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The effect of the sintering temperature on the properties of porous YAG ceramics

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Pure yttrium aluminum garnet (YAG) powders and the porous YAG ceramics were prepared via co-precipitation method and using vacuum sintering technology, respectively. Through an analysis and discussion, porous YAG ceramics, with a homogeneous and regular pore microstructure, a pore size of about 5 μm, regular crystalline particles, showing intergranular fracture, were sintered at 1500 °C. Porous YAG ceramics, with a homogeneous and regular pore microstructure, a pore size for about 2-5 μm, crystals with a rod-shape or acicular structure, showing intergranular fracture and intracrystalline fracture, were sintered at 1550 °C. Porous YAG ceramics, with an extension pore microstructure, a crystalline laminate structure, showing intracrystalline fracture, were sintered at 1600 °C. With an increase in the sintering temperature, the porosity is decreased gradually and the energy consumption is increased. The best sintering temperature for porous YAG ceramics was decided to be 1550 °C through considering the performance price ratio among the porosity, the mechanical properties and the energy consumption.

Key words: YAG porous ceramics, Sintering temperature, Microstructure, Porosity, Mechanical property.

Introduction

Yttrium aluminum garnet (YAG) with a chemical composition of $Y_3Al_5O_{12}$ is an important advanced structural and functional material [1-3]. Because of its relatively stable lattice structure and large thermal conductivity, it is used as a host for solid-state laser materials in luminescence systems and in the window material for a variety of lamps. YAG also has a great potential application as a high-temperature engineering material because of its good high-temperature strength as well as its superior creep resistance. In addition, YAG is a promising fiber material for the preparation of ceramic composites [4-6].

By comparison with single crystals, the mass manufacture of YAG polycrystalline powder materials is easily realized [7-8]. The performance of polycrystalline materials is better than that of single crystal materials under specific conditions so they can be used as a substitute for single crystal materials to produce structural and functional materials [9-11].

Due to some excellent properties of YAG, porous YAG ceramics were prepared and the new functions explored, which hope to apply as high-temperature catalysts and filters to replace the usual porous ceramics. In this paper, the effect of the sintering temperature on the microstructure and mechanical properties of porous YAG ceramics are investigated, which lay the base for the preparation of the high-performance porous YAG ceramics.

Experimental procedures

Analytical grade aluminum nitrate, yttrium nitrate and ammonia was used. The YAG precursor prepared via the co-precipitation method and was calcined at 1100 °C for 1 hr and superfine and pure YAG powder was obtained. The sintering aid (CaO) and the gassing ageal were mixed into the YAG powder using the ball milling method. The ceramic bodies were moulded via the dry press molding technology, and then the ceramic

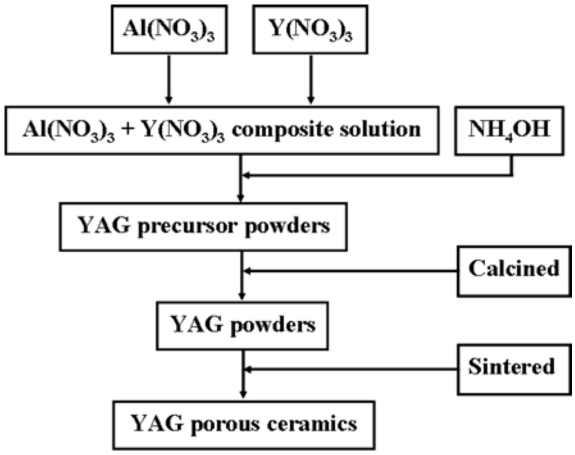

Fig. 1. Process flow diagram for the preparation of porous YAG ceramics.

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bodies were sintered in a high-temperature vacuum carbon tube furnace (Model: ZT-55, China) to obtain the porous YAG ceramics. Fig. 1 shows a flow diagram of the preparation process.

A microstructural analysis of the porous YAG ceramics was performed with a scanning electron microscope (SEM, TESCAN VEGA II, Czech Republic). The compressive strengths of porous YAG ceramics were tested by a universal mechanical tester (Model: AGS-5KNJ, Japan). The porosity was measured via the Archimedean method.

Results and Discussion

The effect of the sintering temperature on the pore microstructure of porous YAG ceramics

