MECHANOSYNTHESIS OF MMC CuC DOPED WITH Ti FOR APPLICATION OF PANTOGRAPH CONTACT STRIP (PCS)

PEMBUATAN METAL MATRIK KOMPOSIT CuC YANG DIDOPING DENGAN Ti UNTUK APLIKASI PANTOGRAPH CONTACT STRIP (PCS)

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Abstract

This research was conducted to determine the effect of the addition of Titanium (Ti) and the sintering temperature variation on MMC CuC alloys as reinforcing elements. The process of this research uses powder metallurgical method with an alloying technique in Mechanical Alloying using a Planetary Ball Mill (PBM) machine with a speed of 600 rpm for 2 hours, the ratio of powder to the ball mill is 10:1. The compacting process is carried out using dies 11 mm in diameter and compacting pressure of 90 Kg/cm^2. The sintering process is carried out three times, with variations in sintering of 800^{o}C, 900^{o}C, and 1000^{o}C with sintering time for 1 hour in the tube furnace in the argon gas vacuum environment. The number of samples used in this study amounted to 9 samples with variations in alloy and temperature sintering, consist of MMC CuC alloy with addition of Ti 0%, 0.5%, 1.5% (T=800 ^{o}C), MMC CuC with addition of Ti 0%, 0.5%, 1.5% (T=900 ^{o}C), and MMC CuC with addition of Ti 0%, 0.5%, 1.5% (T=1000 ^{o}C). The tests included Vickers hardness testing, metallography testing, XRD testing, and SEM-EDS testing. The addition of Ti elements and varying sintering temperature had an effect on the hardness value of MMC CuC material with the highest hardness value in samples with 1.5% Ti alloy (800oC) which is 87.25 HV, and the lowest porosity value is 2.491% in the sample of 1.5% Ti (1000^{o}C).

Keywords : MMC CuC; Mechanical Alloying; Titanium; Pantograph Contact Strip

Abstrak

Penelitian ini dilakukan untuk menentukan pengaruh penambahan titanium (Ti) sebagai penguat dan variasi temperatur sintering MMC paduan CuC alloys. Proses penelitian menggunakan serbuk dengan teknik pemaduan mekanik menggunakan mesin Planetary Ball Mill (PBM) dengan kecepatan 600 rpm selama 2 Ratio antara bola grinding dan serbuk 10:1. Proses kompaksi dilakukan menggunakan cetakan dengan diameter 11 mm dan tekanan kompasi sebesar 90 Kg/cm^2. Proses sintering dilakukan dengan variasi sintering of 800^{o}C, 900^{o}C, dan 1000^{o}C dengan waktu sintering selama 1 jam dalam tungku tabung dengan atmosfer lingkungan gas argon. Jumlah sampel dalam penelitian ada 9 dengan variasi komposisi paduan dan temperatur sintering, Sampel paduan MMC CuC terdiri dari paduan dengan penambahan Ti 0%, 0,5%, 1,5% dan temperatur sintering 800^{o}C, 900^{o}C dan 1000^{o}C. Pengujian sampel hasil sintering meliputi Vickers microhardness, metallography, XRD, dan SEM-EDS. Penambahan unsur Ti pada paduan CuC dan variasi temperatur sintering mempengaruhi kekerasan paduan dan porositas paduan CuC-Ti. Harga kekerasan tertinggi terjadi pada paduan CuC-Ti dengan konsentrasi Ti 1,5% temperatur sinter 800^{o}C yaitu 87,25 HV, sedangkan porositas terendah yaitu 2,491% pada sampel CuC dengan konsentrasi 1,5% temperatur sinter 1000^{o}C.

Kata kunci : MMC CuC; Pemaduan mekanik; Titanium; Pantograph Contact Strip

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INTRODUCTION

In recent years, Electric Railways have developed rapidly due to the timeliness, ease and low environmental pollution in many countries throughout the world[1]. In China, the operating speed of the Electric Train system has reached more than 380 km/h, and the driving force has reached 10,000 kW[2]. In Indonesia, the Electric Train (KRL) currently has 80 stations and has 6 lines. In 2017 the number of KRL passengers reached 316 million users. The average speed of a KRL reaches 40 km/h (25 mph) with a top speed reaching 70 km/h (43 mph) and has a route as far as 235 km (146 mi) in Indonesia[3].

