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IMPROVED WEAR RESISTANCE OF AN ALUMINUM – ZIRCONIA COMPOSITE

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The wear resistance of aluminum has been improved with zirconia material. The method consists in compacting aluminum powder and the compacted piece immersed several times in a colloidal zirconia solution until a constant weight was reached. The solution penetrated the piece and infiltrated the preform. A wear test was carried out in a pin-on-disc machine. By measuring the weight loss, it was shown that the composite had significant improvement in wear resistance compared to pure aluminum.

Key words: zirconia, aluminum-powder, wear-resistance.

INTRODUCTION

Aluminum-based MMCs (using alloys) can provide excellent wear resistance, provided the possible limitations of the benefits of reinforcement are appreciated [1]. Aluminum matrix composites have been utilized in high-tech structural and functional applications including aerospace, defense, automotive, and thermal management areas, as well as in sports and recreation [2].

From the industrial standpoint, it is advantageous to fabricate metal matrix-particulate composites using powder metallurgy because the fabricated composites possess a higher dislocation density, a small subgrain size, and limited segregation of particles [3]. Aluminum-matrix-based composites have exhibited further improvement of the mechanical properties of ceramic particulates. The wear resistance of a new powder metallurgy (P/M) Al – Si alloy has been studied [4]. Also the wear resistance of aluminum matrix composites, manufactured with Al_2O_3 and Al_4C_3, were studied using the powder metallurgy technique of ball-milled mixing in a high-energy attritor and cold compaction followed by hot extrusion at 500°C [5].

There are few investigations of aluminum-matrix based composites reinforced with zirconia, which has low adhesion to aluminum, Therefore, the processing of powder metals has one more advantage in comparison with the conventional method of casting. A nanocrystalline ZrO_2/Al composite has been fabricated by the squeeze casting route using specially designed casting equipment [6]. Aluminum-matrix composites containing nanometer-sized particles of zirconia, manufactured using the hot pressing technique, showed an increase in hardness [7]. Studies on Al – metal matrix composites synthesized with nanosized dispersions of mullite and zirconia through uniaxial hot-pressing at temperatures in the range of 450 to 610°C showed that the values of dislocation density increase with temperature [8].

In this present work, results on infiltration through an ammonium zirconium carbonate solution are presented. The wear resistance of aluminum-based metal matrix composites obtained by powder metallurgy, where the reinforcing zirconia was infiltrated to the optimum, is reported.

METHODS OF STUDY

The composites were created by compacting aluminum powder (Almex) at room temperature in an automatic hydraulic press, Graseby T-40. The mold was filled with aluminum powder and cellulose fibers, then 175 MPa of pressure was applied for 30 sec to obtain cylindrical pieces 20 mm in diameter and 7 mm in height. The size distribution of the aluminum powder particles facilitated the filling process, since the empty spaces between the larger particles were filled by smaller particles. The fibers were eliminated and the compacted pieces were immersed several times in the stabilized ammonium zirconium carbonate solution (Mel Chemicals) until the weight reached a constant value. This solution, with a viscosity of 5 Pa · sec, penetrated the piece, infiltrating the

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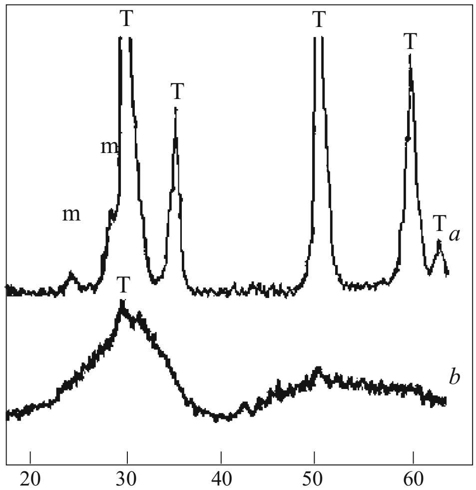

Fig. 1. XRD diffractogram of zirconia after sintering.

