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A water-soluble magnesium sulfate bonded sand core material for manufacturing hollow composite castings

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ABSTRACT

A high-strength and water-soluble magnesium sulfate bonded sand core (WSMBS) material cured by twice microwave heating was successfully fabricated using magnesium sulfate aqueous solution as a binder, which is suitable for manufacturing hollow composite structures castings. The effects of various factors on the properties of WSMBS were investigated. The results shows that WSMBS possesses some advantages of good water solubility, high curing speed and strength. The tensile strength of WSMBS is more than 0.6 MPa under optimal parameters, and when the temperature of WSMBS ranges from 105 °C to 116 °C, the tensile strength is superior and $MgSO_4{\cdot}7H_2O$ is dehydrated to $MgSO_4{\cdot}4H_2O$ or $MgSO_4{\cdot}3H_2O$. The moisture absorbability of WSMBS is quite high, and it rises with increasing the stored time and the magnesium sulfate binder content. The scanning electron microscope analysis shows that there are some micro-cracks or holes in the bonding bridge that decreases the strength of WSMBS after being put in humidistat for several hours. The energy dispersive X-ray analysis shows that the bonding bridge mainly comprises magnesium sulfate and so the use of WSMBS in casting does not release toxic gases. The water-solubility rate of WSMBS is 57.9 $kg{\cdot}min^{-1}{\cdot}m^{-2}$, which can be dissolved in water quickly after casting and overcome the poor leachability of the common bonded sand core, and therefore the used WSMBS can be easily reclaimed by water scrubbing method and the use of WSMBS can improve the production efficiency of the complex hollow composite castings with many interior channels or passages, undercuts. What is more, the aqueous solution of magnesium sulfate can be made from waste water which is used for dissolving the sand core after casting, and therefore it can realize green casting with no toxic gas during casting and recycling magnesium sulfate binder.

1. Introduction

With the rapid development of the aerospace and automobile industry, the structures of casting parts are developed toward to integration, hollow thin wall, composite and complication [1,2]. There are many slender bend channels and undercuts in the interior of the castings. Traditionally, the channels and undercuts are formed by sand core material using casting method [3]. The precise fabrication of complicate, hollow composite and thin-walled castings requires that the performance of the sand core should possess good formability, sufficient room-temperature strength, limited gas evolution and excellent collapsibility. However, the common core material, such as resin bonded sand core, fused silica-based ceramic core and alumina-based ceramic core, are usually removed by hot method, chemical corrosion or mechanical stripping methods, which destroy castings or need dedicated device [2,3]. These problems make the castings become more expensive and low efficient production.

The water-soluble sand core can solve the above problem with outstanding casting collapsibility, high strength, low gas evolution and green environmental protection, which can greatly improve the production efficiency of complex castings and has greater prospects in forming complex hollow composite castings because it can be easily removed in water [4–6]. In the previous research articles, there were many kinds of binder systems used to form the water-soluble sand core, such as sodium chloride [4], potassium carbonate [5,6], potato starch [7], sodium silicate [8], plaster [9], magnesium sulfate [10] and so on. Generally, the curing process heated in industrial furnace or hot box is used to form the water-soluble sand core because the aqueous solution of salt used as a binder [4–10]. However, the above conventional heating curing process has some shortcomings, such as low efficiency, high energy consumption, easy stratified and so on [3]. In recent years, microwave heating process has been successfully used in food, automobile, rubber and other processing industries [11–14]. The microwave heating which offers volumetric heating has many advantages over conventional heating, such as uniform heating, fast heating, high efficiency, energy-efficient, clean production and so on [11]. Recently, the

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microwave heating process has been used to cure sodium silicate bonded sand core material [15–18], the sodium silicate bonded sand core material cured by microwave heating process could fully develop sodium silicate bonding potential and reduce sodium silicate content. However, during the microwave heating process, the requirement of mold materials is severe [15]. A new microwave heating process, called twice microwave heating process, was invented by our research group [19], which allowed employing the common wood or plastic mold and could greatly reduce the requirement of mold materials. Therefore, the water-soluble sand core cured by twice microwave heating process possesses an important application prospect, and it can greatly improve the production efficiency of complex hollow composite castings.

In this paper, the water-soluble magnesium sulfate bonded sand core (WSMBS) cured by twice microwave heating process was investigated. The properties and microstructures of WSMBS were tested and discussed. The bonding and moisture absorption mechanisms of WSMBS were discussed.

2. Materials and methods

2.1. Materials and equipment

The experimental materials mainly include raw sand and magnesium sulfate binder, and the raw sand was Dalin scrubbed silica sand with 50/100 meshes. The magnesium sulfate binder was aqueous solution of industrial magnesium sulfate with the mass fraction of 30%. The raw sand was coated with magnesium sulfate including some crystal water to fabricate WSMBS.

