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TRIBOLOGICAL ANALYSIS OF ALUMINA NANOCOMPOSITES FOR ORTHOPEDICS APPLICATIONS

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ABSTRACT
In this study the tribological analysis of Al_2O_3 nanocomposites/Al_2O_3 pair; proposed as a candidate material to fabricate hip prostheses was carried out. Nanopowders of Al_2O_3 (AKP 50, 300 nm), TiO_2 (PS-25, 50 nm) and Co metallic powder (Nilaco, 28 nm) were mixed and hot pressed. Wear test was carried out in a pin-on-plate tribometer, with a frequency of 1 Hz, a load of 49 N, for 4h; the counterface used was Al_2O_3. Mechanical properties as Vickers hardness, fracture toughness and Young's modulus were estimated using the indentation method. Distilled water and fetal bovine serum solution (FBSS) were used as environment. It was found that the specific wear rate of Al_2O_3 nanocomposites was about $10^{-8}mm^3/N{*}m$ and the coefficients of friction were around 0.3-0.5 for FBSS. Worn surfaces were observed using SEM.

INTRODUCTION
High-purity aluminum oxide is potentially an attractive implant material for total synovial joint replacement, because of its bio-inertness, excellent corrosion resistance, low friction, high wear resistance and high strength [1]. The main problem of alumina is its relatively low fracture toughness, which make it prone to catastrophic failure.

The drive toward the use of nanoscale ceramics and ceramic nanocomposites is the improvement in properties such as strength, hardness, and wear resistance that they can offer.

In earlier works low levels of wear has been found when 10 mol% of TiO_2 [3] and the same amount of TiO_2 and a variation of (0-5) mol% SiC [4] with a nanometer particle size were added to an alumina matrix. Since 1997 Niihara has studied the mechanical properties of Al_2O_3 nanocomposites with the addition of Co [5], 12mol%Ce-TZP [6], Ce-TZP [7] and TiO_2 (0-2) mol%; at that moment it was found that they have a high mechanical strength. Tanaka *et al* [8] proposed the same Ce-TZP/Al_2O_3 nanocomposites with small amounts of TiO_2 as candidate material of hip joint, but still it has not been used clinically and keeps in study.

Furthermore, it should be keep in mind that the failure of ceramic bearings in vivo commonly results from slow crack growth under the static or repetitive loading experienced in the body, until fracture occurs.

For these reasons the purpose of this work is to fabricate Al_2O_3 nanocomposites with high wear resistance, hardness, fracture toughness and low friction for hip prostheses. It seems that this nanocomposite would be a good material, which means a long free-wear time for the patient given a better quality of life.

EXPERIMENTAL PROCEDURE
Al_2O_3, (AKP-50,300nm, Sumitomo Chemical Co., LTD, Japan), TiO_2 (Aeroxide, P25, 21nm, Germany) and Co metallic powder (Nilaco, 28 nm, Japan) were used as starting powders; compositions are shown in the Table 1. Disks of 50 mm in diameter were hot pressed at 1500º C, 15 MPa, by 1 hour in

vacuum. Samples were cut and polished as mirror-like surface using diamond cloth paths and slurries. Vickers Hardness and Young's modulus were obtained by the indentation method, using a Dynamic Ultra Micro Hardness Tester. Wear test were carried out in reciprocating pin-on-disk tribometer, during 4 hours, with an sliding speed of 20 mm/s, 288 m as sliding distance, with a load of 49 N and a frequency of 1 Hz. The counterfaces used were alumina balls of ¼ inches in diameter. Distilled water and fetal bovine serum solution diluted at 30% were the media in wear test.

Table 1 Compositions of alumina nanocomposites.

Sample	Al_2O_3 (mol%)	TiO_2 (mol%)	Co (mol%)	Y-TZP (mol%)
AT	90	10	0	0
ATZ75	82.5	10	0	7.5
ACo	90.4	0	9.6	0
ATCo	80.4	10	9.6	0

RESULTS AND DISCUSSION

In the Figures 1 and 2 the coefficients of friction of Al_2O_3 nanocomposites with different doppants are shown, in distilled water and FBSS, respectively.

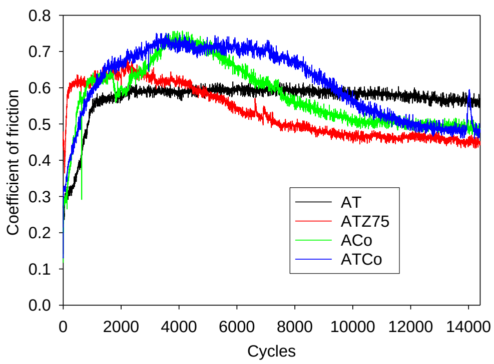

Figure 1 Coefficient of friction of alumina nanocomposites against alumina in distilled water.

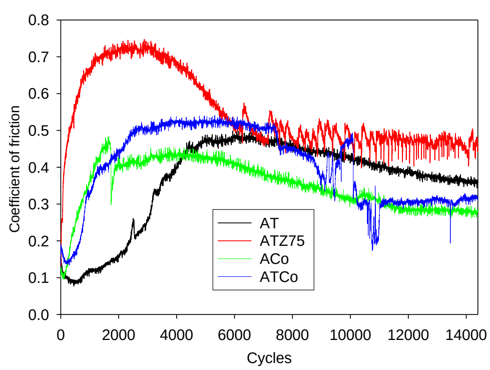

Figure 2 Coefficient of friction of alumina nanocomposites against alumina in bovine serum solution.

