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Properties of wear rate and electrical conductivity of carbon ceramic composites

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Morphology, electrical conductivity, specific wear rates, and densities of carbon ceramic composites as a result of the distribution of organic coconut coir powder in the organoclay matrix, and sintering temperature variations had been investigated and studied. The raw material of matrix was tested with XRF and XRD. The higher the content of coconut coir powder and the pyrolysis sintering temperature, the higher the electrical conductivity of the composite, and the lower the composite wear rate. This fabricated carbon ceramic composite is unique, the content of coco fiber powder, which turns into carbon, decreases the wear rate, increases electrical conductivity, and produces an increasingly lightweight ceramic carbon composite.

Key words: Specific wear rate, Electrical conductivity, Organoclay, Carbon ceramic composites, Sintering pyrolysis.

Introduction

Clay is an important component in making ceramic blends, because of its plasticity, ease of use, strength and final properties obtained by heat treatment [1, 2]. Ceramics have excellent mechanical and thermal properties. It has been widely used for tribological applications such as bearings, cylinder liners, and mechanical seals. Friction appears as resistance to movement when the solid surface moves above another surface. The two-part surfaces are rubbing against each other faced with high local pressure [3, 4]. Many functional elements, for example, cell electrodes, chemical sensors, conductive thin films, electrothermal heaters, etc. which is made of conductive ceramic material [5].

The purpose of this study was to provide information on the properties of wear resistance and electrical conductivity of the research results of carbon ceramic composites fabricated from dispersion of coconut coir waste powder in oragnoclay matrix. Carbon ceramic composites are applied to advanced machine elements that require wear-resistant mechanical properties and electric conductive properties focused on the research, such as carbon sticks on electric train pantographs.

This study used local materials such as organoclay as a matrix obtained from Purwakarta, West Java, Indonesia, and coconut coir powder as an electrical conductor was processed from organic waste. This research was based on similar research articles with different materials. The influence of Ifon (Ondo State, Nigeria) clay and sintering temperatures on the phase and the physicomechanical development of mullite-carbon ceramic composites was investigated. The researcher has used clay and graphite to fabricate carbon ceramics [6]. This type of conductive aggregate was prepared by calcining ceramic matrices and dispersed graphite powders. Conductive aggregates were used in a mortar containing carbon fiber, and electrical resistivity. The use of a conductive aggregate in mortar significantly improved its electrical conductivity [7]. The composites were synthesized from a mixture of the same versatile Si3N4 ceramic powder (MWCNT's) but used two different sintering techniques: (1) Hot Isostatic Pressing (HIP) and (2) Spark Plasma Sintering (SPS) [8]. Fatigue behavior and oxidation resistance of two types of carbon composites were studied. CC (carbon) composites derived from metals and CC/ceramic (carbon/ceramic) composites obtained by CC composite impregnation with polysiloxane-based preceramic and advanced heat treatment [9]. Green ceramic composites were consolidated with various starches and sintered at different temperatures in the argon atmosphere. This carbon network produced porous composites that had high electrical conductivity, which depends on the type of starch and the nature of its porosity [10]. The composition of ceramic materials was prepared by incorporating waste into two types of clays, from Argentina and Brazil. The raw materials used in this work were (a) steel furnace wastes to be combined and (b) two different types of

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clay function as matrices. Raw materials were characterized by mineralogical composition, chemical composition, and particle size distribution [11]. Ceramics from a nanoscale structured hybrid formed from organoclay during pyrolysis had been fabricated. It acted as a filler, amplifier, and binder for carbon/carbon (C/C) composites. The heat that suppresses organoclay formed a black monolithic sheet with high thermal stability, electrical resistivity, flexural strength, modulus, and low ductility [12].

Experimental Procedure

This research was experimentally conducted by following the sequence of research works as follows.

Material Preparation

The waste of coco fiber was dried at 150 ºC, for 24 hours in the dryer oven, and chopped up with a disc mill machine, and sieved with mesh of 150. The density of dry coconut husk was 0.09 ± 0.04 [g/cm^3]. Organoclay was dried and crushed into powder, with mesh of 150. The density of organoclay was 2.31 ± 0.07 [g/cm^3], tested by Archimedes method. The element content of organoclay was tested with XRF ANALYZER: TORONTECH TT-EDXPRT. The test results are shown in Table 1.