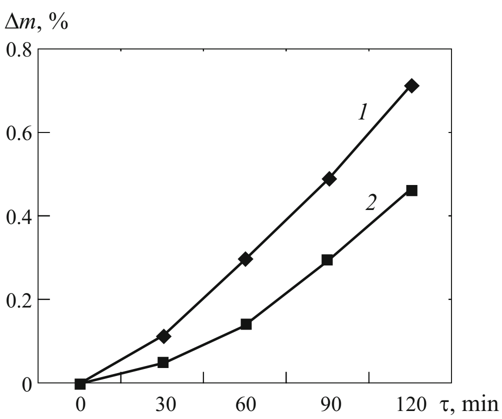

Fig. 2. Wear vs. time for aluminum – zirconia composites and pure aluminum.

narrow channels of the preform. Afterwards, when the solution was dry, it changed to a gel.

Specimens were sintered at a temperature of 600°C in standard atmosphere in a Lindberg oven, model 51848 CTD, for 3 h. During the sintering, the lowering of the free energy of the particles produced agglomeration [9]. The composites and pure aluminum were subjected to wear resistance test and compared.

Wear resistance is measured by various methods; in this work it was done in a pin-in-disk machine. The pin is an aluminum cylinder that is pushed from above to a level surface of a rotating steel disk. To carry out the wear resistance tests, a Jean Wirtz polishing machine, TG-250, with an odometer to measure the rpm was used. A steel disc, treated thermally to achieve a hardness of 48 *HRC* in the Rockwell scale, was employed. We attached the steel disc to the machine to produce wear; also an additional part was connected to the pin so we could add and change weight during the sliding wear tests.

The composite pins were submitted to wear tests on the disc, at a speed of 360 rpm and with a load of 9 N without lubrication for 2 h. The weight loss of the piece due to wear was measured every 30 min.

RESULTS AND DISCUSSION

After the treatment, the zirconia presented crystalline phases, both monoclinic and tetragonal at low temperatures. Figure 1 shows the corresponding XRD patterns: at 450°C there exists a transformation from amorphous to tetragonal structure, and at 600°C, monoclinic and tetragonal phases coexist. This is important because the sintering of aluminum must take place at temperatures lower than its fusion point (660°C).

The wear behavior of composites was studied in dry sliding against steel counterfaces. The results of the wear resistance tests are shown in Fig. 2. The reinfiltration with the colloidal solution was carried out until it reached a constant weight. Afterwards, the preform was sintered. The tribological behavior can be seen in the figure, where there is less loss of weight of the composite compared to pure aluminum. This composite showed the best results when 0.05 wt.% of fibre was used.

In Fig. 3 SEM micrographs of the interior of a preform of the composite Al – zirconia is shown. In these figures, the porosity can be observed, allowing infiltration with a larger

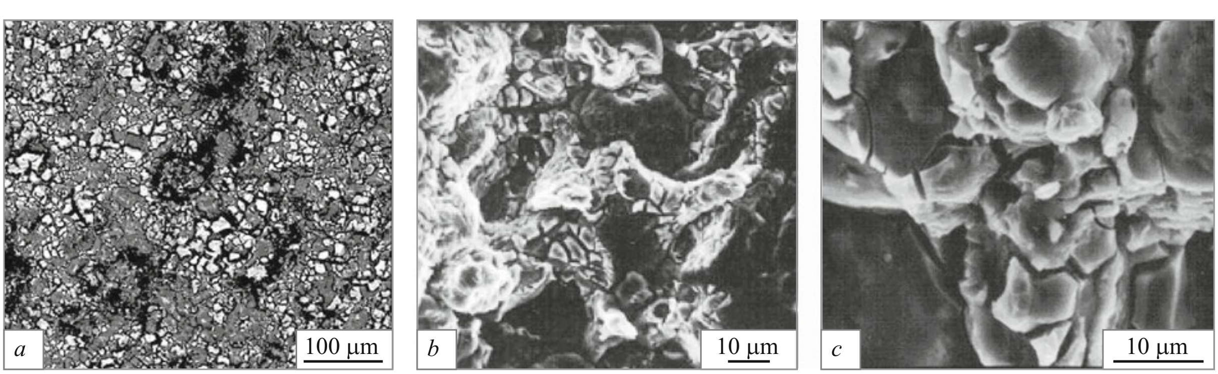

Fig. 3. SEM Micrograph of aluminum – zirconia composite.

