Volume 14, Issue 3, Page 151-155, 2025 https://doi.org/10.46810/tdfd.1695605 Research Article

BİNGÖL UNIVERSITY

Türk Doğa ve Fen Dergisi
Turkish Journal of Nature and Science
www.dergipark.gov.tr/tdfd

Investigation of the Joining of SiC-Reinforced Copper Matrix Composites via Friction Welding

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(Received: 09.05.2025, Accepted: 02.09.2025, Online Publication: 26.09.2025)

Keywords
Friction welding,
SiC,
Copper matrix composite,
Microstructure

Abstract: Considering that it is inevitable to use dissimilar materials together with the rapidly developing industry, this makes it necessary to join materials with different properties with each other. From this point of view, friction welding method gives good results among solid state welding methods. In the study, the joining of Cu matrix composite material with SiC reinforcement at different rates, produced by using powder metallurgy method, among themselves and with pure copper (Cu) rods via friction welding method was investigated. Optical, SEM, hardness and strength tests were performed after the joining process. As a result of the analysis, it was concluded that it was difficult and problematic to join SiC-reinforced Cu matrix composites via friction welding.

Sürtünme Kaynağı ile SiC Takviyeli Bakır Matrisli Kompozitlerin Birleştirilmesinin Araştırılması

Anahtar Kelimeler
Sürtünme kaynağı,
SiC,
Bakır matrisli kompozit,
Mikroyapı

Öz: Günümüzde hızla gelişen sanayi ile birlikte farklı özelliklere sahip malzemelerin birlikte kullanımı kaçınılmaz hâle gelmiştir. Bu durum farklı fiziksel ve mekanik özelliklere sahip malzemelerin birleştirilmesini zorunlu kılmaktadır. Bu bağlamda katı hâl kaynak yöntemleri arasında yer alan sürtünme kaynağı yöntemi başarılı sonuçlar vermektedir. Bu çalışmada toz metalurjisi yöntemiyle üretilen farklı oranlarda SiC takviyeli Cu matrisli kompozit malzemelerin hem kendi aralarında hem de saf bakır (Cu) çubuklarla sürtünme kaynağı yöntemiyle birleştirilmesi incelenmiştir. Kaynak işlemi sonrasında optik mikroskop, SEM, sertlik ve mekanik dayanım testleri uygulanmıştır. Yapılan analizler sonucunda SiC takviyeli Cu matrisli kompozitlerin sürtünme kaynağı ile birleştirilmesinin zor ve çeşitli problemler içerdiği sonucuna varılmıştır.

1. INTRODUCTION

Advances in technology have led to the need to improve many of the properties of materials and have made a major contribution to the development of materials science [1-9]. Thus, serious efforts are made to improve materials [10-13]. The desired properties have led to the combined use of dissimilar materials [14-18]. Composites are called as material groups consisting of two or more components that do not visibly dissolved in each other and have the desired properties of the materials used [19, 26]. Ersoy [20, 26] defined composite materials as a group of materials formed by combining at least two different materials for a specific purpose. It typically consists of a composite material, a low-strength resin or matrix, and a small number of reinforcing elements. The components of composite materials are combined at the macro level to maintain their boundaries. When composite materials are examined, it is seen that the components are selected and at a distinguishable level. Even though these materials have homogeneous properties, they actually have heterogeneous structures. In this regard, materials combined at the molecular and atomic level do not belong to the class of composites, even though they appear homogeneous [20, 26]. Powder metallurgy is one of the common methods used in the manufacture of metal matrix composites (MMC). Sintering, hot isostatic pressing, hot pressing, nano particle techniques, powder metal injection and mechanical alloying methods are the advanced technologies addressing an ever-growing market in powder metallurgy [22]. This method allows us to obtain durable objects with the help of pressure and temperature below the molten temperature of metals and alloys [23]. Friction welding is a solid-state joining method. Friction welding is a welding method in which the parts to be welded rotate at a certain speed and are joined by pressure. Friction welding is one of solid-state methods that can be used to join metals with different thermal and mechanical properties. The fact that the temperature in the friction welding process is below the melting temperature and the joining time is short allows the joining of materials that are difficult and problematic to join with other methods [24, 26].

The joining problem in the application area of composite materials has been the cause of an increase in studies on this subject. The present study was conducted to investigate the hardness, strength, and microstructures of the welding interface formed upon joining of SiC-reinforced copper matrix via friction welding, one of the joining methods.

