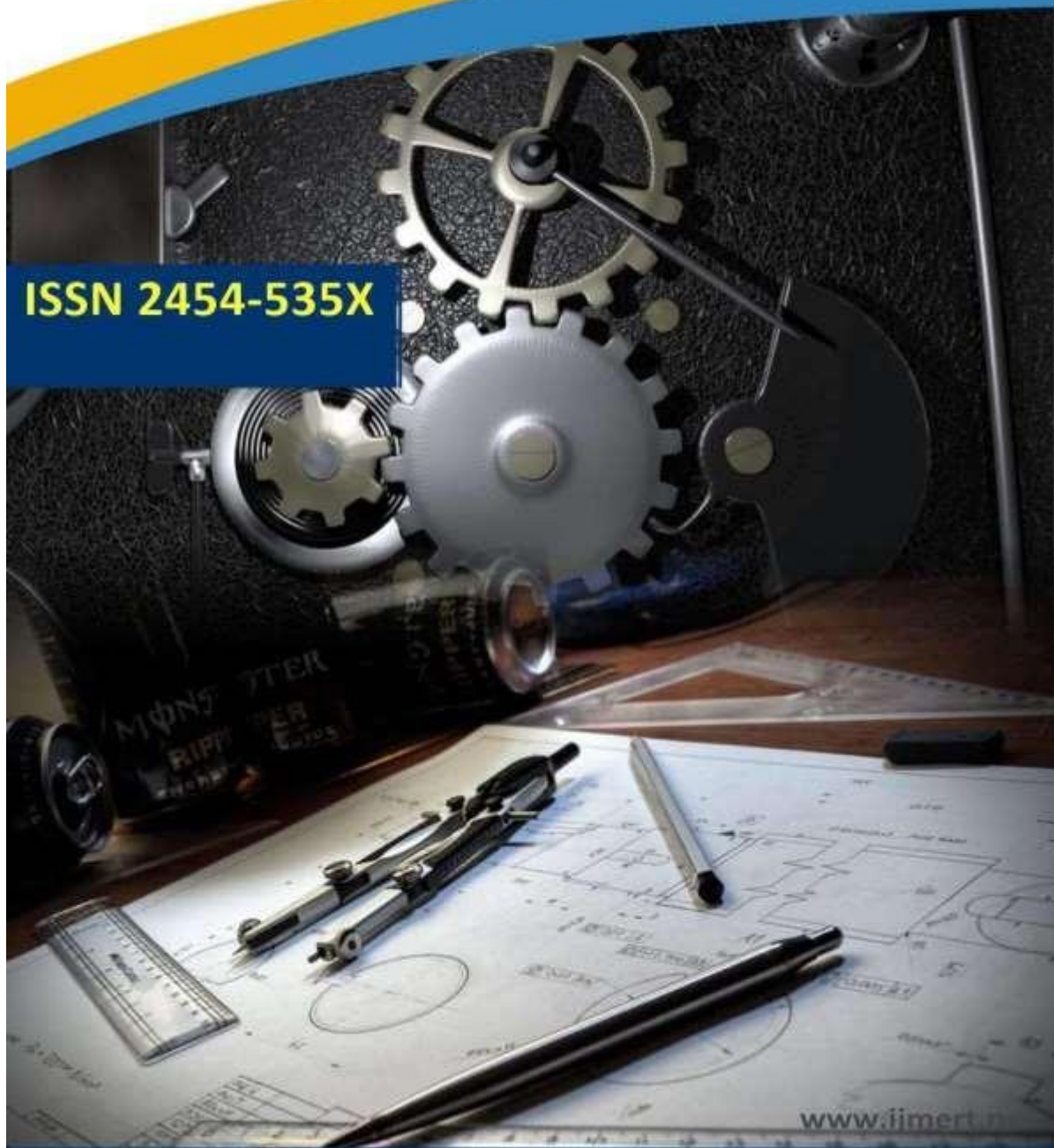




International Journal of Mechanical Engineering Research and Technology

ISSN 2454-535X



www.ijmert.net

Email ID: info.ijmert@gmail.com or editor@ijmert.net



Study on Recyclability of Graphite Cutting Chips as Conductive Fillers

M. Shravya Reddy*, N. Swetha Reddy & B. Supriya

Osaka Prefecture University College of Technology, 26-12 Saiwai-cho, Neyagawa-shi, Osaka 572-8572, Japan

*E-mail: SNBS@osaka-pct.ac.jp

ABSTRACT:

