APPLICATION OF NUMERICAL SIMULATION ON ELIMINATING SHRINKAGE DEFECT OF AUTOMOBILE WHEEL HUB

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Abstract:

Shrinkage defect is a serious problem encountered during the development of automobile wheel hub made from ductile cast iron. In order to find out the reason for shrinkage formation and eliminate it in time, numerical simulation technology was performed to analyze the casting solidification process, and two modified casting projects were brought forward. Based on the simulation result, the solidification characteristics of the original project were compared with two modified projects and accordingly the optimized casting project with chill and rider feeding was selected for application during the development of the wheel hub. The result shows that casting shrinkage defect has been effectively controlled and the trial production cycle of the wheel hub was significantly shortened.

1 Introduction

The wheel hub (also abbreviated as wheel or hub) is a critical safety component of transportation equipment such as vehicles like automobiles and trains, and it has close relation with many performances of vehicles, for example motion properties, comfortability and dependability. For light-loaded vehicles such as car, the wheel exhibits an increasing trend towards the use of aluminum alloy and its complicated material as well as magnesium alloy due to lightweight, rapid dissipation of heat and beautiful appearance [1-3]. However, for heavy-loaded vehicle e.g., truck and railway, and due to a longer in-service durability, materials with a combination of high fatigue strength, high ductility as well as excellent wear resistance etc., are usually required for the wheels mainly made from ductile cast iron and cast steel [4, 5]. The above excellent properties of castings are affected by not only their microstructure, but also their casting defects e.g., shrinkage. Many attempts have been devoted to revealing of the formation mechanisms, affecting factors, and control methods of defects [6-11]. To eliminate shrinkage defect, the optimization of process factors e.g., pouring temperature, chemical composition, feeding as well as gating system etc. [8, 10, 11, 12], has been often adopted. However, for pasty alloys with wide freezing ranges such as ductile cast iron and some aluminum alloys, these measures are frequently found to be too difficult to effectively avoid shrinkage defect, even by employing risers for feeding required molten metal during solidification. The use of chill can form the high temperature

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gradient which can improve the properties of cast iron and aluminum alloys etc. [13-15], and more importantly, it promotes directional solidification which may conduct the effective feeding at hot spot zones; thus the solidification procedure of the castings can be so adjusted that shrinkage, porosity and other casting defects are eliminated and sound castings are achieved [13, 15, 16, 17]. Therefore, the paper presents extensive research into the chill process to eliminate shrinkage during the development of ductile iron wheel hub. At the same time, to shorten the trial cycle of a new production, a numerical simulation technique was applied to study solidification characteristics of the original and two modified methods, of which one project with chill was designed for comparison purposes. The simulation result was analyzed, and finally its practical effect of the mass production was also examined.

2 Initial conditions and casting defect

The wheel hub was cast from ductile cast iron of equivalent QT450-12（close to 65-45-12 in ASTM A536, i.e., it is required with the lowest tensile strength of 450 MPa and the smallest elongation of 12% and so on.

The casting has a mass of 22.2 kg, the dimension of Φ 335×187 mm, wall thickness with a minimum of 11 mm and a maximum of about 50 mm. The casting is shown in Fig.1. As seen from Fig. 1 (c), there exist hot spot zones at the junction of the cylinder and flange of the hub, especially near the four rims. Seiatsu molding line has been applied to a mold which can be used for two castings, as shown in Fig. 2. The core has been produced by shell core process with resin sand. The iron melting is prepared with intermediate-frequency induction furnace with the capacity of 3 ton, the molten iron is tapped from the induction furnace at the temperature of 1480～1500℃; Spheroidizing and inoculation process in ladle have been conducted during tapping with rare earth-magnesium-ferrosilicon alloy as nodulizer and 75SiFe as inoculant, respectively. Pouring temperature is in the range of 1400～1420°C. In the trial period of the hub, even if some measures such as adding feeding risers were preformed (as shown in Fig. 2), shrinkage defect was still discovered around the four rims of the hub, as shown in Fig. 1 (marked with the arrows).

Figure 1. (a) The surface of the wheel hub with four rims, (b) The back surface of (a), (c) hot spots of (a).

(a) the original project, (b) the first modified project, (c) the second modified project

Figure 2. Casting process project of the wheel hub.

