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The Effect of Ceramic Oxide Type on Compressive Strength and Abrasive Wear Behavior in Different Ceramic Oxide Reinforced Al2024 Composites

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Abstract **–** In this study, particulate tungsten trioxide (WO_3), Neodymium oxide (Nd_2O_3), zirconium oxide (ZrO_2) and aluminum oxide (Al_2O_3) ceramics were separately reinforced at 10% weight ratio into 2024 aluminum matrix material by powder metallurgy method. Abrasive wear and compression strength tests were carried out on the composite samples. According to the data obtained, the type of ceramic oxide reinforcement in the composite structure was compared according to the wear behavior and compressive strength. As a result of the abrasive wear tests carried, the lowest wear loss amount was obtained from the Al_2O_3 reinforced composite, while the highest wear loss value was obtained from the WO_3 reinforced sample. Looking at the compressive strengths, it was seen that the highest compressive stress was obtained from the Al_2O_3 reinforced composite, while the lowest compressive stress value was obtained from the Nd_2O_3 reinforced sample. It was understood that the hardness values of the ceramic oxides doped into the Al2024 matrix directly affect the wear loss and compressive strength values of the composite structures. It was concluded that WO_3, Nd_2O_3, ZrO_2 and Al_2O_3 reinforcement elements in the form of particles doped into the Al2024 matrix improve the mechanical properties of the composite structure.

Keywords – Aluminum Composite, Al2024, WO_3, Nd_2O_3, ZrO_2, Al_2O_3, Abrasive Wear, Compressive Strength

I. Introduction

The usage of composite materials has emerged and increasingly expanded over the past half-century in response to the continuously growing human needs and rapidly evolving engineering sector, where traditional engineering metals prove inadequate in certain circumstances. One type of these composite materials is aluminum matrix composites (AMC). Aluminum and its alloys are preferred more as metal matrix due to their many positive properties [1]. Aluminum is the second most used metal in the world after steel. In addition to its advantages such as low density, good machinability, high thermal and electrical conductivity, aluminum is limited in use in a significant part of industrial applications due to some properties such as low hardness value, low abrasion resistance and low melting point. Al_2O_3, SiC, BN and B_4C etc. to improve the mechanical properties of aluminum matrix composites. ceramic reinforcements are used [2]. Ceramic materials, SiC, B_4C, TiC etc. carbide ceramics, oxide ceramics such as Al_2O_3, SiO_2, ZrO_2, borides such as TiB_2, ZrB_2, HfB_2 can be mentioned in 3 basic ceramic groups. The common feature of all these materials is their high thermal resistance and very high hardness compared to aluminum. When the literature is examined, it has been seen that many different ceramic materials with low density and expansion coefficient, high strength, high elastic modulus and high hardness are used as reinforcement materials [3-5].

For this purpose, aluminum matrix composite materials were produced by powder metallurgy method by reinforcing Nd_2O_3, WO_3, ZrO_2 and Al_2O_3 ceramic particles to Al2024 matrix material. In the literature, it has been determined that rare earth element oxides such as Nd_2O_3 contribute to thermal stability, fatigue resistance and grain refinement of composite materials [6]. Due to the very good chemical stability and strengthening effect with aluminum, the production of W-Al intermetallics and composites by mechanical alloying and powder metallurgy has been reported [7-9]. With the addition of ZrO_2, it has been stated that excellent mechanical and abrasion resistance at high temperatures is obtained [10, 11]. In addition, it has been observed that ZrO_2 reduces thermal expansion and glaze melt fluidity due to its high melting point and high surface tension [12].

There are two basic production methods of metal matrix composites, liquid phase and solid phase. Powder metallurgy (PM) is one of the most important solid phase production methods and is frequently preferred in practice. The production method with PM is a manufacturing method in which mixed metal powders are pressed at room temperature or high temperatures, in a mold with the shape and dimensions of the part to be produced, followed by sintering at a certain temperature. The main problem in the production of such composites is the low wetting between the matrix metal and the reinforcement particles. With the powder metallurgy (PM) method, the control of the interface kinetics can theoretically be well achieved [13].

