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Shell Mould Composite With Rice Husk

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Abstract. For many years, precision investment casting foundries have periodically reported serious casting defects. One source is associated with the brittle ceramic shell mould which is very weak in tension and highly expose to the cracking mechanism. This situation not only lead to the appearance of defect in the end cast product but always attribute to the handling problem at the earlier stage in the investment casting industry. Due to this fact the strengthening mechanism of the brittle shell mold using reinforcement method was studied and investigated in this work. Rice husk was chosen as a reinforcement material as it contains silica element which can withstand high temperature of molten metal. Several testing procedures and characterization technique were carried out in order to measure the performance of the reinforced shell mould. Results show that the MOR value for the green reinforced shell mould is higher than the green body of non reinforced shell mould. Scanning electron microscope observations also show that the fiber alignment across the matrix structure increase the failure resistance and yet increase the strength of the shell mould green body. Furthermore, this reinforcement method using organic fiber leads to the pore enhancement and also leads to the new phase formation (zircon) in the fired reinforced body. Overall, this reinforcement method using rice husk increase the properties of the green and fired body of ceramic shell mould system.

Introduction

In investment casting the production of casting component involves the making of ceramic shell mould at the beginning stage using wax pattern. Basically, the making of shell mould involves the dipping of wax pattern into ceramic slurry for several times and follows by the consolidation of ceramic structure via drying and firing stages [1]. This consolidation ceramic structure increases the strength of the shell mould and allows the pouring process of hot molten metal into the mould. Typically most of the failure in casting component is due the failure of the brittle fired shell mould and the low strength of the green shell mould system. The defects can be originated in the firing stage due to the excessive shrinkage or low strength of the dried green body that highly exposed to the breaking failure. Therefore, The strength and integrity of the mould play an important role in ensuring that the end cast product has a proper dimension and is free from any defects and cracks .

In general production of investment casting ceramic shell mould is a crucial part of the whole process. The requirement for investment casting shell mould are; sufficient green strength for handling process and can withstand the dewaxing process, sufficient fired strength to withstand the weight of cast metal, high thermal shock resistance to avoid cracking mechanism during casting, sufficient mould porosity for the air cavity during pouring process etc [2]. These shell mould characteristics are especially critical for manufacturing high performance components, such as super alloy parts used in the air craft and power generation energy. Many conventional shell moulds do not exhibit sufficient strength at high casting temperatures. Therefore, the mould becomes susceptible to bulging and cracking when it filled with the molten metals that result in failure of the mould [1]. The failure in producing the ceramic shell mould not only leads to the defect appearance in cast component but also increase the cost of raw material and the production time.

As reported recently, the advancement of the shell mould system involves the fiber reinforcement into the brittle ceramic shell mould [3, 4]. This reinforcement method increases the strength of the green shell mould and prevents an excessive change in dimension by holding together its particles via network alignment across the structure; this directly can reduce the possibility of the defects appearance the final cast body. Typically colloidal slurry produces ceramic shell mould with very low green strength which is prone to cracking especially during dewaxing and handling[5]. Furthermore, the ceramic structure theoretically is highly sensitive to any thermal changes and also inherited the brittle property [6,7] which are very critical especially during the handling part in the processing stage. Therefore, in the present work the strengthening mechanism of the shell mould system using reinforcement method with organic fibers was introduced. In fact in the last few years, several investigations have been carried out in order to improve casting quality by incorporating fiber either in the form of organic and synthetic [2, 8, 9] into the ceramic shell mould system. Most of these researches proved that these fibers enhance the strength of the green and fired body of the shell mould system [2].

In this research, rice husk which is an organic fiber was chosen as fiber reinforcement. The selection of organic fiber from the agro waste is one alternative in reducing abundant agro waste problem [10] and also reducing emission level that always associated to the shell mould casting industry. Typically burning rice husk also resulting to the formation of black ash containing silica that carries too many impurities [11]. Most of the rice husk ash contains 90-97% of silica and it has a great potential to be used as reinforcing filler in natural rubber products as its can increase the mechanical properties of products compared to the commercial silica [11]. In fact, the use of rice husk ash in concretes also showed that the positive effect on the compressive strength of concretes [12]. Prior to the mixing and reinforcement stage, in this work the rice husk fiber was treated using certain chemical solutions regarding to the previous work [13, 14]. Most of the lignin layer will be eliminated via this treatment and in fact this treatment also leads to the formation of rough surface. Previous work on the reinforced composite with treated natural fiber indicates that this procedure can improve the mechanical properties of the composite system.

Experimental

Chemical treatment of rice husk. The raw rice husk used in this work was collected from Kelantan. As mentioned before, the rice husk fiber is chosen as reinforcement in this work because it consists of silica element which is can withstand high melting temperature of molten metal and sintering temperature. Silica forms the main component (90–97%) of the ash with trace amounts of CaO, MgO, K_2O and Na_2O [15, 16]. When rice husk is burnt, the resulting black ash contains silica that carries too many impurities. It has been reported that purity of silica is highly affected from chemical treatment [17-20], than thermal treatment [21]. Therefore in this work, the rice husk was treated chemically to produce high purity of silica. Prior to use, the rice husk was ground and sieved to produce 6mm particle size. The rice husk was immersed chemically in 5% NaOH and 95% of water for 24 hours. Then, the rice husk was thoroughly washed by distilled water several times to remove the chemical. After that, it dried in the drying oven at 80°C for 12 hours.

