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RESEARCH ARTICLE OPEN ACCESS

Different ratios CrC particle-reinforced Cu matrix composite materials and investigation of wear performance

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ABSTRACT
In this paper, Cu matrix composites (Cu-MCs) were fabricated using powder metallurgy (PM) technique and using different proportions of CrC particles in Cu matrix. CrC particles were added into pure Cu powder at different ratios as 5%, 10%, 15% and 20% by weight. The prepared composites were formed with 400 MPa pressure. The formed parts were sintered 60 minutes at 950°C. Sintered samples were evaluated by observating the density and scanning electron microscopy (SEM) images. Mechanical properties and microstructure of the produced composite materials (CMs) were investigated. Microscope examinations were carried out with SEM. Hardness, one of the mechanical properties, is determined by the Vickers method, which is a method of hardness measurement. According to SEM examination, the CrC phase in the Cu-MCs composed of coaxial grains were balanced. It has also been observed that the hardness increases with increasing CrC ratio. The wear behaviours of the produced CMs were analyzed with pin-on-disk wear test. According to this investigation, 50N and 75N loads were applied to the composite materials and wear depths, friction coefficient variation, wear diameter variation and weight loss were investigated at a slip speed of 0.4 m/s and a slip distance of 1200 m. According to these investigations, it was observed that as the ratio of CrC particle reinforcement increased, wear resistance amount increased regularly.
Keywords: Copper; wear; composite; sintering; chromium; hardness;

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I. INTRODUCE

Technology has been developing rapidly and different materials are being advanced using new manufacturing methods. These materials are more suitable for today's conditions and their utilization is becoming widespread. MMC materials have been largely used and developed recently, according to these purposes.

Rohatgi et al. (1992), said that metal MMCs are known for their stronger tribological properties such as high hardness and high strength. Alpas and Zhang (1992); (Chen et al., 1997), according to the studies conducted, it has been determined that wear resistance of MMCs can be improved by particle reinforcement in different amounts.

The materials used for tribological practise ought to be able to support a load without fracture or deformation. The friction coefficient of these materials must be low and provide low wear during sliding. It is known that the tribological behaviour of composites is influenced by the type, shape, and volume ratio of the reinforcement, which is one of the microstructural characteristics of the matrix. In addition, operating conditions such as sliding speed, temperature and load speed are other factors to be considered (Yu et al., 1997).

There are many factors affecting the wear behaviour such as microstructure, alloy and material ratio, the load applied to the sample, temperature, sliding distance and speed. Apart from these factors, the way the experiment is conducted is also important. Pin-on-disc test, which is among the different test methods such as cylinder on the plate, pin on disk, block on the ring and wear test for coated products are very suitable (Hassan et al., 2009; Kato et al., 2003; Ramesh et al., 2010; Winzer et al., 2011).

Copper-based composites containing various secondary phases have interesting thermal and electrical conductivity ratings, good strength at high temperatures and good tribological properties, in addition to being used in the chemical industry and electro-technologies. The wear behaviour of fine particle reinforced copper based composites is better than pure copper. Because of these properties, these composites are used in electrical connections and welding electrodes (Bargel, 1980; Bera and Manna, 2012; Marques et al., 2005; Shojaeepour et al., 2012; Sobhani et al., 2013; Tandon and Tian, 1993).

Safari et al. (2017), produced Cu matrix composites by adding 1%, 3%, 5% and 7% of Zn by weight into Cu element. They investigated wear behaviours of the composites they formed in a pin-on-disc tester under a load of 10 N, at a speed of 0.5 m/s and at a sliding distance of 1000 m. As the result of the experiment, they observed that as the weight ratio of Zn increases, the wear rates and friction coefficients of the formed composites decrease

Meher and Chaira (2017), in their study carried out to improve the mechanical and electrical properties of the Cu element, Meher et al. reported that Cu-Graphite-SiC and Cu-SiC composites were obtained by adding 1%, 3%, 5%, 10% and 15% graphite by volume and 2%, 5% and 10% SiC by weight. They compared the hardness values and electrical conductivities of the metal matrix composites they produced. The hardness of the composites decreased as the volume ratio of graphite decreased and increased with increasing SiC weight. In addition, electrical conductivity decreased as graphite and SiC ratios increased.

