Chapter 16
Manufacturing of Copper Based Composites Reinforced with Ceramics and Hard Intermetallics for Applications of Electric Motor Repair Parts

G. Zambelis, E. Bayraktar, D. Katundi, and I. Miskioglu

Abstract In the present work, a recycled copper based composites reinforced with ceramic as an alternative replacement for the application of electric motor repair parts with the use of novel processing techniques.

A practical solution was proposed as cost effective economic manufacturing of the composites for this type of applications. Copper based composite design (Cu-Al-Nb_2Al) was based on the ceramic reinforcements such as titanium carbide (TiC) in different percentages and niobium aluminate intermetallics (Nb_2Al). Because TiC and Nb_2Al make a good combination of thermal and electrical conductivities, microstructural stability and strength retention at elevated temperatures, etc. These reinforcements increase considerably wear resistance of the composites for electrical contact applications. Otherwise, certain percentage of fresh scrap aluminium powder, the mixture of AA1050 (80 wt% + AA7075 (20 wt %) chips were used to create an exothermic combustion reaction in the process for helping diffusion bonding process of the ceramics to the copper matrix. At the first stage of the present work a preliminary study has been carried out for developing a cost effect and high wear resistant electrical brushes for aeronautical applications. Microstructural and wear analyses have been carried out to optimize the process conditions for a practical tool that will be used for final industrial applications. Three basic compositions were prepared depending on the percentage of TiC. The microstructure and damage analyses have been carried out by Scanning Electron Microscope (SEM).

Keywords Copper matrix composites · Titanium carbide · Ceramic reinforcements · SEM-microstructure

16.1 Introduction

Safety design of the high resistance and high toughness composites is a vital requirement for operational materials that will be manufactured for critical and safety applications, in there early fracture cannot be accepted. The development of high resistance but high toughness composites has usually been a bridge between hardness vs. ductility. In the present work, a recycled copper based composites (Cu-Al-Nb_2Al) reinforced with ceramic as an alternative replacement for the application of electric motor repair parts with the use of novel processing techniques. Our motivation is on the interpretation of the microstructure of this composite developed in this work and explain the interface relationship between the matrix and reinforced elements and micro-mechanisms at the interface. This idea can help the significance of the relation between strength and toughness in the composites. As well known, copper is very important materials for this application especially for the electrical contact such as for the manufacturing of the brush used in the electrical motors as an important parts and/or other electronic devices. However, the copper based composites have lower wear resistance.

In the literature, different kind of compositions have been proposed for finding a solution to this problem. Generally, these solutions proposed as high strength and high wear resistant composites for electronics applications in the commercial markets are expensive and takes a long production time. For this reason, we have tried to propose a solution as cost effective economic manufacturing of the composites for this type of applications. Copper based composite design was based on

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the ceramic reinforcements such as titanium carbide (TiC) in different percentages and niobium aluminate intermetallics (Nb_2Al). Because TiC and Nb_2Al make a good combination of thermal and electrical conductivities, microstructural stability and strength retention at elevated temperatures, etc. These reinforcements increase considerably wear resistance of the composites for electrical contact applications. Otherwise, certain percentage of fresh scrap aluminium powder, the mixture of AA1050 (80 wt% + AA7075 (20 wt %) chips were used to create an exothermic reaction in the process for helping diffusion bonding process of the ceramics to the copper matrix.

The first stage of the present work a preliminary study has been carried out for developing a cost effect and high wear resistant electrical brushes for aeronautical applications. Microstructural and wear analyses have been carried out to optimize the process conditions for a practical tool that will be used for final industrial applications.

16.2 Experimental Conditions

In the present work, an alternative copper based composite was designed. As the basic ceramic reinforcements such as titanium carbide (TiC) in different percentages and niobium aluminate intermetallics (Nb_2Al). These ceramic reinforcements make a good combination of thermal and electrical conductivities, microstructural stability and strength retention at high temperatures, etc. Additionally they increase considerably wear resistance of the composites. Copper and aluminium fresh scrap recycled chips in the atomized form given by French aeronautic company. The composites was fabricates through the combined method of powder metallurgy (Sintering) followed by Forging at high temperature.

A typical Cu-Al-Nb_2Al matrix was developed and reinforced basically with TiC (10, 20 and 30 wt %) and Nb_2Al.

