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EFFECT OF ADDITIVE ELEMENTS ON ABRASION WEAR OF AA7075 BASED ZrO_2/GNP ADDED HYBRID COMPOSITES

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Abstract: *In this study, the abrasive wear behaviours of hybrid composite structures with AA7075 matrix zirconium oxide (ZrO_2) and graphene nanoplatelets (GNP) additives were investigated. For this purpose, hybrid composite samples were produced by adding 10% ZrO_2 and 0.5–1.0–2.0–4.0% GNP into AA7075 using powder metallurgy technique. The microstructures of the composites were examined and their hardness values were measured. Then, abrasive wear tests were performed using the pin-on-disc method. The experimental results were evaluated using analysis of variance. It was observed that ZrO_2 in the composite increased the hardness value and reduced wear losses. In addition, it was determined that the hardness values increased slightly with the GNP added to the structure together with ZrO_2 and that wear losses first decreased and then gradually increased. The lowest wear loss was obtained from the AA7075 hybrid composite sample with 10% ZrO_2 and 0.5% GNP additives. The lubricating properties of ZrO_2 and the dry lubricant properties of GNP acted together, resulting in less wear loss compared to the AA7075 reference sample without additives. It was evaluated that the porosity formed in the structure caused an increase in wear losses as the GNP amount in hybrid composites exceeded 1%. According to ANOVA analysis, the material was 99% effective in wear losses.*

Keywords: *Powder metallurgy, AA7075, ZrO_2, GNP, Hardness, Abrasive wear, Microstructure, ANOVA*

1. INTRODUCTION

Metal Matrix Composites (MMC) are increasingly used to replace traditional metallic alloys in aerospace, automotive, marine and other mechanical industries [1]. This is due to their outstanding physical, mechanical and tribological properties [2]. In order to improve the properties of the matrix, hard reinforcements such as Al_2O_3, SiC, B_4C, TiC etc. in the form of particles or fibres are widely used in aluminium MMCs.

The serious problem encountered today is to resist wear, especially leading to frequent replacement of components. The high wear resistance of particle reinforced aluminium composite is due to the presence of hard ceramic particles that protect the matrix from wear [3]. One of the popular reinforcements recently used in aluminium-based metallic composites is ZrO_2 (zirconia). ZrO_2 has been found to exhibit better strength, hardness and fracture toughness with a slight decrease in ductility [4]. ZrO_2 has the capacity to maintain high strength at high temperature and exhibits excellent mechanical and wear properties [5].

ZrO_2 is used extensively in fuel cell technology, catalyst or catalyst support, protective coating for optical mirrors and filters, ceramic biomaterial production and thermal barrier coating [6]. When the literature is examined, it is seen that there are different studies investigating the mechanical properties of ZrO_2 reinforced aluminium composites [7-9].

It is also produced as a hybrid composite by adding a second reinforcement material to aluminium. It is seen that nano materials such as graphite, graphene, carbon nanotube are mostly preferred in the materials used as the second reinforcement element. It is reported that graphene particles act as solid lubricants and the composite material which is self-lubricating, especially in applications where tribological performance is desired to be improved [10]. Graphene is elastic and flexible, but also very hard and hundreds of times stronger than steel [11].

In this study, 7075 aluminium based ZrO_2 and GNP reinforced hybrid composites were produced and their wear behaviours were investigated. Unlike the numerous adhesive wear studies in the literature, abrasive wear tests were performed on abrasive sandpaper. The obtained data were optimized with full factorial experimental design and evaluated together with hardness and surface morphology.

2. MATERIALS AND METHODS

In this study, AA7075 powder with a size of 44 microns, ZrO_2 powder with a particle size of 44 microns and graphene nano plates with a size of 6-16 nm were used. The matrix-reinforcement ratios of the composite samples produced by powder metallurgy are given in Table 1.

