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Cu-SiC Kompozitlerin Mekanik Özelliklerinin Ultrasonik Kullanılarak Karakterizasyonu

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Anahtar kelimeler
Ultrasonik özellikler; Cu-SiCkompozitler; Sertlik; Young'smodülü

Öz

Bu çalışmada, bakır matriks kompozit temas malzemesinin mekanik, fiziksel özellikleri ve mikro yapısı üzerindeki SiC takviyesinin etkisi ultrasonik ölçümlerle incelenmiştir. % 3-12 oranında SiC takviyeli Cu matrisi içeren kompozit malzemeler toz metalurjisi yöntemi kullanılarak üretilmiştir. Ultrasonik test (UT) malzemelerin karakterizasyonu ve değerlendirilmesi için en yaygın kullanılan tahribatsız muayene tekniklerinden biridir. Ayrıca, ultrasonik ölçümler için tahribatsız yöntemlerden biri olan Pulse-eko tekniği kullanılmıştır. Isıl işlem görmüş malzemede saf bakır ve bakır matriks kompozit oranı üzerinde farklı SiC takviyesinde ultrasonik hızında, zayıflamada, Young's modülünde ve sertlikte değişiklikler gözlenmiştir. Sonuç olarak tüm kompozitlerde, ultrasonik karakterizasyonlar (boyuna ve enine hız, zayıflama ve Youngmodülü) ve sertlik değerleri SiC takviyesindeki artış ile artmıştır. SiC takviyeli Cu-SiC kompozitlerinin saf bakır malzemelerden daha iyi mekanik özellikler gösterdiği görülmüştür.

Characterization of Mechanical Properties of Cu-SiC Composites Using Ultrasonics

Keywords
Ultrasonic properties; Cu-SiC composites; Hardness; Young's modulus

Abstract

In this study, the effect of SiC reinforcement on the mechanical, physical properties and microstructure of copper matrix composite contact material was investigated with ultrasonic measurements. The composite materials containing 3-12 vol% SiC reinforced Cu matrix were produced by using the powder metallurgy method. Ultrasonic testing (UT) is one of the most widely used non-destructive testing techniques for the characterization and the evaluation of materials. Also, for the ultrasonic measurements one of the non-destructive methods; pulse-echo technique is used. Changes in ultrasonic velocity, attenuation, Young's modulus and hardness are observed in heat-treated material at pure copper and different SiC reinforcement on copper matrix composite ratio. As a result, the ultrasonic characterizations (longitudinal and shear velocity, attenuation and Young's modulus) and hardness values in all composites increased by the increment in the SiC reinforcement. It is observed that Cu-SiC composites with SiC reinforcements revealed better mechanical properties than pure copper materials.

1. Introduction

Composite materials are using as advanced engineering materials for applications in automotive, aerospace, and other industries, which are becoming increasingly more popular among many centers in the country and in the world (Yönetken 2018; Tang et al. 2003; Zang et al. 2005; Wu et al. 2014;Jarząbek et al. 2017). More research than ever relates to powder materials used primarily for sintered materials (Zygoń et al. 2015, Wittmann et al. 2002; Dudek 2011).Copper, its alloys and Cu based metal matrix composites are used in many electrical contacts, thermal and electronic packaging applications as they possess high thermal and electrical conductivity as well as good corrosion resistance (Meher and Chaira 2017). Since SiC has a high thermal conductivity and offers good usability, low price and possible processability, it can be used as a reinforcement in copper-based composites for high-performance heat-absorbing materials and packages (Gwoździk and Bałaga 2018; Celebi et al. 2012).

Non-destructive testing (NDT) is widely implemented for characterising material properties and it is an extensive field that plays a vital role in ascertaining efficient functioning of systems and structural components (Nanekar and Shah 2003; Nanekar 2001; Berger 1992).Although NDT techniques are generally used for characterization and detection of defects in the material, these techniques have the ability to characterize the metallurgical and mechanical properties of the materials (Toozandehjani et al. 2016; Özkan et al. 2013; Sarpün et al. 2013).

Pulse-echo method is one of the effectively used techniques to measure velocity and attenuation for ultrasonic characterization of samples. In this technique,the thickness of the samples was measured using a micrometer. The velocity of the wave as it travelled through the material was determined by equation (1) (Khan et al. 2015):

$$V_L = \frac{2\times d}{t} \quad (1)$$

where V is the velocity of the wave (m/s); d is the samplethickness (m); t is the arrival time between the front and backreflection (s).Also, the determination of ultrasonic velocities can be used to measure Young’s modulus of materials and this parameter can be related with the material properties like the density of the solid material (ρ), Young’s modulus (E) ultrasonic velocities (v) as shown in Equation (2)(ErenGültekin 2018):

$$E = \rho V_T^2 \frac{3V_L^2 - 4V_T^2}{V_L^2 - V_T^2} \quad (2)$$

By measuring echo heights of successive peaks on the screen of ultrasonic flaw detector, attenuation coefficient of sample could be determined

$$\alpha = \frac{1}{d} 20log \frac{A_1}{A_2} \quad (3)$$

where$d$ is the thickness of sample, A_1 and A_2 are the successive echo heights (Ale 2011).

