Self-Cooling Hollow Mold With Containing Water and Its Effect on Microstructure and Mechanical Properties

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ABSTRACT:The solidification process of castings directly determines the intrinsic quality and performance of castings, so controlling the cooling process during solidification of castings can eliminate or reduce defects such as shrinkage and porosity, cracks, deformation, etc., and then improve the performance of castings. 3D printing sand mold technology provides more options for the production of complex and high-quality castings, and improves the flexibility and innovation of the design of the sand structure. In order to control the sequential solidification of the castings, a new process of self-cooling hollow mold with containing water is proposed. The hollow mold is of a multi-shell structure which can contain water in the gaps between shells. Thus, it is convenient than the water dipping method or the bottom water cooling chill plate method. After pouring the molten metal, cooling water is pumped into the gaps between the shell layers, and the water level of the cooling water can be controlled to rise gradually to drive the solidification front per request, so as to realize the forced cooling of the castings from bottom to top, i.e., sequential solidification. By the casting experiment of barrels of aluminum alloy A357, it was found that the water cooling of the multi-layer shell hollow sand mold accelerates the cooling rate of the castings, the cooling rate increased by approximately 190% compared to natural cooling. The tensile strength of castings is 160 MPa, representing an increase of 14.3%, and the microhardness is 72.3 HV, showing an increase of about 43.5%.

Keywords: Hollow sand mold; Multi-layer shell structure; Controlled cooling; Casting; 3D printing

1 Introduction

Controlling the cooling process of castings can eliminate or reduce the defects and improve the performance of castings. In the solidification process of castings, external media such as cooling water and wind can be used to enforce the cooling of castings. Wladysiak [1, 2] used a rotating nozzle to spray waterfall on the metal mold surface for cooling, and found that an open multipoint waterfall cooling system effectively controlled the cooling process, and the uniformity of the microstructure of the casting was improved. John Robert Grassi [3] proposed the Ablation casting cooling technique, where a water-soluble inorganic binder is used for the sand mold, and a stream of water is sprayed on the outer surface of the sand mold while the casting is solidifying. In addition, the design of special cooling channels inside the sand mold, through the cooling medium for forced cooling, can also control the local temperature of the casting, shorten the local solidification time of a casting. However, the above methods are very limited into certain conditions, and the more complex and larger the casting structure, the more difficult to use these methods.

The emergence of 3D printing sand mold technology for the complex structure of the production of sand mold provides more options, and improves the flexibility and innovation of the design of the sand structure. Jinwu Kang et al [4] proposed hollow sand mold structure which can be adjusted by local spraying cooling water or blowing air to regulate the local cooling of the casting, and hollow sand shell surface and the external air heat transfer is more effective, the casting heat dissipation rate is greater than traditional sand mold. In this paper, the self-cooling device of multi-layer shell hollow sand mold is developed, and the influence of multi-layer shell hollow sand mold on the cooling rate, microstructure and mechanical properties of barrel castings is discussed.

2 Experimental procedure

The self-cooling method of multi-layer shell hollow sand mold was designed, as shown in Fig. 1.

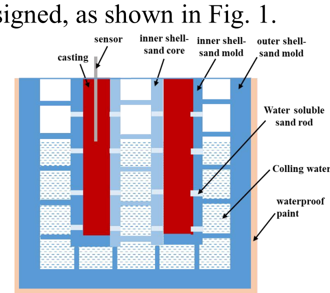

Fig. 1 Self-cooling device with multi-layer shells hollow sand mold.

In this new method, the sand mold/core are designed as an integrated hollow structure, which mainly includes the inner shell, outer shell and reinforcement structure between the shells; the inner shell is used for pouring the liquid alloy, and the cavity between the outer shell and the inner shell is for the cooling water. When water cooling is required for the casting, the cooling water is gradually pumped into the cavity between the shells, thus, the rising cooling water promotes the rapid sequential cooling of the casting from bottom to top. In order to prevent cooling water from leaking out of the sand mold, a waterproof coating is therefore applied to the outer surface of the sand mold.