Reusing graphite cutting chips as thermal and electrically conductive fillers in heat-resistant ceramics is the goal of this work. Using packing cokes, graphite-containing ceramic test pieces can be consolidated in an oxidation-free environment; the maximum permitted concentration of supplied graphite chips is 60 weight percent. However, by reducing the chip particle size below 157 m and preparing their slurry with ceramic particles and surfactant water solution prior to the manufacturing of test pieces, better thermal and electrical properties can be produced. The addition of refined graphite chips up to 80 weight percent greatly improves the thermal and electrical properties of composite test pieces, although the maximum thermal property is obtained with the filler quantity of 60 weight percent. Due to the inability of forming enough heat conduction pathways with

KEYWORDS: thermal; graphite; ceramic; surfactant

INTRODUCTION

It is well known that carbon graphite has superior thermal and electrical conductive properties [1]. Lately, a variety of carbon graphite products are available in cookware / kitchenware such as ANAORI CARBONPOT® presented in Figure 1. Such products are manufactured by mechanically carving out pure graphite blocks exerting their excellent conductive and emissive performances.



Figure 1. Graphite block workpiece (left) and ANAORI CARBONPOT® (right)

However, this process generates a huge amount of graphite cutting chips that are currently no-use and only disposed as industrial wastes. Although these graphite chips still have good conductive properties, it is technically difficult to regenerate them into the original graphite blocks.

The purpose of this study is to examine a procedure to reuse the wasted graphite cutting chips as thermal and electrical conductive fillers in heat-resistant ceramics. The priority is to make the process less expensive and to find out the optimum condition of graphite cutting chips in order to provide sufficient conductive properties and densification with ceramics matrices in recycled products.



METHODS

Preparation of test pieces

Graphite cutting chips used in this study were supplied by Anaori Carbon Co. Ltd. The cutting chips have randomly mixed particle sizes ranging from several μm to several mm as shown in Figure 2.



Figure 2. Supplied graphite cutting chips (left) and their scanning electron micrograph (right)

The graphite chips were kneaded with heat-resistant kaolinite pottery clay (white) while adding an appropriate amount of water. The composite clay was kneaded sufficiently until its color turns black uniformly as shown in Figure 3. The kneaded composite clay was molded into the test piece shape of $20 \times 40 \times 8 \text{ mm}$, and dried at room temperature for one week to eliminate any residual water.

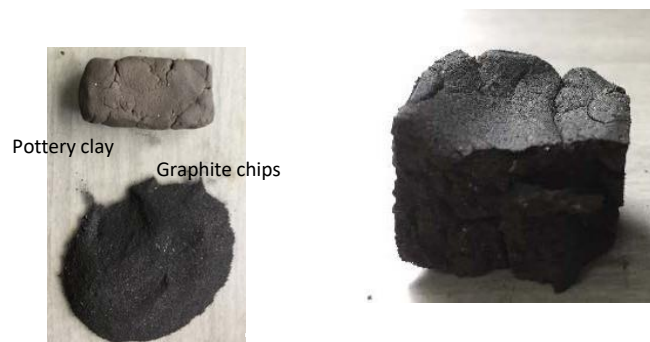


Figure 3. Constituent materials used (left) and their composite material after kneading (right)

The composite clay was sintered by an electric furnace to obtain heat-resistant ceramics test pieces. It is preferable to use a vacuum furnace to prevent oxidation of graphite particles; however, an inexpensive process using packing cokes was adopted in this study [2]. As shown in Figure 4, packing cokes were filled surrounding the composite sample in an alumina crucible to prevent oxidation of graphite fillers. Figure 5 shows thermal programs of the firing process. The composite test pieces were sintered at 800°C for 7 hours to remove water of crystallization, then finally sintered at 1280°C for 10 hours to allow sufficient densification of ceramics particles [3].

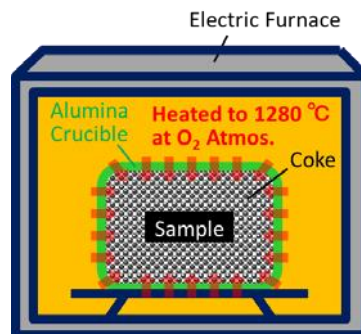


Figure 4. Schematic depiction of the sintering process.