quantity of zirconia, up to 3 wt.%, and also homogeneity of the zirconia throughout the interior of the preform. The interconnected porosity of pure Al was 5.39%, and of composite Al – zirconia, 5.04%. The wear behavior is important in tribological comparison of evaluations. In reporting wear, the wear coefficient K is often used, which was introduced in accordance with the Archards equation:

$$K = \frac{VH}{WS},$$

where V is the wear volume, L the normal load, S the sliding, and H the Brinell hardness. The wear coefficient for pure aluminum is $K = 8.208 \cdot 10^{-4}$, at that $V = 938.08$ mm^3, $W = 9$ N, $S = 4825.486$ m, 38 *HB*. The wear coefficient for composite $Al – ZrO_2$ is $K = 3.950 \cdot 10^{-4}$, at that $V = 439.823$ mm^3, $W = 9$ N, $S = 4825.486$ m, 39 *HB*.

Thus, the wear coefficient for composite $Al – ZrO_2$ is reduced; this material shows better behavior to wear than pure aluminum.

CONCLUSIONS

The process described is rather simple. The pieces were obtained in the best conditions of compaction and immersion. The cellulose fibres used during the compacting process increased the porosity and allowed a homogeneous distribution of zirconia; also, the quantity of zirconia present was increased in the interior of the aluminum preforms.

The best wear resistance was observed in the composite of Al – zirconia. The decrease in wear is due to the fact that the ceramic material introduced into the pores acts as a reinforcement. The best tribological behavior of this composite was achieved when there was a bigger presence and distribution of zirconia in the performs.

The wear coefficient of composite and pure aluminum shows that using this new methodology, a composite with improved wear resistance (twice as much) can be obtained.

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REFERENCES

1. I. M. Hutchings, S. Wilson, and A. T. Alpas, "Wear of aluminum-based composites," *Comprehensive Compos. Mater.,* **3**, 501 – 519 (2000).
2. M. K. Surappa, "Aluminum matrix composites: challenges and opportunities," *Sadhana*, **28**(1 – 2), 319 – 334 (2003).
3. Y. B. Liu, S. C. Lim, L. Lu, and M. O. Lai "Recent development in the fabrication of metal matrix-particulate composites using powder metallurgy techniques," *J. Mater. Sci.*, **29**(8), 1999 – 2007 (1994).
4. D. Casellas, A. Beltran, J. M. Prado, A. Larson, and A. Romero, "Microstructural effects on the dry wear resistance of powder metallurgy Al – Si alloys," *Wear*, **257**(7 – 8), 730 – 739 (2004).
5. G. Abouelmagd, "Hot deformation and wear resistance of P/M aluminum metal matrix composites," *J. Mater. Proces. Technol.*, **155 – 156**, 1395 – 1401 (2004).
6. L. Geng, S. Ochiai, H. X. Peng, et al., "Fabrication of nanocrystalline ZrO_2 particle reinforced aluminum alloy composite by squeeze casting route," *Scr. Mater.*, **38**(4), 551 – 557 (1998).
7. S. K. Pradhan, A. Datta, A. Chatterjee, et al., "Synthesis of aluminum matrix composites containing nanocrystalline oxide phase," *Bull. Mater. Sci.* (India), **17**(6), 849 – 853 (1994).
8. S. K. Shee, S. K. Pradhan, and M. De, "Effect of thermal stress on the microstructures of aluminum metal matrix composites," *Mater. Chem. Phys.*, **52**(3), 228 – 234 (1998).
9. J. M. Ruiz Prieto, L. García Cambronero, J. M. Torralba, and F. Velasco, *Manual de Pulvimetalurgia*, Edited by: Cátedra Höganäs de Pulvimetalurgia de la Universidad Carlos III de Madrid (1999).