Li et al. (2015), produced hot-pressed Cu-GNSs and Cu-Gr composites by adding graphite and graphite nano-sheets (GNSs) at a rate of 2.5%, 5% and 7.5% by volume, to compare mechanical and tribological properties. According to the investigations carried out, Cu-GNS composites were found to have higher relative density, hardness and strength than the Cu-Gr composites, in the comparison of the composite materials mixed at the same ratios. In the results of the ball on disk wear test at 2000 m sliding distance, 2N load and 1 m/s speed, friction coefficient and wear rate were significantly decreased by adding GNSs.

In this paper, CMs were fabricated by reinforcing Cr particles on Cu matrix using PM method. Microstructure of fabricated samples which produced with Cr reinforcement in the range of 5-20% by weight and different ratios were carried out by using SEM. In determining the mechanical properties, pin-on-disc wear test and hardness measurement method were used.

II. MATERIAL AND METHOD

2.1. Experimental Samples Preparation

In experimental studies, Cu particle dimension was used under 70 µm. CrC powder particle dimension was chosen as ≤ 70 µm. The Cu-CrC powder's SEM image is presented in figure 1 and in table 1, the EDS (energy dispersive X-Ray spectroscopy) analysis report is given.

Figure 1. Cu-CrC powder SEM image containing 5% CrC by weight

Table 1. Cu-CrC powder EDS analysis report by weight 5%

Elements	Line	Intensity, (c/s)	Error, (2-sig)	Conc.	Units
C	Ka	9,16	6,134	2,579	wt.%
Cr	Ka	91,34	10,638	2,529	wt.%
Cu	Ka	1,271,99	32,555	94,892	wt.%
				100,000	wt.%

MMC materials are produced by PM method. CrC reinforcement in the rates of 5%, 10%, 15% and 20% by weight was made into the metal matrix and mixed for 24 hours using a Turbula mixer to obtain a homogeneous mixture. In the EDS analysis which performed, it was determined that the mixture was homogeneous distribution (Fig. 2).

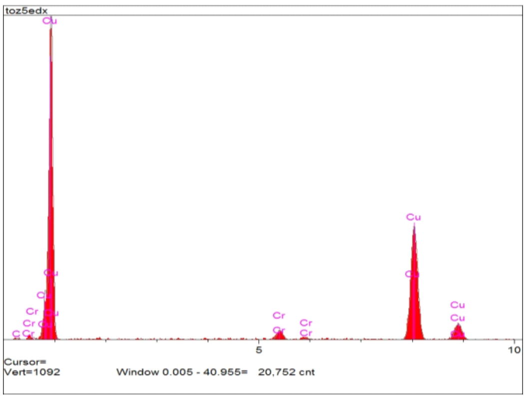

Figure 2. Graph of EDS analysis

The blended powders were then shaped using a hydraulic press under a pressure of 400 MPa. The mold used for shaping was a cylindrical type Ç1040 (C40) steel mold, which was 25 mm deep and 12 mm in diameter (Fig 3).

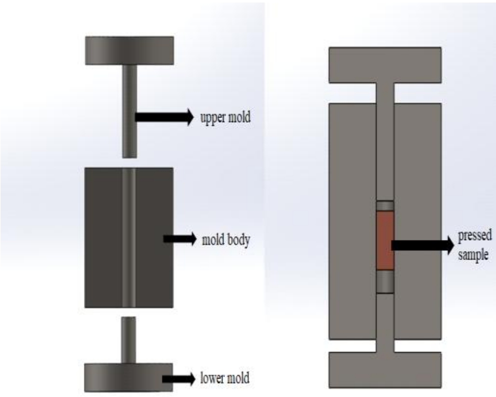

Figure 3. Assembly of pressing mold

The samples which obtained after pressing were sintered at 950^{0}C for 60 minutes under a protective atmosphere. This experiment was carried out using the Protherm GSL-1500X brand tube furnace. Using the A & D HR-250AZ precision scale, the weight of the sintered sample was determined.
The volumes of the samples were found after their lengths and diameters were measured.

(1)

ρ_{true}: The actual density of the samples (g / cm^3), m: the mass of the samples (g), v: The volume of the samples (cm^3)
The actual density was determined with formula 1.
The theoretical density of the samples are;

(2)

D_t: Theoretical density of the sample (g / cm^3)
D_{Cu}: Density of the copper sample in (g / cm^3)
D_{Cr}: Density of the chromium sample in (g / cm^3)
D_C: Density of the carbon sample in (g / cm^3)
W_{Cu} %: Percentage of Cu by weight
W_{Cr} %: Percentage of Cr by weight
W_{Cr} %: Percentage of C by weight
was determined with formula 2. The relative density was determined by proportioning the actual density to the theoretical density (Fig. 10).

