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Preparation for femur prosthesis of ceramic-metal combination artificial hip joint①

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[Abstract] Al_2O_3 material was synthesized by using high purity alumina micro-powder and Mg-Zr-Y composite additives at temperature of 1 600 ℃, which had good mechanics property of 416 MPa bending strength and 5.46 MPa·$m^{1/2}$ fracture toughness. Femur head prosthesis of hip joint was prepared by using this material; Ti alloy femur handle was sprayed bioactive hydroxyapatite (HA) by plasma on surface, which improves the chemistry stability and biocompatibility of Ti alloy; ceramic-metal combination artificial hip joint femur prosthesis was made by combining Al_2O_3 femur head with Ti alloy femur handle, so the manufacturing process is improved and the property and application flexibility are advanced.

[Key words] Al_2O_3; mechanics property; femur prosthesis; spraying; combination
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1 INTRODUCTION

The artificial hip joint femurs used in clinical at present are made of metal and alloy, which mainly include stainless steel, Ti alloy and Co alloy etc.[1] These materials have super mechanical process property and high strength, but their chemistry stability and biocompatibility are not good, they are easy to abrade and dissolve out toxic ions[2]. As biomedical material, Al_2O_3 has excellent biocompatibility, physiologic inertia, physics and chemistry stability, high hardness and wearability, but it is crisp and difficult to prepare. Based on the invention of "inner casting metal Al_2O_3 ceramic combination artificial hip joint", which gained China National Invention 3rd Prize in 1995, this study aims at preparing a kind of ceramic-metal combination artificial hip joint femur prosthesis so as to amplify the advantages of the two kinds of materials and improve the technics and performances.

2 PREPARATION METHODS

2.1 Al_2O_3 material synthesizing

2.1.1 Raw material and additives

High purity alumina micro-powder was used as raw material. The components are shown in Table 1. The average grain size is 0.35 μm.

MgO, ZrO_2 and Y_2O_3(AR) were used as additives, which can promote sintering and improve mechanical and biological properties of material[3].

2.1.2 Synthesizing technics

Technics process is shown in Fig. 1.

Table 1 Components of Al_2O_3 powder

(w, %)

Al_2O_3	K_2O	CaO	Na_2O	MgO
99.948 4	0.021 0	0.015 0	0.009 2	0.006 4

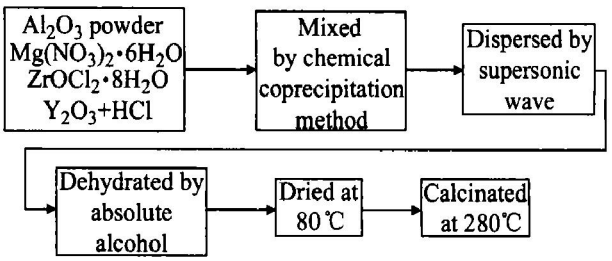

Fig. 1 Al_2O_3 material synthesizing process

2.2 Preparation of Al_2O_3 femur head

Technical process is shown in Fig. 2. Femur head fabrication is shown in Fig. 3. Finish machining and polishing were achieved through correcting precision with diamond abrasive tools and graded polishing with SiC micro-powder and diamond paste.

2.3 Surface spraying of Ti alloy femur handle

Surface of Ti alloy femur handle was sprayed bioactive HA by plasma[4~6], coating thickness is 60 μm.

3 TEST AND DISCUSSION

3.1 Performance test of Al_2O_3 material

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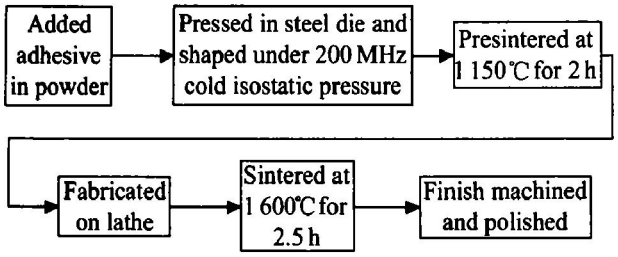