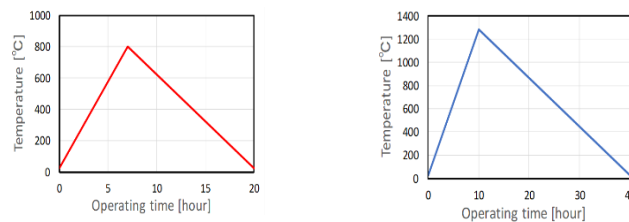


Figure 5. Thermal programs of the sintering process

Observation of test pieces

External and microscopic observations of composite test pieces were carried out by scanning electron microscope (JSM-6060LA, JEOL Ltd.) to confirm residual graphite fillers and densification of ceramics particles.

Measurement of thermal conductive properties

Thermal conductive properties of composite test pieces were tested by the experimental setup shown in Figure 6. The test piece shape of 20×40×4 mm was placed on a sheet silicon-rubber heater heated to 200°C while covering the lateral sides of the test piece by heat insulations. The exposed top surface of the test piece was observed by a thermography camera (R300, Nippon Avionics Co. Ltd.) to capture the transition of thermal image.

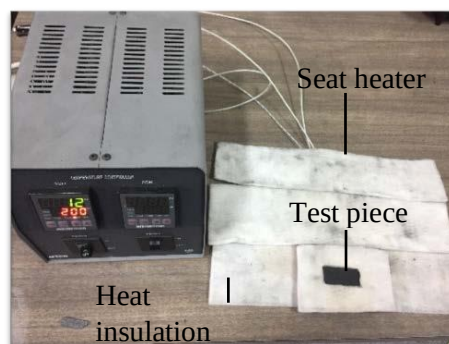


Figure 6. Experimental setup of thermal conductive test

Measurement of electrical conductive properties

Electrical conductive properties of composite test pieces were tested at room temperature (20°C) using a resistivity



meter (Loresta-GP, Mitsubishi Chemical Analytech Co. Ltd.) with a 4-point sensing probe [4-10].

RESULTS AND DISCUSSION

Appearance and microstructure

Figure 7 shows test pieces including 60wt% graphite fillers after sintering in oxidation and non-oxidation conditions, respectively. The test piece sintered without packing cokes showed shrinkage and depletion of graphite fillers, whereas the sample made in non-oxidation state kept its initial shape and the content of graphite fillers.



Figure 7. Test pieces sintered in oxidation state (left) and non-oxidation state (right)

Figure 8 shows test pieces sintered in non-oxidation condition. Colors of composite samples became dark with the increase of graphite fillers. The surface flatness was maintained up to the filler content of 20wt%. It took a longer time to knead composite clay when graphite fillers of 50wt% or more was added; however, the composite sample with 60wt% graphite fillers could be solidified.

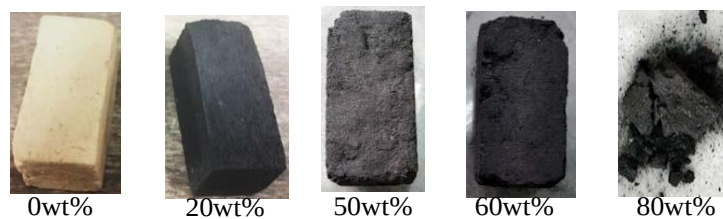


Figure 8. Appearances of test pieces (20×40×8mm) including different amounts of graphite fillers

Figure 9 shows cross-sectional micrographs of samples including different filler quantities. The test piece with no graphite fillers had well-densified ceramics particles including voids as large as 100 μm. The composite with 20wt% graphite fillers also had densified ceramics particles and indicated traces of separation of graphite. For the composite samples with graphite fillers of 50wt% or more, cohesions of uneven graphite particles were dominant than densification of ceramics particles.

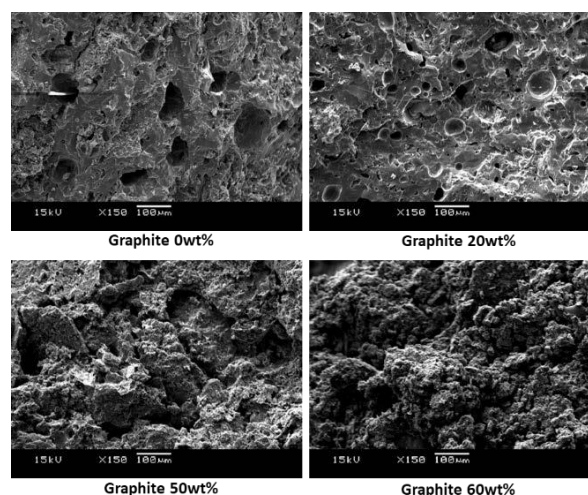


Figure 9. Cross-sections of test pieces including different amounts of graphite fillers