In this experimental study, the ceramic oxide reinforcements in the aluminum matrix and four different ceramic oxide reinforced composite materials were investigated for abrasive wear.

II. Materials and Method

In this experimental study, Al2024 quality powder aluminum alloy with a size of -105 microns was used as matrix material, and WO_3, Nd_2O_3, ZrO_2 and Al_2O_3 ceramic materials in particle form were used as reinforcement elements. In Table 1, some technical properties of matrix and reinforcement materials are given.

Table 1. Some properties of test materials

Material	Density, g/cm^3	Melting point, °C	Hardness, HV
Al 2024	2.78	640	137
WO_3	7.16	1473	1360
Nd_2O_3	7.24	2270	669
ZrO_2	5.00	2823	1570
Al_2O_3	3.98	2277	2035

For the production of composites via powder metallurgy; firstly, Al2024 powder and WO_3, Nd_2O_3, ZrO_2 and Al_2O_3 ceramic powders were mixed with 10% reinforcement and 90% matrix and compressed under 700 MPa pressure Then, composite specimens with a diameter of 16 mm and a length of about 20 mm were obtained by sintering at 580 ^oC for 120 minutes. The image of the composite samples produced is given in Figure 1.

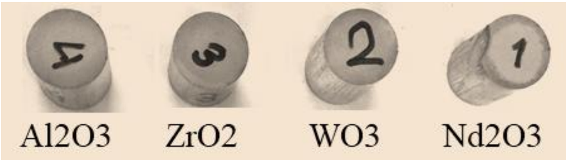

Fig. 1 Composite samples

III. Results

A. Abrasive Wear Resistance

The abrasive wear tests of the composite specimens were carried out with the pin-on-disk method at a sliding speed of 0.8 ms-1, a constant load of 30 N and a constant wear distance of 120 m. Abrasive with 600 mesh SiC abrasive size was used as the abrasive element. The graph drawn according to the data obtained from the wear tests is given in Figure 2.

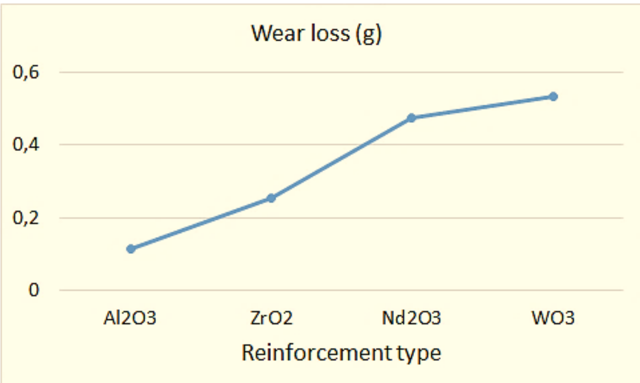

Fig. 2 Amount of wear loss

Looking at the graph given in Figure 2, it is seen that the least wear loss occurs in Al_2O_3 reinforced aluminum composite and the highest wear loss in WO_3 reinforced aluminum composite. There are different reasons affecting the wear mechanism in such metallic based and hard particle reinforced composites. In this study, the hardness value of the composite structure has emerged as the most important of these reasons. When the hardness values in Table 1 are examined, it is understood that the wear resistance of the Al_2O_3 reinforced composite, which has the highest hardness value, is the highest. However, this situation differed for Nd_2O_3 reinforced composite. Although the Nd_2O_3 reinforced composite had the lowest hardness among the oxide ceramics used as reinforcement elements, it showed less wear loss than the WO_3 reinforced sample. Although the hardness value of the materials affects the wear behavior, other factors may come to the fore in some cases. It can be said that the homogeneity of the composite structures produced in this study and the amount of porosity in the structure are also effective on the wear behavior. Similar results have been reported in the literature [13, 14]. In this case, it is thought that the porosity in the WO_3-reinforced composite sample is higher than the other composite samples, and the WO_3 particles that were clumped here during the abrasion tests are massively detached from the structure. As a result, the highest wear losses occurred in WO_3 reinforced composite. In order to examine the porosity in composite structures, the digital microscope images in Figure 3 are given.