2. MATERIAL AND METHOD

Before the welding process, standard copper material and SiC-reinforced Cu matrix composite materials obtained by powder metallurgy method were cut in Ø12x40 mm size. These parts were cleaned from rust, foreign matter and oxide layer on the front surfaces on CNC lathe and made suitable for friction welding.To apply the friction welding method, a continuous drive friction welding machine was used, which is schematically shown in Figure 1. The setup of this welding machine consists of five parts including movable chucks, fixed chucks, drive motor, reciprocating bearing and directional control valves.

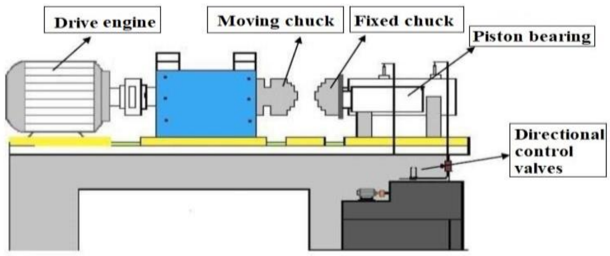

Figure 1. Schematic view of a continuous drive friction welding machine [25]

The parameters that have a significant effect on the mechanical and microstructure of the friction welded joints obtained parameters are temperature, rotation speed, friction pressure, rates of reinforcing element, and upsetting pressure. In the present study, temperature, rotation speed and friction pressure were taken as constant and the rate of reinforcing element in the specimen was considered as a parameter.

Table 1. Parameters used in friction welding

Sample no	SiC (%)	Rotation speed (rpm)	Temperature (^{0}C)	Friction pressure (MPa)
S1	0	1700	1000	30
S2	5			
S3	10			
S4	15			

As shown in Table 1, 5%, 10% and 15% silicon carbide-reinforced copper composite specimens were friction welded at 1700 rpm and 10000C with a friction pressure of 30 MPa. Pure copper specimens were connected to the rotational mirror connected to the engine of the machine and Cu-SiC specimens were connected to the axially moving hydraulic mechanism. The produced specimens were cut from the welding joint area for microstructure analysis, then the welded area was sanded with 80-1200 mesh sandpaper and polished with 3% diamond paste. After sanding and polishing, they were etched with Nital etchant.

As a result of friction welding, it was observed that the deposit formed on the surface of the weld zone varied. Figure 2 shows the bonding of pure copper and SiC-reinforced copper matrix composites paired for the bench. Figure 3 shows the composites produced by powder metallurgy method and the composites joined via friction welding.

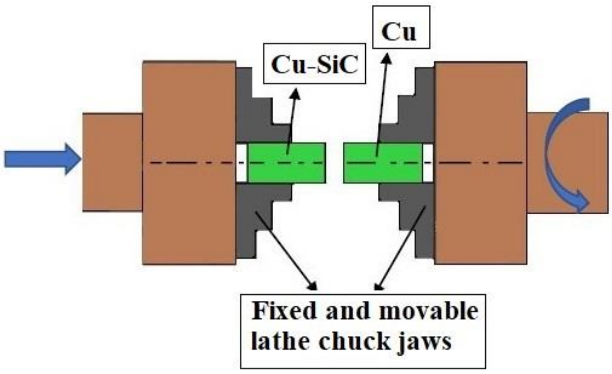

Figure 2. Joining way of the parts [25]

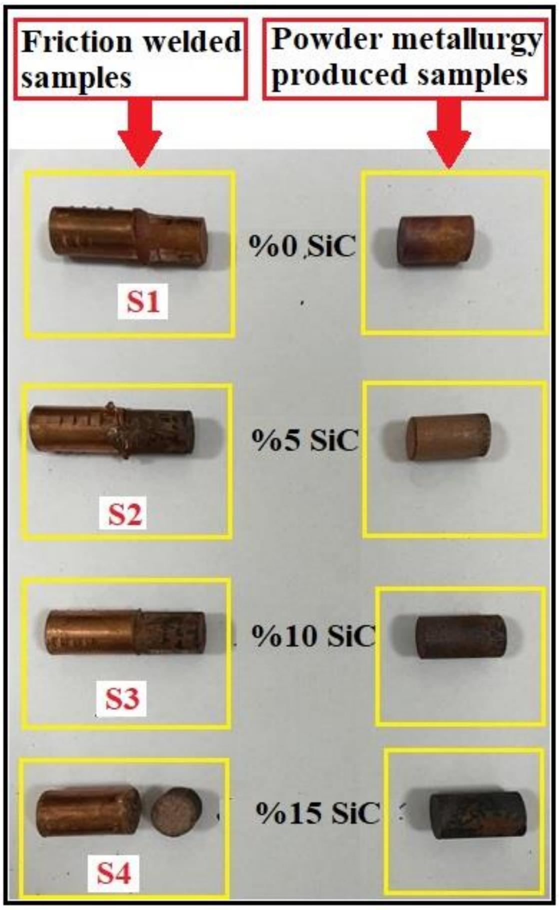

Figure 3. Images of the composites produced and friction welded specimens of these composites [26]

