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Mechanical properties of silicon carbide sintered with additive $Y_3Al_5O_{12}$

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ABSTRACT

In this work, silicon carbide ceramics were sintered by using $Y_3Al_5O_{12}$ as a sintering additive, and its mechanical properties were investigated. The sintering condition of hot-pressing is 1800 °C, 2 h, vacuum atmosphere. The amounts of $Y_3Al_5O_{12}$ as a additives was 3, 5 and 7 wt%. Effects of $Y_3Al_5O_{12}$ as an additive on mechanical properties of SiC ceramics were evaluated. And the effect of heat treatment was also investigated. Mechanical properties (density, flexural strength, hardness, fracture toughness) of SiC ceramics showed an upward tendency with increment of the additive. The flexural strength of SiC samples sintered by $Y_3Al_5O_{12}$ additive was about 630 MPa, and it was increased up to 720 MPa by an annealing treatment at 1200 °C for 2 h in oxidation atmosphere.

1. Introduction

Silicon carbide is one of the most promising structural materials for many applications because of its excellent mechanical properties, high thermal conductivity and good chemical stability at elevated temperature. Above all, it has been considered as a successful candidate for fusion/fission structural materials for its good irradiation resistance. Based on these characteristics, nowadays, SiC_f/SiC composites have been researched and developed for fusion power plant components such as the blanket or diverter [1,2].

In order to improve the high performance of SiC composites, it is very important that SiC matrix must be fabricated with optimum sintering conditions. It includes the grain size of initial powder, sintering time and temperature, types of additive [3,4].

Especially, the characteristics of ceramics materials vary sensitively with quantity and types of sintering additive.

There are some additives on sintering of SiC ceramics effectively. Generally many SiC ceramics were fabricated with SiC–Y_2O_3–Al_2O_3 compositions.

Meanwhile, it is very important issue to improve mechanical properties of SiC ceramics at elevated temperature. However, sintering additives exist in grain-boundary as glass phase after sintering process. And at elevated temperature, the fracture occurs is accelerated by micro-cracks in softened glass phase. Therefore, much quantity of sintering additives takes negative effects on the ceramics' strength at elevated temperature directly [5]. Considering this fact, alternative additive which can sinter effectively with less quantity is absolutely required.

In this study, silicon carbide ceramics were fabricated with $Y_3Al_5O_{12}$ as new alternative additive. One major purpose of this study was to investigate the effect of $Y_3Al_5O_{12}$ on the mechanical properties of silicon carbide ceramics. The effect of heat treatment on the strength of SiC ceramics was also investigated.

2. Experimental procedure

2.1. Sample preparation and fabrication

The starting SiC powder was super fine SiC (Marketech, USA) with average size of about 50 nm was used. The used sintering additive was $Y_3Al_5O_{12}$ (99.99%, High Purity Chemicals Co. Ltd., Japan) with average size of about 0.3 μm. The $Y_3Al_5O_{12}$ powder was added to SiC about 3, 5, 7 wt.%, respectively, and the powder batches were mixed in ethanol for 12 h using a Planetary Ball-milling in 150 rpm, and subsequently dried for 48 h at 40 °C. The dried powder was passed through a 100 mesh sieve and sintered by hot-pressing in vacuum atmosphere. Table 1 represents the composition batches and sintering conditions. The powder was heated to 1200 °C at rate of 80 °C/min, and to sintering temperature of 1800 °C at rate of 40 °C/min. The SiC mixture was sintered under pressure of 20 MPa for 2 h.

Sintered bodies were cut into the dimension of 4 mm(W) × 36 mm(L) × 3mm(T). All specimens were polished and chamfered. Span length and Cross-head speed were 30 mm, 0.5 mm/min, respectively. To improve the strength, heat treatment was also conducted at 1200 °C for 2 h in oxidation circumstance. The fracture surfaces were observed by a scanning electronic microscope.

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Table 1
The compositions and sintering conditions for SiC ceramics.

Specimen	Sintering additive (wt.%)	Sintering temperature (°C)	Process pressure (MPa)	Sintering time (h)
A	3	1800	20	2
B	5			
C	7			

2.2. Evaluation of mechanical properties

Sintered density was determined by Archimedes' Principle and measured as bulk density, and the relative density was determined from the theoretical density calculated by the rule of mixture. The hardness of SiC ceramics was evaluated by Vickers Hardness tester on the pressure of 49 N. The fracture toughness was evaluated by Lawn and Fuller equation which can calculate without materials' elastic modulus [6]. The flexural strengths of SiC ceramics were examined at room temperature using the three-point bending test method. All evaluations was performed at least 10 measurements. And then, the results were the average of these measurements except for the lowest and highest values.

