCNT, where the density and hardness have the values of 3.63 g/cm^3 and 20.13 GPa respectively. This mean, at this composition, the SWCNT disperse excellently.

ACKNOWLEDGEMENT

This work was funded by the International Islamic UniversityMalaysia (IIUM) under Grant FRGS14-164-0405.

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