

Effects of SiC and MgO on alumina-based ceramic foams filters

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Abstract: Alumina-based foam ceramic filters were fabricated by using alumina, SiC, magnesia powder as major materials. It has been found that this ceramic filter has a uniform macrostructure for filtering molten metals. The influences of SiC and magnesia content, the sintering temperatures on ceramic properties were discussed. Alumina-based foam ceramic filters containing 2.2 mass% magnesia and 7.6 mass% SiC has a compressive strength of 1.36 MPa and a thermal shock resistance of 5 times. Its main phases after 1 hour sintering at 1 500°C consist of alumina, silicon carbide, spinel and mullite.

Keywords: alumina-based; foam ceramic filters; compressive strength; molten metal; MgO; SiC

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Ceramic foams have many potential advantages, such as high temperature strength, high resistance to chemical attack, high refractoriness and good insulating characteristics. These properties make ceramic foams suitable for many applications such as filters for removing entrained solids from molten metals, membranes for separation, catalyst supports, sensors, radiant burners, dust or soot collectors, heat exchangers, refractory linings for furnaces, and porous implants in the areas of biomaterials [1-6].

Molten metal, particularly aluminum and its alloys, in practice generally contains a lot of entrained nonmetallic inclusions, which are considered to be sources causing casting defects [7]. The entrained nonmetallic inclusions are particles that are present virtually in all metals and alloys. Depending on the shape, size, number and distribution, the inclusions can influence the mechanical properties of the metal and alloys, and subsequently the quality of the finished product [7,8]. The use of conventional gating systems is not sufficient to hold up enough slag and nonmetallic inclusions into the final casting. In order to obtain the high quality castings, it is necessary to adopt ceramic foam filters [9].

The common filter to cleaning molten aluminum and its alloys is alumina-based foam ceramic filter, which has some excellent properties such as high porosity and high resistance to molten aluminum attack [9, 10]. In this work, it was aimed to produce foam ceramic filter that is suitable for filtering molten aluminum and its alloys to remove entrained solids inclusions. The effect of SiC and MgO additions on properties of ceramic filter has

been investigated.

1 Materials and test procedure

1.1 Materials

Commercial polyurethane sponges with open porosity of approximately 10–15 pores per inch were chosen. The complete pyrolysis of the polyurethane sponge was accomplished before 600°C.

Commercial alumina powder (ceramic grade, α -alumina > 95 mass%) was milled using ball mill for 12 h and sifted out by 325-mesh screen. Commercial silicon carbide (SiC > 97%, 325 mesh) and magnesia powders were used as additives. Commercial silica sol (SiO₂ = 30 ± 1%, PH = 12.5) was used as a binder, and polyethylene imine (PEI) was added into the slurry as a thickening agent.

1.2 Preparation of ceramic slurries

The 22–24 mass% deionized water was first mixed with 6 mass% silica sol by stirring for 1 min, and then 70 mass% ceramic powders were added to the liquid and the mixture was stirred for 15 min, followed by the PEI thickening agent. The slurry continued to be stirred for 30 min, and the ceramic slurry with 70 mass% solid loading was prepared.

The polyurethane sponges were immersed in the slurry so that the web is coated therewith and the voids of the sponge are substantially filled, the impregnated sponge is then compressed by means of pressing it with two parallel plates having a constant gap, so that preferably about 80% of the slurry is expelled from the impregnated sponges. After removal of the excess slurry, the coated sponge material was then dried at room temperature for at least 24 h. The samples were then placed in a drying oven at 120°C for at least 12 h. Firing of the samples was conducted in a programmable furnace. First the samples were heated slowly at

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a heating rate of 2°C per minute to 600°C to drive off the water and allow the polyurethane fibers to volatilize and/or burn out without collapsing the ceramic and without destroying the filamentary ceramic configuration. Subsequently sintering was carried out in air at a heating rate of 5°C per minute to 1 650°C and holding for 1 h, which allowed the fused ceramic foam to have a great number of interconnected voids surrounded by a web of bonded or fused foam ceramic filters.

1.3 Test procedure of samples

The compressive strength of ceramic foams filter was measured using a universal testing machine (SJ-IA, made in China). To determine the thermal shock resistance of filters, the samples were first heated to 1 300°C, held for 5 s, and then dropped from the oven for water quench (20°C). The samples were examined for cracks or fracture.

The microstructures of the foam ceramic filters were investigated by a SSX-550 (Japan) scanning electron microscope (SEM). Phase analysis of the sintered ceramic products was performed by X-ray diffraction (XRD).

2 Result and discussion

2.1 Effect of sintering temperature on alumina-based foam ceramic properties

In order to determine the effect of sintering temperature on alumina-based foam ceramic properties, the samples in Table 1 were prepared at the same condition except the sintering temperature.