The pore microstructure of porous YAG ceramics marked differed with an increase in the sintering temperature, which is shown in the Fig. 2. When the sintering temperature is 1500 °C, the pores of porous YAG ceramics show a regular and well-distributed structure, a pore size of about 5 μm, a is shown in Fig. 2(a). When porous YAG ceramics are sintered at 1550 °C, the pore microstructure shows a regular and well-distributed structure, but the pore size is 2~5 μm, a is shown in Fig. 2(b). When porous YAG ceramics are sintered at 1600 °C, the pore structure has gradually disappeared and the ceramics show a liquid-phase sintered microstructure, the crystal particles have grown to a larger laminate structure, a is shown in Fig. 2(c). The cause is that the raw materials in the ceramic body have melted and became the liquid phase with an increase in the sintering temperature [12]. When sintering temperature is lower in the early stage of sintering, the liquid phase shows a higher viscosity, which cannot flow to fill the pores of the ceramic body, and the liquid phase shows a surface tension effect, which makes the liquid phase adhere on the pore walls, so the pores show a similar rounded microstructure. The amount of the liquid phase is increased with an increase in the sintering temperature, the liquidity of the liquid phase sufficient to overcome the surface tension effect of the liquid phase, and the liquid phase can flow to fill the pores of the ceramic bodies, this cause the pore size and the porosity to be decreased. With a further increased in the sintering temperature, the liquid phase content is sufticient increased, that the pores of the porous ceramics is filled to make the pore structure disapear gradually, which shows the porosity of the porous YAG ceramics is decreased (Fig. 3).

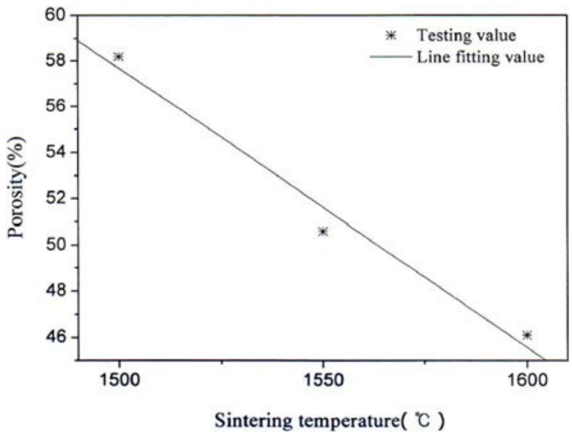

Fig. 3. Effect of the sintering temperature on the porosity of porous YAG ceramics.

The effect of the sintering temperature on the crystal microstructure of porous YAG ceramics

From Fig. 4(a), When the porous YAG ceramics is sintered at 1500 °C, sintering necks are shown among the YAG particles, this shows that the porous YAG ceramics are sintered during the increase in the sintering temperature and the crystal particles show a regular graininess. When the sintering temperature is increased from 1500 °C to 1550 °C, the crystal structure shows a rod-shape or acicular structure. However, the width of the rod-shape or acicular structure crystal is approximately equal to the crystal particle size of the porous YAG ceramics prepared at 1500 °C, as shown in Fig. 4(b). Because the sintering temperature is increased, the YAG crystal particle has preferentially grown under the driving force of the temperature. In addition, the porous ceramics supply bigger spaces for the

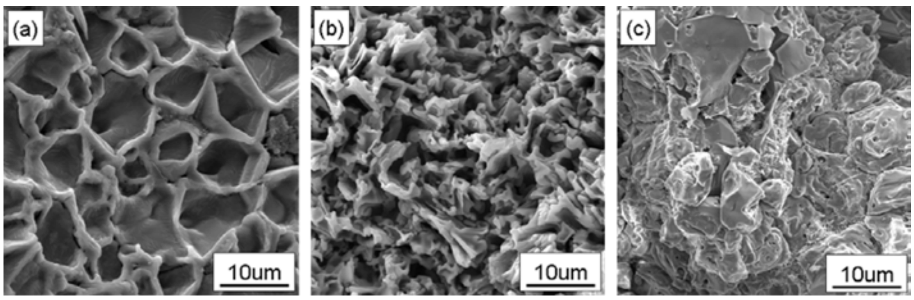

Fig. 2. Effect of the sintering temperature on the microstance of porous YAG ceramics.

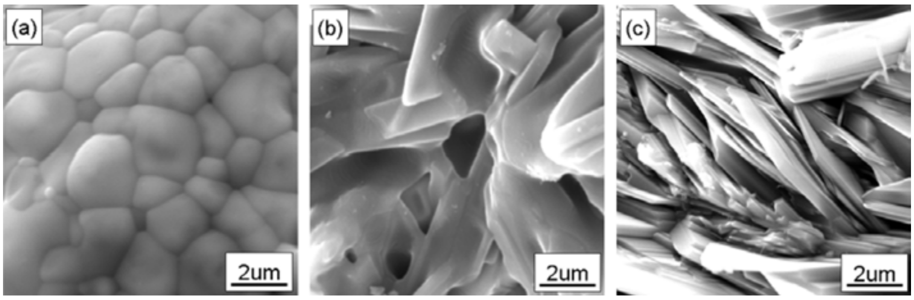

Fig. 4. Effect of the sintering temperature on the crystal microstucture of porous YAG ceramics.

preferential growth of crystals. This makes the energy power driving action to be decreased, that is to say the sintering temperature may be decreased. The amount of the liquid phase is increased with an increase the sintering temperature, which is advantageous to the preferential growth of crystals to form the rod-shape or acicular structure. The crystal structure of porous YAG ceramics prepared at 1600 °C show a laminate structure, as shown in Fig. 4(c). It is concluded that the growth of crystals is inhibited in the original directions due to a lack of growth space. The starting growth direction of crystals is transformed, the preferential growth direction of crystal is shown at the other direction under the enough driving power action of crystal growth [13-14]. In addition, the sintering temperature is higher, the liquid phase content is more, the matter condition of crystal growth is more easily satisfied, it make the crystal show the integrated structure.