2.2. Metallographic Studies on Experimental Samples

After the pressing process, the sintered samples were abrasived in water using 400, 800 and 1000 mesh SiC abrasives and the surface was polished using a diamond paste. Samples was cleaned using ethyl alcohol after being polished with the diamond paste.

Each of the polished samples was cauterized using 5% Nital, then cleaned with ethyl alcohol and subjected to a drying process with hot air at 50°C in a hot air oven for about 1 hour to perform microstructural examinations. After drying process of the samples, their microstructural properties were examined in a JEOL JSM-6510 SEM machine.

2.3. Hardness Measurements

The hardness measurements were determined on a Mitutoyo Hardness Meter Machine under the load of 200 gr, for 10 seconds, taking measurements from five different points, using the Vickers micro hardness measurement method. (Fig. 4).

Figure 4. Hardness teste

2.4. Wear Test

After preparing the wear samples for the pin-on-disc wear test device, they were examined the wear properties of the test samples. For wear test, a turning operation was performed on the end portions of the test samples by giving a 4 mm radius on the CNC turning machine (Fig. 5).

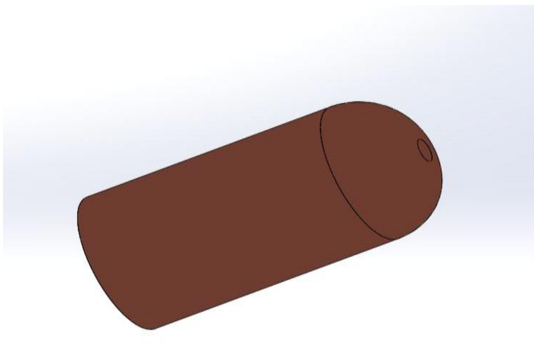

Figure 5. Display of samples to be subjected to wear test in CAD environment

The wear tests of the samples were performed on a pin-on-disc wear test device which conforming to ASTM-G99-05 standard (Fig. 6).

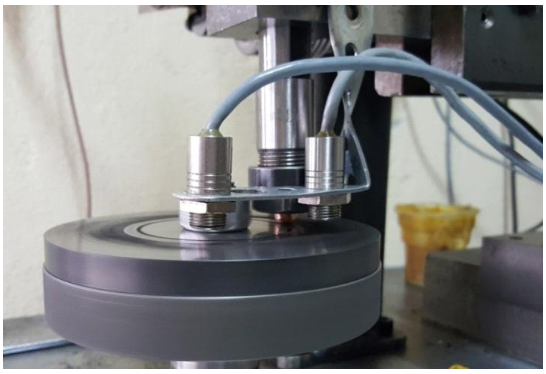

Figure 6. Pin-on-disc wear test device

In this test device, a metal disc was used as an abrasive. This metal disc of the test apparatus is made of AISI 1050 steel and is 100 mm in diameter. The surface of this disc was hardened with nitration heat treatment. After heat treatment, the hardness values were determined from four different parts of the disc for 10 seconds under 1 kg according to the Vickers hardness measurement method. The average hardness value was found to be 596.3 HV. Prior to the wear test, the weight of the samples were measured with having a sensitivity of 0.0001 mg. The wear test was repeated for each sample, at 25°C, under 50N and 75N constant load; in an equal sliding distance of 1200 m and a sliding rate of 0.4 m/s for every sample. Through each repetition, different surfaces and different diameters of abrasive discs were used. The experiment that was carried out at different rotation speeds took about an hour for every sample. The worn samples were cleaned with ethyl alcohol after the wear test. The samples weight were measured with having a sensitivity precision scale of 0.0001 mg. Drying of the samples was completed in 24 hours at room temperature

After the test, friction coefficients, mass losses and wear depths of these composite materials were determined and compared. Additionally, the wear surfaces of the samples were again prepared for metallographic examinations. They were examined on SEM device and information about wear surface and wear diameters were obtained.