The largest content of the clay was silica, the same XRF test was also performed by other researchers and showed the greatest content was silica [1, 11, 13]. The raw material was also tested with X-ray diffraction to identify the material content phase, XRD test results are shown in Fig. 1. Based on the XRD test, the main content is located at 20-30 [2θº], and the main content of this raw material is silica, clay by other researchers also showed the same 2θº position, which shows the silica content [6], [14], [15].

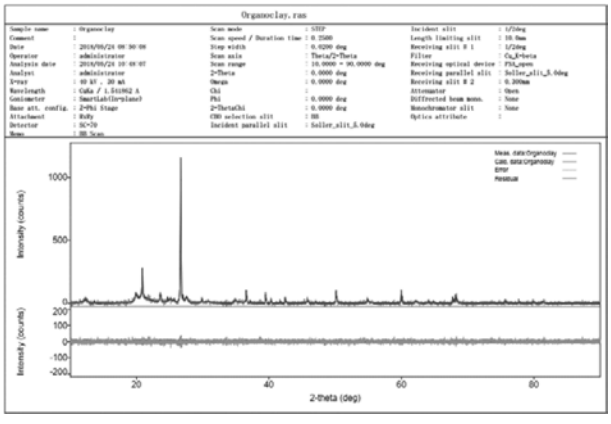

Fig. 1. X-Ray powder Defractogram of organoclay.

Green compact fabrication

Dry coconut powder was dispersed in organoclay, with composition ratios of 1:10, 2:10, and 3:10 in weight percentage, added as adhesive of 40% water of mixture weight.

The plastic mixture was molded into a tablet with a diameter of 40 mm, and a thickness of 10 mm, dried for 3×24 hours at room temperature, being green compact. Number of specimens is shown in Table 2.

Sintering pyrolysis process of carbon ceramic composite

Sintering pyrolysis was meant to convert green compact composites to be electrically conductive ceramic. Organoclay would become ceramics, and coco fiber powder would become electrically-conductive carbon. This process used an airtight reactor tube. Dry green compact was sintered by pyrolysis at varying temperatures of 600; 700; 800; 900; 1000 ºC. Heating rate 2 ºC/min. Cooling speed was naturally conducted until it reached the room temperature at 40 ºC. The green compact composite before sintering is shown in Fig. 1(a), while carbon ceramic composite after pyrolysis sintering is shown in Fig. 1 (b).

Morphological testing

Scanning electron microscope testing was performed to determine the morphological appearance of a bond

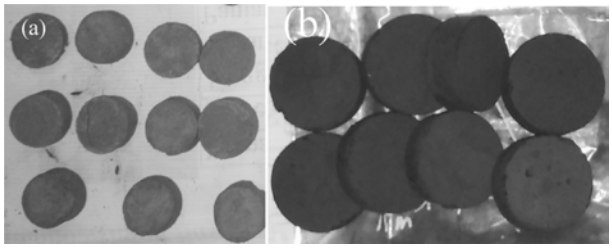

Fig. 2. (a) Green compact composite; (b) Ceramic carbon composite.

Table 2. The number of specimens.

Composition ratio	The number of specimens, tablets				
	600 ºC	700 ºC	800 ºC	900 ºC	1000 ºC
1:10	10	10	10	10	10
2:10	10	10	10	10	10
3:10	10	10	10	10	10

Table 1. Elements of organoclay.

Elements	Si	Fe	Al	Ti	Mn	Zr	Zn	Ni	Cu	Ga	Pb	Total
% weight	50.8	28.7	16.2	2.6	1.35	0.21	0.08	0.03	0.03	0.01	0.01	100
± %	1.3	1.9	1	0.15	0.11	0.03	0.01	0.01	0.01	0	0.01	

existing between carbon fiber and clay matrix.

The test was conducted using scanning electron microscopic Hitachi SU 3500.

Electrical conductivity test

Electrical conductivity testing was performed using two-point probe methods [16-18], with a copper plate electrode. Electrical conductivity was measured according to ASTM D257 standard. Electrical resistance, specimen thickness, and specimen cross-sectional area were measured. Electrical static resistance was calculated by the equation,

$$\rho = \frac{R \times A}{l} \quad \text{[2, 17, 18] (1)}$$

The electrical conductivity was determined by the equation,

$$\sigma = \frac{1}{\rho} \quad \text{[2, 17, 18] (2)}$$

Note: ρ is static electricity resistance [Ωm]; R is electrical resistance [Ω]; A is the cross-sectional area of the composite specimen [m^2]; l is the length of the current path [m]; σ is the electrical conductivity of composite specimens [1/Ωm] or [S/m].