Mixture has been carried out by using high energy milling in a planetary ball mill for 4 h.

Three composites were prepared with three different percentages of TiC, here called after S1, S2 and S3 also one composition was kept without TiC reinforcement (SB) for comparison with the reinforced ones. Otherwise, for easy wettability of the reinforcement of TiC and Nb_2Al, percentage of fine graphite +5 wt % GnPs (graphene nano particles and fine aluminium powder was added in the mixture. In fact, the mixture of AA1050 (90 wt % + AA7075 (10 wt %) chips were used to create an exothermic reaction in the process for helping diffusion bonding process of the ceramic reinforcement and Nb_2Al intermetallics to the copper matrix. Hot compaction was made at 300 MPa and sinter + forging has been carried out at 850 °C under inert atmosphere. The composites produced with this novel combined method have certain advantages regarding to conventional manufacturing processes such as low cost, capability of manufacturing of the pieces with complex shapes, and processing simplicity, etc. The compositions of the three groups developed in the present work were given in Table 16.1.

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Microstructural characterization and Mapping analyses was done by means of scanning electron microscope (SEM). The dispersion of reinforcement particles in the matrix and interface at matrix/reinforcements was evaluated. Micro hardness tests ($HV_{0.1}$) have been carried out on the polished and etched specimens.

All the density measurements of the specimens were carried out by using *Archimedes* method. These values change between 7.82, 6.88, 7.65 and 7.90 ± 3 for the SB, S1, S2 and S3 respectively.

Wear resistance was measured by scratch wear tests at a frequency of 15 Hz. All of the compositions were tested in two different numbers of cycles, $50*10,^3$ $100*10^3$ cycles. After scratch test, damaged zone was investigated by 3D optical roughness meter. Surface and volume loss/time and maximum depth were evaluated for damage characterization.

Table 16.1 Copper based composites and distribution of the reinforcements in the matrix

Cu based composites Cu-Al-Nb_2Al	SB	S1	S2	S3
Major reinforcementTiC (wt %)	–	10	20	30

16.3 Results and Discussions

16.3.1 Microstructure and Mapping Analyses of the Compositions Produced by "Sinter + Forging Process"

General microstructures of the four compositions (SB, S1, S2 and S3) were presented in the Fig. 16.1. It is noted that the main structure of SB without reinforcement is eutectic structure with aluminium, TiC and Nb_2Al contents. Distribution of elements in the matrix quasi homogenous with mutual diffusion can be observed very clearly the reinforcements with matrix. It seems that certain elements are smoothly precipitated around the grain boundaries.

However, local agglomeration of the graphite with graphene is also observed in certain zones. This case is directly related of mixture conditions. All of the specimens were prepared under our laboratory conditions, therefore, it should be improved operational conditions. As for the reinforcements, Titanium carbide was appeared on the microstructure.

The microstructure of the composites with reinforcements obtained thorough the combine method sinter + Forging are seems very homogeneous and improved with a good diffusion bonding due to the addition of the aluminium in the matrix that creates an exothermic reaction. The eutectic structure was observed in the structure and mainly the reinforcement particles made a good diffusion chemical bonding with matrix by means of the exothermic reaction of the aluminium in the matrix. At the second stage of the process, it means that hot forging influences the microstructure considerably. For this reason, this novel techniques should be accepted as more advantageous than the conventional methods.

As obtain vey homogenous structure with the combined method, the microstructure and mapping quantitative analyses have been carried out by SEM to see the distribution of the reinforcement and further auxiliary elements in the composites. Mapping Figs. 16.2, 16.3, 16.4 and 16.5 present the general distribution of the micro and nano size particles in the microstructures of the four compositions, respectively. It is noted that the distribution of certain auxiliary elements, for example, Nb_2Al, and Graphite and GnPs show small agglomeration in the matrix but the main particles are very smoothly distributed. This is main advantage of the combined method; sinter+forging. In any case, these structures can be improved by means of operating parameters it means that experimental parameters such as milling conditions, sintering and forging temperature, etc. should be controlled for obtaining ideal microstructures. For each composition, "EDS" analyses were given in the same mapping figures.