3. RESULTS

3.1. Optical Analysis

The specimens were sanded, polished, and then etched with a Nital solution in order to see the microstructural properties. Optical microscope and SEM images were taken to get an idea of the different structures in this microstructure. The optical images taken from specimen S3, which contained standard 10% SiC, were observed to have five different regions and they are shown in Figure 4. These regions were defined as the intermediate zone (A), the heat affected zones (D-B), and the base materials (E-C). As can be seen from the optical image, it is clear that the SiC grains in the copper have a density under heat and pressure toward the intermediate zone. From this point of view, it was observed that the SiC rate had a negative effect on the joint quality and the joint was achieved in all specimens other than the specimen containing 15% SiC. In their study, Meral et al., observed a good bond between the coating and the substrate in the SiC-reinforced specimens. However, they noted that the coating quality was negatively affected in the 16% SiC-reinforced specimen and there was a lot of uncoated area in the coating area. They also mentioned that increasing rate of the SiC reinforcement increased the number and size of fire channels, which impaired the quality of the coating [27].

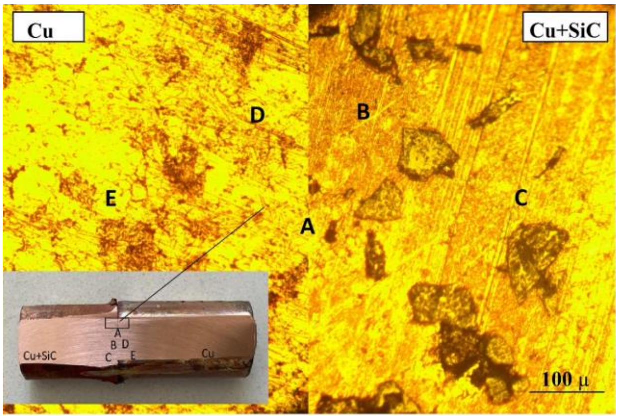

Figure 4. Optical image of the specimen S3

3.2. SEM Analysis

Figure 5 shows the SEM images taken from the specimens with different SiC rates. When these specimens are examined, it was observed that an complex porous structure dominated in specimen S1, and the grain boundaries were clear. However, with SiC reinforcement, the grain boundaries in the composite material become more pitted and bonding quality of grains impaired. Increasing SiC reinforcement caused a negative effect on the friction welded joint of the composite materials and did not show a homogeneous structure. It is clear that both the production of composite material and its joining with Cu via friction welding were negatively affected by this irregularity. Buytoz et al., mentioned in their study that the presence of SiC reinforcement affected the formation of the microstructure, low powder content produced softer dendritic structures, while high powder content produced harder and more durable structures [28].

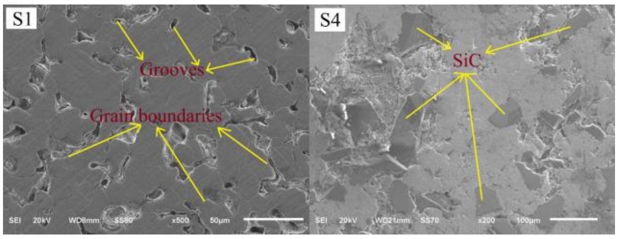

Figure 5. SEM images of specimens S1 and S4

3.3. Microhardness Analysis

Figure 6 shows the results of microhardness measurements of SiC-reinforced Cu matrix composites joined via friction welding. While the average hardness values both on the composite side and Cu side were around 50 HV in specimen S1, an increase of 16-18% was observed in specimen S2 with 5% reinforcement. In specimen S3 with 10% reinforcement and S4 with 15% reinforcement, the hardness values increased by 60-64%. This average increase in hardness is thought to be caused by the presence of carbide formations and intermetallic compounds in the microstructure with increasing SiC reinforcement. Kılıç et al., mentioned in their study that SiC reinforced specimens were approximately twice as hard as unreinforced specimens [29].