III. RESULT AND DISCUSSION

In this paper, Cu-MCMs were fabricated by powder metallurgy method by adding CrC particles to Cu metal matrix powders in different quantities. The hardness values and the microstructures of the produced materials were examined and the following results were given.

3.1. Mechanical Properties of Experimental Studies

After sintering, the surface was cauterized. SEM images of cauterized samples were taken. SEM images of the samples, which have pure copper sample and the percentages between 5 and 20% by weight were shown in Fig. 7.

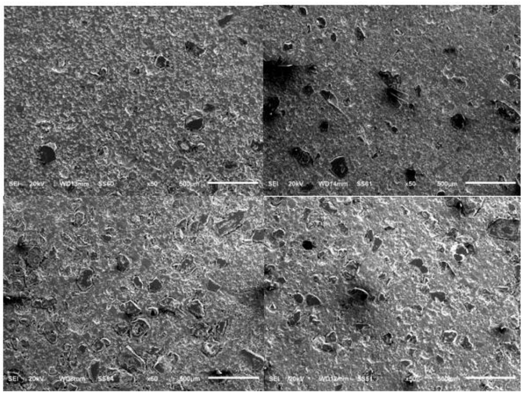

Figure 7. a) SEM image of a Cu-CrC containing 5% CrC b) 10% CrC c) 15% CrC d) 20% CrC particles

SEM images show that there was a healthy twinning between the granules, a decrease in the porous structure, and a clear view of the particle boundaries was provided after sintering. The reinforced CrC particles are homogeneously spreaded and not accumulate in any region. From the SEM images, it was determined that the grain sizes were below 60 µm, so there was no grain coarsening. Since the CrC concentration value is lower than the pure copper concentration value, the theoretical density of the samples decreases as the CrC addition rate increases. When the actual density values are also measured, the actual density value is found to be lowered together with the CrC particle reinforcement. When the two cases are compared, it is seen that the actual density values are lower than the theoretical density values. Due to the fact that the amount of decrease is greater than the theoretical density, the relative intensity graph shows an upward trend. Powdered materials cause the density of the partially porous structure to decrease during the time they are pressed (Fig. 8).

Figure 8. CrC particle reinforcement ratio - relative density graph

In the microhardness measurements, as long as the hardness of samples values increase in, the CrC particle ratio by weight increase in (Yonetken et al., 2015). The averages of measurements on five different points of 15 samples, 3 from each test sample, are given in Fig. 9. The increase in hardness measurement values in another study also supports the findings of this study.

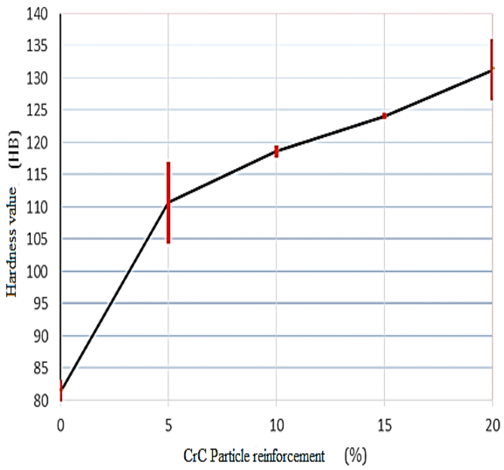

Figure 9. Hardness Measurements

In the study, the highest hardness value was found in samples with 20% CrC particle reinforced with a value of 132 HV. This increase in hardness values is in line with the CrC reinforcement rate. Hardness increase in samples indicates that the increase in CrC reinforcement rate was also positively reflected to other mechanical properties.

3.2. Wear Experiment

For Cu-MCs which have different CrC reinforcement rates, friction coefficient, weight loss, wear depth and wear diameter of each sample were measured at 50N and 75N, at a constant sliding velocity of 0.4 m/s and a sliding distance of 1200 m.

As a result of the measurements carried out before and after the wear experiment, the data obtained regarding the weight losses are given in Fig. 10.

Figure 10. CrC particle reinforcement ratio - weight loss graph

During mass measurement, it was observed that the highest mass loss was in pure copper, and the lowest mass loss was in 20% CrC reinforced sample. In general, weight loss is reduced by increasing the CrC reinforcement ratio. Therefore, when the results of the tests carried out with loads of 50 N and 75 N are analysed. As long as CrC reinforcement ratio in each load group increases, the wear rate decreases. When the wear resistances of CrC particle reinforced samples were compared with pure copper samples, it was seen that CrC particle reinforced samples made a very serious positive contribution.