16.3.2 Wear (Scratch) Test Results

Reduction of friction is always a significant task for wear-resistant composites. The actual composite (Cu-Al-Nb_2Al) was developed for the future electronic devices, especially for the electrical brushes, etc. where the wear resistance is needed. For this reason, all of the specimens taken for each composition were measured their wear resistance experimentally. Evaluation of the wear resistance of these composites have been carried out in two different numbers of cycles, $50*10^3$, and $100*10^3$ cycles. Influence of reinforcement elements and essentially influence of the manufacturing processes, sinter + Forging are observed for four different specimens in the Fig. 16.6 and also wear (scratch) test results were given in Table 16.2 for the specimens SB, S1, S2 and S3 respectively.

The surface damage (mm^2), volume lost (μm^3) and the depth (μm) values are presented in the same figures for each test condition. Effects of reinforcements and obviously, the effects of the sinter + Forging process are observed as an advantage over others.

As shown in the results of scratch tests, the composites reinforced with ceramics, TiC and hard intermetallics Nb_2Al has shown always higher wear resistance regarding to the simple structures. In this particular case, the size of the reinforcements and their dispersion on the matrix should have contributed to improve the wear resistance under experimental conditions carried out in the present work.

Micro hardness evaluation has been carried out on the mounted and polished specimens obtained only by the combined method; Sinter + Forging. It is noted that the hardness values have shown an increase but these are not so considerable increase as shown in the Table 16.3. This increase was observed directly with the percentage of the reinforcement elements. In fact, the reinforcements used here, such as boron oxide TiC and also auxiliary Nb_2Al have a considerable effect on the mechanical properties that can be optimized by using these composites.

Total evaluations of the microstructure and also wear-scratch tests give a clear idea about the combined process (sintered + forging). This process applied for these types of composites is caused by bonding diffusion at the interface between matrix and reinforcement and some of the particles were forced into the grains during the forging (second) stage of this process. For