A barrel casting is designed as shown in Fig. 2(a), the corresponding dense sand mold, double-shells and triple-shells hollow sand molds were designed and generated by using FT-HollowMold software self-developed by Tsinghua University, as shown in Fig. 2(b-d). The alloy used for casting is A357 aluminum alloy. During the solidification of the castings, natural cooling was adopted for the dense sand mold, and water cooling was adopted for the double-shells and triple-shells hollow sand molds, and the rise rate of the cooling water was 0.8 mm/s. When the temperature of castings dropped to below 473K, shakeout was carried out.

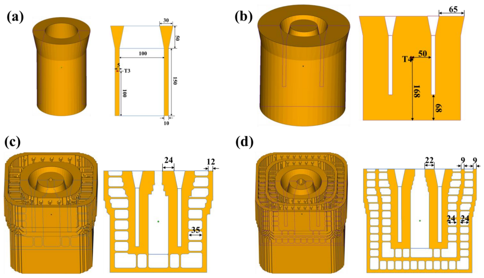

Fig. 2 Schematic diagram of casting and sand molds (unit: mm): (a) Casting; (b) Dense sand mold (P2DN); (c) Double-shells hollow sand mold (P2TN); (d) Triple-shells hollow sand mold (P2MN).

3 Result and discussion

Fig. 3(a) shows the temperature fields of the three groups of sand surface acquired by a infrared imaging camera during casting process. Under natural cooling conditions, the surface temperature distribution of dense sand mold is more uniform, and most of the surface temperature reaches 330K at 800s. For the multi-layer shell hollow sand mold under water cooling, the temperature of water at 100s is low, the heat transferred to the outer shell is low, and the temperature of outer surface is low, while the temperature of cooling water at 800s is significantly increased, and was observedto boil, so the heat transferred by the cooling water to the outer shell increases, then the temperature of outer surface also increases correspondingly. Fig. 3(b) shows the cooling curves of the castings. The castings of multi-layer hollow sand mold were forced to cool immediately after pouring for 200s. When the casting temperature drops to 573K, the casting of dense sand mold needs 1600s, and the castings of multi-layer shell hollow sand molds under water cooling only need 500s, which is 69% shorter than the casting of dense sand mold under natural cooling. The multi-layer shell hollow sand mold under forced water cooling have stronger heat transfer capacity, which significantly shortens the cooling time.

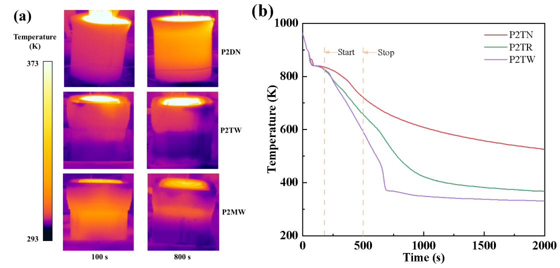

Fig 3. (a) surface temperature field of sand molds; (b) temperature cooling curve of the castings.

Fig. 4 shows the tensile properties of the castings. The tensile strength of casting of dense sand mold is 140 MPa, and the yield strength is 80 MPa. Under the condition of water cooling, the strength is obviously improved, the tensile strength and yield strength are 160 MPa and 116 MPa, respectively, with an increase of 14.3% and 45.0%, but the elongation of castings is reduced. Under the condition of water cooling, the content of strengthening elements in Al matrix phase is improved, thus, the strength properties of castings are improved.

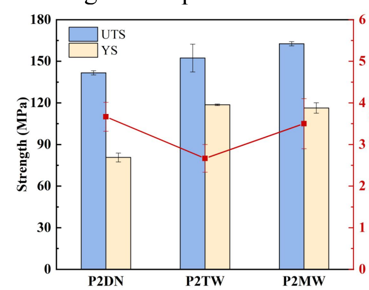

Fig. 4 The tensile properties of the castings.

4 Conclusion

A self-cooling with multi-layer shell hollow sand mold containing water was developed, the water was pumped into the cavity between the shells for forced cooling during casting process, which can enfore the cooling ofcastings and improve the mechanical properties of the castings.

Acknowledgments

The project was funded by the Beijing Nature Sciences Fund—Haidian Originality Cooperation Project (No. L212002).

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