In the electric train construction, there is a component called pantograph/pantograph contact strip with the location on the top of the electric train and contact with the cable power line. Pantograph contact strip has an essential role in the electric train operating system. Pantograph contact strip (PCS) functions as an electrical conductor which is the primary power source on the KRL so it can move[1]. The characteristics of existing PCS are a critical basis for the schematic design and parameter selection of new contact lines. PCS must have certain basic features, which conform to the specified application. PCS characteristics have a significant impact on the quality of PCS operations and the overhead contact line system. Perfect design ensures suitable PCS operating performance on various contact lines[4].

Ensuring excellent contact between PCS and the catenary system has always been a goal for many researchers. However, contact performance is still far from satisfying at the moment, because PCS and the catenary system must experience a shock load caused by several factors, such as wear/friction, arc abrasion, and environmental erosion, and so on. This evolutionary process of PCS requires more comprehensive research[5].

There are many types of PCS materials, but only carbon composite metals are used, both domestically and abroad. Copper material is advantageous when combined with metals for PCS material. Pure carbon and carbon added to metals for PCS materials significantly increase wear resistance due to excellent lubrication properties[2]. Therefore, to meet the requirements for making pantograph contact strips (PCS) on KRL, we can use materials made from carbon and copper by addition from other elements. In this study focuses on studying the effect of addition Ti gave on the PCS characteristics produced, among them the effect of variations in composition and sintering temperature on MMC CuC material.

MATERIALS AND METHODS

The design of the research experiment to be carried out, as shown in Figure 1. The first stage is mixing the raw materials of MMC CuC and Ti, which varies in composition 0%Ti, 0.5%Ti, and 1.5%Ti. Then the CuC-Ti alloys are compacted with a pressure of 90 kg/cm^2. The results of compacting are then sintered at varying temperatures, 800^{o}C, 900^{o}C and 1000^{o}C.

The design of the powder composition to be made is shown in Table 1. The powder composition used was calculated based on weight per cent and for each sample with different Ti composition variations. The naming of the sample shows numbers and letters. The numbers indicate the addition of Ti elements in per cent (0; 0.5; 1.5), while the letters after the numbers indicate differences in sintering temperatures, namely A (800^{o}C); B (900^{o}C); and C (1000^{o}C). The nine samples were compacted with a pressure of 90 kg/cm^2.

Table 1.
Materials Balance Used in Research

Samples	*Temperature Sintering (ºC)*	*Weight %*		
		Cu	C	Ti
0 A	800			
0 B	900	99.4	0.6	0
0 C	1,000			
0.5 A	800			
0.5 B	900	98.9	0.6	0.5
0.5 C	1,000			
1.5 A	800			
1.5 B	900	97.9	0.6	1.5
1.5 C	1,000			

MMC CuC-Ti alloy samples were characterized by hardness, XRD, SEM, and metallographic testing. Hardness testing using Vickers with a load of 50 kg and a magnification of 100 µm. XRD (X-Ray Diffraction) testing aims to analyze the composition of the phases and compounds contained in the sample[6]. The SEM-EDS (Scanning Electron Microscopy - Energy Dispersive Spectrometer) test aims to determine the surface morphology of the specimens and analyze the elements formed in the material[7].

SEM-EDS testing uses the SU3500 type HITACHI instruments. Metallographic testing was carried out with an optical microscope with a magnification of 50, 100 and 200 to determine the microstructure formed. All characterization results are compiled and processed in graphical form, which correlates process parameters with characteristics of microstructures, and composition of elements.

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RESULT AND DISCUSSION

Research data can be obtained from the processed characterization results consisting of values and graphs. The characterization or testing process carried out on samples is Vickers hardness testing, Metallographic and Porosity testing, SEM-EDS testing, and XRD testing.

Hardness Testing (Vickers)

The results of the analysis of Vickers hardness testing of MMC CuC-Ti alloy samples are shown in Table 2.