Specific wear rate testing

The wear rate test was carried out to determine the resistance of carbon ceramic composite to friction by using disc wear tester [17], [19]. The Testing followed ASTM C1243-93 (2015) standard. Specific wear rates were calculated by equations,

$$w_{rate} = \frac{B}{L \times P}\left[\frac{\pi \times r^2}{180} arc\ \sin\left(\frac{b}{2.r}\right) - \frac{1}{2} \times b(r-h)\right] \quad \text{[17, 19] (3)}$$

Note: W_{rate} is the specific wear rate [mm^3/Nm]; b is the trace length [mm]; L is the distance [m]; P is the load used [N]; r is the disc radius [mm]; B is the trace width [mm]; h is the trace depth [mm].

Density testing

The density of carbon ceramic composites was investigated to determine the effect of composition ratio and sintering temperature variation on bulk density of carbon ceramic composite. The composite density test was carried out following the Archimedes method, the equation is as follow, where A is the weight specimen in air, and B is the weight specimen in water.

$$\rho_{carbonceramiccomposite} = \frac{A}{A-B} \times \rho_{waterdistillation} \quad \text{[6], [20] (4)}$$

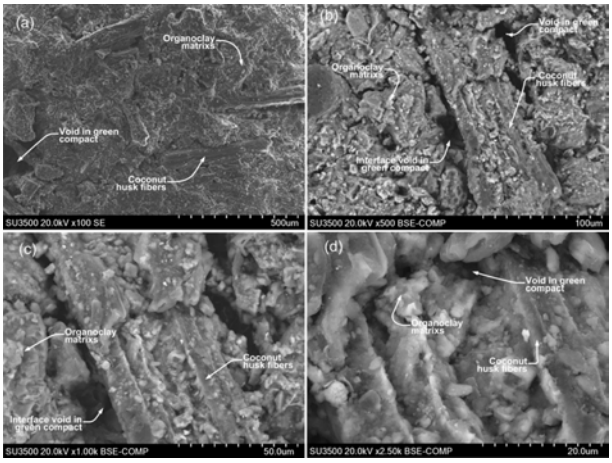

Fig. 3. Morfology of composite green compact (before sintering).

Results and Discussion

Morphology of carbon ceramic composites

Composite morphology shows the bond condition between the carbon powder and the organoclay in the carbon ceramic composite. The cavities and cracks within the organoclay matrix or carbon, as well as on the interfaces could be represented by the morphology of the composite.

The morphology of the composite green compact mixture of organoclay and coco fiber is shown in Fig. 3. The morphology shows the condition of ceramic composite carbon before sintering. Fig. 3(a), with magnification 100 times, indicates coco fiber with longitudinal features, while the clay matrix is shown in the irregular shape. Fig. 3(b), with magnification 500 times, shows a clearer feature of all the elements and morphological conditions of the green compact. The contact surface crack between the fiber and the clay matrix is also shown in the morphology. The surface contact cavities between the coco fiber and the matrix are more clearly shown in Fig. 3(c), with magnification 1000 times. In 2500 magnification times, the morphology of organoclay matrix granules is clearly indicated. The cavities formed between the grains of the matrix, and between the grains of the matrix with the coco fiber are also shown in Fig. 3(d).

The cavities will remain until the green compact is sintered. Furthermore, the cavities form the porosity of the carbon ceramic composite. Cavities separate mechanical bonds between ceramic matrices, thereby weakening the mechanical strength of the friction resistance of carbon ceramic composites. Likewise, the cavities and cracks occurring between the carbon weaken the electrical conductivity. This fact is evidenced by the results of testing the mechanical properties of wear rate, and the electrical conductivity