Table 1 Effect of sintering temperature on alumina-based foam ceramic properties

Sintering temp. °C	Compressive strength, MPa	Absorption water ratio %	Linear shrinkage %	Appearance
1 450	0.628	14.17	10.11	Good
1 500	0.814	10.40	14.34	Good
1 550	–	–	–	Collapsed

Table 1 shows that compressive strength and linear shrinkage increase with increasing sintering temperature from 1 450°C to 1 500°C. However, when sintering temperature rises to 1 550°C, foam ceramic collapsed. It is also noted that the absorption water ratio decreases with sintering temperature.

For each filter, a substantial shrinkage occurred as polyurethane was burnt out and the particles, which were initially packed loosely, approached and contacted, i.e. densification process. The removal of polyurethane left holes in the center of webs, as shown in Fig.1. The sintering of alumina ceramics depends mainly on diffusion of void and the particles of alumina. These holes were the source of void that would move from the center to the outer surface during the procedure of sintering, at the same time the particles moved toward the internal surface of webs. These movements led to the shrinkage of foams and the shrinkage became intensive with increasing sintering temperature. As a result of shrinkage, the holes in the center of the webs became

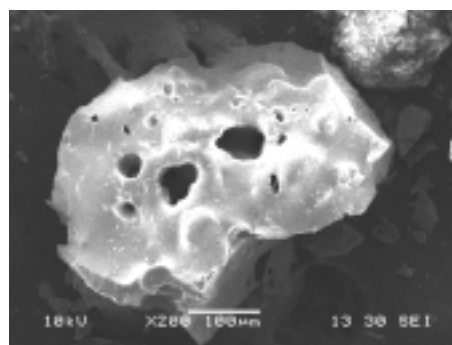


Fig. 1 SEM image of holes in the center of webs of foam ceramics

smaller. The shrinkage of holes and webs led to the increase of the foams' density. Studies of brittle porous materials have demonstrated a relationship between the compressive strength and relative density. Generic expression has the following form at the sintering temperature from 1 400°C to 1 600°C [11]:

$$\sigma_{fc} = C \sigma_{fs} (R)^{3/2} \quad (1)$$

Where σ_{fc} is compressive strength, C is a geometric constant characteristic of the unit cell shape, σ_{fs} is the webs strength, R is relative density that can be expressed by porosity P as:

$$R = 1 - P \quad (2)$$

So the relationship between compressive strength and porosity can be written as:

$$\sigma_{fc} = C \sigma_{fs} (1 - P)^{3/2} \quad (3)$$

Because porosity decreased with increasing sintering temperature as discussed above, the compressive strength should increase and absorption water ratio decrease with the increasing sintering temperature.

2.2 Effect of SiC content on alumina-based foam ceramic properties

SiC is used as sintering additive. Its content has great influence on foam ceramic properties. In this work, the effect of SiC content was investigated at the addition of 6, 6.5, 7.2 and 8.2 mass%, respectively, on compressive strength and thermal shock resistance of alumina-based foam ceramic, as shown in Fig.2. The sintering temperature was maintained at 1 500°C and held there for 1h. As can be seen from Fig.2, the thermal shock resistance of foam ceramic increases from 5 to 7 times with the increasing of SiC content. The compressive strength increases with increasing content of SiC first and reached its maximum of 0.89 MPa at addition of 7.2 mass% SiC, but then decreases sharply.

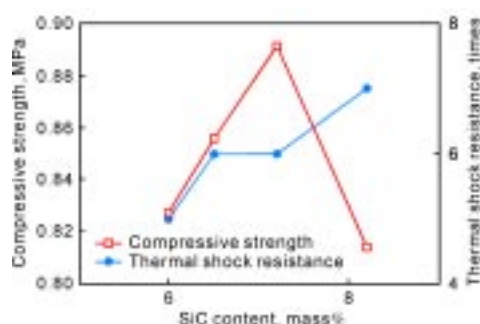
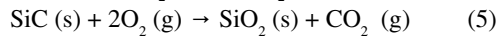
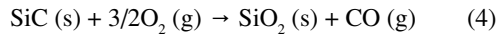
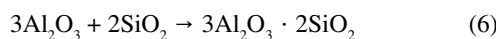


Fig. 2 Effect of SiC content on compressive strength and thermal shock resistance of foam ceramic filters

SiC and α -Al₂O₃ cannot be sintered together without sintering additives because of the strong covalent bond. However, particle surface of SiC was oxidized at sintering temperature. The oxidation of SiC proceeded by either or both of the reactions as follows [1]:



The oxidation products of SiC at 1 200°C are cristobalite [1,12]. The oxidizing reaction of SiC at sintering temperature proceeds vigorously, thus generating large numbers of SiO₂. It is interesting to note that mullite peak occurs in the XRD pattern, as shown in Fig.5. The SiO₂ from silica sol and the oxidation product of SiC can react with Al₂O₃ to form mullite [13], and its formation reaction is:



Al₂O₃ can promote more SiC to oxidize and more gas is released, hence allowing the compressive strength to decrease sharply. So the optimal content of SiC should be in the range of 6.5–7.2 mass%.