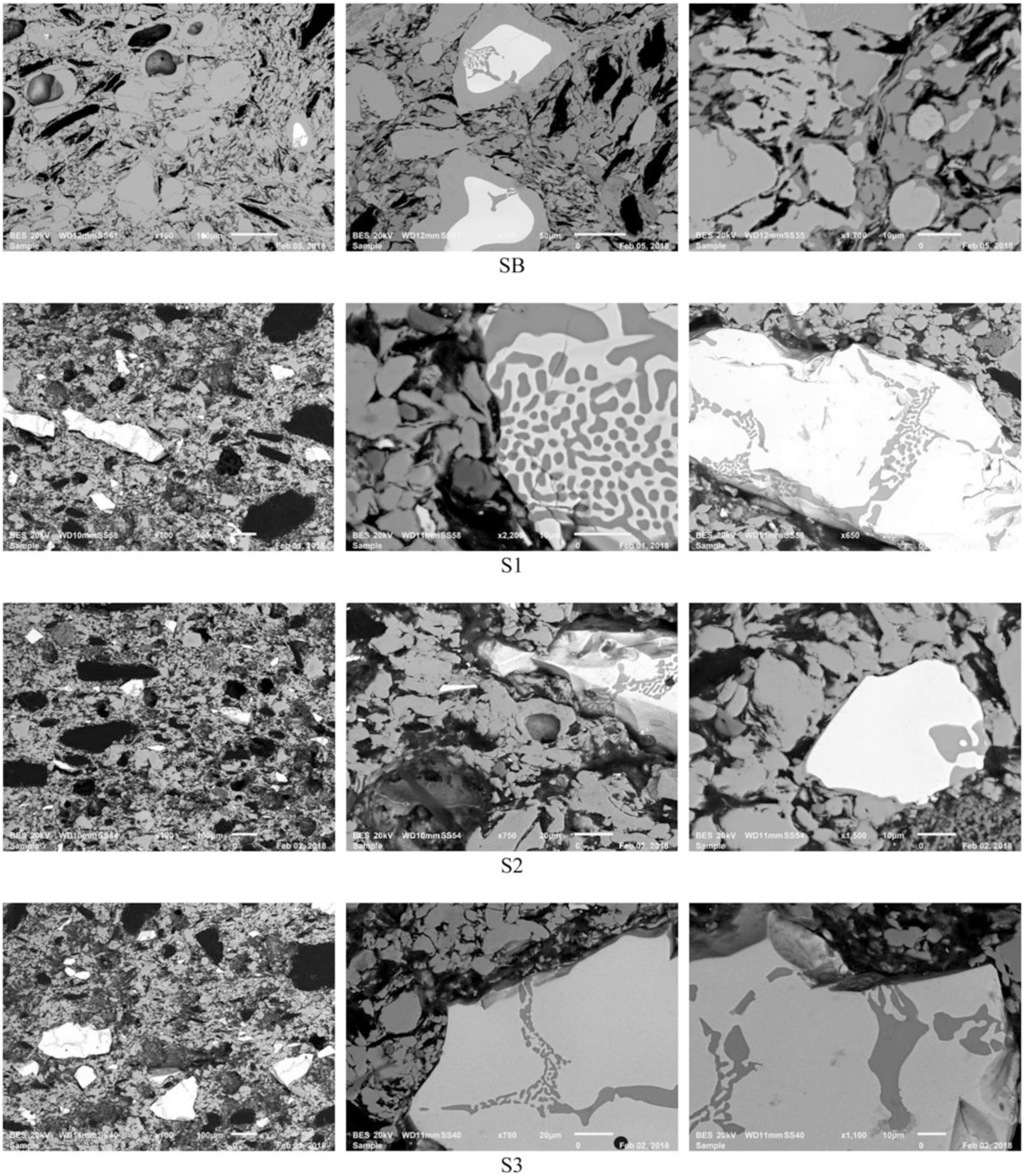

Fig. 16.1 General microstructure of the compositions produced by double process; sintering + Forging), SB, S1, S2vand S3, respectively

this reason, very tough, solid and homogeneous composite structure could be obtained. Porosity and other structural – micro defects were quasi eliminated.

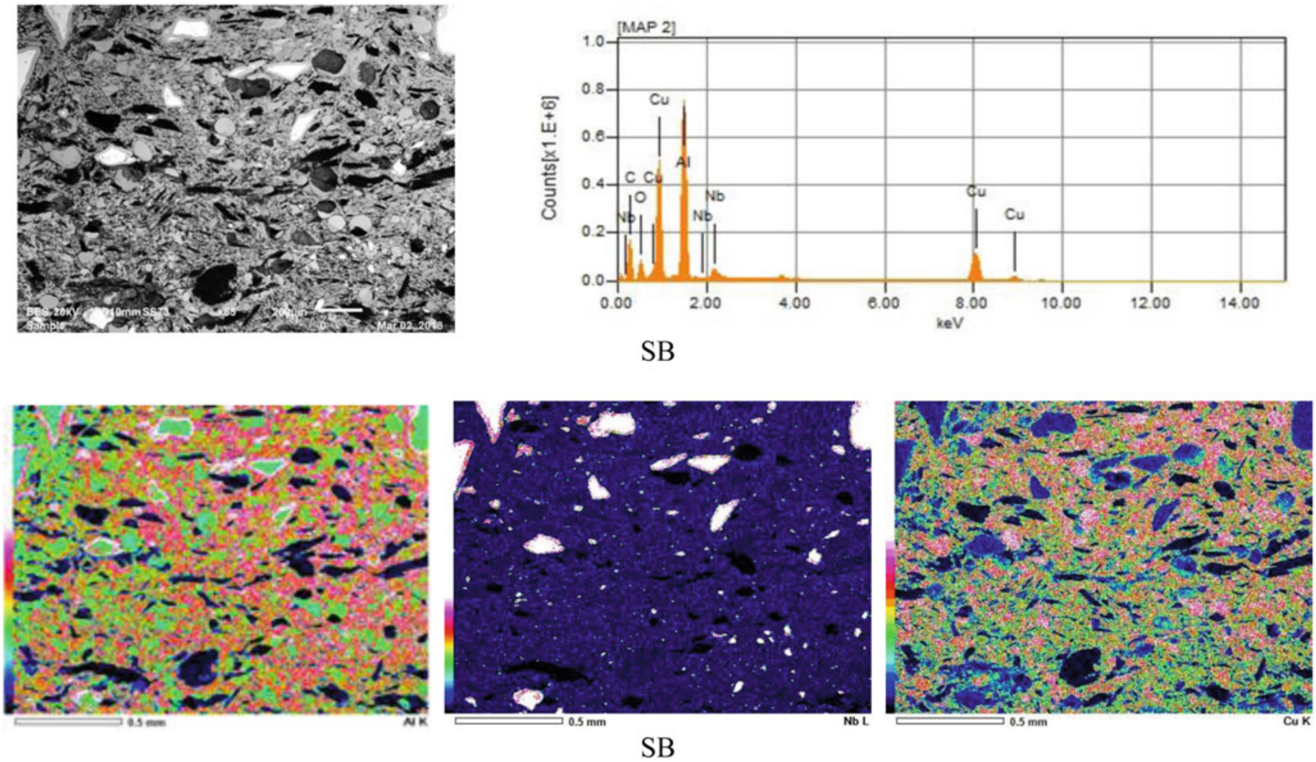

Fig. 16.2 Mapping analyses of the composite for SB produced by combined process; Sinter + Forging