Table 2.
Value Hardness Vickers

Samples	*Hardness (*HVN*)*			*Average (*HVN*)*
	I	II	III	
0A	41.35	30.26	38.45	36.69
0.5A	52.00	63.63	61.29	58.97
1.5A	86.43	96.15	79.16	87.25
0B	27.52	29.28	28.28	28.36
0.5B	62.77	44.70	43.02	50.16
1.5B	50.46	59.96	52.28	54.23
0C	27.53	28.43	28.58	28.18
0.5C	39.67	34.57	39.88	38.04
1.5C	48.43	50.46	43.00	47.30

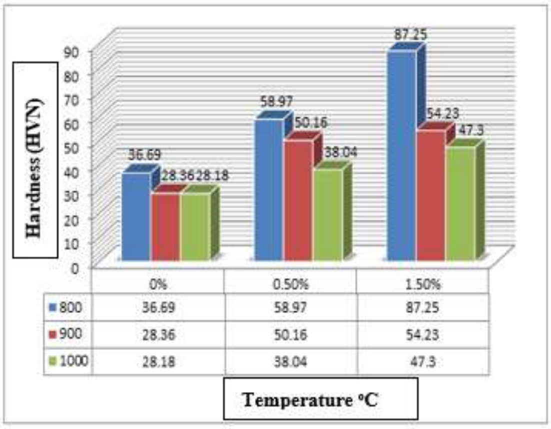

Figure 1.
The Average Hardness Testing Result

The data shows that the higher Ti addition to the mixture of MMC CuC, the mechanical properties will be more robust. Strengthening of the dispersion occurs in powder metallurgical processes, where the compacting process followed by the sintering process is carried out in the mixing of hard powders and functional matrix powders. The hard particle will oppose the movement of dislocation. Overcoming dislocation occurs and dislocation[8] which lead to an increase in the strength of mechanical properties.

The CuC alloys, which are sinter at the temperature of 900°C and 1000°C have a lower hardness value compared with 800°C. This occurred because the sintering process at high temperature occurs thermally and requires a diffusion process and resulting coarsening Cu become large grain[9].

Metallography Testing

Metallographic testing was carried out on MMC CuC-Ti alloy samples from the sintering process with temperatures of 800°C, 900°C and 1000°C. Metallographic testing is carried out to examine the microstructure formed on the CuC alloys.

