Research on Metal Mold Casting Technology of Copper Alloy High Pressure Valve

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Abstract: This paper introduces the structure and technical requirements of copper alloy high-pressure valve bodies. Based on the structural characteristics and quality requirements of the castings, a precision casting process combining metal mold with 3D printed cores is proposed, and the casting process is designed accordingly. Detailed explanations are provided for the parting surface, gating system, and riser design of the casting. Computer simulation software is employed to analyze the filling and solidification processes of the copper liquid, and the process is optimized based on the simulation results. Various issues such as the integrity of filling for thin-walled complex castings like high-pressure valve bodies, mold venting, structural shrinkage, and solidification cracks are addressed, leading to the development of a stable production technology suitable for complex structured high-pressure valve bodies with high quality.

Keywords: copper alloy; high-pressure valve body; metal casting; numerical simulation

1 Introduction

Shipboard high-pressure valve bodies serve as critical components in high-pressure pipeline systems, with numerous supporting products and stringent quality requirements. These products are structurally complex, with significant differences in wall thickness and numerous thermal junctions, making it difficult to compensate for solidification shrinkage. Traditional sand casting methods, previously used for similar valve bodies, suffer from poor dimensional accuracy, high gas emission rates, and low thermal conductivity and capacity, significantly impacting the solidification quality and dimensional accuracy of copper alloy castings [1]. As a result, the yield rate of the product has been consistently low, and its quality unstable [2].

To address these challenges, a study was conducted on the precision casting process for copper alloy using a combination of metal molds and 3D printed cores, taking into account the characteristics and quality requirements of the product and leveraging advanced production modes for copper alloy castings. This approach maximizes the advantages of metal molds, such as fast heat transfer, dense casting structure, excellent surface quality, and high dimensional accuracy, resulting in superior internal quality of the castings.

2 Experimental procedure

The maximum wall thickness of the copper alloy high-pressure valve body is 39 mm, while the minimum wall thickness is only 6 mm. The material of the casting is ZCuAl10Fe3, with its chemical composition and mechanical properties meeting the requirements of the GB/T 12225-2018 standard. 100% of the casting's interior undergoes radiographic inspection, conducted in accordance with the procedures outlined in NB/T 20003.3, and acceptance criteria align with ASTM-E-272 standards at Level 3. The casting dimensions adhere to the CT10 level tolerance specified in GB/T 6414-97. High-pressure testing involves applying pressures ranging from 10 to 80MPa. Consequently, the quality requirements for high-pressure valve body castings used in QT applications are extremely stringent.

3 Result and discussion

The rationality of the aforementioned casting process scheme was validated through simulation analysis using ProCast software. The simulation process parameters were as follows: mold preheating temperature of 300 °C, pouring temperature of 1,200 °C, ambient temperature of 23 °C, and pouring time of 14 seconds.

Filling Simulation Results

The filling simulation results of the casting at different times are shown in Figure 1. The filling of the alloy liquid is smooth without significant turbulence. This facilitates the overflow of gases, slag, and other impurities, preventing the formation of secondary oxide inclusions.

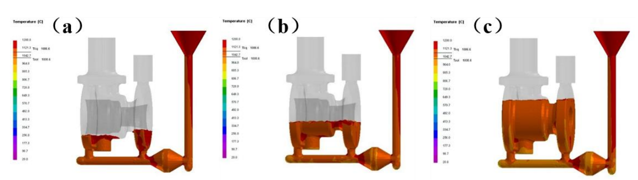

Figure 1 Simulation of mold filling process (a-3 s, b-5 s, c-8 s)

Simulation results of temperature field

The simulation results of the temperature field are shown in Figure 2. From Figure 2(a), it can be observed that at location I, the alloy liquid has the longest solidification time. To avoid the formation of shrinkage cavities, additional measures such as adding chills to accelerate its solidification rate need to be implemented at this location.

Since risers are not suitable to be placed at this location, internal chills are added instead.

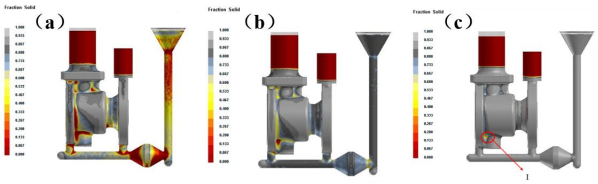

Figure 2 Simulation results of temperature field (a-17 s, b-27 s, c-30 s)

Simulation results of defects

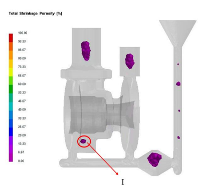

Figure 3 Simulation of defect distribution

The simulation results of shrinkage and shrinkage porosity defects are shown in Figure 3. A relatively severe shrinkage porosity defect has formed at location I, which is consistent with the conclusion drawn from the temperature field simulation, where the longest solidification time is required at this location.

Final process plan and production validation

The final process plan, optimized accordingly, is depicted in Figure 4. Internal chills are placed at position I of the casting to expedite its solidification rate, thereby achieving sequential solidification.

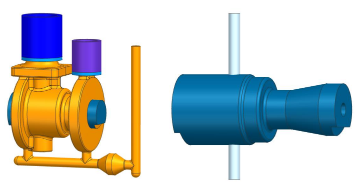

Figure 4 Optimized process scheme

Following the optimization of the casting process, production validation was conducted on the valve. The castings produced after process optimization exhibited good formability and precise dimensional control. The mechanical properties, high-pressure test results, and radiographic inspection results of the castings all meet customer requirements. The mechanical performance test results of the product are shown in Table 1.

Table 1. Product mechanical performance test results

No.	R_m/MPa	$R_{P0.2}$/MPa	A/%	HBW
GB/T12225	≥490	≥180	≥13	≥100
ZCu201914	642	250	21.5	145

4 Conclusion

This study combines advanced copper alloy casting production methods and employs precision casting technology using metal molds with 3D printed cores for copper alloys. Through the design of the process and optimization using computer simulation-assisted techniques, the produced castings have undergone high-pressure testing (import pressure ranging from 10 to 80 MPa) with excellent air tightness. The composition, dimensions, radiographic inspection results, and mechanical properties of the castings all meet the relevant requirements. Various issues such as the integrity of filling for thin-walled complex castings like high-pressure valve bodies, mold venting, structural shrinkage, and solidification cracks have been effectively addressed.

References

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