VOL. 11, NO. 18, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences


www.arpnjournals.com

CARBON-COPPER (C-CU) COMPOSITES USING LOCAL CARBON MATERIAL THROUGH WARM COMPACTION PROCESS FOR POTENTIAL ELECTRICAL AND ELECTRONIC APPLICATIONS

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ABSTRACT

The carbon-copper (C-Cu) composites combine the positive characteristics of thermal and electrical conductivity from Cu, low thermal expansion coefficient and lubricating properties from conventional carbon/graphite. For that particular application, C-Cu composites are widely used as electrical contact devices such as carbon brushes and current collector for railway power collection system. Due to economic and environment concern, activated carbon produced from MPOB oil palm kernel shell (OPKS) is studies as replacement for conventional carbon/graphite in C-Cu composites. This study intended to investigate the effect in term of characterisation using different particle size of carbon (<90µm and <150µm) and determine the optimum parameter of C-Cu composites to enhance the physical and mechanical properties. The preparation for producing the sample was started with the OPKS through the crushing and sieving process as well as mixed with copper powder and epoxy resin at selected ratio before it is compacted into shape and then undergoes with warm compaction and post baking process. The effects of different particle size of carbon to physical and mechanical properties of the C-Cu composites were analysed. It is found that the improvements of the mechanical and physical properties are strongly affected by the fine particle carbon (<150µm) and after passing warm compaction at 150 ˚C and post baking at 200 ˚C conditions. It is concluded that the sample prepared in ratio 65% C (<150µm) + 20% Cu + 15% Epoxy resin with warm compaction 150 ˚C, post baking 200 ˚C condition is the optimum sample parameter to fabricate of current collector.

Keywords: C-Cu composites, local carbon, different particle size of carbon, warm compaction, post baking, mechanical and physical properties.

INTRODUCTION

C-Cu composites are widely used in various electrical and electronic applications such as carbon brushes for the engine and generators as well as pantograph contact strips (current collector) for railway power collection system. C-Cu composites also are known for their high electrical conductivity and good wear resistance [1]. Besides that, C-Cu composites combine the positive characteristics of thermal and electrical conductivity from Cu and low thermal expansion coefficient and lubricating properties from graphite or carbon [2]. Most of electrical contact devices and current collector for railway power collection are made of carbon-copper. Nowadays, peoples are more concern about replacing the raw materials with renewable energy and hence, using waste to replace conventional materials.

In this case, activated carbon produce from Malaysian Palm Oil Board (MPOB) oil palm kernel shell is studied as a replacement for conventional carbon/graphite used in current market. Palm oil is one of 17 major oils trade in the global edible oils and fat market. Being the world's largest producer and exporter of palm oil, Malaysia earned about RM 45.2 billion in foreign exchanged in 2007 [3]. Thus, high amount of wastes is produced as a major by-product. One of oil palm industry's major by-products is kernel shell. Large quantities of kernel shells are produced after extraction of the palm oil and mostly left as waste. It is either burned as a low value energy resource of discarded in the field. Both of the methods are unfavourable to the environment. Therefore, studying kernel shell as replacement for conventional carbon is a great way to solve the problem and creating value added products.

There are several applications that are using palm oil waste as one of its materials. One of the examples is carbon black. It is reported that oil palm empty fruit bunches (EFB) was used to produce carbon black using carbon activation on the precursors of EFB before it undergo a carbonization process [1]. With the recent rises in coal and petroleum prices, carbon powder from EFB would be able to competitive. The conventional method of producing C-Cu composites is by using press and sinter method. Mostly, the main processes include powder metallurgy (PM) technique and infiltration of carbon network by liquid copper. However, the fabrication of C-Cu is difficult due to the low solubility of carbon-copper and thermally treated up to 2500°C, it will consume very high cost [4]. Thus, liquid Cu could not wet the carbon even by liquid phase sintering and resulting in C-Cu composites with weak interface bonding and poor mechanical properties as well as it will be difficult to attain a uniform quality in the production of components [4].