Table 1. Matrix-Reinforcement Ratios

Samples	AA7075 %	ZrO_2 %	GNP %
Reference	100	0	0
S1	90	10	0
S2	89,5	10	0,5
S3	89	10	1,0
S4	88	10	2,0
S5	86	10	4,0

The microstructures of the samples were imaged and hardness measurements were performed using the Brinell method. In the final stage, 2 repeated wear tests were performed with 325 mesh abrasive SiC-based sandpaper under dry conditions, at a constant wear load of 20 N and a wear distance of 200 m, at a wear speed of 1 ms^{-1}. Before and after each experiment, weight measurements were made on a precision balance to determine wear losses. The obtained data were analysed using one-way ANOVA. Figure 1 shows the pin-on-disc abrasive wear test device.

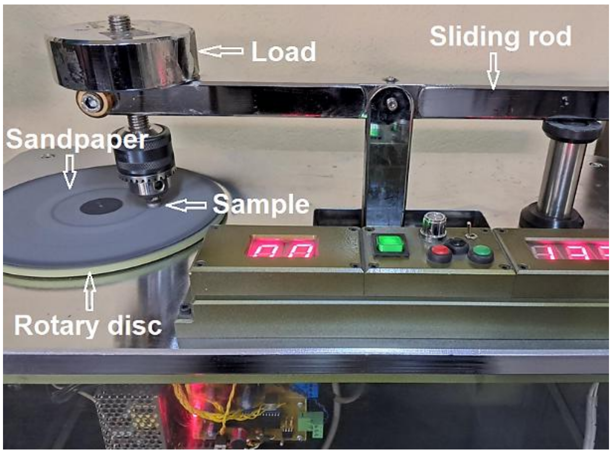

Figure 1. Pin-on-disc abrasive wear tester

3. RESULTS AND DISCUSSION

3.1 Microstructures

In Figure 2, stereo microscope images of the reference sample 100% AA7075, the 10% ZrO_2 added S1 sample and the 2% GNP added S4 sample are given to see the difference in GNP added. When the images in Figure 2 are examined, it is seen that the unadded AA7075 reference sample has a different microstructure than the others. The effect of ZrO_2 particles is revealed in the composite structure with 10% ZrO_2 added S1. It is understood that the light coloured particles are ZrO_2 particles. It is evaluated that the black areas seen on the surface of the S4 coded sample are the areas where GNP particles are located.

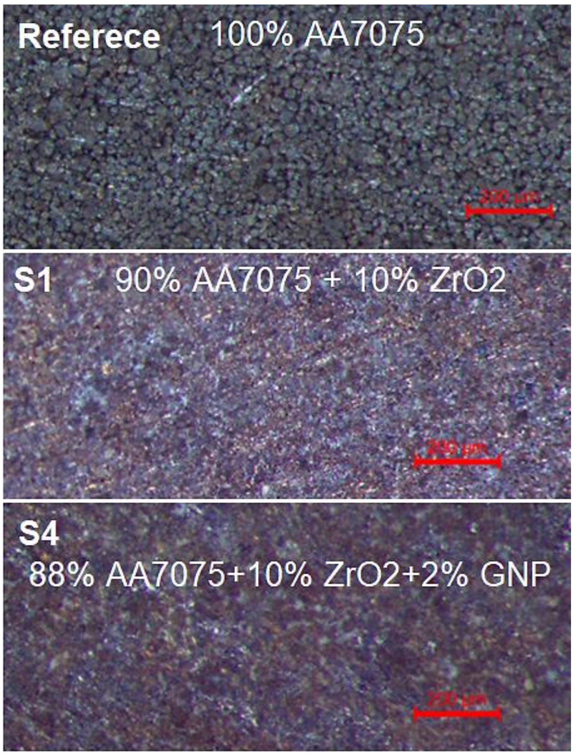

Figure 2. Microstructures of test samples

3.2 Hardness

The average hardness values of AA7075/ZrO_2/GNP hybrid structures measured according to the Brinell method are given in the graph in Figure 3.