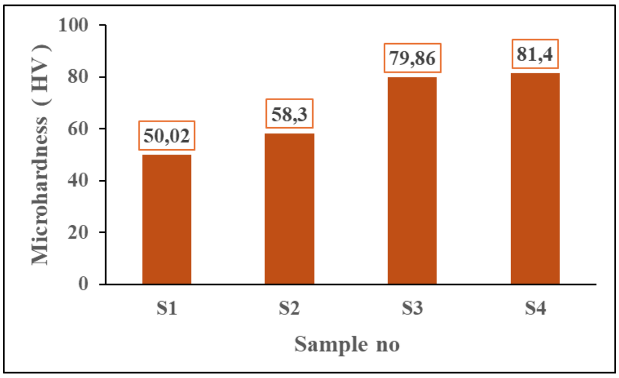

Figure 6. Microhardness values of Cu matrix specimens

3.4. EDS Analysis

Figure 7 and Table 2 show the EDS images and results obtained from specimens with different SiC rates. While the Cu content in the unreinforced specimen was around 95.755%, it was 89.382% in the 5% SiC-reinforced specimen, 69.346% in the 10%-reinforced specimen, and 54.702% in the 15%-reinforced specimen. From the EDS results, there was also presence of oxygen due to some oxidation in all specimens. Kılıç et al., stated that SiC increased the solid phase formation in the coating, changed the chemical distribution and made the microstructure more homogeneous based on EDS analysis [29].

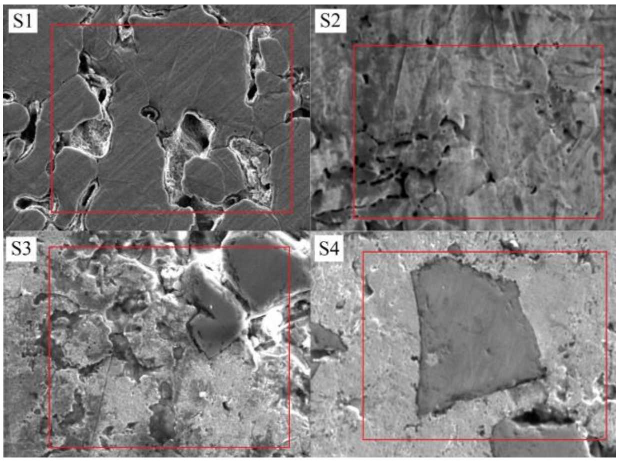

Figure 7. EDS images of specimens S1, S2, S3, and S4

Table 2. EDS results of specimens S1, S2, S3, and S4

Elements (wt.%)	Sample no			
	S1	S2	S3	S4
C	1.976	9.622	9.581	7.524
O	1.270	0.772	12.406	5.812
Si	-	0.223	20.667	31.962
Cu	95.755	89.382	57.346	54.702
Total	100.000	100.000	100.000	100.000

3.5. Impact Analysis

Charpy impact tests were carried out using TERCO MT 3016 impact tester at room temperature with a maximum energy of 150 Nm. Figure 8 shows results of the notch impact test as a bar graph. Increasing SiC rate caused a decrease in impact energy. Forty-five J was obtained in specimen S1, 32 J in specimen S2 and 28 J in specimen S3. Specimen S4 was unsuccessful.

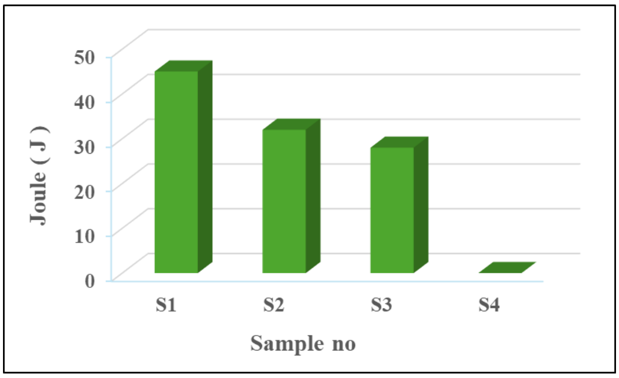

Figure 8. Impact test results of the specimens

4. DISCUSSION AND CONCLUSION

It was observed that the results varied in friction welding of Cu matrix composites containing different rates of SiC depending on the SiC reinforcement rate. As a result, it is clear that friction welded joint of Cu matrix SiC-reinforced composites produced via powder metallurgy method with Cu material is difficult and problematic. No joining process could be achieved above 15% reinforcement rate.

It was observed that the hardness-value of the specimens increased as the carbide content increased. Although SiC particles decreased the density of the composite material, they improved its mechanical properties. However, they also reduced the friction welding capability.

In the present study, it was thought that the reason for the lack of joint due to the increase in SiC reinforcement rate was the atomic structure, melting temperatures, different welding capabilities, and the pressure applied in friction welding.

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