Strength measurements. The strength of brittle ceramic property can be measured using Modulus of Rupture (MOR) testing procedure. Three point bending test was done according to ISO 178:93 (International Standards Organization) methods by a SHIMADZU Universal Testing Machine (Model AG-1). This testing procedure was carried out for several samples for each case. The samples were prepared upon a wax pattern with dimensions of 100mm length x25mm width x5mm thickness.

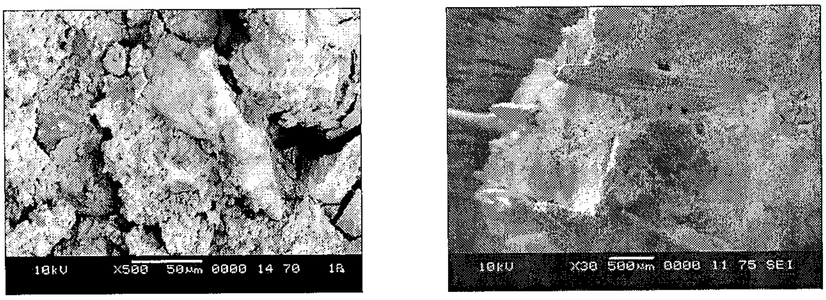
Microscopy. Scanning electron microscopy machine was used to view the fracture surface of the green body and microstructure of the fired body of ceramic shell mould. Micrographs of the samples were obtained by using a JEOL, JSM-638OLA of Scanning electron microscopy machine. Samples observed under the SEM were sputter coated with either gold or carbon to form a conducting layer to avoid electrical charge.

Results and discussion

Modulus of Rupture and fracture surface. The result of MOR values for the green shell moulds with four layers system are shown Table 1. In both cases five samples of the green shell mould were prepared and tested to get the range of MOR values. Green shell mould reinforced with rice husk fiber shows the higher MOR value compared shell mould without fiber as shown in Table 1 below. Further observation on the fracture surface using secondary electron image indicates that the higher mould value is due to the resistance in fracturing the ceramic structure especially in the embedded fiber zone. As shown in Fig 1 below the green fracture with fibers which appears to have been pulled from the ceramic network.

Table 1: MOR value of the green shell mould system with 4 layers

Shell mould system	**MOR value(MPa)**
Shell moulds without fiber	0.5-1.0
Shell moulds with rice husk fiber	1.2-1.5

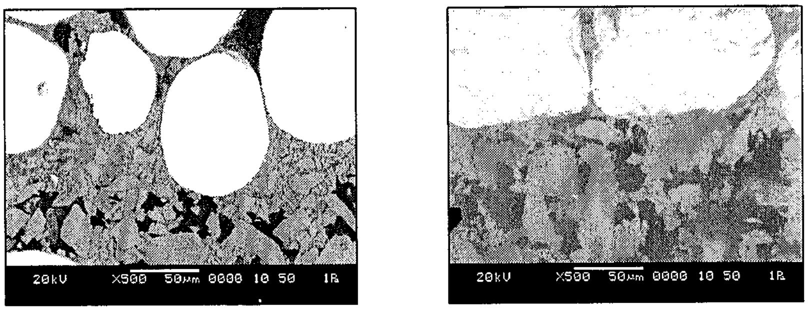


(a) (b)

Figure 1: (a) brittle fracture surface of green shell mould without rice husk fiber, (b) fracture surface of green shell mould with treated rice husk

This is as expected with a composite system in nature, where the energy required to remove fibers in this manner increases the strength required to break the sample [11, 12]. Furthermore the rough surface of fiber (treated rice husk) creates a strong bonding with the brittle ceramic matrix structure and increase the friction between fiber and matrix and increase the energy required of fiber to pull out and ultimately increase the strength. The strength of the shell mould green body before firing stage is very important in most of investment casting industry in order to avoid any crack in the shell mould at the early stage or to control the dimension changes in the later firing stage [5, 7].

Pore Structure



(a) (b)

Figure 2: Backscattered electron SEM image of cross sectional view of ceramic shell mould showing porosity left (a) ceramic shell mould without fiber; (b) ceramic shell mould with rice husk fiber

Fired microstructure of the shell mould with and without fiber were analyzed using SEM via back scattered SEM to determine the porosity distribution. As clearly shown in Fig 2 above the fired shell mould with rice has a bigger porosity compared to the nonreinforced shell mould. This is due to the fact that the rice husk fiber contains volatile material (80%) and treatment procedure only eliminates the lignin layer but not the others volatile materials. This volatile element will contributes to the increment of the pore structure in the fired shell mould body. Basically the firing and drying of the shell mould lead to the bigger pore formation due to the consolidation of ceramic particles via diffusion process between particles. In fact, the connected nature of this porosity enhances the porosity of the fired shell, providing a great deal of connected pathways through the ceramic and greatly increasing the permeability of the ceramic during casting. This is very import during the pouring and casting process so that the air leaves the cavity quickly and completely can prevent trapping and subsequent porosity during the displacement of liquid metal [4, 8,10].

