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Original Research Article

Performance of water-soluble composite sulfate sand core for magnesium alloy castings

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ARTICLE INFO

Article history:
Received 22 October 2015
Accepted 4 March 2016
Available online 30 March 2016

Keywords:
Twice microwave heating
Sulfate
Water-soluble sand core
Tensile strength

ABSTRACT

A novel water-soluble sand core hardened by twice microwave heating was fabricated using composite solution of magnesium sulfate and sodium sulfate as a binder. The tensile strength, water absorption rate, gas evolution and water-soluble rate of the water-soluble composite sulfate sand core (WCSSC) were studied. The micro-morphology of WCSSC was observed by scanning electron microscope (SEM). The results show that tensile strength of WCSSC is 1.2 MPa, and the 4 h storage tensile strength exceeds 1 MPa, and also the water-soluble rate is about 42.65 kg/(min m^2), which indicates that WCSSC possesses good moisture resistance and water-soluble collapsibility. The microscopic analysis demonstrates that there are some micro-cracks or holes in the bonding bridge that decreases the strength of WCSSC after being put in humidistat for several hours.

1. Introduction

A lot of high-strength and low-density magnesium [1] or aluminum [2] alloys are applied in the new generation aviation castings [3], and the structures of casting parts are developed toward to integration, hollow thin wall and complication [4], therefore it makes the casting parts and the foundry sand cores become very complex, and the intracavity pores of casting parts are difficult to be clean [5]. Most of complex thin-walled magnesium alloy castings often possess complex cavities or thin, curved, long pore structures [6], which makes the foundry sand core very complicated, and even an integral sand core is usually composed of several sand cores [7]. But magnesium alloy possesses a low pouring temperature (700–760 °C) and small hot-melt content, and so the sand core is difficult to be collapsed by solidification latent heat, which increases cleaning work after casting, and thereby reduces the production efficiency of the castings [8]. The water-soluble sand core can solve the above problem with outstanding casting collapsibility, high strength, low gas evolution and green environmental protection [9,10]. The water-soluble sand core can greatly improve the production efficiency of complex castings, and has greater prospects in forming magnesium alloy castings with complex cavity structures [11,12]. In the previous research papers, there were many binders used to form the water-soluble sand core, such as sodium hydrogen phosphate [13], potassium carbonate [9,14], plaster [12], magnesium sulfate [15] and so on. Generally, the curing process heated in industrial furnace or hot box was used to form the water-soluble sand core because the aqueous solution of salt used as binder [9]. However, the above conventional heating curing process has some shortcoming, such as low efficiency, high energy consumption, easy

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http://dx.doi.org/10.1016/j.acme.2016.03.006

stratified and so on [7]. Recently, microwave heating process has been successfully used in food, automobile, rubber and other processing industries [16]. Microwave heating is a volumetric heating mode with advantages of uniform heating, high efficiency and environmentally friendly [17], and it can fully develop inorganic binder bonding potential and reduce the binder content [18,19]. Therefore, the water-soluble sand core hardened by microwave heating process has an important application prospect, and it can greatly improve the production efficiency of thin-walled complex magnesium alloy castings [20].

In the paper, the water-soluble composite sulfate sand core was prepared by twice microwave heating process. The tensile strength, water absorption rate, gas evolution and water-soluble rate of the sand core were investigated. ESEM was used to investigate the micro-morphology of WCSSC.

2. Experimental

2.1. Materials and equipment

The raw sand was Dalin scrubbed silica sand with 50/100 meshes. The binder consists of industrial magnesium sulfate ($MgSO_4{\cdot}7H_2O$), analytical pure sodium sulfate ($Na_2SO_4{\cdot}10H_2O$) and water. The microwave heating device was the type DWIM-2F microwave oven with the power level 1400 W. The sand mixer was the type SHY blade-type sand mixer. The sand samples were fabricated manually using a standard "8" font wood mold with the dimension of 22.36 mm × 22.36 mm × 66 mm and a cylindrical wood mold with the dimension of Φ30 mm × 30 mm. Other test equipment included the type SWG lever-type universal strength testing machine, the type JA5003N electronic balance with the accuracy of 0.001 g, the type GET-III intelligent gas evolution tester, the rotating-screen surface performance tester and Quanta 200 environmental scanning electron microscope (ESEM).