Thermal conductive properties

Figure 10 compares thermal images of top surfaces of specimens made by pure pottery ceramics and composite ceramics including 50wt% graphite fillers. The composite test piece indicated 20°C higher surface temperature than the no-graphite filler sample at 3 minutes after the initiation of the test. Figure 11 shows the change of surface temperature obtained from the heat transfer tests. The heat transfer performance improved with the increase of graphite fillers; the time required to raise the temperature from room temperature to 80°C was reduced by 40% as compared with the pure ceramics by adding 50wt% graphite fillers. However, the quality of test piece including 50wt% graphite fillers was not so stable showing some individual differences; some samples did not show superior results compared with the specimens including 44wt% graphite fillers.

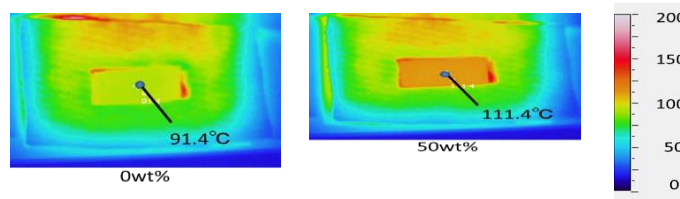


Figure 10. Typical thermal images obtained from heat transfer tests of test pieces (20×40×4mm).

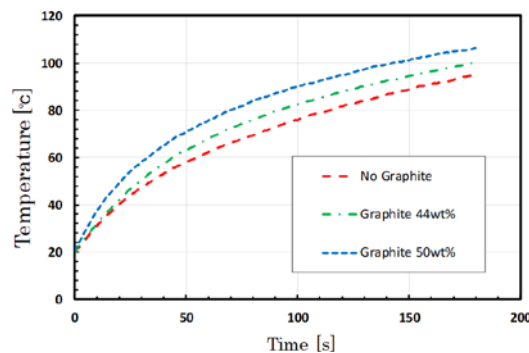
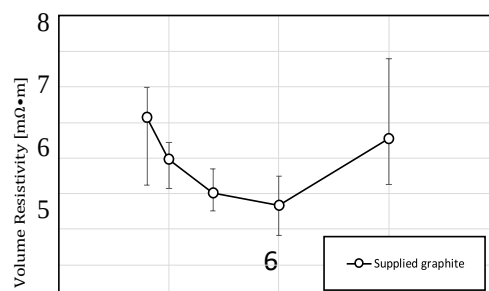


Figure 11. Heat transfer test results of test pieces including different amounts of supplied graphite fillers

Electrically conductive properties

Figure 12 shows the measurement results of volume resistivity obtained from test pieces with different graphite filler quantities. The volume resistivity decreased and the electrical conductivity improved with the increase of graphite fillers up to 50wt%; however, by adding 60wt% graphite fillers, the volume resistivity increased while showing a large data scatter. It is deduced that the inferior electrical conductivity may be due to the difficulty of the kneading process of composites adding graphite fillers of 50wt% and more. As SEM observations of those samples showed cohesions of uneven graphite particles, it is clear that some improvements are needed for the preparation process of composite clay.



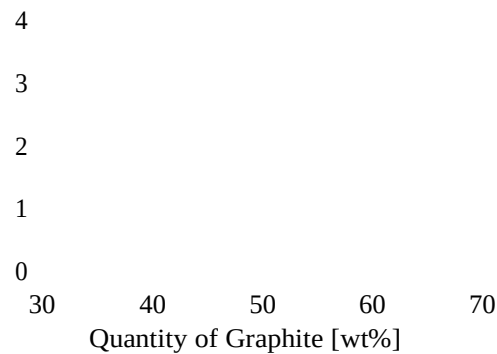


Figure 12. Volume resistivity test results of test pieces including different amounts of supplied graphite fillers

Refinements of constituent materials

In order to improve final qualities of ceramics composites, refinements of constituent materials were attempted. First, dried bulk pottery clay was mechanically crushed into powders with the average size less than $100\mu\text{m}$. Graphite cutting chips were also filtered to gain particles with the average size less than $157\mu\text{m}$ (Figure 13). Those refined materials were mixed in surfactant water solution to make feed slurry which was poured into the test piece mold and sintered afterwards.