The sand mixing was used by a type SHY sand mixer. Standard cylindrical samples and "8" word-like wood samples were used to fabricate the testing sand samples. The sand samples could be heated in a microwave oven with three power levels of 700 W, 1400 W and 2000 W. The tensile strength tests were measured by a type SWG lever-type universal strength testing machine, and the moisture-absorbability weight was tested by a type JA5003N electronic balance with the accuracy of 0.001 g [20,21]. The humidity was control by a type KCS-3100 constant temperature and constant humidity box. Gas evolution was tested by the type GET-III intelligent gas evolution tester. The morphology of bonding bridge of the sand samples was investigated using Quanta 200 environmental scanning electron microscope (ESEM). The thermoanalysis of magnesium sulfate heptahydrate was used by Diamond TG/DTA thermal analyser.

2.2. Methods

Fig. 1 shows the simplified flowchart of the manufacturing process. Firstly, raw sand and magnesium sulfate binder were mixed uniformly with a certain proportion, and then the mixed sands poured into the wood mold. Secondly, the wood mold with unheated magnesium sulfate boned sand cores were heated in the microwave oven for a little time to obtain the stripping strength of the sand samples, and then the wood mold was taken out from the microwave oven and the sand samples were demoulded. Finally, the sand samples were heated for the second time to obtain the applying strength of the sand samples. This process could greatly decrease the requirements on the mold material of microwave heating and increase the efficiency of heating curing [19].

The strength (σ_0) and storage strength (σ) of the sand samples were tested. In this paper, the strength is the tensile strength of WSMBS cooled to the room temperature after being heated in the microwave oven. The storage strength is the tensile strength of WSMBS after being put into the constant humidity condition for several hours. The moisture-absorption rate (w) of WSMBS can be calculated by the equation of $w = 100\% \times (M_t - M_0)/M_0$, where w represents the moisture-absorption rate of the sand samples, M_t is the mass of WSMBS exposed in the constant moisture surroundings for t hours, M_0 is the initial mass of WSMBS. The water-solubility rate of WSMBS can be calculated by the equation of $K = m/S \times t$, here K represents the solubility rate of WSMBS, m, S and t are the mass, the surface area and the solution time of WSMBS, respectively [22]. All the testing and calculating results were the average value of five measurements.

3. Results

3.1. The tensile strength of WSMBS

(1) Effect of magnesium sulfate binder adding quantity and twice microwave heating time

When microwave power is 1400 W and the once microwave heating time of the twice microwave heating process is 60 s. The effects of magnesium sulfate binder adding quantity and twice microwave heating time on the strength of WSMBS are shown in Fig. 2.

As shown in Fig. 2, the tensile strength of WSMBS firstly increases and then decreases after the strength reaches the peak strength with the increased microwave heating time, which is caused by superheating that generates some micro-cracks or holes in the cured bonding bridge [23].

The peak strength of WSMBS improves with the increased the magnesium sulfate binder adding quantity. When the twice heating time is 100 s, the tensile strength of WSMBS with the magnesium sulfate binder adding quantity of 1% and 2% of raw sand both can attain a maximum value, while the peak strength of WSMBS with the magnesium sulfate binder adding quantity of 3% of raw sand needs 120 s. Therefore, the magnesium sulfate binder adding quantity has a great influence on the curing strength and the curing rate of WSMBS. The curing speed is mainly affected by the crystal water content in the sand samples, the more the quantity of the magnesium sulfate binder is, the more crystal water is brought in, which leads to reduce forming rate of cured bonding bridge that provided the strength of WSMBS. In a word, there is an optimal magnesium sulfate binder adding quantity of WSMBS with enough strength, good curing efficiency and low cost. In this study, the amount of magnesium sulfate binder is selected 2% of raw sand (mass fractions) for the subsequent experiments.

(2) Effect of microwave power on the tensile strength

When magnesium sulfate binder adding quantity is 2% of raw sand (mass fractions) and the once microwave heating time of the twice microwave heating process is 60 s. Fig. 3 shows the strength of WSMBS with different microwave power.

As seen in Fig. 3, the peak strength of WSMBS has no obvious changes when the microwave power increases from 700 W to 2000 W. When the microwave power increases from 700 W to 1400 W, the curing speed increases obviously, while the curing speed approaches the same values with the microwave power of 1400 W and 2000 W. Therefore, the microwave power has a great impact on the curing speed of WSMBS. In this study, the microwave power is selected 1400 W for the subsequent experiments.

(3) Effect of temperature on the tensile strength

When magnesium sulfate binder adding quantity is 2% of raw sand (mass fractions) and the once microwave heating time of the twice microwave heating process is 60 s. Fig. 4 shows the tensile strength of WSMBS with different temperature of the sand samples.

As shown in Fig. 4, the tensile strength of WSMBS firstly increases and then decreases after the strength reaches the peak strength with the raised temperature, and the reason is dehydration of magnesium sulfate binder. The low temperature leads to the more crystal water existing on the bonding bridge which cannot obtain high strength, while the high temperature makes the bonding bridge present more small pores for escaping water which would decrease the strength, and the morphology