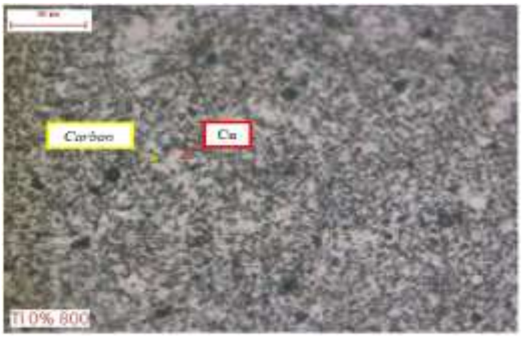

Figure 2.
Microstructure of the Specimen Ti 0%, 800°C

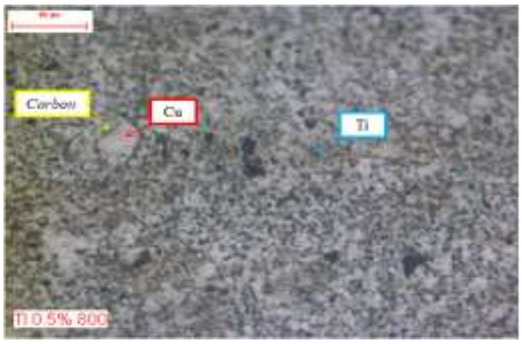

Figure 3.
Microstructure of the Specimen Ti 0.5%, 800°C

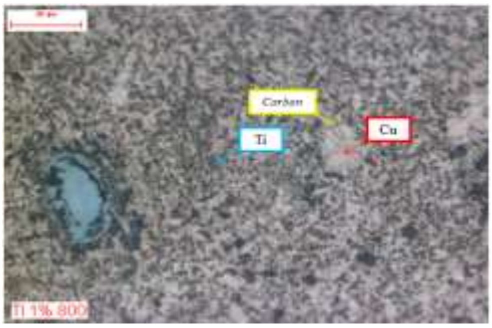

Figure 4.
Microstructure of the Specimen Ti 1.5%, 800°C

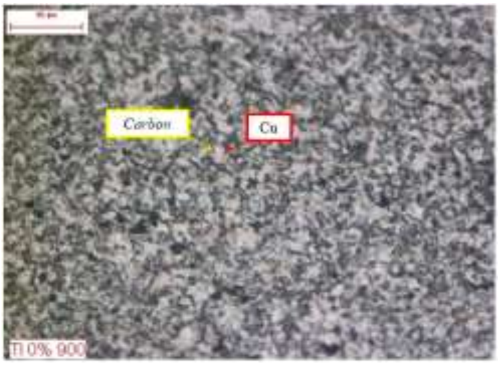

Figure 5.
Microstructure of the Specimen Ti 0%, 900^{o}C

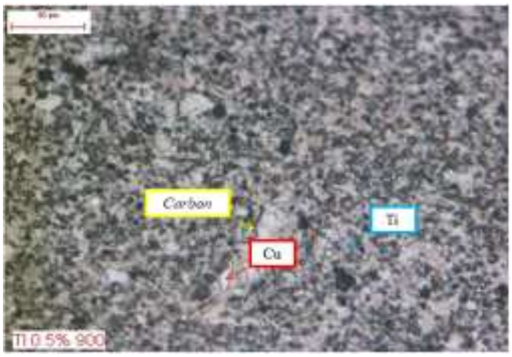

Figure 6.
Microstructure of the Specimen Ti 0.5%, 900^{o}C

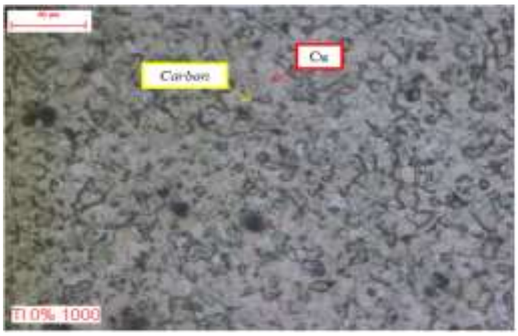

Figure 7.
Microstructure of the Specimen Ti 1.5%, 900^{o}C

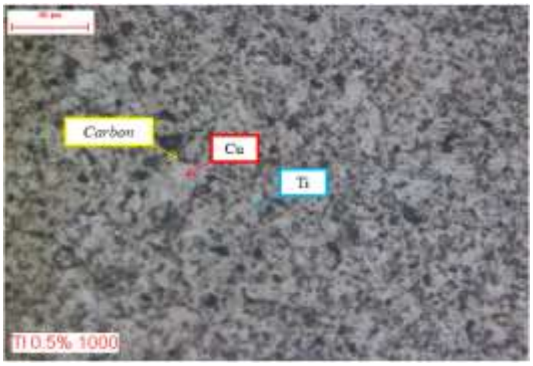

Figure 8.
Microstructure of the Specimen Ti 0%, 1000^{o}C

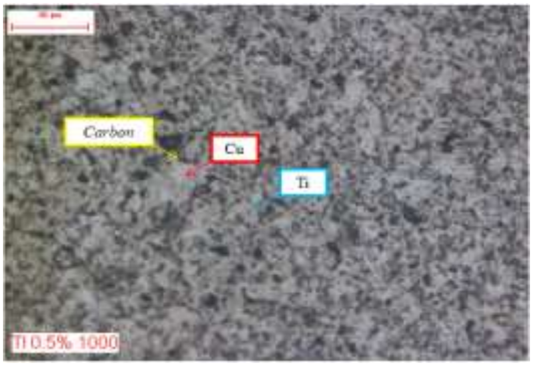

Figure 9.
Microstructure of the specimen Ti 0.5%, 1000^{o}C

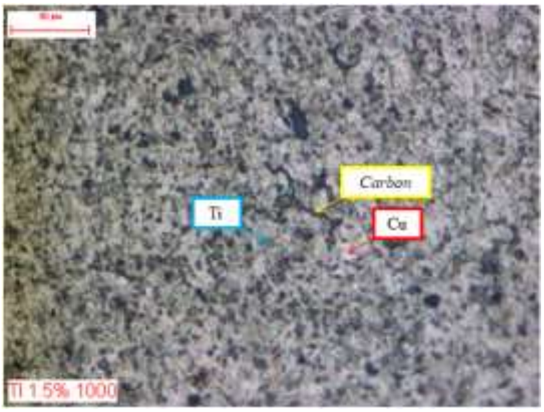

Figure 10.
Microstructure of the Specimen Ti 1.5%, 1000^{o}C

A number of the images above are the result of metallographic testing using an optical microscope with 200 magnification. After doing a qualitative analysis on the sample, it can identify the phases that appear, items with a bright colour (Cu), black with a position on the grain boundary (Carbon)[10)], and grains with a grey colour (Ti)[11)]. From the above data, it can also be seen that there are several microstructures with large grains. This is caused by an increase in temperature, which will affect the mechanical properties of the material. This event is following the sound of Hall-petch law, the larger the diameter of the grain the material hardness will decrease[8)]. Hall-petch's law can be proven by conducting quantitative analysis of microstructure.