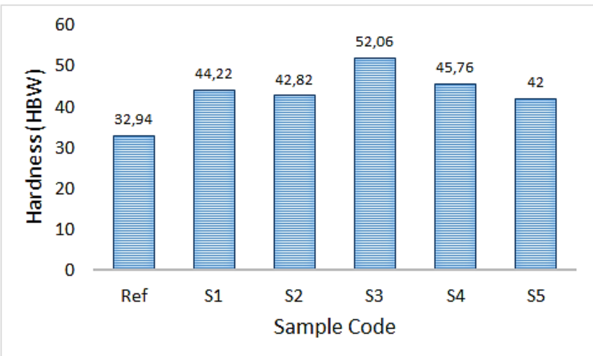

Figure 3. Brinell Hardness Values

In Figure 3, it is seen that the ZrO_2 and GNP additives added to the AA7075 alloy increase the hardness value of the composite structure. With only 10% ZrO_2 addition, the hardness of the reference sample, which was 32.94 HBW, increased to 44.22 HBW. The highest hardness value was reached with 52.06 HBW in the S3 coded sample added with 10% ZrO_2 and 1% GNP. Similar results have been reported in some studies in the literature [4,5,12]. It was observed that very similar results were achieved in a study in the literature [13]. Although the hardness values gradually started to decrease in the S4 coded samples with 2% GNP reinforcement and S5 coded samples with 4% GNP reinforcement, they were recorded as higher values compared to the reference sample. In such nano graphene reinforced composites, porous regions may occur in places due to reinforcement agglomeration with increasing reinforcement amount. The formed porous structure leads to a decrease in hardness values.

3.3 Abrasive Wear

The wear loss values determined after the abrasive wear tests of AA7075/ZrO_2/GNP hybrid structures with the pin-on-disc method are given in Table 2.

Table 2. Abrasive Wear Losses (g)

	Matrix-Reinforcement Ratios	Test 1	Test 2
Ref	100AA7075	0,7712	0,7951
S1	90AA+10ZrO_2	0,6071	0,6292
S2	89,5AA+10ZrO_2+0,5GNP	**0,5827**	**0,5946**
S3	89AA+10ZrO_2+1GNP	0,6842	0,6947
S4	88AA+10ZrO_2+2GNP	0,7825	0,7748
S5	86AA+10ZrO_2+4GNP	**0,8498**	**0,8292**

When Table 2 is examined, it is seen that the wear losses first decreased and then increased slightly compared to the reference sample. The ZrO_2 and GNP reinforcement elements in the AA7075 matrix structure generally had a reducing effect on wear losses. The ZrO_2 surface is a ceramic with a slippery structure. The other reinforcement element, graphene, has a self-dry lubrication feature [14]. These features caused the abrasive SiC particles to slide on the surface in places in the experiments, leading to a decrease in the amount of material removed. However, the wear losses, which increased with the increase in the amount of GNP in the structure to 1%, reached the top in the 4% GNP reinforced sample numbered S5 and exceeded the loss in the reference sample. It was evaluated that this was caused by the increasing porosity formed together with the GNP agglomerations in the structure. During the experiment, the abrasive SiC sandpaper grains clung to these pores and caused more material to be removed from the structure. The worn surface images with the least and the most wear loss are given in Figure 5.