3. Results and discussion

3.1. Density of SiC ceramics

Generally, more additive not only could create more liquid phase during sintering process, and it facilitated the substantial mobility of sintering but also give negative effect on the strength of ceramics at elevated temperature.

The effect of additive $Y_3Al_5O_{12}$ on the densities of SiC samples is shown in Fig. 1. All specimens showed good relative density. As increasing the content of $Y_3Al_5O_{12}$, the density was increase slightly. Especially, SiC sample had excellent density of 3.2 g/cm^3, which corresponds to about 98% of theoretical density, when sintered with 7 wt.% of the additive. This is the less amounts than that of conventional additives [9], and it can be said that $Y_3Al_5O_{12}$ is very effective additive on sintering of SiC ceramics.

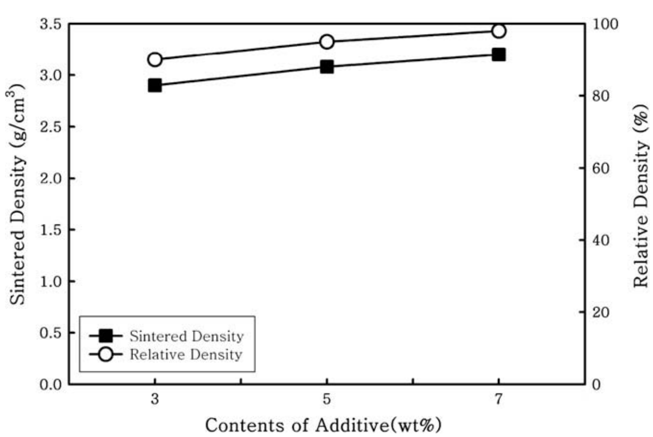

Fig. 1. The density of SiC with $Y_3Al_5O_{12}$ additive.

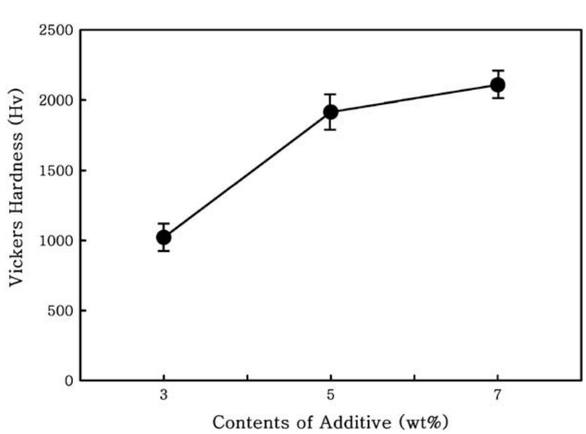

Fig. 2. Vickers Hardness of SiC with $Y_3Al_5O_{12}$ additive.

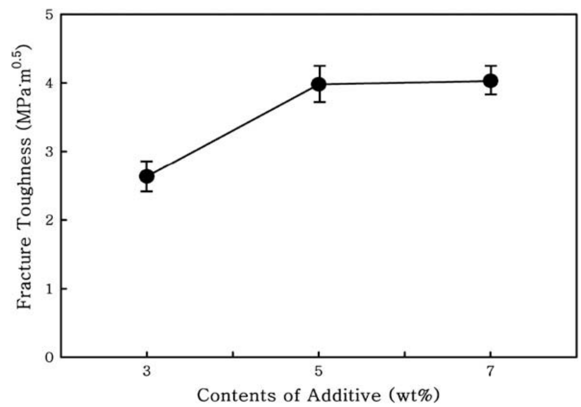

Fig. 3. Fracture toughness of SiC with $Y_3Al_5O_{12}$ additive.