Previously, addition of small amounts of lead improved densification of C-Cu since lead solder copper particle together and will increase the strength of the

material and will produce lower resistivity. However, it is banned in carbon brushes products due to public awareness issues [5]. This finding was proved from the previous project and from many research works that have been done in C-Cu composites materials. Although, there are many processes that are applicable to produce high density products, warm compaction is considered as most economic and effective method as well as produce environmental friendly (lead-free) product. The advantages of OPKS as recycle materials are non-renewable can be replaced with renewable as well as encourage utilisation of renewable sources. Although the usage of OPKS as local carbon is still new and unproven in electrical and electronic application, they are already being used in automobile disc brake, carbon activation for water purification, a concrete ingredient in building industry and fuel for heat generation and thermal insulator.

Nowadays, current collectors used by Projek Usahasama Transit Ringan Automatik (PUTRA) RapidKL are still imported from the main manufacturer in France and Canada, which cost a huge amount of RM 2 million yearly. By using the local carbon material, this problem can be overcome as it is much cheaper and the C-Cu composites will exhibit better properties than the existing products. Therefore, the objective of this study is to investigate the effect in term of characterisation using different particle size of carbon (<90µm and <150µm) and determine the optimum parameter of C-Cu composites to enhance the physical and mechanical properties.

Basically, C-Cu composites are dispersed of copper in graphite matrix. They can combine exhibit high electrical conductivity, good wear resistance and those graphite (i.e. small thermal expansion coefficient and good tribological property) [6]. Thus, it can be utilized for applications in electrical contact devices, such as electrical brushes for engines and generators, pantograph and contact strips (current-collector). Moreover, it is also very difficult to attain a uniform quality in the production of components via the PM process due to a major density difference between carbons and copper [1]. Besides that, to fabrication of the composites is difficult because the mutual solubility of carbon and copper and wettability of carbon liquid copper is extremely low [6]. Generally, the main processes to manufacture these materials are [6]. Infiltration of carbon fibres network or graphite network is by liquid copper. A dry-pressed tungsten skeleton is prepared first, and then molten copper is infiltrated into the skeleton [7]. Wetting and the capillary force play an important role in filling the micro-cavities in the green body. Press and sinter processing is a traditional PM method of making low cost, near net shape components. The process produces small diameter, high purity metal powder. The powder can be used to fabricate low cost, near net shape components via casing and various PM techniques (press and sinter, pneumatic isostatic forging, hot isostatic pressing, adiabatic compaction, etc.) [8].

Sintering is a process in which an assembly of loose or compacted particles metallurgical bond into a coherent body at elevated temperature. During the processing of a PM component, the sintering step subjects the fragile green compact to heating in a protective atmosphere to establish the desired mechanical properties by causing the powder particles to form coherent bond to alloy and admixed elements. The conventional method for the fabrication of C-Cu composite using the press and sintering method has certain limitations such as, the poor affinity (lack of wetting effect) and the high contact angle between C (3826 °C) and Cu (1083 °C) [2]. At that time will cause difficulties to prepare C-Cu composites with good interface bonding since liquid Cu does not wet carbon, even by liquid phase sintering (LPS) above the melting point of the Cu phase. As a result, C-Cu produced will exhibit poor mechanical properties and it will be difficult to attain a uniform quality in the production of components.

Warm compaction technologies were employed for single press or single sinter at both conventions and high temperatures to produce many application productions [9]. These new powders and premix technologies offer PM users greater flexibility in mechanical properties at traditional part densities. With minor modification of the conventional PM equipment and approximately 20% higher than the cost of conventional compaction, iron base green compact with the density of 7.4 g/cm^3, with is equivalent to a relative density of 95%, can be obtained by single phase (compared to a density of 7.1 g/cm^3, which is equivalent to a relative density of 91%, obtained by conventional compaction) [10]. Traditional methods used to achieve higher densities include the use of copper infiltration, double-pressing or double-sintering (DP/DS), and powder forging. Because these techniques involve the use of secondary processing, significant cost penalties are encountered, often negating the potential cost savings realized by powder metallurgy [11]. Thus, warm compaction is the most economical and effective way.

Potential application of warm compaction is proved, because warm compaction is a single-press and single-sinter process, the process is ideal for complex multilevel PM parts that require high mechanical properties that cannot be obtained at conventional compaction densities. Higher density (or equivalent density at lower compaction pressures) can be achieved with warm compaction as compared with cold compaction [11].

