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Properties of hybrid fibre reinforced shell for investment casting

Kai Lü*, Xiangdong Liu, Zhaoxin Du, Yanfen Li

School of Materials Science and Engineering, Inner Mongolia University of Technology, Hohhot 010051, China

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ABSTRACT

In order to improve the properties of silicon sol shell for investment casting process, a varying content of hybrid fibres (aluminium silicate and polypropylene) was introduced into slurry for preparation of fibre-reinforced shell in the present work. The bending strength, self-load deformation at elevated temperature, and the permeability of fibre-reinforced shell specimens were investigated and the fracture surfaces of shell specimens were observed by SEM. The results show that the bending strength of green shell increases with content of fibres in it. The maximum bending strength of 4.96 MPa was obtained in the fired shell with 0.6 wt% hybrid fibres addition. The high temperature self-loaded deformation of specimens of shell reinforced with a hybrid fibre addition above 0.6 wt% is higher than that of the unreinforced. However, the shell with a hybrid fibre addition up to 0.4 wt% exhibits the lower self-loaded deformation at high temperature compared to the unreinforced. It is also found that the permeability of shell specimens can be improved by hybrid fibres addition. Based on the fracture surfaces observation using a scanning electron microscope (SEM), the failure mode of the green shell reinforced with hybrid fibres is identified as fibre rupturing from the substrate of shell specimens, and/ or debonding from adhesive film surrounding it in shell. Even though the specimens of shell being fired at 900 °C for 2 h, the same failure features also exist in the fracture surfaces of specimens. This indicates that the specimens of shell can still be reinforced with aluminium silica fibres (residue of hybrid fibres) for their interpenetrating fibres network structure although go through firing.
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1. Introduction

Investment casting offers high standard of dimensional accuracy, surface finish and design flexibility and is applicable to alloys virtually any composition. One survey clearly projects that the investment casting is well-known for its ability to produce castings with complex shapes [1]. So, it has been an important manufacturing process for producing complex hollow turbine blades for many past years. The shell for investment casting is formed by repeated dipping and stuccoing of wax patterns until the expected thickness is obtained. It is well known that the exacting requirements of an investment casting mould include the high green and fired strength, dimensional stability, and permeability of the shell, besides other technical properties [2,3]. It should be pointed out that, the dimensional changes of the shell during handling, dewaxing, melt pouring, filling, and solidifying, etc., strongly depend on the green strength and elevated temperature strength. In addition, the permeability of the shell is required to evacuate air and other entrapped gases promptly during melt filling. So far, high green and fired strength of shell for complex and large components are usually achieved by increasing its thickness in the foundry practice. However, low permeability, cooling rate, and collapsibility of shell result from excess large thickness of shell. For this reason, some researchers have attempted to develop a noval method for reinforced and thin shell. But almost exactly at this moment, it comes into notice that fibre has been successfully employed in the improvement of cement and concrete composites, a kind of cementitious materials, similar to shell [4–6]. In this technology, fibres, including inorganic and organic fibres, have been widely employed as reinforcement in cement and concrete composites. Probably, it may be applicable to improvement of shell. Just for this reason, there is a report on comparison of a polymer-modified ceramic slurry system and a fibre-modified ceramic slurry system. The results showed that the use of fibre in the ceramic shell slurry increased the shell thickness by 15% over a primary +4 coat shells built without adding extra coats [7]. For example, the ceramic moulds modified with needle coke, with a fibre structure, exhibit higher “green, and dry” strength, and show less reduction in “green, and wet” strength [8]. The polymer fibre-modified ceramic shell exhibits higher dry and green strength, and the shell thickness greatly increases, especially on edges, leading to the possibility of using fewer coats for equivalent ceramic thickness and mechanical performance with a significant decrease in production costs [9]. These fibre were burnt and/or evaporated during the firing of the

* Corresponding author.
E-mail address: lk830909@126.com (K. Lü).

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Table 1
Slurry components for ceramic specimens.

Coat	Refractory	Binder	Hybrid fibre addition
1,2	Zircon sand (325Mesh)	25% Silica	0
3–5	Mullite sand(30/ 60Mesh)	25% Silica	0.2–1.0 wt% of the weight of refractory

Table 2
Shell build for fibre modified ceramic specimens.

Coat	Stucco	Dip time (s)	Dry time (h)
1,2	Zircon sand(100/120Mesh)	30	24
3–5	Mullite sand(16/30Mesh)	30	2