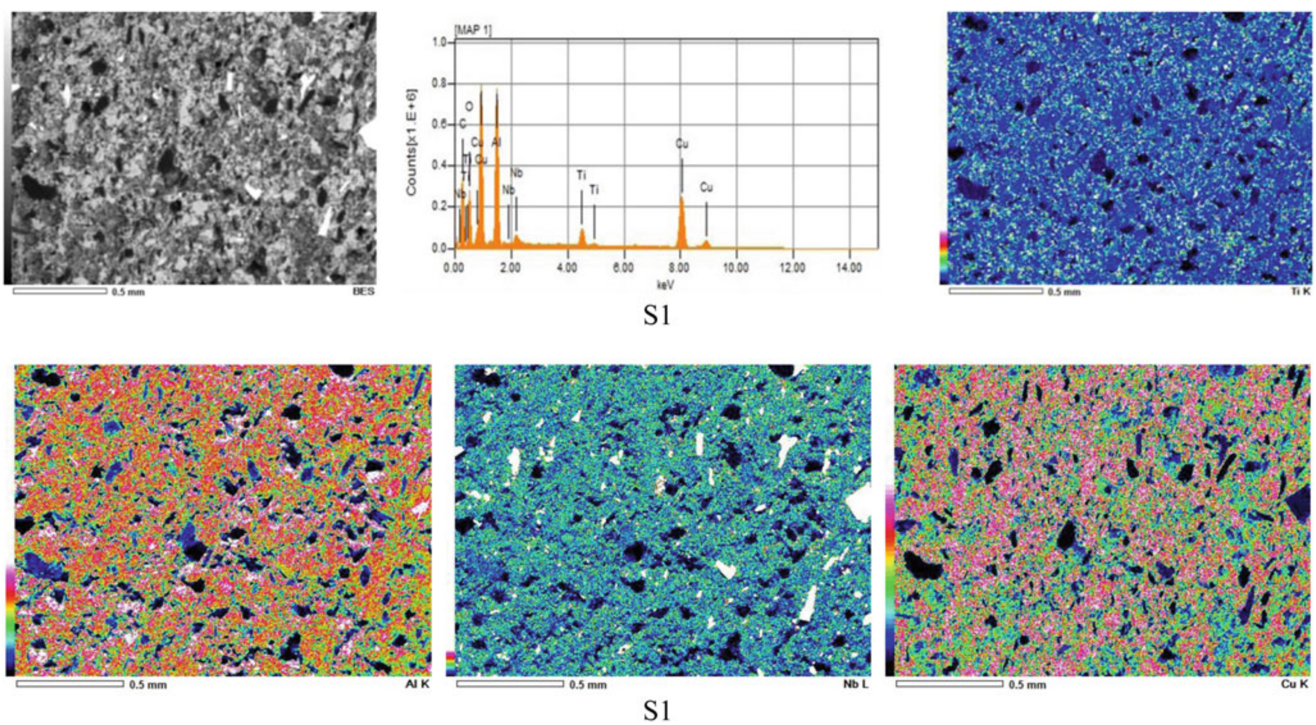

Fig. 16.3 Mapping analyses of the composite for S1 produced by combined process; Sinter + Forging