METHODOLOGY

Activated carbon from MPOB oil palm kernel shell (OPKS) is used to replace conventional carbon with the composition of 65% of carbon, 20% of copper and 15% of epoxy resin (65C-20Cu-15ER) during mixing process. However, the OPKS is crushed before to obtain a finer and homogeneous particles size. During the crushing process, tungsten balls are added with 5:1 of ball to powder ratio using Turbular Shaker Mixer for 1 hour and speed at 50 rpm. The powder obtained was sieved to separate the powder into different sizes. It was also done to observe the finest size of powder obtained from the crushing process. In this process the <90µm and <150µm

size of carbon powder was selected as raw materials for formulation. Then, the sieved carbon was mixed with copper and epoxy resin using dry mixing process by using Turbular Shaker Mixer (3D rotation machines). The mixture is mixing within 1 hour with 50 rpm.

After that, the mixed powders are compacted to preform in rectangular shape with (25 mm length × 25 mm width) using Automatic Hydraulic Press 30T machine at 18 tons for 1 minute holding time prior to warm compaction process. The temperature during warm compaction process applied the various temperatures that are 150 ˚C, 200 ˚C and 250 ˚C. The preform is subjected to pressure of 50 tons with holding time of 5 minutes by using Automatic Hydraulic Press 200T machine. After the warm compaction process, it continues with the post baking process. Post baking process was done using microprocessor controlled oven. The cycle of time was applied to 8 to 9 hours and with applied the various temperatures that are 150 ˚C, 200 ˚C and 250 ˚C.

Lastly, the physical and mechanical properties of the C-Cu composites sample were analysed. Relative densities of the sample are measured by using Electronic Densimeter. Then the hardness was conducted using Rockwell Hardness tester at load 60 kgf and indentation ball of ½ inch. Next, the resistivity test was tested using Digital Resistivity Meter and transverse rupture strength (TRS) of the sample was done using Universal Testing Machine (UTM). For the friction coefficient (wear) was tested by using Chase Machine, mineralogy was done by using X-ray Diffraction (XRD) and microstructure characterisation by using Scanning Electron Microscope (SEM). All result value of investigated materials was calculated as the average of at least three readings. Then, the analyses data has compared with commercial current collector standard.

RESULTS AND DISSCUSSIONS

Dimensional measurement

Based on Figure-1, the samples become different dimension when the pressure and temperature was applied in warm compaction process. After warm compaction, the sample was hard or solid and the dimension of the sample was reduced and increased from green body. This has happened because the pressure that applied during warm compaction makes the sample becomes packed and the temperature applied was affected the resin curing uniformly in sample become the mass decreased.

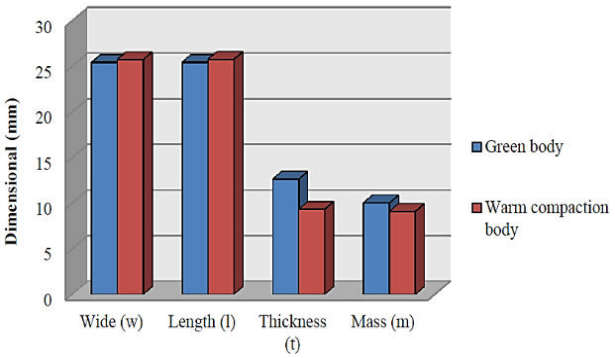


Figure-1. Average dimensional change of C-Cu composites.

Density

Based on the result in Figure-2, the highest warm compaction of the sample is at W.C-250 of temperature with 1.600 g/cm³ for fine particle carbon (<90µm). Besides that, the highest reading for the warm compaction and post baking sample is at W.C-150, P.B-250 of temperature with 1.625 g/cm³ for fine particle carbon (<150µm). Mostly, the density value of the fine particle carbon (<150µm) sample are lowest than fine particle carbon (<90µm) sample. However, the main factor to influence the density value due the volume and mass of the samples. It is probability the volume and mass have been loss in fine particle carbon (<150µm) sample due the minor error while grinding process.

