

THE NEXT GENERATION BEARING - ZIRCONIA TOUGHENED ALUMINA

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Introduction

Alpha-Alumina and partially stabilized Zirconia (YPSZ) are accepted and standardized ceramic materials in clinical use today, and have a long clinical history in hip joint replacement in articulation with Polyethylene or themselves (Alumina). Although effective, both materials have specific potential disadvantages. Alumina exhibits excellent hardness and wear properties, however it is a brittle material with a risk of fracture. Also certain design restrictions apply to Alumina due to this property. Zirconia has only 50% of Alumina's hardness but transformation toughening improves fracture resistance. Therefore, its overall toughness and bending strength are substantially higher than Alumina. However because Zirconia is in a metastable form, phase transition can occur and affect its overall stability. The poor thermal conductivity of Zirconia that increases this phenomenon is also of concern. Therefore the ideal ceramic would be a material that combines the best properties of Zirconia and Alumina.

The objective of this study is to investigate the feasibility of a new Alumina based ceramic material with improved toughness for hip joint articulation applications against PE, itself or Alumina. This objective can be met by increasing the toughness and bending strength of Alumina, through the addition of Zirconia, whilst maintaining all other properties such as wear, hardness, stability and chemical inertness. Additions of approximately 25% Zirconia to Alumina during the manufacturing process have been shown promising to achieve the objectives (Zirconia Toughened Alumina, ZTA [1]).

Materials and Methods

Two candidate Zirconia Toughened Alumina (ZTA) ceramics were obtained. The samples were supplied in the form of bars (45 x 4 x 3 mm), flat polished coupons and ball heads as well as inserts for modular cups (28 mm). At least 10 samples per test were used.

One ZTA (NZTA) had a composition of 75% Alumina and 25% Zirconia, the other one, (CZTA) had a composition of 74% Alumina, 24% Zirconia and 1% mixed oxides. To characterize the two new ZTA's several methods were used. Alumina served for all tests as a reference. Mechanical testing involved: hardness (HV), flexural strength (ASTM C1161) and indentation fracture toughness determination. X-ray diffraction (XRD) was used to measure the crystalline phase composition of the ZTA's and was also used to monitor any transformation during aging. Aging was conducted in two ways; by accelerated aging (5 hrs at 134°C in a steam autoclave, equivalent to 20 years in vivo) and real time aging for one year (Ringer's solution at 37°C) at intervals of 6 months. Wear simulator testing has been carried out applying a six-station physiological hip simulator, described elsewhere. The simulator testing was done using standard conditions and in micro-separation mode [2]. All test data was analyzed by descriptive statistics where applicable.

Results

The results obtained for the unaged specimen are summarized in table 1. One candidate material (NZTA) has a significantly lower flexural strength than the other one (CZTA). However even this value is between 50% to 75% stronger than Alumina; statistically significant at $p < 0.05$. The indentation fracture toughness was measured and gave a K_{Ic} of 4.1 MPa*m^{1/2} for both ZTA materials as opposed to 2.78 MPa*m^{1/2} for Alumina. The ZTA ceramics maintain almost the same hardness values as the base Alumina, statistically not significant at $p > 0.05$.

Test	Units	Alumina	CZTA	NZTA
Flexural Strength	MPa	466 ± 106	1203 ± 101	800 ± 131
Fracture toughness	MPa*m ^{1/2} Indentation	2.78	4.1	4.1
Hardness	HV(30)	1878 ± 60	1840 ± 60	1840 ± 60

Table 1. Mechanical test results for the unaged ZTA ceramics

The two ZTA ceramics differ in the crystalline form of Zirconia seen at the surface when measured by XRD. NZTA contains Zirconia in a purely tetragonal crystalline form with no measurable monoclinic phase present. CZTA contains Zirconia with up to 35% of the monoclinic phase present at the surface. No further transformation in the Zirconia phase was observed after accelerated aging and up to 12 months real time aging for both ZTAs'. This indicates the ZTA is a chemically stable ceramic. The wear testing, in standard simulator mode, showed that both ZTA - ZTA couples articulating against themselves have even lower wear than Alumina - Alumina couples, this wear rate being reported elsewhere [3]. Using the micro separation simulator set-up, similar results for both ZTA - ZTA combinations were obtained. Although the overall wear rate was increased in this mode, it also reached a steady state after 1 million cycles. ZTA's wore also in this test set-up - statistically not significant - less than the Alumina - Alumina combination.

Discussion

The objective of this innovation was to increase the toughness and bending strength of Alumina. This was achieved through the addition of ca. 25% Zirconia to the Alumina matrix. The hardness is not affected but the toughness and the flexural strength of the ceramic has been increased by up to 50% thus reducing the risk of fracture with such ceramic implant components. This two different ZTA's demonstrate their ability to achieve superior properties to Alumina and maintain them during accelerated and normal aging. The wear properties under standard and adverse tribological conditions also demonstrate improvement over Alumina, although statistically not significant. Zirconia Toughened Alumina looks promising for the next generation of fracture and wear resistant ceramic bearings for hip joint prostheses.

[1] G.Orange, G.Fantozzi, P.Homerin, F. Thevenot; Journal of European Ceramic Society, 9 (1992) 177-185.

[2] J.E. Nevelos et al; Journal of Arthroplasty, 2000, in press.

[3] J.E. Nevelos et al; ORS, 46th Annual Meeting, Orlando, FL/March, 12-15, 2000.

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