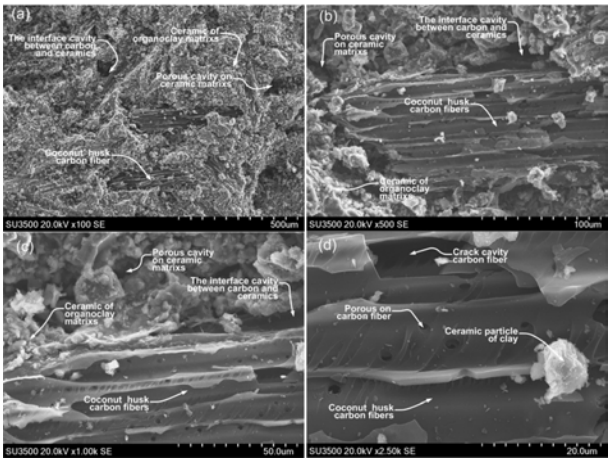

Fig. 4. Morphology of carbon ceramic composite.

of carbon ceramic composites. The morphology of carbon ceramic composites is shown in Fig. 4. The cavities and cracks of carbon and the cavities and cracks in ceramics occurred on the composites, as shown in Fig. 4(a). The image shows distinct feature differences between ceramic powder and carbon fiber from coco fiber. Carbon fibers are characterized by an elongated geometric shape, while organoclay ceramics are characterized by irregular geometric grains.

Fig. 4 (b), the morfology magnified 500 times shows a clearer geometric difference between the finer matrix and the carbon fiber. Cracks and cavities on carbon fibers are more clearly shown in the figure. Dark elongated features shows a crack in the interface between the carbon fiber and the ceramic matrix. Fig. 4 (c), morfology that show the carbon features contained in the carbon ceramic composite. The porosity and geometric cavities of the irregular organoclay ceramic grains are also clearly indicated in the figure. Fig. 4 (d) very clearly shows carbon fiber fractures and a clear cavity on the carbon and at the interface between carbon and ceramics. The morphological condition shown in Fig. 4 is thought to be the cause of the weakened friction resistance and weakened the electrical conductivity of the carbon ceramic composites.

Electrical conductivity

Electrical resistance of the carbon ceramic composite materials is measured in order to determine the electrical conductivity of the composite material. Initially, they were qualitatively measured in order to observe the presence of electric currents. This was carried out with a series of electric lamp circuits. Electrical resistance was measured after leveling the surface of the material with sandpaper. The purpose of the measurement of electrical conductivity is to determine the composite variant of carbon ceramic composite having the highest electrical conductivity value. The highest value of electrical conductivity is

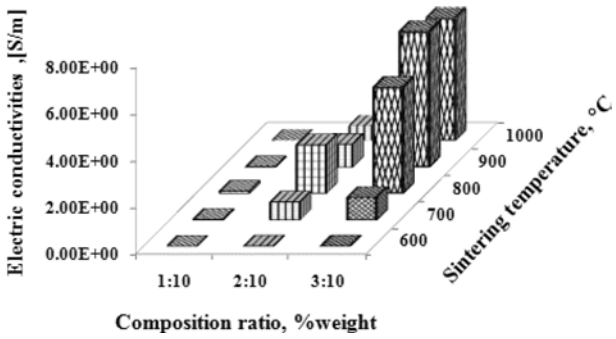

Fig. 5. The electrical conductivity of carbon ceramic composite.

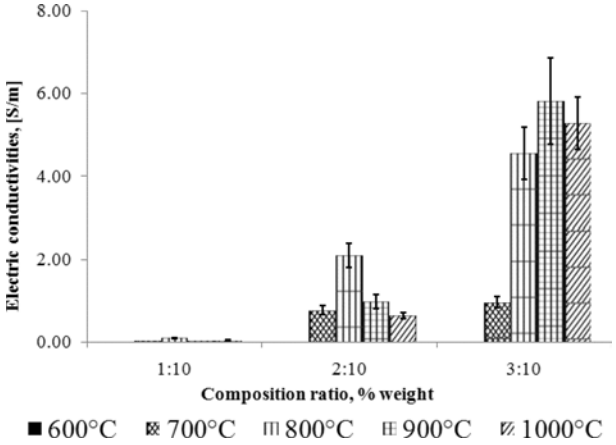

Fig. 6. The relationship of electrical conductivity vs. composition ratio.

shown by carbon ceramic composites at a pyrolysis sintering temperature of 900 °C, the ratio of the composition of coconut coir powder of which is 3:10 clay in weight percentage. Composites of a 1:10 composition ratio type for all variations in pyrolysis sintering temperatures resulted in low electrical conductivity. The higher the content of coconut coir powder, the higher the electrical conductivity of carbon ceramic composites. The effect of pyrolytic sintering temperature on composite electrical conductivity is significant. It tended to be that the higher the sintering temperature, the higher the electrical conductivity of the composite; however, it tended to decrease at temperatures above 900 °C. This is shown in Fig. 5.