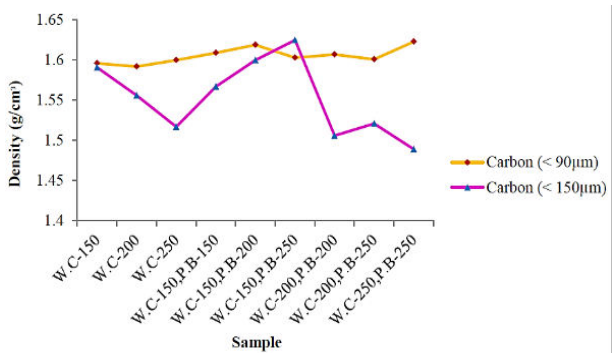


Figure-2. Sintered density of C-Cu composites for different carbon particle size.

Hardness

Based on Figure-3, all samples in warm compaction condition are shown the improvement of the hardness properties after proceed in post baking process. From the result, both of carbon particle size samples are possess the higher hardness properties at warm compaction 150 ˚C, post baking 200 ˚C condition which the carbon (<150µm) sample with the 124.1 HRR and carbon (<90µm) sample with 122.3 HRR respectively. From the observation, it is clear that the fine particle carbon (<150µm) samples are more proper in term hardness characterization was selected as optimum sample.

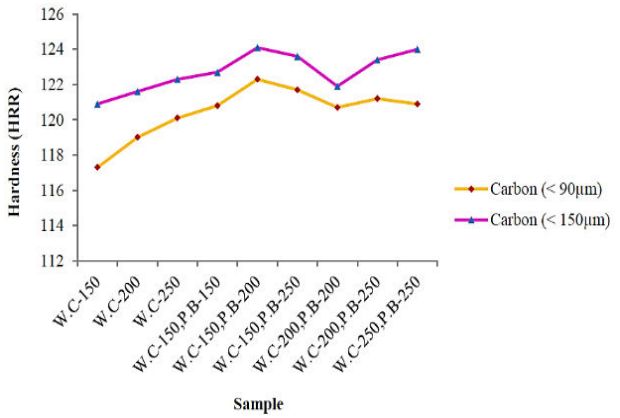


Figure-3. Rockwell hardness testing (HRR) of C-Cu composites for different carbon particle size.

Resistivity

Based on the result in Figure-4, the lowest resistivity warm compaction of the sample is at W.C-150 of temperature with 2.308 Ωmm for fine particle carbon (<150µm). Besides that, the lowest resistivity for the warm compaction and post baking sample is at W.C-200, P.B-250 of temperature with 1.952 Ωmm for fine particle carbon (<150µm). It is clear, mostly the fine particle carbon (<150µm) samples are more proper in term electrical properties. It is due the average resistivity value the fine particle carbon (<150µm) samples are lowest than the fine particle carbon (<90µm) samples.

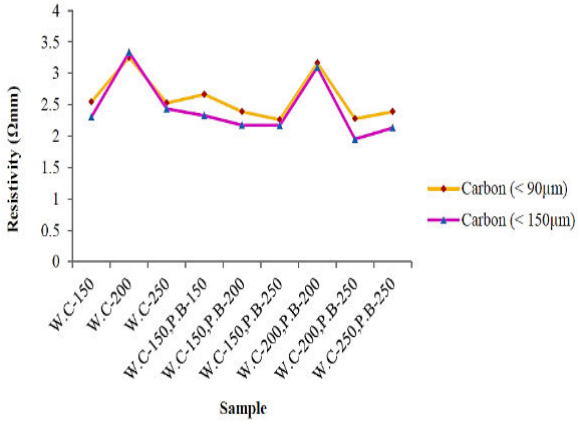


Figure-4. Resistivity of C-Cu composites for different carbon particle size.

Transverse rupture strength

Based on the result in Figure-5, the highest strength for warm compaction sample is at W.C-250 of temperature with 43.373 Mpa for fine particle carbon (<150µm). Besides that, the highest strength for the warm compaction and post baking sample is at W.C-150, P.B-200 of temperature with 57.751 Mpa for fine particle carbon (<150µm). From the observation, the samples that used fine particle carbon (<150µm) possess more capability to resist deformation under high load than fine particle carbon (<90µm) due the TRS result is higher. Then, the both samples of carbon particle size identified to achieve the maximum of potential rupture strength at warm compaction 150 ˚C, post baking 200 ˚C condition.