Grain Size Measurement

The grain size measurement is conducted so that the grain size owned by each microstructure of each sample can be measured. The grain size then is related to the hardness testing result conducted on each specimen. The measurement process of this item uses two methods, namely the Heyn method and the Jeffries method, which refers to the ASTM E112 standard[12)].

Table 3.
Value Average Grain Size Measurement

No.	% Ti	*Temperature Sintering* (°C)	*Grain Size Average* (μm)	
			Method Heyn	*Method Jeffries*
1	0%		2.89	10.22
2	0.5%	800	2.39	9.66
3	1.5%		2.00	9.28
4	0%		3.07	10.30
5	0.5%	900	2.64	9.84
6	1.5%		2.50	9.69
7	0%		3.25	11.58
8	0.5%	1,000	3.03	9.95
9	1.5%		2.81	9.60

The measurement of the grain size of the microstructure of each sample shows that the average grain size will get bigger as the sintering temperature increases. The ideal sintering temperature is at 813°C. If the given temperature has exceeded the ideal sintering temperature will result, in not only melting the surface of the grain but almost completely, especially at temperatures of 1,000°C which results in over sintering and grain enlargement [13]. Based on the results of the calculation of average grain size with the Heyn method, the largest average grain size is 3.25 μm in the Ti sample of 0% (1,000°C) and the smallest average size of the meat is 2.00 μm in the Ti specimen of 1.5% (800°C). Likewise, with the results of the Jeffries method which is directly proportional to the Heyn even though the nominal yields are different.

Porosity Measurement

Table 4.
Data Sample Porosity Measurement

No.	*Composition*	*Temperature Sintering* (°C)	*Porosity* (%)
1		800	10.279
2	CuC+Ti 0%	900	6.265
3		1,000	3.393
4		800	7.591
5	CuC+Ti 0.5%	900	4.626
6		1,000	3.022
7		800	5.589
8	CuC+Ti 1.5%	900	4.035
9		1,000	2.491

Porosity data obtained from the observation of microstructure with a magnification of 200 and supported by image J software that aims to facilitate the porosity calculation process in the sample. The results shown are in the form of red areas indicating grain and black is porosity.

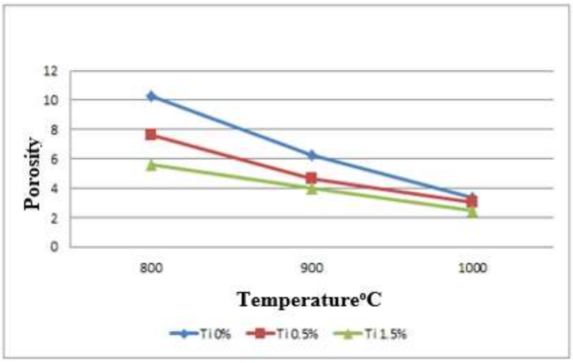

Figure 11.
Effect of Ti Concentration on
the Porosity of CuC

Based on the results of porosity testing using Image-J software on a microstructure with a magnification of 200 shown in Table 4 and Figure 11, porosity decreases with increasing sintering temperature. Increasing the temperature becomes greater causing an enlargement of the necking area on each powder particle which will cover the cavities between the powder particles, and the binding of the powder particles so that the percentage (%) porosity will decrease[14]. The lowest porosity value is owned by a temperature of 1000°C, with Ti 1.5% of 2.491. In comparison, the highest porosity% value is at a temperature of 800°C with Ti 0% of 10.279%.

XRD Testing (X-Ray Diffraction)

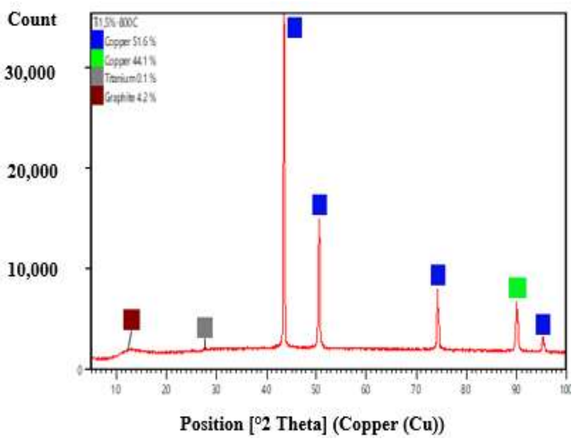

Figure 12.
XRD Specimen of Ti 1.5%, 800°C

Table 5.
XRD Specimen of Ti 1.5%, 800°C

No	*Symbol*	*Position [2 Theta] (Cu)*	Cu	Ti	*Graphite*
1		43.508	✓		
2		50.607	✓		
3		74.312	✓		
4		90.089	✓		
5		95.313	✓		
6		27.643		✓	
7		12.218			✓