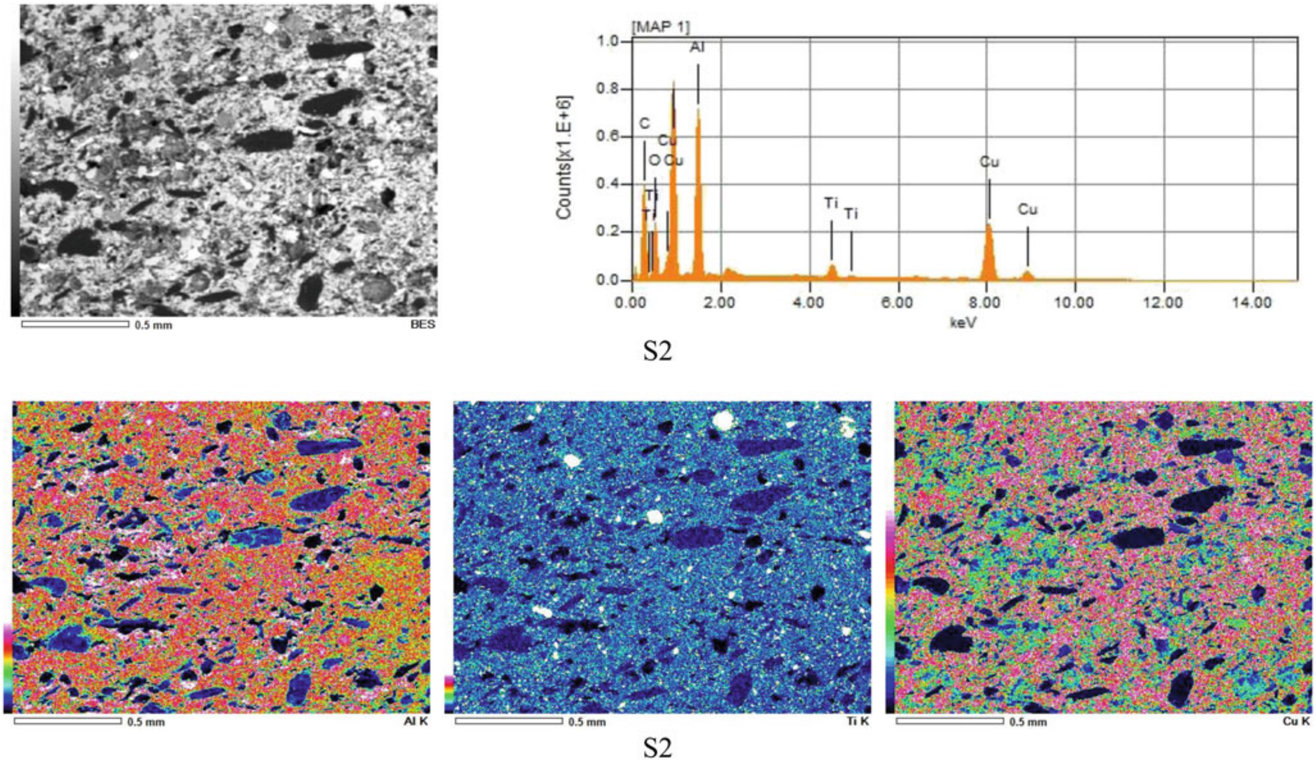

Fig. 16.4 Mapping analyses of the composite for S2 produced by combined process; Sinter + Forging