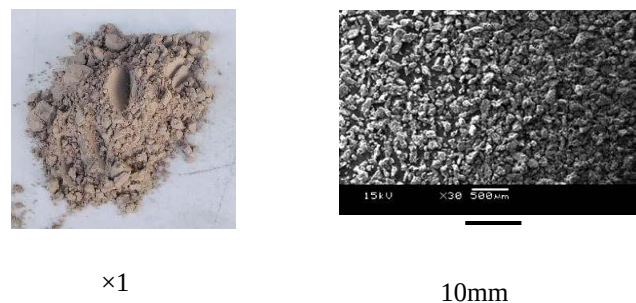


Figure 13. Refined pottery ceramics (left) and graphite cutting chips (right) with controlled particle sizes

Figure 14 compares appearances of test pieces including 60wt% graphite fillers with/without the refinements of particle sizes. It is apparent that the surface flatness was improved by controlling the filler size. As shown in Figure 15, it was even possible to solidify the composite test piece including 80wt% graphite fillers after refining the particle size.

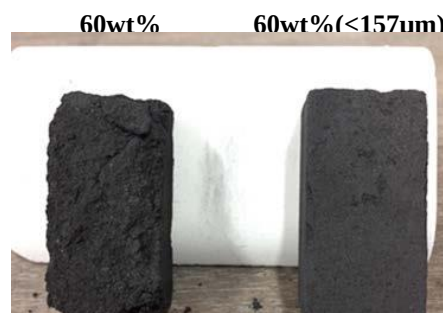


Figure 14. Appearances of test pieces (20×40×8mm) with 60wt% graphite fillers; supplied (left) and refined



(right) graphite.

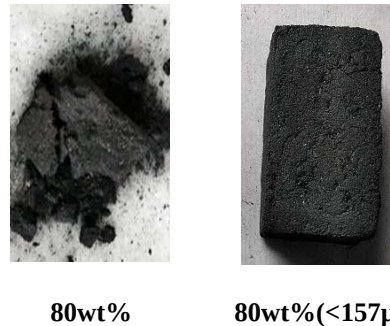


Figure 15. Appearances of test pieces (20×40×8mm) with 80wt% graphite fillers; supplied (left) and refined (right) graphite

Thermal conductive properties of refined composites

Figure 16 shows the results of heat transfer tests for composite test pieces including supplied/refined graphite fillers. The surface temperature of composite was higher and more stable by adding refined graphite fillers; however, there was no significant difference between the filler quantities of 60wt% and 80wt%.

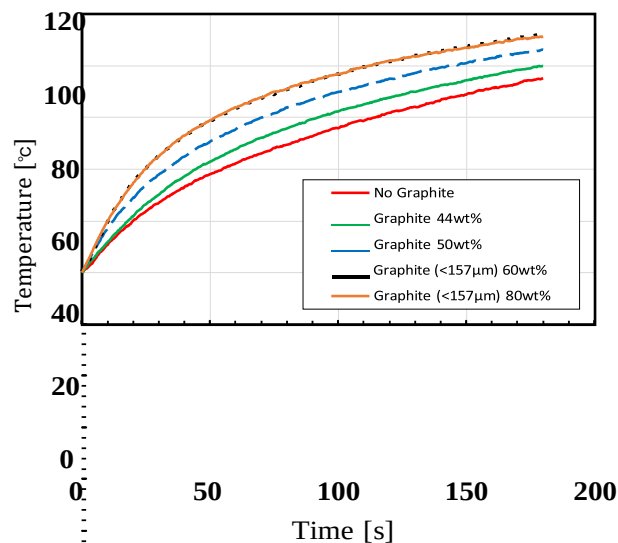


Figure 16. Comparison of heat transfer test results between supplied and refined graphite filler composites

It must be noted that there is little densification of ceramics particles in composites including 80wt% graphite fillers. Figure 17 shows a scanning electron micrograph of a cross-section of composite with 80wt% refined graphite fillers. White saturated areas indicate charging-up of electrons due to the existence of non-conductive ceramics. It is deduced that ceramics particles could not be densified sufficiently among graphite particles generating considerable voids, which prevented heat conduction within the composite.

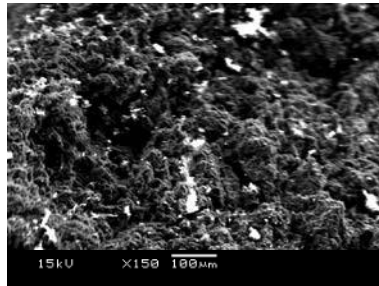


Figure 17. Cross-section of test piece including 80wt% graphite fillers with restricted densification of ceramics
Electrical conductive properties of refined composites

Figure 18 shows the results of volume resistivity tests for composite test pieces including supplied/refined graphite fillers. The composite samples with 60wt% graphite fillers indicated much better electrical conductivity and restricted deviation after refining the graphite particle size. The electrical conductivity further improved by adding 80wt% refined graphite fillers.