This occurred in all variants of the carbon ceramic composite sintering temperatures in this study. In a 2:10 composition ratio, there is a decrease in electrical conductivity at 900; and 1000 °C sintering temperatures. This is thought to be due to many cavities in the electrical path of the carbon ceramic composite. One of the research result suggested that due to the addition of black carbon to the matrix is able to lower down electrical resistivity, especially when the carbon black volume fraction exceeded the percolation threshold [21]. Fig. 6 shows that the content of carbon volume increase, and it raised the electrical conductivity of the

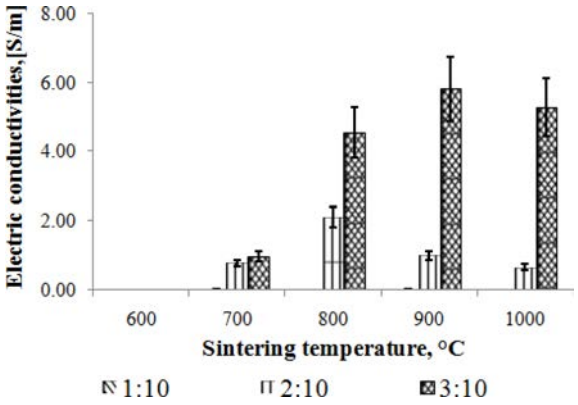

Fig. 7. The relationship of electrical conducivity vs. sintering temperature.

composite.

Likewise, an increase in pyrolysis sintering temperature had proven to increase the electrical conductivity of carbon ceramic composites. This is shown in Fig. 7. As a comparison, below were findings of electrical conductivity generated by other researchers. Thalita found out that the ceramic composite of the sepiolite matrix and coco fiber reinforcement material resulted in the highest electrical conductivity amounting to 2.31×10^{-5} [S/m] [22]. Meanwhile, Andi Wang found out that the composite carbon ceramic matrix organoclay with a Thornel P-25X carbon fiber reinforcing material resulted in an electrical conductivity of 11.11 [S/cm] [12]. The additional 0.6 vol % carbon graphite to the clay matrix generated an electrical conductivity value amounting to 0.126 [S/cm]. This research was conducted by Yongjia He et al. [23].

The electrical conductivity value resulting from the addition of 0.4 wt% graphene in the ceramic composite sample with the BaTiO3 matrix in Lucia's study was 2.5×10^{-5} [S/cm] [24]. The additional 10 wt% of the toner printer to the composition of the clay matrix ceramic composite studied by Yongjia resulted in an electrical conductivity value amounting to 0.117 [S/cm] [5]. In a study conducted by Gurdial on the addition of CNFs on Alumina matrix ceramic composite, it was found out that the highest conductivity value of 900 [S/m] existed in ceramic composites with the addition of CNFs of 12.5 wt% [25]. Meanwhile, Lucia also conducted a research on the addition of CNFs on the alumina matrix ceramic composite. She found out that the highest conductivity value was 10^{-2} [S/cm] with a 9% vol % CNFs increment ratio [26]. Yu-Kwang Seo conducted a research on the addition of BN content to SiC ceramic composite matrix. It resulted in the highest electrical conductivity value amounting to 60.3 [S/cm] with the addition of BN ratio on a composite of 35% [27].

Specific wear rate of carbon ceramic composite

Specific wear rate is one of the mechanical properties

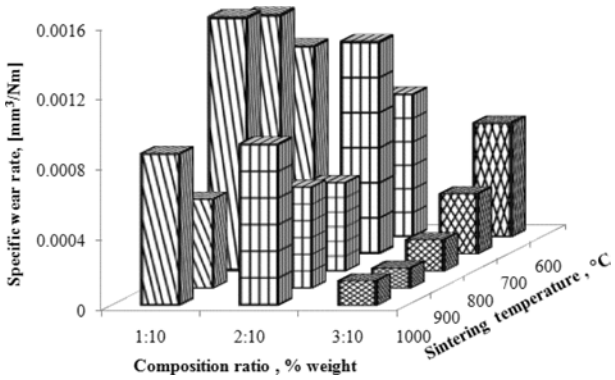

Fig. 8. The relationship of specific wear rate vs. composition ratio vs. sintering temperature.