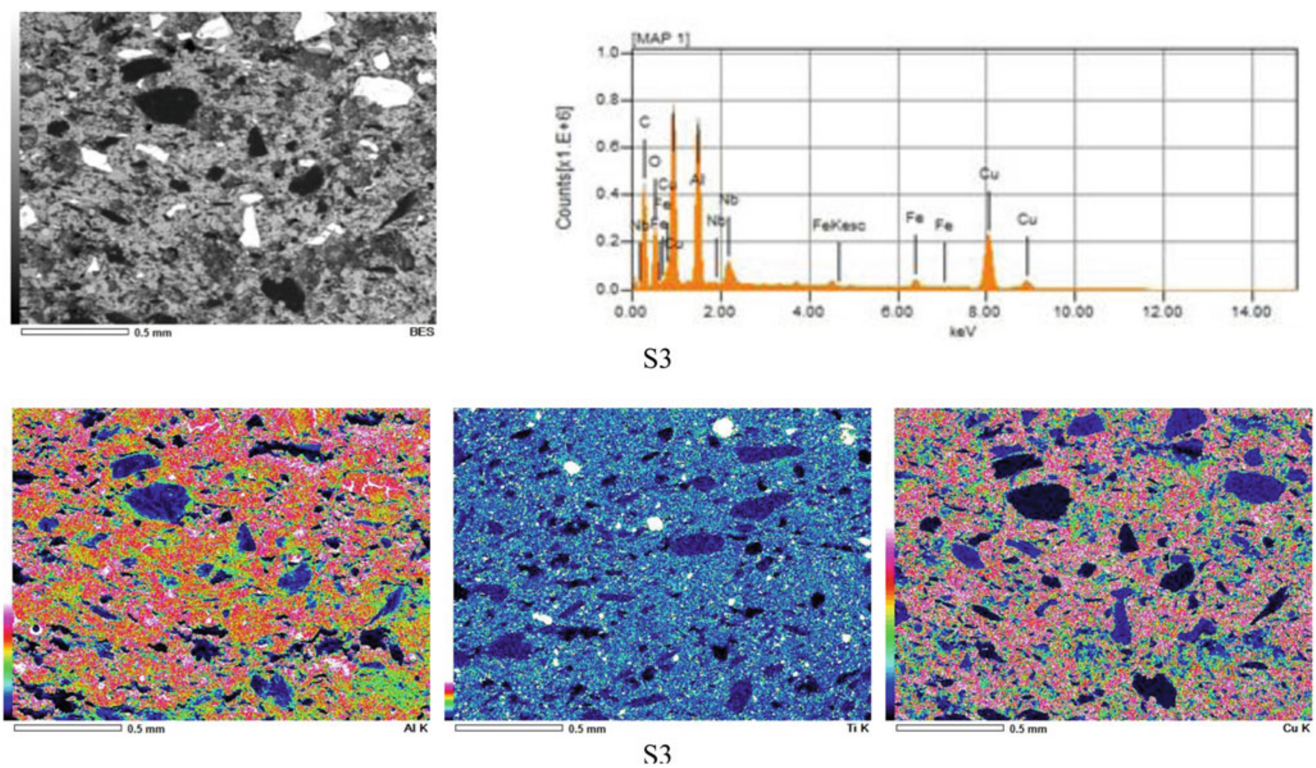

Fig. 16.5 Mapping analyses of the composite for S3 produced by combined process; Sinter + Forging