Measurement of wave speed within the material and attenuation of ultrasonic waves are parameters important to materials characterization. The objective of the study is to investigate the relationship between mechanical properties and NDT measurements.

2. Experimental procedure

2.1 Material and heat treatment

The material used in this work was composite materials containing 3-12 vol% SiC reinforced Cu matrix. The composition of Pure Cu-SiC, Cu-%3 SiC, Cu-%6 SiC, Cu-%9 SiC and Cu-%12 SiC powders specimens were prepared in cylinder-shaped steel mold. The diameter and thickness of each circular-shaped specimen were 15 and 5 mm, respectively. The thickness of the specimen is important for the observation of ultrasonic parameters. In ultrasound measurements, it is undesirable that the sample is too thick or too thin. All the powders were pressed using a hydraulic press at a pressure of 305.9 kg/cm^2, then sintered at 1100°C for 2 hours in a traditional tube furnace using Argon gas atmosphere.

2.2 Ultrasound velocity and attenuation measurement

Longitudinal/shear ultrasonic velocity and attenuation were measured using SonatestSitescan150 Ultrasonic Flaw Detector and thickness gauge with pulse-echo technique. In this methodtransducer generates an ultrasonic pulse of energy that travels through a coupling medium and it is also received simultaneously for the reflected energy which is the pulse and echo method. The ultrasonic pulse-echo technique is generally used for exact measurement of ultrasonic velocity and attenuation in the megahertz and gigahertz frequency regions, to assess elastic modulus, to determine microstructure characterization, and to evaluate mechanical properties.A longitudinal beam probe 4MHz (Sonatest SLH4-10, T/R) frequency and a shear beam probe 4 MHz (GE Inspection Technologies MB 4Y 66100541) frequency was used to determine the ultrasonic parameters, ultrasound velocity and attenuation. Sonatestsonagel-W liquid gel was used as a coupling agent between the probes and the sample to improve the coupling between the probe and the surface of the specimen. The thickness of the test specimen was measured with an error of ±0.1 mm. In addition, a uniform pressure was applied to the sample with the probe in all measurements. Ultrasonic longitudinal and shear velocity was estimated using the A-cal menu provided in SonatestSitescan 150 flaw detector and was calculated using Equation (1). During pulse echo method, the attenuation coefficient is generally obtained by the ratio of the amplitudes of the first back-wall echo to that of the second back-wall echo and attenuation measurements were calculated using Equation (2). Young's modulus is a material property. The bonds, orientations and interactions between atoms and molecules in a structure become clear with Young's modulus. The Young's modulus of a material can also be calculated using Equation 3, based on ultrasound wave velocities (longitudinal and shear) and density.

2.3 Hardness measurement

METTEST-HT (Vickers) micro hardness testermachine was used for the hardness measurement of the composite sample after eachheat treatment. The hardness test was performed on the specimens using Vickers hardness at 0,5 kg load.In addition, the hardness values obtained from 10 different regions of the composite samples were given by taking the average.

3. Results

In the study, the Pure Cu-SiC, Cu-%3 SiC, Cu-%6 SiC, Cu-%9 SiC and Cu-%12 SiC composite samples prepared and shape were sintered at 1000°C temperatures in conventional furnace and made ready for physical and mechanical analyses. The main focus of this study was to characterize the Cu-SiC composites according to ultrasonic wave speed and attenuation. The ultrasonic velocity, attenuation, elastic modulus, structureand hardness behavior of Cu-SiC composites can beseen in Table 1. According to Table I, ultrasonic longitudinal and shear velocity, ultrasonic longitudinal and shear attenuation, elastic modulus and hardness–% SiC graphs were plotted and given in Figs. 1, 2 and 3, respectively.