2.3 Effect of MgO content on compressive strength of foam ceramic

The effect of MgO content on the compressive strength was investigated at the additions of 1.5, 2.0, 2.2 and 2.5 mass% respectively, as shown in Fig.3. The content of SiC was maintained at 7.2 mass% and the foam ceramic was sintered at 1 500°C for 1 h.

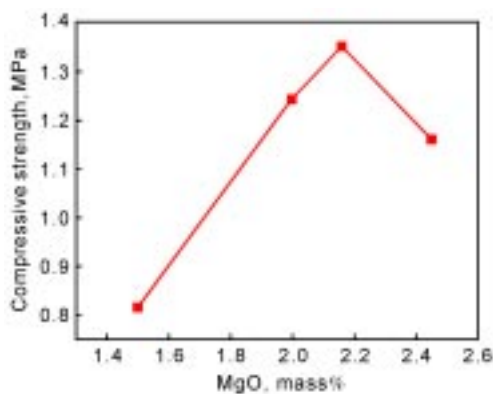


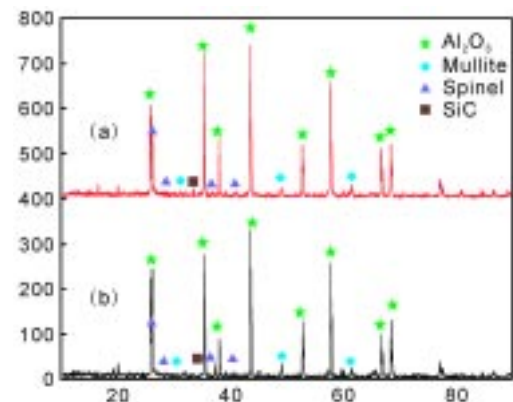
Fig. 3 Effect of MgO content on compressive strength of foam ceramic filters

It can be seen that MgO content has a strong effect on the compressive strength of Al₂O₃-SiC ceramic foams. The compressive strength increases with the increase of MgO content and reached 1.36 MPa when addition of MgO up to 2.14 mass%, but the superfluous additions decrease the compressive strength sharply.

Foam ceramic filter produced with 2.20 mass% MgO is shown in Fig.4. Figure 5 gives the XRD result of the foam ceramics with MgO contents of 2.14 mass% and 2.2 mass%. It can be seen from Fig.5 that the main identified phases of the sintered ceramic body is composed of alumina, silicon carbide, spinel and mullite phase. The spinel phase formation maybe take place by reaction $\text{Al}_2\text{O}_3 + \text{MgO} = \text{MgAl}_2\text{O}_4$ during sintering.



Fig. 4 Optical photo of foam ceramic



(a) 2.14 mass% MgO; (b) 2.2 mass% MgO

Fig. 5 XRD patterns of the sintered Al₂O₃ foam ceramics with different MgO content.

MgO is an effective “sintering additive” in Al₂O₃ ceramics, the role of MgO in the sintering of alumina is attributed mainly to its ability to lower the grain-boundary mobility and increase the densification rate directly through a raising of the diffusion rate, which has been used to enhance the densification rate of Al₂O₃ during sintering in air [14, 15].

Meanwhile, MgO must be present with a proper ratio of Si. That is, when the concentration of Si increases, the amount of Mg necessary to put Si into solution increases too. The reduction in the concentration of Si⁴⁺ at the grain boundary is due to increased solubility of Si⁴⁺ with additions of Mg²⁺. The solubility of Mg²⁺ and Si⁴⁺ was found to increase with increasing both elements in accordance with the presence of Al₂O₃. The dissolution of Si⁴⁺ into Al₂O₃ favors a substitution mechanism with V_{Al} as compensating defect. MgO dissolves into alumina substitutionally with the compensating defect V_O. With Si and Mg both present in the lattice, charge compensation occurs and reduces the heat of solution in the lattice, thus increasing the solubility of both impurities [16-18]. And hence, reduces the segregation of Si⁴⁺ to grain boundary. So, the compressive strength of foam ceramics increases primarily with MgO addition.

However, the cosolubility limit of Mg+Si can be reached at a high concentration of Si, and a silicate-based liquid phase persists even after doping with large concentrations of MgO [18]. Thus the compressive strength decreases sharply if the content of MgO exceeds 2.14 mass%.

3 Conclusions

(1) Alumina-based foam ceramic filters with high porosity, light weight, higher flexural strength and higher thermal shock resistance, and with a uniform macrostructure were fabricated.

(2) The main phase compositions of the samples consist of alumina, silicon carbide, spinel, mullite after 1h sintering at 1 500°C.

(3) Compressive strength of 1.36 MPa and thermal shock of 5 times for alumina-based foam ceramic filters containing 2.2 mass% MgO and 7.6 mass% SiC can be achieved.

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