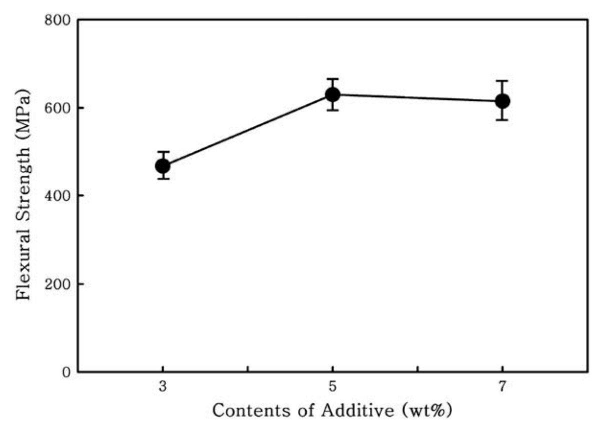

Fig. 4. The strength of SiC with $Y_3Al_5O_{12}$ additive.

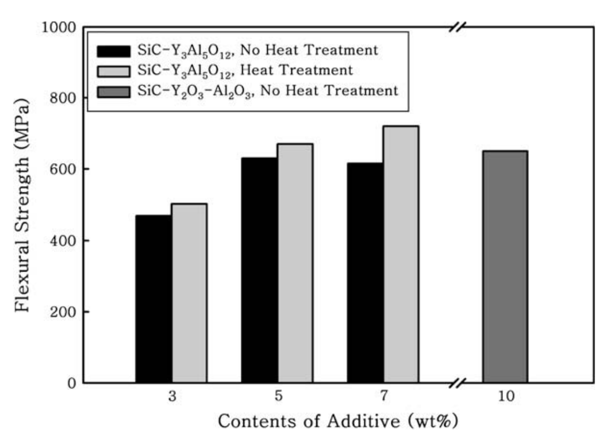

Fig. 5. Effect of heat treatment on SiC fabricated with $Y_3Al_5O_{12}$ additive and comparison with conventional additive SiC ceramics.

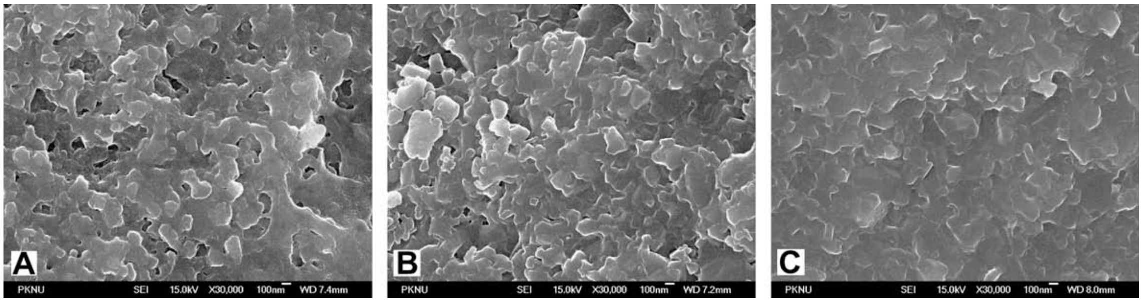

Fig. 6. Fracture surface of SiC ceramics sintered with $Y_3Al_5O_{12}$ additive; A of 3 wt.%, B of 5 wt.%, C of 7 wt.%.

3.2. Hardness and fracture toughness

In Fig. 2, the results of Vickers Hardness on SiC ceramics according to sintering additive are presented. Vickers Hardness increased slightly as increasing the amount of sintering additive. SiC ceramics with 7 wt.% of $Y_3Al_5O_{12}$ showed good hardness of about 2100 Hv. Fig. 3 is the results of fracture toughness on SiC ceramics evaluated by the indentation fracture method. Fracture toughness also showed increment tendency with an increase in additive quantity.

Both results mean that the $Y_3Al_5O_{12}$ influenced strongly to the sintering of SiC ceramics.

3.3. Flexural strength of SiC ceramics

Fig. 4 is the variations of flexural Strength of SiC ceramics against the contents of additive $Y_3Al_5O_{12}$. The variation tendency of flexural strength with the sintering additive was very similar to those of fracture toughness and density. In this test, obtained flexural strength of SiC was about 630 MPa. And, the strength of SiC ceramics with 5 wt.% additive was similar or higher than that of 7 wt.%. This means that the $Y_3Al_5O_{12}$ is very available additive on the sintering of SiC ceramics. Generally, the strengths of ceramics are largely affected by impurities, pores, micro-cracks and residual stress during sintering and polishing process. Specially, it is well known that the effect of residual stress to the strength of ceramics is considerable [7]. To estimate the effect of heat treatment on HP sintered SiC ceramics using additive $Y_3Al_5O_{12}$, some of SiC samples were annealed at 1200 °C for 2 h in oxidation atmosphere.