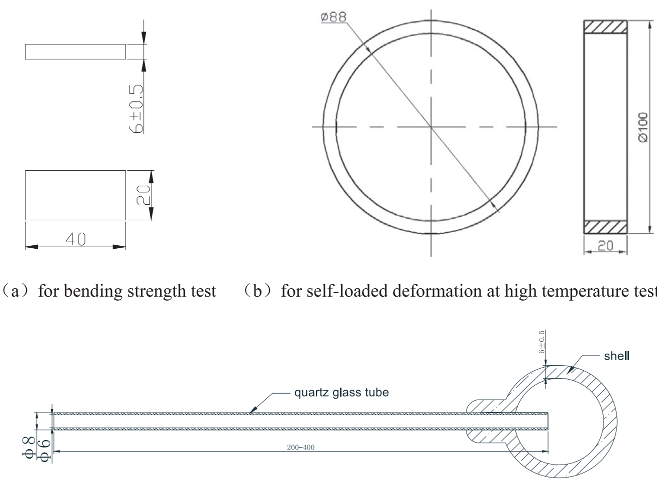
ceramic shell, leaving some pores inside the ceramic shell to enable the passage of hot gases [10]. This method could represent a new way to improve the permeability of the ceramic shell to some extent. It should be noted that shells need be fired before being employed in pouring melt. As a result, the organic fibre in fibre reinforced shell can be ablated completely during shell firing. This contributes to a large number of in-situ formation of microholes in shell, however, in the meantime, decreasing of fired strength at high temperature. On the contrary, reinforced with single inorganic fibres, the shell can achieve not only a high green and fired strength of shell, but also a high residual strength, but, unfortunately, the later causes a terrible problem to low collapsibility of shell.

In view of above mentioned reasons, in this work, a kind of hybrid fibre of aluminium silicate and polypropylene fibres was employed in reinforcing shell in order to improve its green, fired strength and the permeability. It is expected that the hybrid fibre play a role of reinforcement effect on green strength of shell, and in following procedure of shell firing as well as melt pouring, and aluminium silicate fibre of hybrid fibre in fired shell still play its role effectively as a reinforcement in resistance to self-load deformation at elevated temperature. Meanwhile, the fired shell maybe exhibit a high permeability and low collapsibility of shell a large number of in-situ formation of microholes resulting from ablating of polypropylene fibre in shell.

Due to limitations of technology, it is very difficult to accurately measure directly at elevated temperature self-load deformation of the shell, in current work, high temperature strength of fired shell and self-load deformation at elevated temperature are measured separately at ambient temperature instead of at high service temperatures according to the aeronautical department standard of China. The permeability of shell was tested at a gradually varying temperature from 50 °C to 1200 °C, similar to the variation of temperature of shell during melt pouring and solidifying in investment casting process. The fracture surfaces of fibre-reinforced shell specimens were characterised and the high correlation between performance and microstructure were also furtherly discussed.

Table 3
Chemical compositions (wt%) of fibre.

Fibre	C	O	Al	Si
Aluminium silicate fibre	–	25.85	35.56	38.59
Polypropylene fibre	96.88	3.12	–	–



（a） for bending strength test （b） for self-loaded deformation at high temperature test

（c） for permeability test

Fig. 2. Illustration diagram of specimens for test.

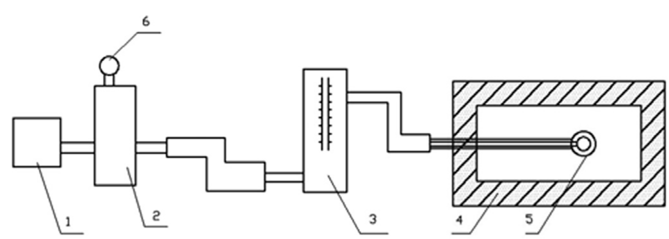


Fig. 3. Testing device of permeability (1. air compressor; 2. pressure regulating valve; 3. gas flowmeter; 4. furnace; 5. specimen; 6. pressure gauge).

2. Experimental materials and methods

Details of slurry composition and shell build are listed in

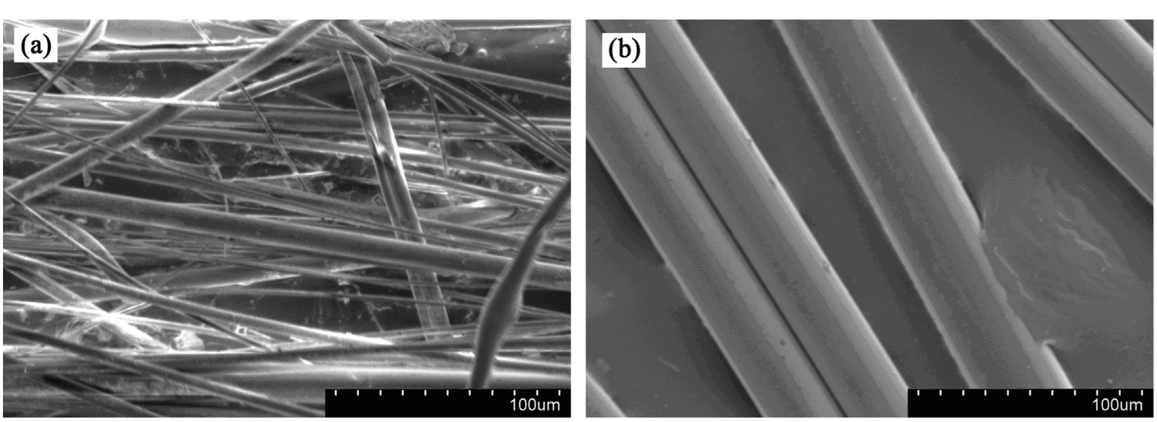


Fig. 1. SEM images of fibre (a. aluminium silicate fibre; b. polypropylene fibre).

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