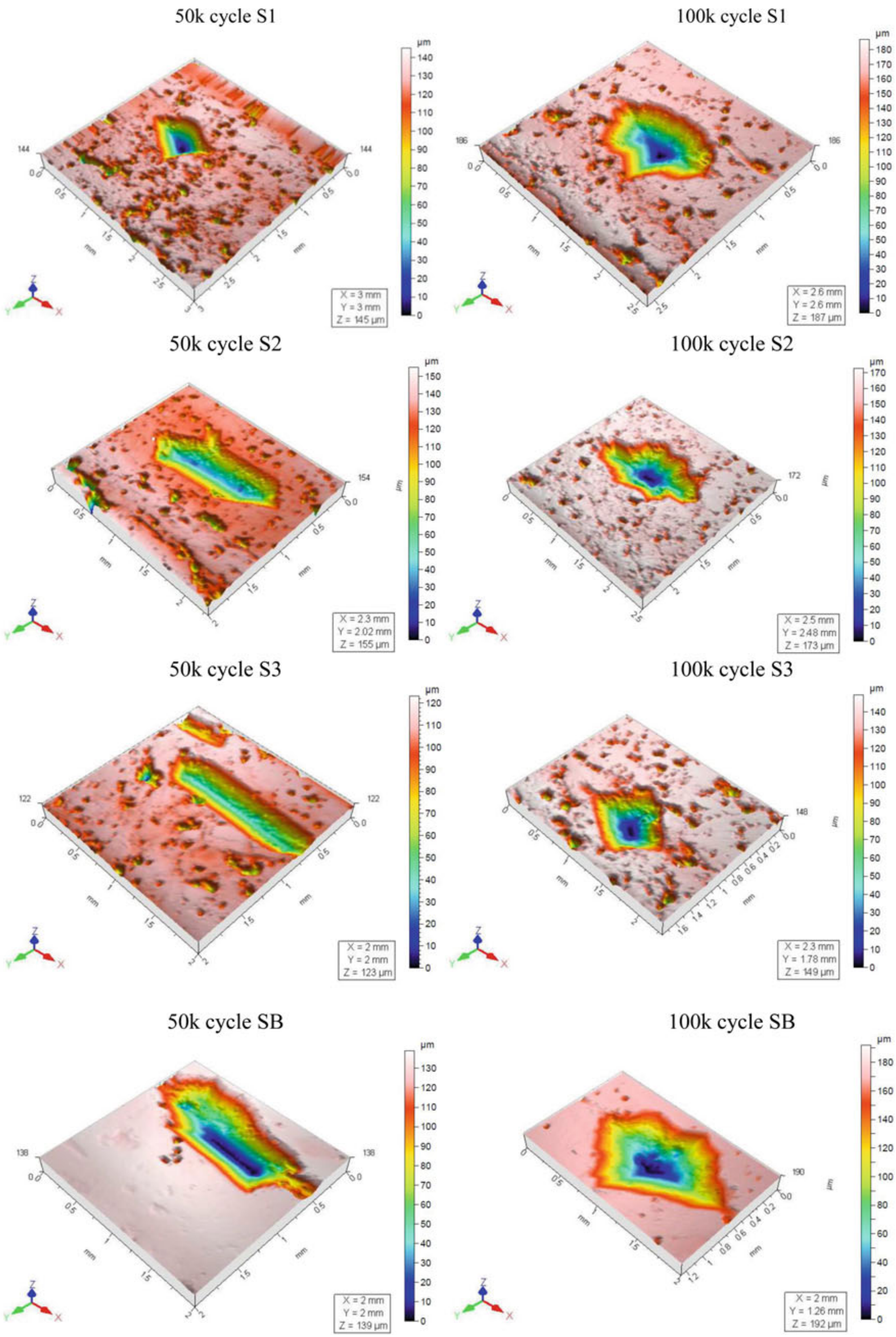

Fig. 16.6 Images of surface damage zones produced by wear – scratch test results for four different compositions in the cycle of $50*10^3$ and 100.10^3 cycles for the comparison of damage zone defined with surface and volume lost

Table 16.2 Wear (macro scratch) test results for tested specimens in this work

Wear test	50.10^3	Cycles	100.10^3	Cycles
Composition	Worn surface mm^2	Worn volume μm^3	Worn surface mm^2	Worn volume μm^3
SB	1.18	52,213,634	1.09	62,269,062
S1	0.859	37,358,445	1.06	58,333,931
S2	0.655	17,914,695	0.531	26,512,388
S3	0.549	23,261,026	1.12	62,225,704

Table 16.3 Micro hardness (HVN) measurements for the compositions as mean values

Cu based composites	Composition			
	SB	S1	S2	S3
Micro hardnessMean values (HVN)	95 ± 15	141 ± 12	174 ± 11	182 ± 24

16.4 Conclusion

In the present work, a recycled copper based composites reinforced with ceramic as an alternative replacement for the application of electric motor repair parts with the use of novel processing techniques.

A practical solution was proposed as cost effective economic manufacturing of the composites for this type of industrial applications. Copper based composite design (Cu-Al-Nb_2Al) was based on the ceramic reinforcements such as titanium carbide (TiC) in different percentages and niobium aluminate intermetallics (Nb_2Al). Because TiC and Nb_2Al make a good combination of thermal and electrical conductivities, microstructural stability and strength retention at elevated temperatures, etc. These reinforcements increase considerably wear resistance of the composites for electrical contact applications. Otherwise, certain percentage of fresh scrap aluminium powder, the mixture of AA1050 (80 wt% + AA7075 (20 wt %) chips were used to create an exothermic reaction in the process for helping diffusion bonding process of the ceramics to the copper matrix. At the first stage of the present work a preliminary study has been carried out for developing a cost effect and high wear resistant electrical brushes for aeronautical applications. By this way, low cost manufacturing of these composites have been successfully managed through the combined method of sinter + forging.

The microstructure of the composites with reinforcements obtained thorough the combine method sinter + Forging are seems very homogeneous and improved with a good diffusion bonding due to the addition of the aluminium in the matrix that creates an exothermic reaction. The eutectic structure was observed in the structure and mainly the reinforcement particles made a good diffusion chemical bonding with matrix by means of the exothermic reaction of the aluminium in the matrix. At the second stage of the process, it means that hot forging influences the microstructure considerably. For this reason, this novel techniques should be accepted as more advantageous than the conventional methods.

Optimizations of the certain parameters such as processing parameters, reinforcement content, etc. need much more experimental work to create real parts in the industrial scales. Here, only limited measurements at room temperature were presented as they are indicative parameters for better understanding the effect of the reinforcements on the microstructure and wear properties of the composites aimed for electrical field area.

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