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Original Research Paper

Investigation of wear behaviours of Al matrix composites reinforced with different B_4C rate produced by powder metallurgy method

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A B S T R A C T

In this study, the effects of wear behaviours of Al matrix composites reinforced with different B_4C rate produced by powder metallurgy method were investigated. Al and B_4C powders with purity of 99.9% and sizes of 25–44 μm were prepared as pure Al, 4% B_4C/Al, 8% B_4C/Al, 12% B_4C/Al and 16% B_4C/Al. After these prepared mixtures were pressed under 350 MPa, they were sintered for 90 min at 580 °C in atmospheric environment. Microhardness and wear tests of the produced samples were carried out. Wear experiments of these composites were performed with specially manufactured test equipment at different application loads (5 N, 10 N and 15 N), different sliding distances (250 m, 500 m, 750 m and 1000 m) and a constant speed of 0.46 m/s. In addition, optical microscope, SEM, EDS analyses were used to determine the microstructural changes in the worn and unworn surface of the manufactured composite materials. The results of experimental studies show that the increasing the B_4C reinforced rate in composites with Al matrix has led to increase of the hardness and to reduce of the wear loss.

1. Introduction

Composite materials are the most preferred type of materials since they provide the opportunity to create a new desired material from different properties of multiple materials whose features are different from each other. Composite materials can be obtained by means of different methods. Powder metallurgy method is one of the most common methods used for the production of composite materials. Since some metals are hard to process via other methods, they can easily be shaped by the powder metallurgy method. The parts shaped by powder metallurgy are produced as final products without any further processing and are used in space, automotive, defence industry, electronic industry and various areas. The superior properties such as high strength, low density and high modulus of elasticity of materials produced by powder metallurgy make these materials indispensable [1,2]. Among composite materials produced by the powder metallurgy method, especially Al and its alloys are the most preferred materials because of their economical, low weight and easy machining qualities. In addition, these materials, which are in powder form, can be provided with desired physical and mechanical properties by adding reinforcement elements in different properties. The usage of B_4C, SiC and Al_2O_3 reinforcing elements, thanks to their excellent mechanical properties such as low density, high hardness, high strength and good chemical stability, has increased [3,4]. Topcu et al. [5] examined the mechanical properties of B_4C reinforced Al composites. They observed that the increase in reinforcement ratio increased the hardness of composite. Varol et al. [6] developed an artificial neural network model to determine the effect on physical and mechanical properties of reinforcement rate of Al2024-B_4C composites produced by the powder metallurgy method. They reported that reinforcement rate has a significant effect on hardness, density and tensile strength.

Materials have both desired and undesired properties. Wear is one of the undesired properties. Under different working conditions, materials are exposed to different loads and moments. In materials interacting with each other, friction factor is an important parameter since the increase of temperature in rubbed materials causes wear [7]. As a consequence of a local relationship between interaction surfaces of materials, wear can be defined as material loss during relative movement [8]. Materials which work interacting with each other wear off more or less depending on working conditions. Different composite materials, such as materials produced by powder metallurgy and coated materials are preferred to reduce the wear; and the wear studies are still being investigated. Deuis et al. [8] examined the wear of aluminium composites under dry sliding conditions at different loads. They

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observed that the wear of composites increased with increasing applied load. They stated that the heat occurred due to friction and the increasing heat accelerated wear. Hasirci and Gul [9] determined the microstructure and hardness of B_4C reinforced Al composites and investigated the abrasion wear behaviours under sliding conditions. They observed that the hardness of composite increased with increasing reinforced B_4C, the 20% B_4C reinforced composite showed the highest hardness and the 10% B_4C reinforced composite showed the highest wear resistance. Jiang et al. [10] produced the Al-5% Si-Al_2O_3 composites by powder metallurgy and natural reactive synthesis technology. By carrying out wear experiments of the produced composites, they investigated that the coefficient of friction depending on load and the wear loss depending on load and sliding distance. They determined that the loss of wear and coefficient of friction increased with increasing load and sliding distance. In this study, abrasion wear, adhesion wear and oxidation wear were determined as wear mechanisms. Siddesh Kumar et al. [11] examined the wear behaviours of hybrid metal matrix composites under dry sliding conditions. Al2219/B_4C & Al2219/B_4C/MoS_2 hybrid composites were produced with casting technique according to ASTM G99-95 standards. As a result of the studies, they observed that wear rate decreased with increasing of B_4C and MoS_2 reinforcements. It was investigated the tribological properties that Al2024 and Al2024/SiCp composites by Mousavi Abarghouie and Seyed Reihani [1], graphite solid lubricant aluminium hybrid composites produced by powder metallurgy method by Ravindran et al. [12], Al-CNT composites by Bastwros et al. [13], Al/SiC/Graphite and Al/FeB/Graphite hybrid composites by Sahin et al. [14], Resin/Graphite composite by Zhu et al. [15] and B_4C and SiC reinforced AA6351 metal matrix composite by Thirumalai Kumaran et al. [16].