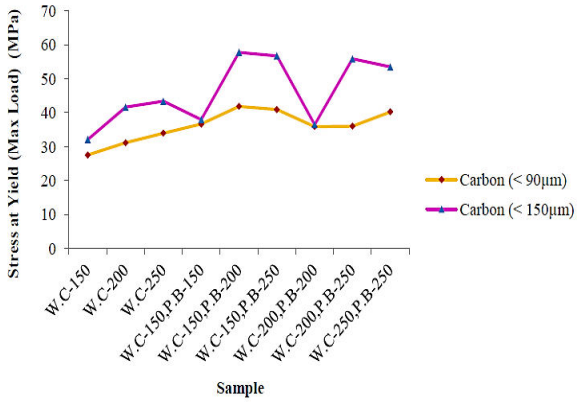


Figure-5. Stress at yield (max load) of C-Cu composites for different carbon particle size.

Friction and wear

From the Table-1-4, the result carbon (<150µm) sample is better than carbon (<90µm) sample and it is due to the pass condition. Then, result for carbon (<150µm) sample is better after passing warm compaction and post baking process compare to warm compaction process only as well as the result approximately with commercial sample. From the observation, it is clear that the fine particle carbon (<150µm) sample was selected as the best sample in this test and undergoes with W.C-150, P.B-200 condition.

Table-1. Friction and result of C-Cu composites for different carbon particle size.

No	Sample	Normal Friction	Hot Friction
1	Commercial (1)	0.355(F)	0.421(F)
2	Commercial (2)	0.352(F)	0.361(F)
3	(<150µmm),W.C-150 (1)	0.229(D)	0.233(D)
4	(<150µmm),W.C-150 (2)	0.221(D)	0.223(D)
5	(<150µmm),W.C-150,P.B-200(1)	0.284(E)	0.256(E)
6	(<150µmm),W.C-150,P.B-200(2)	0.262(E)	0.240(E)
7	(<90µmm),W.C-150 (1)	0.226(D)	0.230(D)
8	(<90µmm),W.C-150 (2)	0.219(D)	0.204(D)
9	(<90µmm),W.C-150,P.B-200(1)	0.234(D)	0.234(D)
10	(<90µmm),W.C-150,P.B-200(2)	0.246(D)	0.235(D)

Table-2. Friction and wear result of C-Cu composites for different carbon particle size.

No	Sample	Initial Weigth (g)	Final Weight (g)	Weight Loss (%)
1	Commercial (1)	9.38	9.28	1.1
2	Commercial (2)	8.30	8.18	1.4
3	(<150µmm),W.C-150 (1)	6.81	6.48	4.8
4	(<150µmm),W.C-150 (2)	7.22	6.86	5.0
5	(<150µmm),W.C-150,P.B-200(1)	6.26	6.00	4.2
6	(<150µmm),W.C-150,P.B-200(2)	6.62	6.39	3.5
7	(<90µmm),W.C-150 (1)	6.53	6.13	6.1
8	(<90µmm),W.C-150 (2)	6.60	6.35	3.8
9	(<90µmm),W.C-150,P.B-200(1)	6.69	6.44	3.7
10	(<90µmm),W.C-150,P.B-200(1	6.45	6.13	5.0

Table-3. Friction and wear result of C-Cu composites for different carbon particle size.

No	Sample	Initial Thickness (mm)	Final Thickness (mm)	Thick-ness Loss (%)
1	Commercial (1)	7.00	6.98	0.3
2	Commercial (2)	6.17	6.13	0.6
3	(<150µmm), W.C-150 (1)	7.09	7.04	0.7
4	(<150µmm), W.C-150 (2)	7.16	7.11	0.7

Table-4. Friction and wear result of C-Cu composites for different carbon particle size.