When the depth of wear in the samples were measured by means of the sensor in the test device, it can be seen that it complies with the results obtained by loss of weight (Fig. 11).

Figure 11. Change of wear depth according to CrC particle reinforcement ratio

Parallel to the diameter measurement, it was found that the wear depth was at the maximum level in the pure sample and was minimum at the 20% CrC reinforced sample. This suggests that CrC reinforcement contributes positively to wear resistance. In the SEM, the diameters of the shapes formed due to the wear on the sample are measured and the values are shown in in Fig. 12.

Figure 12. CrC particle reinforcement ratio - wear depth graph

It is seen that the wear diameter is at its highest value in the sample made of pure Cu and the smallest wear diameter is in the sample with 20% CrC reinforcement ratio. This suggests that as the amount of CrC in Cu increases, wear resistance increases.

In addition, the friction coefficients generated by the 50 and 75 N forces applied in the experiment are presented in the graph in Fig. 13.

Figure 13. Frictional coefficient change in samples according to CrC particle reinforcement ratio

As the weight CrC ratio increased, friction coefficient of decreased. According to the calculated friction coefficient parameter, the highest coefficient of friction was observed on the pure copper sample with 50N load applied. The coefficient of friction at this value is approximately 0.12. For pure copper with a load of 75 N, this value is approximately 0.09. When the frictional force is calculated for this samples, the frictional force will be higher for pure copper with a load of 75 N. Since the wear level of the sample with higher frictional force is larger, this parameter is in line with the previously obtained wear depth and weight loss data. Experiments on specimens with different reinforcement ratios at equal loads indicate that the friction coefficient of the pure copper samples are highest in the other reinforcement rates which means that the frictional force is also highest.

IV. CONCLUSION

In this study, the effects of 5%, 10%, 15% and 20% CrC reinforcement on the wear and mechanical properties of Cu-CrC composites were researched. As result of findings, it was understood that the CrC reinforcement increased the hardness of pure copper sample. Also, wear tests show that CrC reinforcement reduces weight loss, friction coefficient, wear depth and wear diameter, thus creating resistance against wear. Wear sample was closely examined at SEM (Fig. 14).

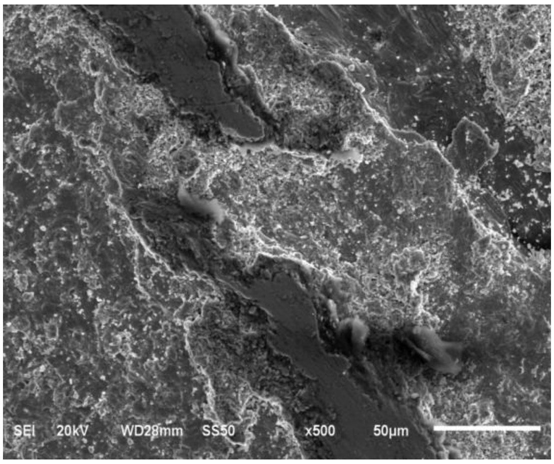

Figure 14. Wear surface SEM image

In the examination of the SEM photographs of the samples, it was observed that the wears are usually in the form of neck fractures. Wear that occurs in the form of particle breakage was seen at a level that it may be called not existing. According to these results, CrC particle reinforcement provided a positive contribution to the formation of resistance to abrasion in Cu-MM specimens.

- Therefore, this study ought to be supported with the tensile strength test.
- In the guidance of this study, materials with superior mechanical properties can be developed by producing copper matrix metal composites with different compositions by micro-level addition of different elemental powders into the Cu-CrC alloy.
- Sintering is a basic step in powder processing. The sintering temperature and the duration are among the most important parameters affecting the change in the microstructure during the transition from the non-sintered product to the sintered product. By changing the sintering temperatures and sintering times, mechanical and wear resistance of these materials can be improved.
- By changing grain sizes and reinforcement ratios, the strengths and performance characteristics of materials can be examined.
- By increasing the applied pressure in the samples, the porosity can be decreased and the density can be increased.
- Machining performances can be examined by designing and producing larger moulds, fabricating large samples using these moulds, and applying metal removal methods on Cu-CrC and other particle-reinforced Cu matrix composite materials.

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Conflict of Interest: The authors declare that they have no conflict of interest.

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