X-ray diffraction. XRD analysis was carried out to identify any phase changes in the shell mould body after firing process. All XRD patterns of the fired shell mould as presented by (a) raw material of shell mould before firing stage, (b) fired shell mould without fiber (c) fired shell with nontreated rice husk, (d) fired shell with treated rice husk were compared and observed as can be seen in Fig. 3 below. As clearly shown in this figure there is an obvious different on the XRD patterns in the 2θ ranging from 50° to 60°, indicating that influence of fused silica originated from rice husk that lead to the new phase transformation of the shell mould reinforced with rice husk for both cases (treated and nontreated). Comparison and observation of the difference in peak appearance within this range are shown in Fig. 4 show that the appearance of new phase which is zircon ($ZrSiO_4$). Basically, burning of rice husk under uncontrolled condition below 1000°C produced fused silica in amorphous condition, as mentioned and proved by the previous works [22, 23]. This was shown and proved with the comparison of the XRD pattern in Fig. 4 where the shell mould without reinforcement only shows the peak of SiO_2 at angle $2\theta=50.167^{\circ}$ indicates the silica from the raw material of mulgrain flour. Most of this synthetic silica exists in the form of crystalline with a stable condition until up to 1700°C [23]. The appearance of this new zircon phase could benefited to the shell mould as its has a low thermal expansion coefficient and high resistance to the thermal shock [24] which can avoid cracking mechanism especially during the pouring of hot molten metal.

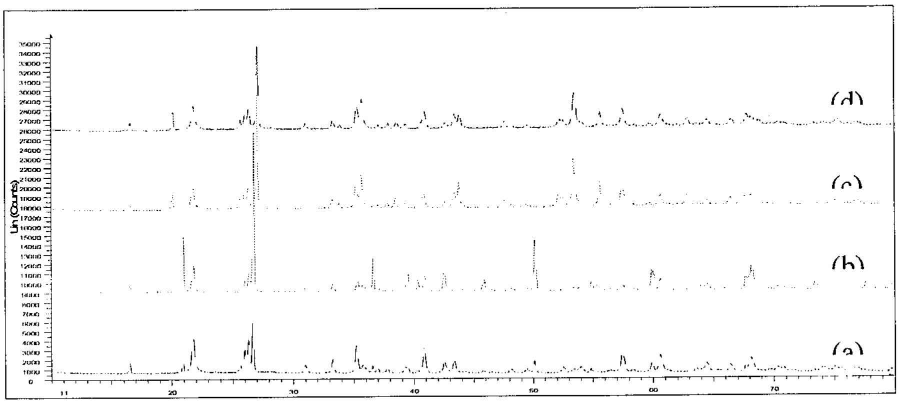
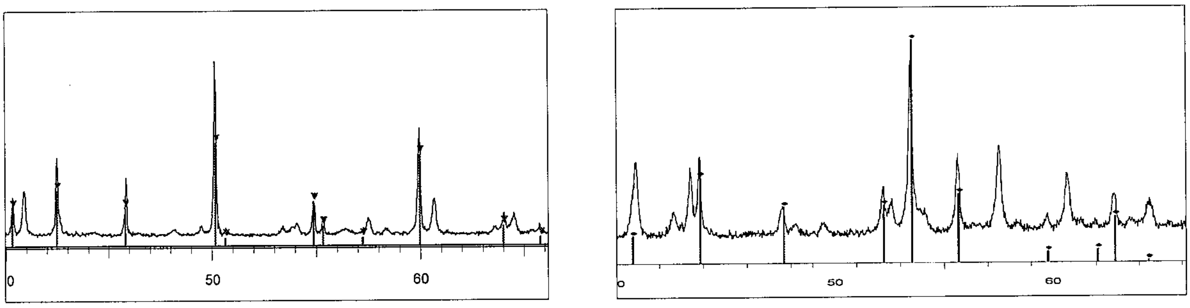


Figure 3: X-ray diffraction patterns for different shell mould composite systems.



(a) (b)

Figure 4: (a) Shell mould without fiber show the appearance of SiO_2 at peak θ=50.167°, (b) Shell mould with treated shell mould show the appearance of $ZrSiO_4$ at peak θ=53.531°.

Summary

The use of rice husk fibers increase the green strength of the shell mould by creating a strong network and the fracture resistance. The advantages of embedded of this organic fiber also lead to the enhancement of pore structure in the fired shell mould as it contains high volatile material. This structure can promote the permeation of air and avoid the trapped bubbles in the casting component. In fact the addition of rice husk lead to the new zircon phase formation which has a low thermal expansion and resistance to the thermal shock and this provide a great benefit for high temperature applications like investment casting.

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