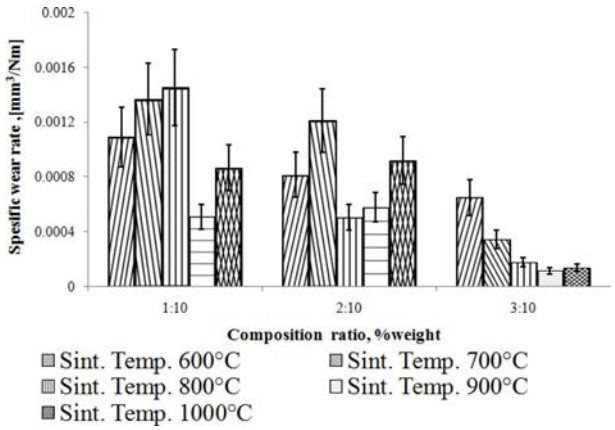

Fig. 9. The relationship of specific wear rate vs. composition ratio.

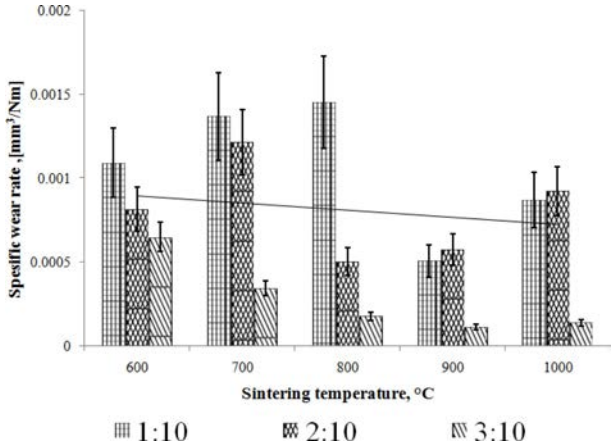

Fig. 10. The relationship of specific wear rate vs. sintering temperature.

of carbon ceramic composites. The purpose of this test is to know the bond strength existing between the matrix particles and the enforcement carbon in the composite when subjected to a frictional load. In addition, this test is also meant to determine the best wear resistance value of this carbon ceramic composite. Findings of the fabrication and the testing of the specific wear rate of the composite shows that the lowest value is 0.000115 mm^3/Nm, composite of 3:10

composition ratio type, the pyrolysis sintering temperature of which is 900 °C. The composites have the best wear-resistant mechanical properties. The highest specific wear rate is shown by the carbon ceramic composites of the 1:10 composition ratio, the pyrolysis sintering temperature of which is 800 °C, and the wear rate value of which is 0.001451 mm^3/Nm. This is shown in Fig. 8.

This type of composite is the most vulnerable and the least resistant to frictional loads. The volume content of carbon in the composite is an evidence of the degree of resilience of carbon ceramic composites to frictional loads. The higher the carbon content in the composite, the lower the specific wear rate of the composite. The study also shows that the composite became harder and wear-resistant. This is shown in Fig. 9. The same trend is generated by all sintering temperatures. The carbon formed in the carbon ceramic composites is due to the pyrolysis sintering process at the carbonization temperature.

The process of sintering pyrolysis in carbon ceramic composites is carried out at temperatures ranging from 600 to 1000°C. In general, the higher the pyrolysis sintering temperature, the higher the composite resistance to mechanical frictional loads. This is indicated by the lower composite specific wear rate. It occurred in all composition ratios as shown in Fig. 10.