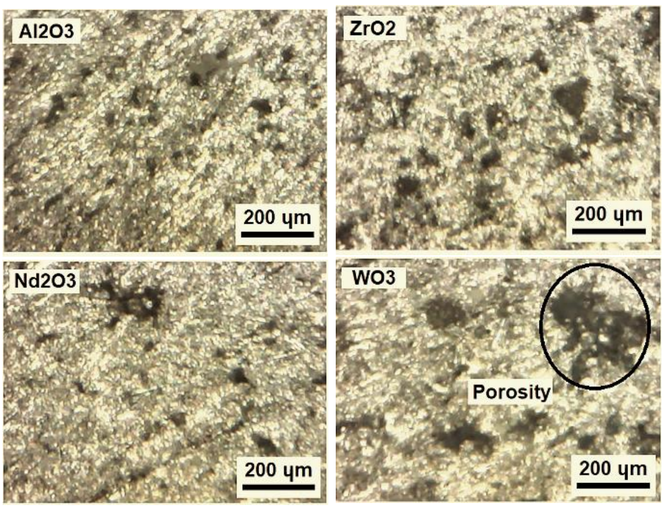

Fig. 3 Ceramic oxide reinforced Al2024 composite structures

As seen in Figure 3, it is understood that the porous regions in the WO_3 composite structure occupy a larger area. It is known that reinforcement particles contained within such pores exhibit a tendency to agglomerate. The reinforcement particles, which form a dense mass by clumping, have a negative effect on both the pore formation and the wetting reaction between the matrix reinforcement. Therefore, due to this porosity, more wear loss occurred in the WO_3 reinforced composite structure than in the Nd_2O_3 reinforced structure, which is in the softer phase.

B. Compressive strength

Composite samples were subjected to compression test with a compression test device (2400±200) N/s loading speed. The graph drawn according to the obtained compressive stress values is given in Figure 4.

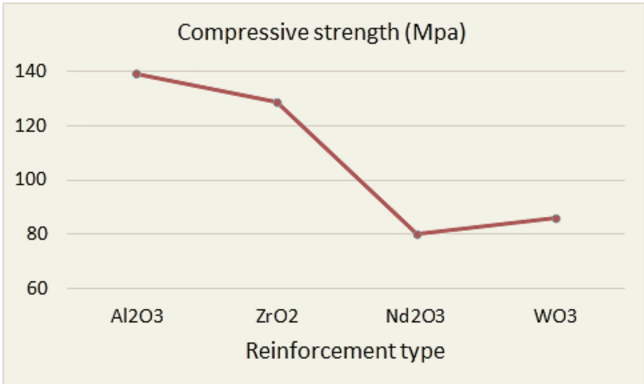

Fig. 4 Compressive Strength Values

Looking at the graph in Figure 4, it is seen that the lowest compressive stress value is obtained from Nd_2O_3 reinforced, and the highest compressive stress value is obtained from Al_2O_3 reinforced aluminum composite. When the relationship of these results with the hardness of the reinforcement materials is considered, it is understood that they are proportional to each other. It is clearly seen that the hardness values of the ceramic oxide reinforcement elements in the composite structure have a direct effect on the compressive strength values. This situation is also expressed in similar studies in the literature [15-17].

IV. CONCLUSION

In the study, ZrO_2, Nd_2O_3, Al_2O_3 and WO_3 oxides were successfully doped into the Al2024 aluminum alloy, and then the abrasion and compression strengths of the composite samples were investigated. According to the data obtained, it was observed that the Al_2O_3 reinforced composite had the lowest wear loss. While the composite reinforced with Al_2O_3 powder with the highest hardness value was observed to have the highest wear resistance, it was determined that the composite reinforced with Nd_2O_3 wore less than the WO_3 reinforced composite despite the lowest hardness value. In the morphological examinations, it was determined that the amount of porosity in the WO_3 reinforced composite sample was higher than the others, therefore, the mechanical strength of this composite material was lower than the others as a result of the massive decomposition of the agglomerated WO_3 particles during both compression and abrasion tests. The obtained results revealed that in the case of a homogeneous mixture, the mechanical properties of the composite materials were improved in parallel with the hardness values of the oxide reinforcement materials.

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