When literature studies are examined, it has been observed that reinforcement rates, pressing pressures, applied loads, sliding distances, matrix and reinforcement particle sizes significantly affect the mechanical properties and wear resistances of the composites. Although there are many studies on wear behaviours of different composite materials, it has been found that there is still a need for scientific studies on wear behaviours of B_4C reinforced Al metal matrix composites produced by especially powder metallurgy. In this study, it was aimed to determine the optimum sintering temperature of B_4C reinforced Al metal matrix composites produced by powder metallurgy and the effects on hardness and wear behaviours of reinforcement ratio of B_4C/Al composites sintered at these temperatures.

2. Experimental procedures

Al and B_4C powders, which have sizes of 25–44 μm and purity of 99.9%, were used to produce composites by powder metallurgy method in this study. These powders were weighed with the aid of the Radwag Brand AS 220/C/2 Model precision scale having a sensitivity of 1 mg at the determined ratios (Table 1). Moreover, zinc stearate powder was added to the powders in 5/1000 rate as a lubricant. Powders, of which weights were determined, were mixed in the Planetary Ball Mill, XQM-2 device. Steel balls having 5 mm diameters were used in the mixing process. The rotation speed of 300 rpm and the mixing time of 20 min were selected. The homogeneously dispersed mixture powders were pressed in the feed rate of 10 mm/min under pressure of 350 MPa by filling into a cylindrical mould having a diameter of 27 mm.

The pressed 8% B_4C reinforced Al matrix materials were sintered at 560 °C, 580 °C and 600 °C for 90 min to determine the optimum sintering temperature. The highest hardness and compressive strength were obtained in case of 580 °C of sintering temperature [17]. Different B_4C reinforced Al matrix materials pressed in this direction were sintered in a Nabertherm Brand oven at 580 °C for 90 min in atmospheric environment. Composite materials are made into final products by subjecting to necessary polishing process. The images of the produced composite materials are given in Fig. 1.

Hardness experiments of composite materials were carried out on a Shimadzu HMV microhardness tester. The hardness values were determined depending on the size of the obtained trace by applying load of 1 N for 15 s to composite materials. The optical image and the trace on image are given in Fig. 2. Average hardness value was calculated by taking hardness values from 5 different points on composite surface. The wear experiments were carried out by specially manufactured experimental setup. A schematic view of the wear experimental setup is given in Fig. 3. Wear experiments were carried out with experimental setup connecting to JETCO JML-3010Y turning lathe at a constant speed of 0.46 m/s, loads of 5 N, 10 N and 15 N, sliding distance of 250 m, 500 m, 750 m and 1000 m. Wear values were determined depending on weight loss. Ti-6Al-4V alloy whose chemical and mechanical properties are given Table 2 and having a diameter of 40 mm and a surface roughness of 2.4 μm were used as abrasive material. A Testo 881-2 brand thermal camera was also used to determine the occurring heat during the wear experiments.

After the hardness and wear experiments of the samples were finished, worn and unworn areas were examined by using the Zeiss brand EVO LS 10 model Scanning Electron Microscope (SEM); and the chemical composition was analysed.

Table 1
Mixing ratios of powders.

Number of Samples	Powders		
	Pure Al	B_4C	Zinc Stearate
1	100%	–	0.5%
2	96%	4%	
3	92%	8%	
4	88%	12%	
5	84%	16%	

3. Experimental results and discussions

The variation of hardness values of B_4C reinforced Al matrix composites produced by powder metallurgy method, the wear behaviours under dry sliding conditions and the heat occurring during wear have been experimentally investigated. In the experimental results, the wear and temperature values are given in Table 3.

3.1. Hardness results

The hardness values obtained from different B_4C reinforced Al matrix composites are given in Fig. 4.

From Fig. 4, it was seen that the lowest hardness value was measured as 48.5 HV from pure Al, and the highest hardness value was measured as 68.1 HV from Al matrix composite with 16% reinforced B_4C. The increase of the reinforcement ratio has contributed to the increase of the hardness value of composite. Because, the B_4C used as a reinforcement element is a very hard material [18]. Therefore, the B_4C reinforcement element causes the hardening of the material to which it is added.

3.2. Wear and heat formation results

The changes in the weight loss depending sliding distance, applied load and reinforcement ratio under dry sliding conditions

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