2.2. Preparation

2.2.1. Composite binder preparation

Firstly, a certain mass fraction of magnesium sulfate aqueous solution was prepared. Secondly, 0.3–1% sodium sulfate crystals ($Na_2SO_4{\cdot}10H_2O$) were added. Finally, the solid–liquid mixture was heated to about 70 °C, meanwhile stirring the mixture until a transparent solution obtained, then the composite binder was prepared.

2.2.2. The sand samples preparation

The raw sand and the composite binder were mixed uniformly with a certain proportion in the sand mixer about 90 s, and then the mixed sand was poured into the wood mold, finally, the sand samples were hardened by twice microwave heating process.

2.2.3. Twice microwave heating process

The power level of microwave oven was 1400 W. First, the sand samples and wood mold were heated in the microwave oven for 60 s to obtain the stripping strength of the sand samples. Next, the two parts were taken out from the microwave oven, and the sand samples were demoulded from the wood pattern. Then, in order to obtain the final strength, the sand samples without the wood mold were heated for a certain time for the second time. At last, the hardened sand samples were obtained.

2.3. Properties test

Room temperature strength (σ_b) is the tensile strength of the samples cooled to the room temperature after microwave heating. Storage strength (σ_s) is the tensile strength of the samples after being put into a humidistat (relative humidity at 98–100%) for a certain period of time. Gas evolution (G) is tested by the type GET-III intelligent gas evolution tester. Water absorption rate (Ψ) can be calculated by the equation of $\Psi = (M_1 - M_0)/M_0$, where M_0 is the original weight (the sample cooled to the room temperature was measured) of a sand sample, M_1 is the weight of the sample after being put into a humidistat for a certain period of time. Surface stability (φ) is tested as follows: the original weight (M) was measured after a sample was cooled to the room temperature, the final weight (M_2) was measured after the sample was put into the rotating-screen surface performance tester for 1 min, then the surface stability was obtained by $\varphi = M_2/M \times 100\%$. Water-soluble rate ($K$) can be calculated by the equation of $K = m/(S \times t)$ [10], where m is the weight of a sample, S is the surface area of the sample, t is the dissolution time of the sample (at 750 °C for 10 min, then cooled to the room temperature) in water. Each result was the average value of five measurements. Microwave heating time is represented by t_m.

3. Results and discussion

3.1. Performance comparison of two simple substance sulfate water-soluble sand cores

Fig. 1 shows the performance comparison of the water-soluble $MgSO_4$ sand core and the water-soluble Na_2SO_4 sand core when the mass fraction and addition amount of the simple substance sulfate binder are 30% and 5% (by weight of the raw sand, the same as below), respectively. The storage strength, water absorption rate, gas evolution and other performances are tested with the maximum room temperature strength of the sand samples, the same as below.

Fig. 1(a) reveals that when the microwave heating time prolongs, the room temperature strength of the sand samples firstly increases and then decreases, the room temperature strength of water-soluble $MgSO_4$ sand core reaches maximum 0.7 MPa with the heating time of 90 s, while the water-soluble Na_2SO_4 sand core reaches maximum 0.11 MPa with the heating time of 100 s. The strength of the sand samples is determined by binder quantity and bonding strength of different bonding between grains of sand, and sulfate hydrates by crystallization forms bonding bridges. As the microwave heating time increases, the heating temperature of the samples rises, and sulfate hydrates firstly crystallizes and precipitates, and then gradually dehydrates, and finally the tensile strength of the samples reaches peak value when