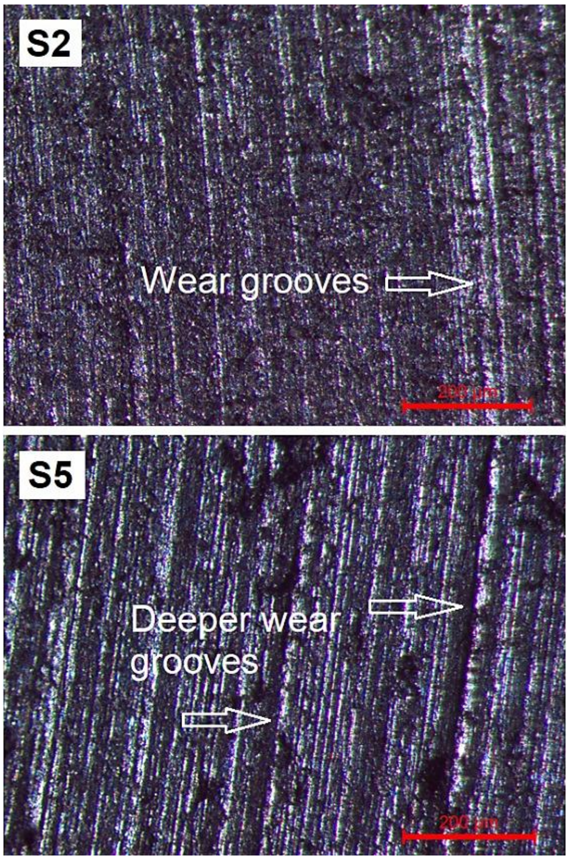

Figure 5. Images of the least (S2) and most (S5) worn surfaces

In all wear experiments, the least wear losses occurred in the S2 coded 0.5% GNP added sample, and the most wear losses occurred in the S5 coded 4% GNP added sample. The dry lubricant feature of the GNP nano material came to the fore in the S2 and S3 coded samples [15]. It is understood that the hollow structure formed within the structure is more effective with the increase in the GNP ratio and has an increasing effect on the wear amounts. When the surface images in Figure 5 are examined, the deep wear lines formed on the surface of the S5 sample, where the most wear loss occurred, are clearly seen.

3.4 Analysis of Variance (ANOVA)

In this study, the abrasive wear behaviour of AA7075/ZrO_2/GNP hybrid materials was investigated and the experimental results were examined by one-way analysis of variance (ANOVA). The full factorial experimental design plan given in Table 2 and the one-way analysis of variance results table based on the experimental results are presented in Table 3. The ANOVA result showed that the material was 99.1% effective on the wear loss and the error amount of the model was 0.9%.

Table 3. Results of ANOVA

Source	DF	Adj SS	Adj MS	F-Value	P-Value	C%
Materials	5	0.1004	0.0201	134.2	0	99.1
Error	6	0.0009	0.0002			0.9
Total	11	0.1013				100

According to the material main effect graph in Figure 6, the wear loss values of all materials except the S4 coded material are different from the reference material and this difference is statistically significant. The S2 coded material showed the highest wear resistance, followed by the S1, and S3 coded materials, respectively. The S5 coded material showed lower wear resistance than the reference material. The reason for this is that the increased GNP additive ratio is not distributed homogeneously enough in the microstructure.

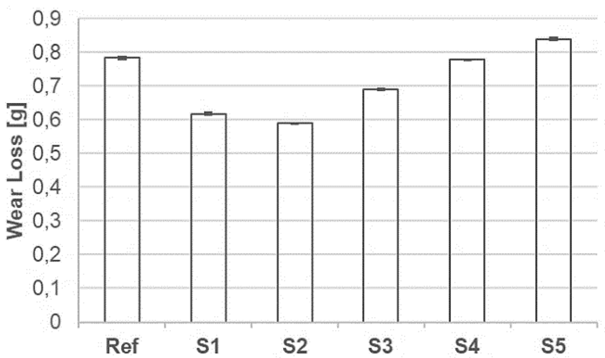

Figure 6. Main effect graph of wear loss

4. CONCLUSION

The abrasive wear behaviours of AA7075/ZrO_2/GNP hybrid materials with different additive ratios were investigated in this study.

ZrO_2 and GNP reinforcement materials increased the hardness of hybrid composites. The highest hardness value was obtained from the S3 coded sample, which contained 1% GNP together with ZrO_2. The hardness of the S3 coded sample increased by 57% compared to the reference sample. With the effect of ZrO_2 and GNP in the structure, the resistance of the composites to abrasive wear increased and wear losses decreased except for the S5 coded sample. It was evaluated that the lubricity and self-dry lubrication properties of the reinforcement materials affected these wear behaviours. It was seen in the ANOVA analysis that the material was 99.1% effective on wear losses.

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