Low specific wear resistance rates indicate that the composites became harder and more resistant to frictional mechanical loads. This performance might have been formed due to the carbon content, either due to the volume of carbon in the composition ratio or due to the pyrolysis sintering temperature. Naturally, carbon is the hardest material, and the characteristics of this carbon contribute to the improvement of the wear resistance properties of carbon ceramic composites observed from this study. Higher hardness of the composites can lead to decreased wear rates [28]. In comparison, the following explanation shows the results of the specific wear rate tests of some researchers. Perez researched on the ceramic composite TiB2 matrix and B4C reinforcement material. The wear test employed a tribometer and showed the lowest test result was to 0.36 [mm^3/Nm] and the highest value was to $1.6x10^6$ [mm^3/Nm] [29]. Borell investigated the effects of adding CNFs on ceramic composites of SiC and alumina matrix. The wear rate test findings proved that the addition of CNFs to the alumina matrix ceramic composite had a lower wear rate (1E-07) mm^3/Nm than that of the SiC ceramic matrix composite (1E-04) mm^3/Nm, [30]. Marquez also tested the erosion in order to measure the wear resistance of polystyrene crystals with clay coatings. The abrasive flow rate was 5.0 ± 0.5 g/s [31].

Densities of carbon ceramic composite

The addition of coconut coir powder, which turns into carbon, will make the composites become lighter, as shown in Fig. 11. The higher the content of coconut coir powder, the smaller the composite density. All pyrolysis sintering temperatures show the same tendency. The highest density of carbon ceramic composite is shown by composites with a 1:10 composition ratio, at a sintering temperature of 800°C, ie 1.63 g/cm^3. Meanwhile, the lightest composite is represented by a 3:10 composition ratio, at a sintering temperature of 700 °C, with a density of 1.27 g/cm^3. Increased sintering temperature has no significant effect on carbon ceramic composite density. Composite density tends to be constant to increase sintering temperature. The resulting density is relatively stable.

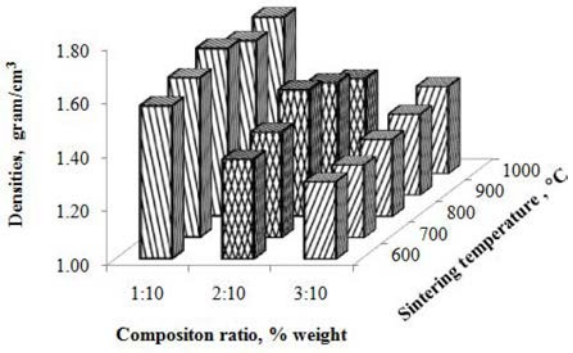

Fig. 11. The densities vs composition ratio vs sintering temperature.

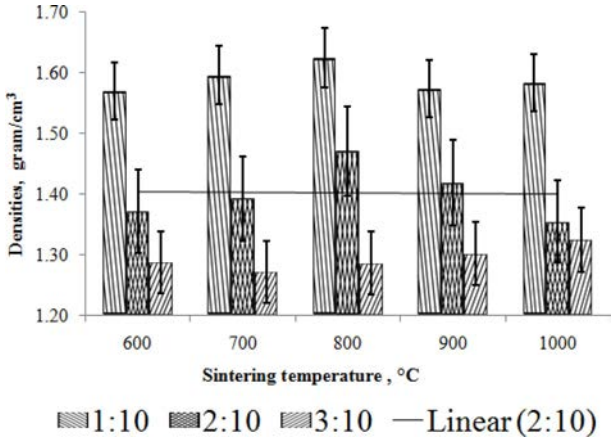

Fig. 12. The trend of the densities of carbon ceramic composites.

This occurs in all compositional ratios of carbon ceramic composites, as shown in Fig. 12. This fabricated carbon ceramic composite is unique, the content of coconut coir powder, which turns into carbon, improves wear or hardness, enhances electrical conductivity, and produces an increasingly lightweight ceramic carbon composite. It also proves that carbon materials are hard and light.

Conclusions

Carbon ceramic composites of coco fiber and organoclay matrix materials with wear-resistant mechanical properties that were electrically conductive had been fabricated. Coconut carbon content and pyrolysis sintering temperature have an effect on to electrical conductivity and wear resistance of the composite. The volume content of carbon in the composite is an evidence of the degree of resilience of carbon ceramic composites to frictional loads. The higher the carbon content in the composite, the lower the specific wear rate of the composite, and the composite becomes harder and more friction-resistant, and carbon ceramic composites are becoming increasingly lighter. The higher the sintering temperature, the higher the electrical conductivity of the carbon ceramic composite. The cavities and cracks formed within the composite are the cause of the weakness of the wear resistance mechanical properties and also weaken the electrical conductivity of the carbon ceramic composites.