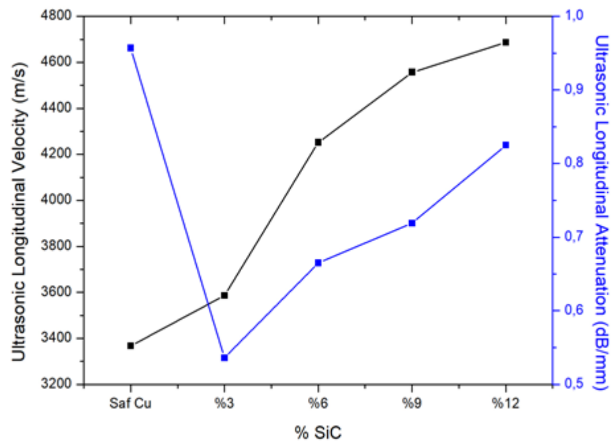


Figure 1. Ultrasonic longitudinal velocity and attenuation values of Cu-SiC composite samples with varying volume fractions (%SiC).

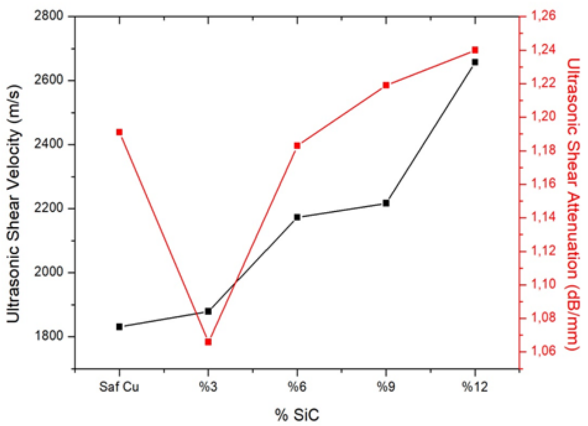


Figure 2. Ultrasonic longitudinal velocity and attenuation values of Cu-SiC composite samples with varying volume fractions (%SiC).

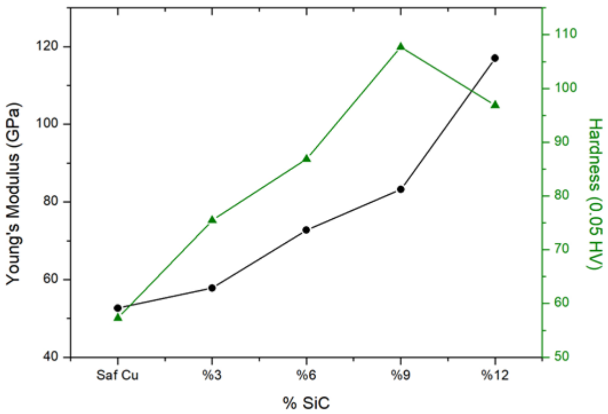


Figure 3. Young's modulus and hardness values of Cu-SiC composite samples with varying volume fractions (%SiC).

The curve is plotted by taking the average values of five measurements. It can be noticed that when the temperature reached in 1000°C, there was a regular increase in the velocity values, whereas, in the case of attenuation there was approximately equal increments at with varying volume fractions For the pure Cu specimen, the ultrasonic longitudinal and shear velocity and the longitudinal and shear attenuation were found to be 3367.3 m/s, 1830.5 m/s and 0.957 dB/mm and 1.191 dB/mm, respectively.

(%SiC).This was because of scattering of the ultrasonic waves due to the variation in grain size. During UT of Pure Cu specimen, it was observed that there were at least four or more reflection or echoed peaks which were clearly visible on the detector. However, after the heat treatment there was hardly any third reflection peak on the detector. This indicated that with increase in the grain size, the signal decay inside the material was also increased. As expected, Young's modulus and the hardness of the material were increased as the varying volume fractions (%SiC) increased. This increase is attributed to bonding between the grains, decreasing porosity of samples and also a good indicator of correct sintering process. Generally grain size, dislocation density, precipitates etc. it has a strong effect on the hardness of materials with almost no change in elasticity.

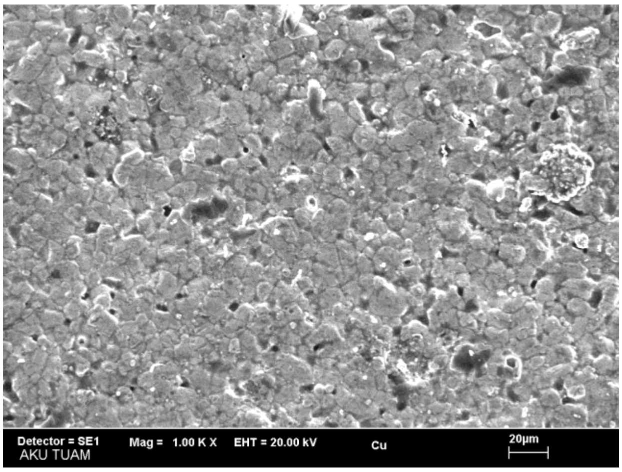
When the studies are observed, there are no apparent changes in (elastic) Young's modulus in metals that have undergone different hardening treatments so the hardness is a good indication of the underlying microstructure.