No	Sample	Condition
1	Commercial (1)	Pass
2	Commercial (2)	Pass
3	(<150µmm),W.C-150 (1)	Fail
4	(<150µmm),W.C-150 (2)	Fail
5	(<150µmm),W.C-150,P.B-200(1)	Pass
6	(<150µmm),W.C-150,P.B-200(2)	Pass
7	(<90µmm),W.C-150 (1)	Fail
8	(<90µmm),W.C-150 (2)	Fail
9	(<90µmm),W.C-150,P.B-200(1)	Fail
10	(<90µmm),W.C-150,P.B-200(1	Fail

Mineralogy (X-ray diffraction)

Based on the Figure-6, the major constituent elements contained in the C-Cu composites are carbon (C) and copper (Cu). The characteristic of the XRD analysis ranges from 10° to 90° 2θ angle. The green line marked carbon while purple line marked copper. From the graph, all elements of phases were shown that carbon is the most abundant element in the C-Cu composites. Mostly the peaks of Cu are shortened and less narrow compared to the corresponding peaks of the C. It means that XRD peaks of Cu are broader than the XRD peaks of C.

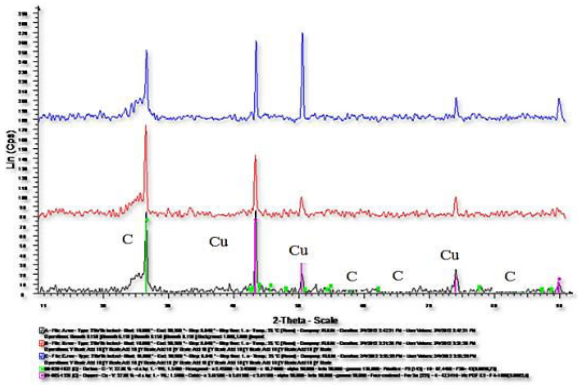


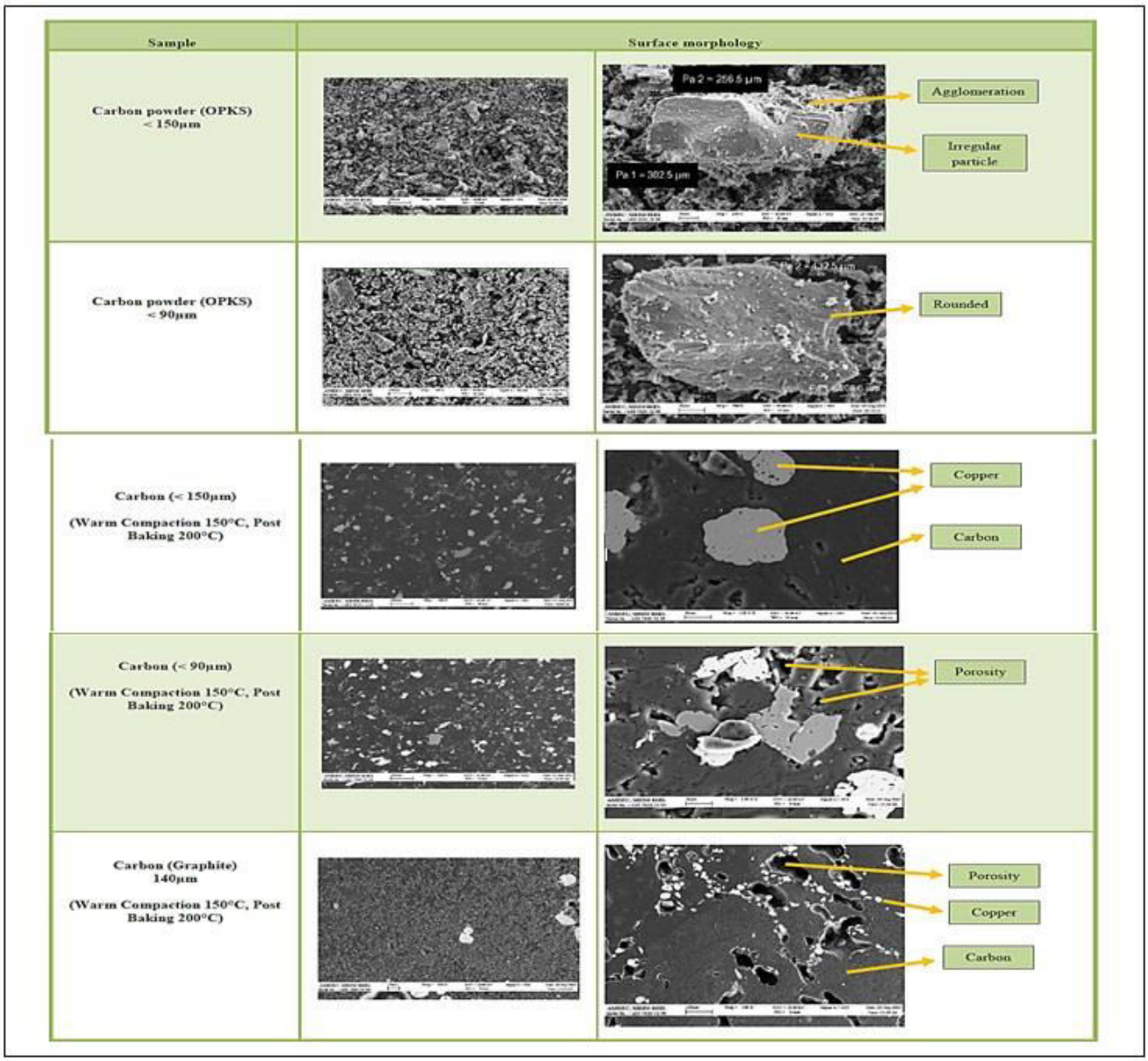
Figure-6. XRD result of C-Cu composites.