Acknowledgements

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Reference

1. Štubňa I, Húlan T, Kaljuvee T, Vozár L., *Appl Clay Sci*.153 (2018) 23-28.
2. Csáki Š, Ondru J, Trnovcová V, Igor Š, Dobro P, Vozár L., *Appl Clay Sci*.157 (2018) 19-23.
3. Ahn S, Nam K., *J Ceram Process Res*. 18[11] (2017) 767-776.
4. Manocha LM, Prasad G, Manocha S., *Mech Adv Mater Struct*. 21[3] (2014) 172-180.
5. He Y, Ping B, Lu L, Wang F, Hu S., *Adv Appl Ceram Struct*. 6753 (2017) 1-7.
6. Aramide FO, Popoola AP., *J Ceram Process Res*. 19[2] (2018) 87-94.
7. He Y, Lu L, Jin S, Hu S., *Constr Build Mater*. 53 (2014) 131-137.
8. Tapasztó O, Lemmel H, Markó M, Balázsi K, Balázsi C, Tapasztó L., *Chem Phys Lett*. 614 (2014) 148-150.
9. Gumula T, Rudawski A, Michalowski J, Blazewicz S., *Ceram Int*. 41[6] (2015) 7381-7386.
10. Menchavez RL, Fuji M, Shirai T, Kumazawa T., *J Eur Ceram Soc*. 34[3] (2014) 717-729.
11. Maurício C, Vieira F, Sanchez R, Neves S, Lalla N, Quaranta N., *j mater res technol*. 2[2] (2013) 88-92.
12. Wang A, Gao X, Jr RFG, Chung DDL., *Carbon*. 59 (2013) 76-92.
13. Pardo F, Jordan MM, Montero MA., *Appl Clay Sci*. 157 (2018) 158-164.
14. Istrate OM, Chen B., *Appl Clay Sci*. 156 (2018) 144-151.
15. Wang Q, Li S, Yu H, Fengzhi Li, Huijun Xu, Haibo Qiao, Juncheng Liu, Qingyang Du., *J Ceram Process Res*. 18[8] (2017) 594-598.
16. Han B, Zhang L, Zhang C, Wang Y, Yu X, Ou J., *Constr Build Mater*. 125 (2016) 479-489.
17. Pramono AE., *J Mater Sci Eng B*. 3[11] (2013) 700-706.
18. Pramono AE, Zulfia A, Soedarsono JW., *J Mater Sci Eng A*. 2[5] (2012) 402-409.
19. Zhang XR, Pei XQ, Wang QH, Wang TM, Chen SB., *Adv Compos Mater*. 3046 (2014) 1-13.
20. Pramono AE, Firdaus MBT, Ratriomasyo W, Nura MZ, Soedarsono JWM., *J Ceram Process Res*.18[10] (2017) 748-753.
21. Wen S, Chung DDL., *Carbon*. 42[12-13] (2004) 2393-2397.
22. Bispo TS, Barin GB, Gimenez IF, Barreto LS., *Mater Charact*. 62[1] (2010) 143-147.
23. He Y, Lu L, Jin S, Hu S., *Constr Build Mater*. 53 (2014) 131-137.
24. Fernández-garcía L, Suárez M, Menéndez JL, Pecharromán C, Menéndez R, Santamaría R., *Nanoscale Res Lett*. (2015) 1-7.
25. Blugan G, Michalkova M, Hnatko M, Pavol S, Minghetti T, Schelle C, Graule T, Kuebler J., *Ceram Int*. 37 (2011) 3371-3379.
26. Fernandez-garcia L, Suárez M, Menéndez JL, Nuzhnyy D, Bovtun V, Savinov M, Petzelt J., *Carbon*. (2013) 1-29.
27. Seo YK, Kim YW, Kim KJ, Seo WS., *J Eur Ceram Soc*. 36[16] (2016) 3879-3887.
28. Zheng G, Zhao J, Zhou Y., *Wear*. 291 (2012) 41-50.
29. Delgado YP, Staia MH, Malek O, Vleugels J, Baets P De., *Wear*. (2014)
30. Borrell A, Torrecillas R, Rocha VG, Fernández A, Bonache V, Salvador MD., *Wear*. 275 (2012) 94-99.
31. Márquez-vera CA, Laguna-camacho JR, Marquina-chávez A, Juárez-morales G., *Wear*. 329 (2015) 132-139.