Table1. Volume fraction (%SiC), ultrasonic velocity, attenuation, Young's modulus, hardness and density values of composite samples.

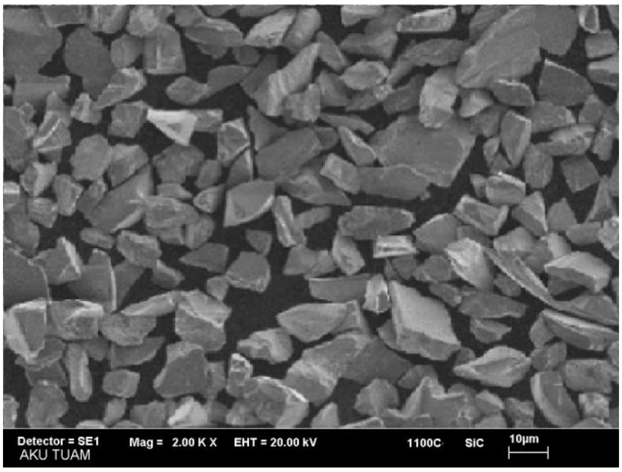
Composite Samples	Pulse-Echo Method				*Young's Modulus (GPa)*	*Hardness (HV 0.05)*	*Density* (g/cm^3)
	V_L (m/s)	V_T (m/s)	*Longitudinal Attenuation (dB/mm)*	*Shear Attenuation (dB/mm)*			
Pure Cu-SiC	3367,3	1830,5	0,957	1,191	52,63	57,31	6,09
Cu-%3 SiC	3586	1879,3	0,536	1,066	57,80	75,46	6,24
Cu-%6 SiC	4251,8	2173	0,665	1,183	72,75	86,85	5,82
Cu-%9 SiC	4557	2216,7	0,719	1,219	83,22	107,7	6,30
Cu-%12 SiC	4686,8	2657,3	0,825	1,240	117,03	96,85	6,56

2.4 SEM Analyses

SEM analysis images of pure copper and Cu-SiC samples are given. Although the image obtained from pure copper has a homogeneous distribution, the grain boundaries are seen. The grain size and grain boundaries became more prominent in the image obtained by adding SiC to copper powders. It was observed that the porosity increased as SiC ratio increased. The addition of SiC increased the hardness of the material while increasing the porosity.

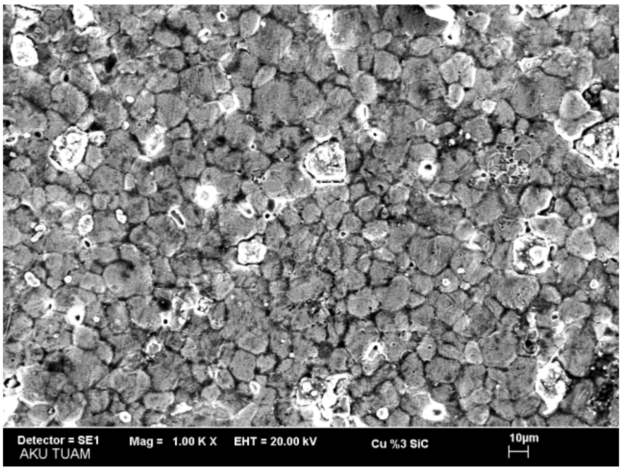


a) Pure Cu



b)

a) Pure SiC



b) Cu and SiC

Figure 4. SEM view of pure Cu, pure SiC and Cu-SiC composite at 1100°C

4. Discussion and Conclusion

The ultrasonic pulse-echo technique is effectively used for characterization of Cu-SiC composite properties in the proposed study.This study will characterize composite materials containing 3-12 vol% SiC reinforced Cu matrix using ultrasonic techniques. In addition, the study focuses on the influence of volume fraction on the ultrasonic properties of these materials. Ultrasonic measurements indirectly showed differences in mechanical properties as well as morphological conditions and microstructure properties. An interesting trend is observed between the mechanical properties (hardness) and ultrasonic parameters (ultrasonic signal velocity and Young's modulus) (Figure 3). Increase in both ultrasonic parameters and hardness was observed in heat-treated specimens at 1000 °C with an increased volume fraction. Also, it has been reported in many previous studies that when the grain sizes increases ultrasonic attenuation increases.These values are within the reported literature values. A relationship between the ultrasonic properties and the mechanical properties of Cu-SiC composite samples is shown.It is observed that Cu-SiC composites with SiC reinforcements revealed better mechanical properties than pure copper materials.

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