Microstructure Characterisation

From Table-5, it is observed the powder formulation was involved two types of carbon powder and in different size of particles. The powder formulation distribution shown uniformly for all types of formulation and the particle size of carbon is bigger than particle size of cooper. The resin in formulation was shown agglomeration. Agglomeration is a tendency for small particle to stick together and appear as larger particle. Additional, only optimum parameter for the sample of warm compaction and post baking with temperature W.C-150, P.B-200 from both samples C-Cu composites was chosen to study the surface morphology.

It is clear from the result, both C-Cu samples exhibited the distribution powder ratio between carbon and copper are homogenous. It is exhibited, founded are more porosities are formed onto the carbon (<90µm) surface morphology sample compare the carbon (<150µm) sample. On the other hand, founded are much porosity formed onto commercial carbon surface morphology sample. Hence, it is clear the porosities sizing of commercial carbon are largest compared local carbon. The hardness of the sample depends on the porosity of sample. Decrease porous will increase the density and properties of product.

Table-5. Friction and wear result of C-Cu composites for different carbon particle size.



CONCLUSIONS

Based on overall results, it is found that the improvements of the mechanical and physical properties are strongly affected by the post baking process. This is an agreement in term of mechanical properties which all samples in warm compaction condition are shown the increasing of the hardness and transverse rupture strength (TRS) properties after proceed in post baking process. It is demonstrated that the effect the hardness strength, it linked with the potential rupture strength as well as affected the friction coefficient properties. Thus, post baking process is very significant to extension the strong cross-linking bonding form of the carbon copper composite (C-Cu composites). The optimum parameter on both types of carbon particle size identified at warm compaction 150 ˚C, post baking 200 ˚C conditions. From the physical properties, the fine particle carbon (<150µm) is chosen as the optimum size particle carbon to formulate the carbon copper composite. It is due the hardness and TRS properties are higher at all warm compaction and post baking condition as well as shows are more proper in term electrical properties due the average resistivity value is the smallest compared fine particle carbon (<90µm). Then, Scanning Electron Microscope (SEM) micrograph shows the porosities that formed onto surface morphology of the carbon (<150µm) sample are less more compared the carbon (<90µm) sample and also shows the porosities size is smaller than commercial carbon sample. It is demonstrated, the fine particle carbon powder (<150µm) is more solid compacted. As conclusions**,** the sample prepared in ratio 65% C (<150µm) + 20% Cu + 15% Epoxy resin with warm compaction 150˚C, post baking

200 ˚C condition is the optimum sample parameter and can be used to fabricate of current collector for potential electrical and electronic applications.

ACKNOWLEDGEMENTS

The authors would like to thank the Universiti Tun Hussein Onn Malaysia for their financial support. Authors would like to acknowledge Ministry of Science, Technology and Innovation (MOSTI), Ministry of Higher Education Malaysia & AMREC SIRIM for their support and assistance with this project and for their access to the research facilities.

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