Fig. 2 Al_2O_3 femur head preparation process

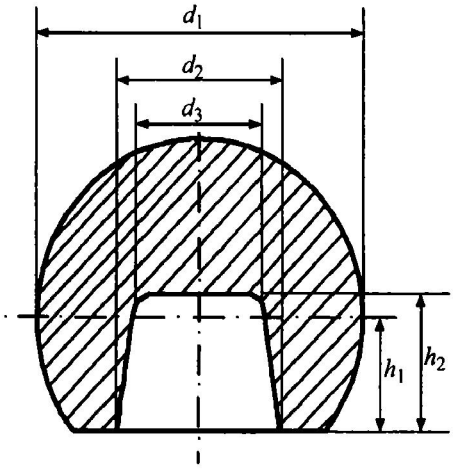

Fig. 3 Schematic diagram of Al_2O_3 femur head fabrication

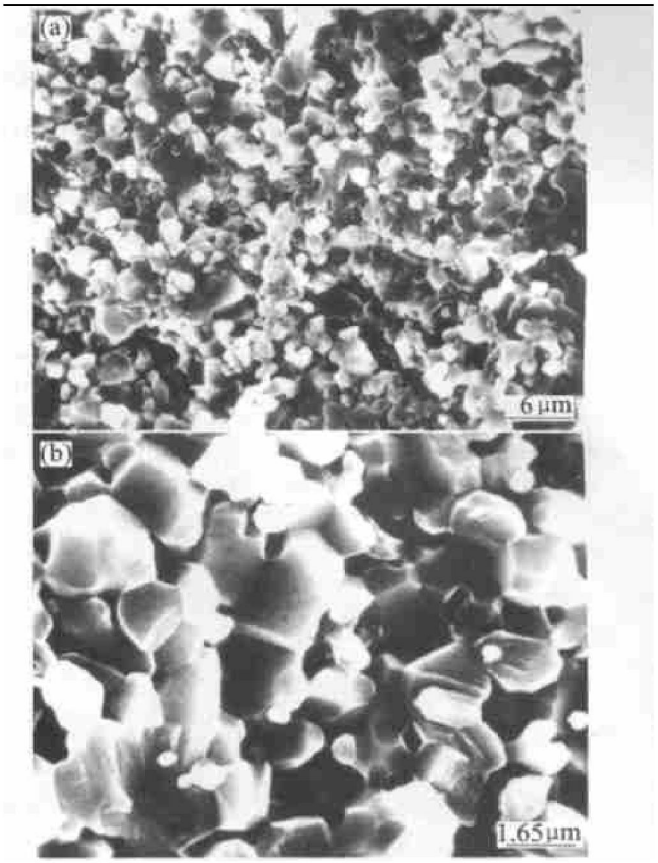

Fig. 4 SEM photos of micro-topography of Al_2O_3 material
(a) —2.50 K; (b) —7.00 K

Three-point bending strength, fracture toughness, volume density, hardness and average grain size of Al_2O_3 material sintered at 1 600 ℃ were tested, the results are shown in Table 2 and Fig. 4.

Table 2 Performance of Al_2O_3 material

Items	Bending strength /MPa	Fracture toughness /(MPa·m$^{1/2}$)	Volume density /(g·cm^{-3})	Rockwell hardness
Average value	416	5.46	3.90	90.2

The average grain size of the material was counted as 2.583 μm based on the statistic results of grain diameter on SEM photos.

3.2 Discussion

By analysis of the test results, we know that the material prepared by adding Mg-Zr-Y composite additives into high purity alumina micro-powder and sintering has perfect multiple property. Pure Al_2O_3 is difficult to sinter because of high temperature (generally at 1 700 ℃~ 2 000 ℃). According to the property demands of products, we should add certain additives to promote sintering. MgO and ZrO_2 create limited solid solution with Al_2O_3. Mg^{2+} and Zr^{4+} whose ion radius are greatly different from Al^{3+} cause the crystal lattice transforming and activating when they enter in Al_2O_3 crystal lattice, so to further the diffusion mass transfer in sintering process[7]. At the same time, MgO solid phase reacts with Al_2O_3 at high temperature and creates $MgAl_2O_4$, which exists on crystal boundary and limits the crystal boundary transference so restrains Al_2O_3 crystal grains from unusual growth[8,9]. SEM photos indicate that the grain sizes of the material are uniform and there are no obvious crystal grains grown up unusually. Additionally, MgO-$ZrO_2(Y_2O_3)$ may create eutectic mixture. Because of liquid phase appearance, solid phase grains keep close and fill in the pores. In the sintering process, small defective crystals have high surface activity and solubility in liquid phase, so they grow continuously and the pores decrease. The small average grain size is beneficial to material strength[10]. Meantime, the tetra-$ZrO_2(Y_2O_3)$ has good malleableizing effect on Al_2O_3 due to phase change[7]. By adding Mg-Zr-Y composite additives, the Al_2O_3 material sintered at lower temperature (1 600 ℃) has perfect mechanical property, which prove Mg-Zr-Y composite additives can promote sintering and improve the property of material efficiently.

Being pressed under cold isostatic pressure and presintered at 1150 ℃, the blank strength satisfies the demands of fabrication. Being sintered at 1 600 ℃, machined and polished, we can prepare the Al_2O_3 femur

head that fit the femur handle fine.

Ti alloy femur handle sprayed HA by plasma can lead bone tissue to grow into its surface micro pores and form bone bonding, which has double fixing roles of biological self-lock and mechanical occluding[4~6].

The Al_2O_3 femur head combined with Ti alloy femur handle is shown in Fig. 5.

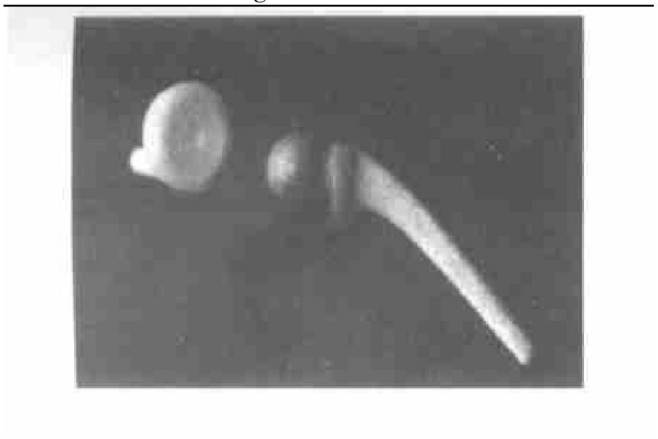

Fig. 5 Photo of combination artificial hip joint femur prosthesis

4 CONCLUSION

Al_2O_3 material which has perfect multiple property can be prepared using high purity alumina micro-powder by adding Mg-Zr-Y composite additives and sintering at temperature of 1 600 ℃. The mechanism of promoting sintering by Mg-Zr-Y composite additives may be to create limited solid solution, activate crystal lattice and liquid phase sinter.

Combinating the Al_2O_3 femur head with the Ti alloy femur handle that be sprayed HA on its surface, one can get the artificial hip joint femur satisfied the design demands, which simplify the preparation technics and improve the performance. The combination femur head can be replaced so the clinical use is more flexible.

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