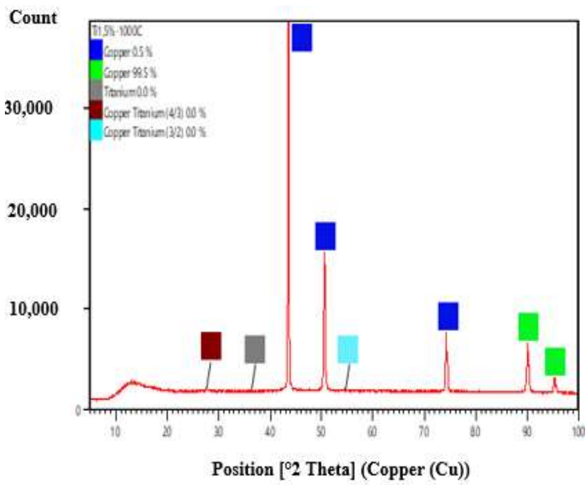

Figure 13.
XRD of Ti 1.5%, 1,000°C

Table 6.
XRD of Ti 1.5%, 1,000°C

No	*Symbol*	*Position [2 Theta] (Cu)*	Cu	Ti	Cu/Ti
1		43.550	✓		
2		50.646	✓		
3		54.523			✓
4		74.331	✓		
5		90.100	✓		
6		95.134	✓		
7		27.670			✓
8		36.334		✓	

X-Ray Diffraction (XRD) testing was carried out on 2 samples, namely samples using sintering temperatures of 800°C with 1.5% Ti composition, and samples using sintering temperatures of 1000°C with 1.5% Ti compositions. The XRD test results are shown in Fig.13 - 14 and Table 5 -6.

XRD testing was carried out on two samples that had been sintered, namely the samples 1.5A and 1.5C. The XRD results show the highest peak obtained in sample 1.5A at position 95.313, while the 1.5C sample with the highest peak at position 95.134 with Cu each at the highest peak.

Data SEM-EDS Testing

SEM is an electron microscope that is designed to investigate the surface of solid objects directly, which has a magnification of 10 - 3000000x, depth of field 4 - 0.4 mm and a resolution of 1-10 nm[15].