Final values are approximately 0.4 to 0.6, and 0.3 to 0.5, for distilled water and FBSS respectively. In Figure 1 a phenomenon denominated start-up state can be observed [2]. After approximately 6000 cycles, the coefficients of friction stabilize reaching a steady state; this trend it thought to be due to running-in. In Figure 2, there is a decrease of the coefficient of friction probably due to a mixed lubrication in the sliding wear test where the proteins and lipids in the fetal bovine serum solution can produces a better mixed lubrication in the sliding wear test [9].

In this study higher fracture toughness was not attaine in the alumina nanocomposites containing TiO_2, Y-TZP or Co, shown in Table 2. The values of Vickers hardness, Young's modulus and average contact pressure are similar to those materials used as for hip and knee joint replacement.

Table 2 Mechanical properties of alumina nanocomposites.

Sample	K_{Ic} (MPam^{½})	HV	E (GPa)	pH (MPa)
AT	3.30 ± 0.56	1972 ±176	250 ± 20	9.05
ATZ75	3.69 ± 0.40	1850 ± 118	246 ± 10	9.04
ACo	1.88 ± 0.20	1870 ±153	114 ± 17	8.38
ATCo	2.49 ± 0.28	1527 ± 100	243 ± 38	9.03

The sample with Co content shows the lowest specific wear rate (6 10^{-9} mm^3/Nm) as shown in Figure 3. This sample shows a lower specific wear rate than the Al_2O_3 nanocomposites reinforced with SiC presented by Rodriguez et al [10].

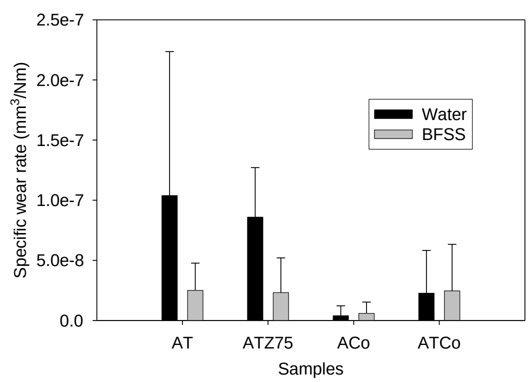

Figure 3 Specific wear rate of alumina nanocomposites against alumina in different media.

In the Figure 4a) roughened surface is shown, evidencing severe wear; where some grains were taken out and reveal severe damage throughout the sliding direction with wavy wear scars; evidencing adhesive wear.

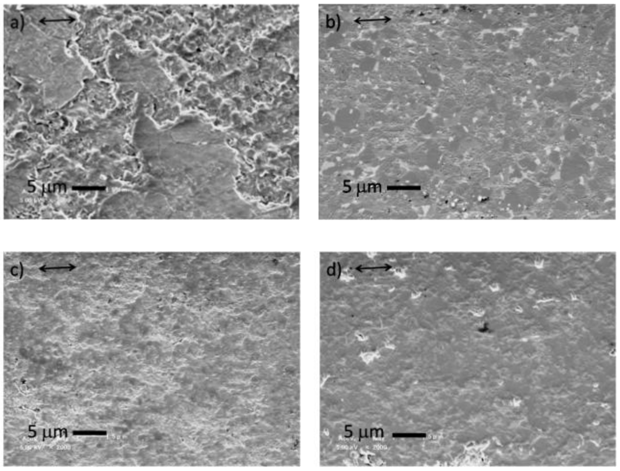

Figure 4 SEM images of worn surfaces a) AT, b)ATZ75, c)ACo and d) ATCo sample against alumina in distilled water.

But in the case of the surface of the sample ATZ75 tested in water, it showed the highest wear but exhibit relatively smooth surface which might not been improved by running in process after initial severe rubbing with large friction variation shown in Figure 1. The worn surface of the ACo sample (Figure 4c) showed a surface rougher than worn surface of the ATCo sample. SEM images of worn surfaces tested in FBSS (Fig 5a-d) showed less roughened surfaces than in water. There are indications of mild plastic flow, grain boundary relief, pits and microcracks along the grain boundaries. In Figure 5b a very smooth surface is shown and remains of the original microstructure are present. In contrast, wavy wear scars are present in the sample ACo, which indicates slight adhesive wear and plastic deformation in the articulating surface, but showed minimum wear.

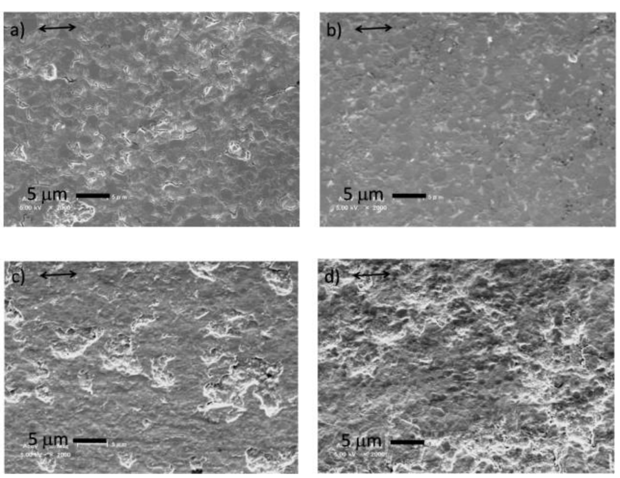

Figure 5 SEM images of worn surfaces a) AT, b) ATZ75, c)ACo and d) ATCo sample against alumina in FBSS.

Even this nanocomposites material did not attained an enhancement in the mechanical properties, although the values of specific wear rate are lower for than those corresponding to alumina/alumina prosthetic pair [11].

CONCLUSION

The addition of cobalt metallic powder has an influence on the tribological behavior of alumina nanocomposites.

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