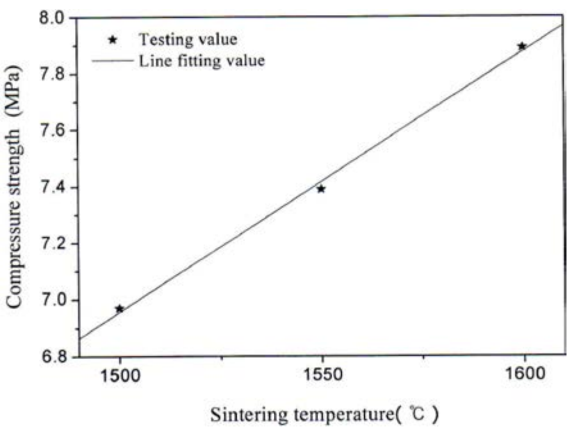

Fig. 5. Effect of the sintering temperature on the compression strength of porous YAG ceramics.

The effect of the sintering temperature on the mechanical property of porous YAG ceramics

From Fig. 5, which indicates the compressive strength of porous YAG ceramics is increased with an increase in the sintering temperature, the mechanical properties of porous YAG ceramics are discussed through the fracture microstructures, a is shown in Fig. 6. When porous YAG ceramics are sintered at 1500 °C, the sintering necks are shown among the YAG particles (Fig. 4(a)), which proves the porous YAG ceramics are sintered during the increase in the sintering temperature, the fracture microstructures of porous YAG ceramics after testing the compression strengths show a few sintering necks are left, a is shown in Fig. 6(a). Most of the sintering necks are destroyed during testing the compression strength, and porous YAG ceramics show the intergranular fracture [15-16], as shown in Fig. 6(a). When the sintering temperature is increased from 1500 °C to 1550 °C, the crystal structure shows a rod-shape or acicular structure, the pinning and engaged action is shown among the crystals of porous YAG ceramics, which has the advantage of improving the mechanical properties of materials. Intergranular fracture and intracrystalline fracture are shown simultaneously in the porous YAG ceramics, the 3 part of the fracture microstructure in Fig. 6(b) is intracrystalline fracture, the 2 part of the fracture microstructure in Fig. 6(b) is intergranular fracture. The crystal structure of porous YAG ceramics prepared at 1600 °C show laminate structure, and the structure in different directions in

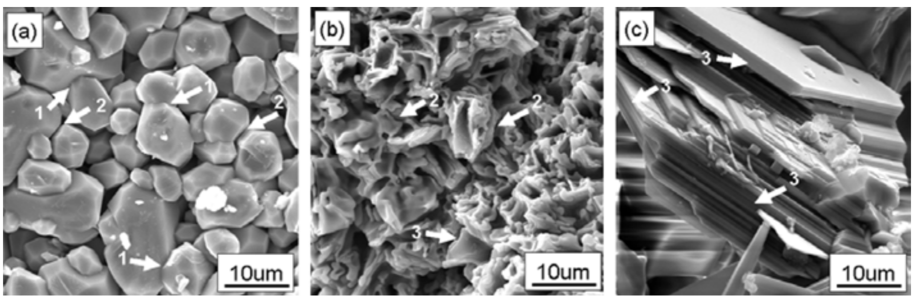

Fig. 6. Effect of the sintering temperature on the fracture microstructures of porous YAG ceramics.

different zones, the fracture of laminate structure crystal is neat, which indicates that it is intracrystalline fracture, a is shown in the 3 part of Fig. 6(c). The strength of the crystals is higher than the strength of the crystal boundaries, so the intracrystalline fracture is an advantage to further improve the mechanical properties of materials [17-18].

With an increase in the sintering temperature, the porosity is decreased gradually and the energy consumption is increased, the sintering temperature of porous YAG ceramics was decided as 1550 °C through considering the performance price ratio among the porosity, the mechanical properties and the energy consumption.

Conclusions

Porous YAG ceramics, with a homogeneous and regular pore microstructure, a pore size of about 5 μm, a regular crystal particle, and intergranular fracture, were prepared by the vacuum sintering method at 1500 °C. Porous YAG ceramics, with a homogeneous and regular pore microstructure, a pore size for about 2-5 μm, crystals with a rod-shape or acicular structure, and fracture and intracrystalline fracture, were prepared at 1550 °C. Porous YAG ceramics, with an extensive pore microstructure, when the materials was sintered at1600 °C, the crystals had a laminate structure, and intracrystalline fracture.

With an increase in the sintering temperature, the porosity is decreased gradually and the energy consumption is increased. The sintering temperature for porous YAG ceramics was decided to be 1550 °C through considering the performance price ratio among the porosity, the mechanical properties and the energy consumption.

Acknowledgments

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