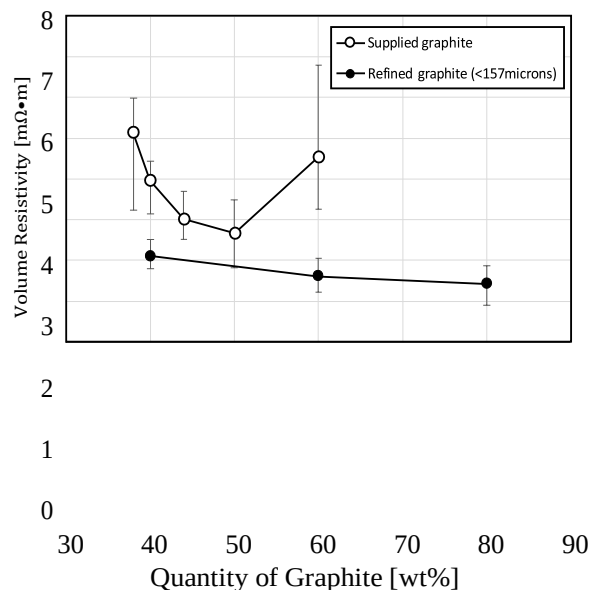


Figure 18. Comparison of volume resistivity test results between supplied and refined graphite filler composites

CONCLUSIONS

This study revealed that graphite cutting chips can be recycled as conductive fillers for pottery ceramics with the filler content of up to 60wt%, and the filler quantity may be increased to 80wt% by refining the constituent materials. The non-oxidation process using packing cokes was adoptable to obtain ceramics composites with high filler quantities. However, densification of ceramics particles was prevented due to cohesions of graphite

particles; therefore, the quantity of ceramics matrix should be retained to some extent to enhance densification and to avoid generating voids between graphite particles to assure mechanical properties of composites. Therefore, it may be needed to add other fibrous conductive fillers such as wasted carbon fibers to form effective conductive paths between a controlled amount of graphite particles.

ACKNOWLEDGEMENTS



The authors wish to thank Anaori Co. Ltd. in Japan for supplying materials and providing technical supports throughout this study.

REFERENCES

- [1] H.O. Pierson. "Handbook of Carbon, Graphite, Diamonds and Fullerenes". Park Ridge, N.J.: NoyesPublications, 1994.
- [2] N. Ahmad, M. Ali, F. Ali, A.M. Khattak. "Left Double Displacement Semigroup: A First Result". *Matriks Sains Matematik*, vol. 2, no. 2, pp. 37-39, 2018.
- [3] S.K. Gugulothu, N.P. Kishore, V.P. Babu, G. Sapre. "Computational Investigation of Mhd Free Convection on A Flat Vertical Plate Embedded with Micro Polar Fluid". *Acta Mechanica Malaysia*, vol. 2, no. 1, pp. 16-22, 2019.
- [4] S.M. Hasan, S.H.K. Tushar, M.H. Rahman, A.R. Shimu. "An Optimized Design of Electromagnet and Float for A Magnetic Suspension System". *Acta Electronica Malaysia*, vol. 3, no. 1, pp. 14-18, 2019.
- [5] H.O. Pierson. "Handbook of Carbon, Graphite, Diamonds and Fullerenes", *Park Ridge, N.J.: NoyesPublications*, 1994.
- [6] Z. Liang, W. Wenshun. "Parametric Architectural Design Based on Optimization Algorithm". *Engineering Heritage Journal*, vol. 3, no. 1, pp. 13-17, 2019.
- [7] V.G. Lee, and T.H. Yeh, "Sintering effects on the development of mechanical properties of fired clay ceramics", *Materials Science and Engineering*, A 485, pp. 5-13, 2008.
- [8] S.M. Lee, D.S. Kang, J.S. Roh. "Bulk graphite: materials and manufacturing process". *Carbon Letters*, Vol.16, pp. 135-146, 2015.
- [9] V.G. Lee, T.H. Yeh. "Sintering effects on the development of mechanical properties of fired clay ceramics". *Materials Science and Engineering*, vol. 485, pp. 5-13, 2008.