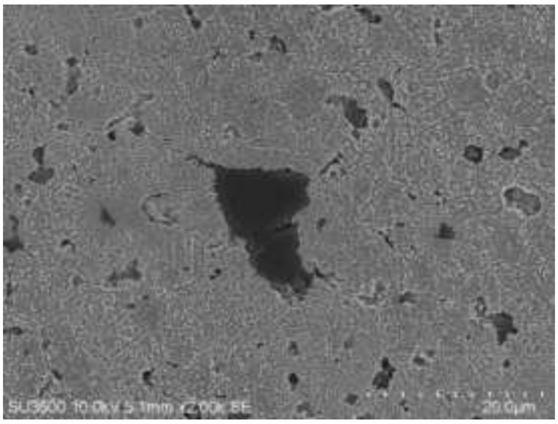

Figure 14.
SEM Specimen of Ti 1.5%, 800°C

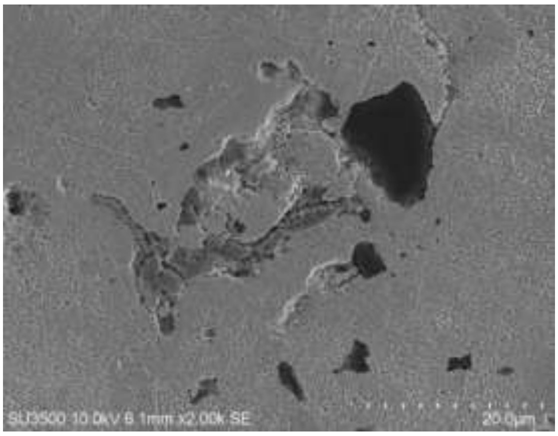

Figure 15.
SEM Specimen Ti 1.5%, 1,000°C

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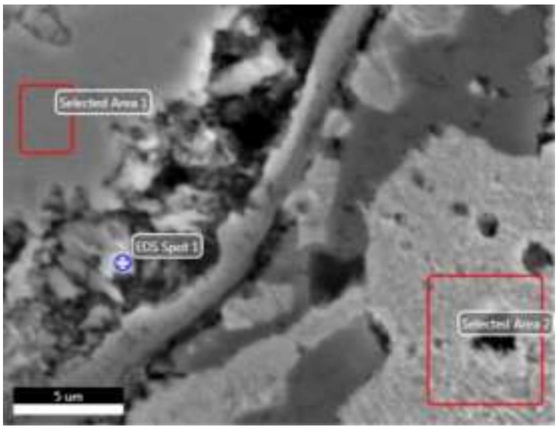

Figure 16.
EDS Specimen of Ti 1.5%, 800°C

Table 7.
Mapping EDS Specimen of Ti 1.5%, 800°C

Content (W%)	*Area 1*	*Area 2*	*Spot 1*
Cu	57.78	73.49	54.67
C	1.44	10.16	3.60
Ti	40.78	16.34	41.74

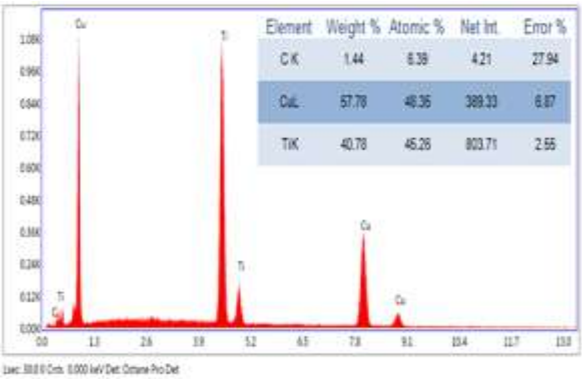

Figure 17.
Result EDS Area 1

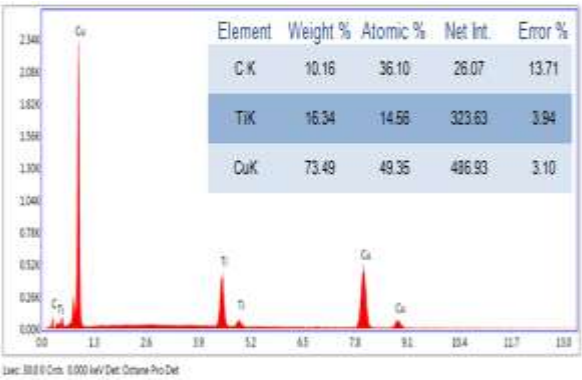

Figure 18.
Result EDS Area 2

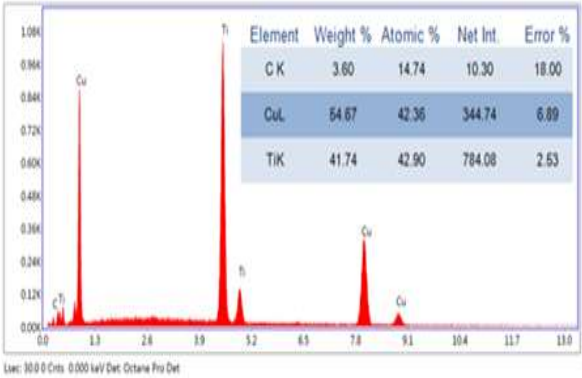

Figure 19.
Result EDS Spot 1

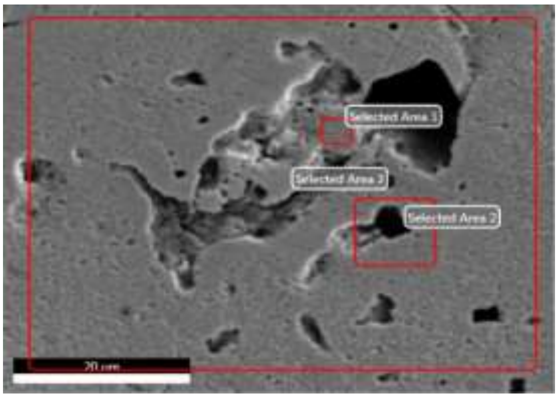

Figure 20.
EDS Specimen of Ti 1.5%, 1,000°C

Table 8.
Mapping EDS (Ti 1.5%, 1,000°C)