Fig. 5 is the comparison result of the strength of heat treated SiC ceramics sample and non-heat treated SiC ceramics sample. As a result, all of SiC ceramics samples' strengths were somewhat improved. This is presumed that the improvement of strength by heat treatment is due to the removal of internal residual stress [7] or crack healing effect [8]. For the comparison, the flexural strength on SiC ceramics with 10 wt.% of conventional additive which fabricated at a same sintering condition is also shown in Fig. 5 [9]. In spite of less amount of sintering additive, it is clear that SiC ceramics in this study are almost equal with the flexural strength level of conventional SiC ceramics. Additives are indispensable materials in sintering process, but it also affects to the high temperature strength of ceramics, because of its glass phase at high temperature. To obtain good strength performance at high temperature, to put less amount of additive in sintering powder is advisable. From the above view point, $Y_3Al_5O_{12}$ is expected as a good additive material on sintering process of engineering ceramics.

4. Microstructures

Fig. 6 is the fracture surfaces of the SiC ceramics sintered with $Y_3Al_5O_{12}$. Among samples, some different microstructures were observed, there are many pores in the fracture surface sintered with 3 wt.% of $Y_3Al_5O_{12}$ and the surface looks rough (Fig. 6(A)). As the increment of additives, these pores decreased in number, and the fracture surface shows constant grain size. These facts mean that 3 wt.% of $Y_3Al_5O_{12}$ is not sufficient amount as additive in sintering process for SiC ceramics, and more than 5 wt.% of $Y_3Al_5O_{12}$ is needed. These aspects of fracture surface could be related to the variation tendency of flexural strength and other mechanical properties of SiC ceramics.

5. Conclusions

SiC ceramics were fabricated by hot-pressing using an alternative $Y_3Al_5O_{12}$ double oxides additive and its mechanical properties and microstructures were investigated. Based on the results, the following conclusions could be drawn:

Silicon carbide with a little quantity of $Y_3Al_5O_{12}$ exhibited sufficient sintering characteristics. The SiC sample with 7 wt% of $Y_3Al_5O_{12}$ showed a good density of about 3.2 g/cm^3, which corresponded to 98% of theoretical density. Density, hardness, fracture toughness and flexural strength of SiC ceramics were tended to increase slightly as increasing of $Y_3Al_5O_{12}$ contents. Especially, SiC ceramics sintered with more than 5 wt% of $Y_3Al_5O_{12}$ had excellent flexural strength of about 630 MPa, and it was similar strength to the conventional SiC which sintered with Y_2O_3, Al_2O_3. After heat treatment in the air, this strength could be improved up to 720 MPa.

References

[1] B. Riccardi, L. Giancarli, A. Hasegawa, Y. Katoh, A. Kohyama, R.H. Jones, L.L. Snead, J. Nucl. Mater. 329–333 (2004) 56.
[2] A. Hasegawa, A. Kohyama, R.H. Jones, L.L. Snead, B. Riccardi, P. Fenici, J. Nucl. Mater. 283–287 (2000) 128.
[3] Y. Katoh, A. Kohyama, T. Nozawa, M. satoh, J. Nucl. Mater. 329–333 (2004) 587.
[4] J.S. Park, Y. Katoh, A. Kohyama, J.K. Lee, J.J. Sha, H.K. Yoon, J. Nucl. Mater. 329–333 (2004) 558.
[5] P.B. Noakes, P.K. Pratt, in: P. Popper (Ed.), Special Ceramics 5, British Ceramic Research Association, Stroke-on-Trent, 1972, p. 299.
[6] B.R. Lawn, E.R. Fuller, J. Mater. Sci. 10 (1975) 2016.
[7] B.A. Kim, K. Ando, S. Sato, Fatigue Fract. Eng. Mater. Struct. 17 (2) (1994) 187.
[8] J. Korous, M.C. Chu, M. Nakatani, K. Ando, J. Am. Ceram. Soc. 83 (11) (2000) 2788.
[9] S.P. Lee, A. Kohyama, Fusion Eng. Des. 81 (2006) 963.