Content (W%)	*Area 1*	*Area 2*	*Area 3*
Cu	96.92	77.81	85.02
C	2.79	21.86	13.54
Ti	0.29	0.33	1.44

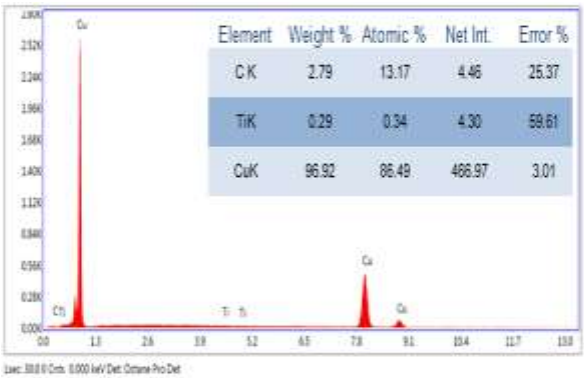

Figure 21.
Result EDS Area 1

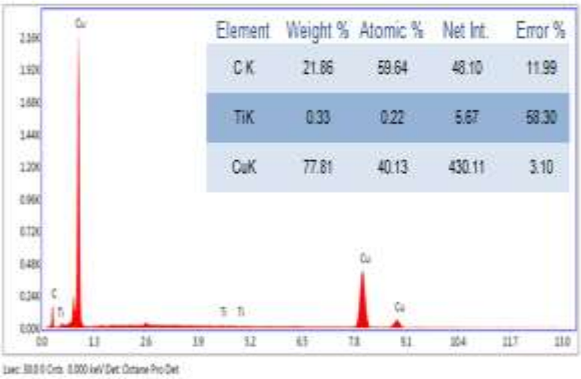

Figure 22.
Result EDS Area 2

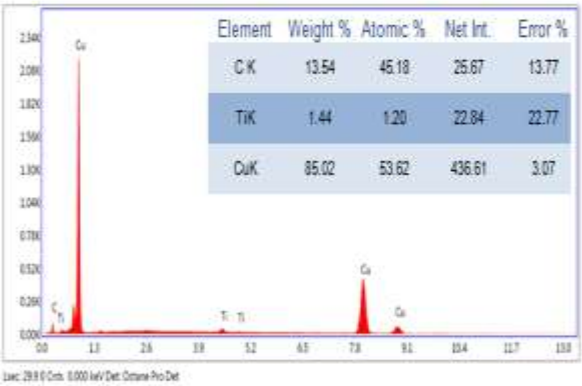

Figure 23.
Result EDS Area 3

Based on XRD and EDS test results, the composition is relatively the same even though the spot and test area differ according to the XRD table in Table 5 and Table 6, and Figure 15 and Figure 16 where the highest element is Cu as the main element then Ti and C which form graphite as well as the EDS test which shows the element Cu as the element with the highest percentage then Ti and C as the reinforcing element[11)].

CONCLUSIONS

From the results of this study, it can be concluded that the addition of Ti can affect the mechanical properties of the material, one of which is hardness. The highest hardness value is owned by samples with Ti 1.5% at 800ºC, which is 87.25 HVN and the lowest hardness is owned by samples with Ti 0% at 1,000ºC temperature which is 28.18 HVN.

The temperature variation influence on the grain size of the material after measuring grain size, the higher the temperature given, the larger the grain size is in line with the decreasing value of the material hardness. After doing a qualitative analysis on the sample, it can identify the phases that appear, items with a bright colour (Cu), black with a position on the grain boundary (Carbon), and grains with a grey colour (Ti). Based on the results of the calculation of average grain size with the Heyn method, the largest average grain size is 3.25 µm in the Ti sample of 0% (1,000ºC) and the smallest average size of the meat is 2.00 µm in the Ni sample of 1.5% (800ºC). Likewise, with the results of the Jeffries method which is directly proportional to the Heyn even though the nominal yields are different. Temperature variation also affects the percentage of porosity of the material, the higher the temperature given, the percentage of porosity decreases due to the greater necking area of each powder particle. The lowest porosity value is owned by a temperature of 1000ºC, with Ti 1.5% of 2.491. While the highest porosity% value is at a temperature of 800ºC with Ti 0% of 10.279%.

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