3 Mathematical model

InteCAST software, a commercial numerical simulation software package whose finite difference method (FDM) is conducted using numerical discretization, can carry out numerical simulation of the flow field and temperature field, etc. This software is described by the continuity equation, momentum conservation (Navier-Stokes) equation and energy conservation equation, respectively. They are given in Ref. [18] in detail. The 3-D geometry models were established by Pro/E software according to casting technology design and saved as *.STL format. Then the 3D models (STL format) were imported into InteCAST software in terms of the importing sequence of casting body→ cores (and chills) → moulds. The simulation model of original process is shown in Fig. 2 (a). The principles of mesh division are to ensure that the thinnest position of hub casting has at least 3 meshes. At the same time computer calculation efficiency is to be considered and enabled. Consequently, the step size was set to be 4 mm due to a minimum wall thickness of 11 mm for the hub body, whereas the total number of mesh is about 2 700 000.

4 Results and discussion

4.1 The original process

Fig. 3 shows the solidification simulation result of the original process, which represents 10%, 50%, 90%, nearly all solidifying processes (full solidification), respectively. It can be seen that the solidifying sequence is as follows: the four rims and the bottom cylinder of the hub were first to solidify, there was a gradual solidification of the top and middle flange, and finally the circumference of the four rims solidified, where some isolated liquid phases could be found after the other parts of the hub had solidified. From Fig. 1 (c) we can clearly know that the wall of hot spot positions is thicker than that of the nearby A zone, of course, much thicker than that of the ingate place (Fig. 2). Meanwhile, there is too long a distance between the riser and the four rims, especially the two rims far away from the ingate. Thus, the ingate place and A zone solidified earlier than hot spot positions, therefore the feeding channels were jammed, namely, the riser had no effect on the hot spot positions. As a result, shrinkage defect easily occurred in the places due to the lack of feeding molten iron, and Fig. 3 revealed clearly the position of isolated liquid phases at the end of solidification, namely the position in which shrinkage defects may have occurred.

4.2 Process optimization

To eliminate the above defect of the original process, two modified processes were brought about as shown in (b) and (c) of Fig. 2. Fig. 2 (b) shows that the top part and the bottom part of the first modified process are just reversed with that of the original process as shown in Fig. 2 (a). For the second modified process, Fig. 2 (c) shows that only a ring-shaped chill is added to every hub casting in comparison with the original process.

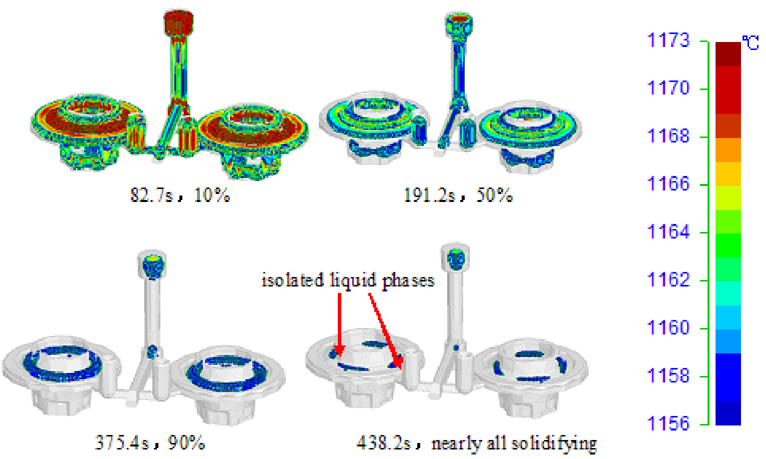

Figure 3. Solidification simulation result of the original project.

For the first modified project, from the simulation results of Fig. 4, we can see that solidification characteristics and defect distribution are similar to those of the original project. Final solidifying place was still the circumference of the four rims, in which some isolated liquid phases at the end of solidification could be clearly found and therefore shrinkage defect was easily initiated. The reason for shrinkage formation, similarly with the original project, is that there exists a too long distance between the riser and four rims, particularly two rims are far from the risers. Thus, the risers also have not got enough feeding effect on hot spots.

For the second modified project, from the simulation results of Fig. 5, we can find that the solidifying sequence was significantly changed as follows: the circumference of the four rims →the bottom cylinder of the hub→ the top cylinder of the hub→ the flange part of the hub→ the runner. The circumference of the four rims firstly solidified due to the accelerated cooling of the chill, and the riser could feed enough molten iron to the flange part and the top cylinder of the casting, namely, in late solidification position, in which shrinkage is easily initiated. Fig. 5 shows that at the end of solidification, isolated liquid phases in hot spots were nearly thoroughly removed. Therefore, shrinkage defects were also expected to be eliminated.

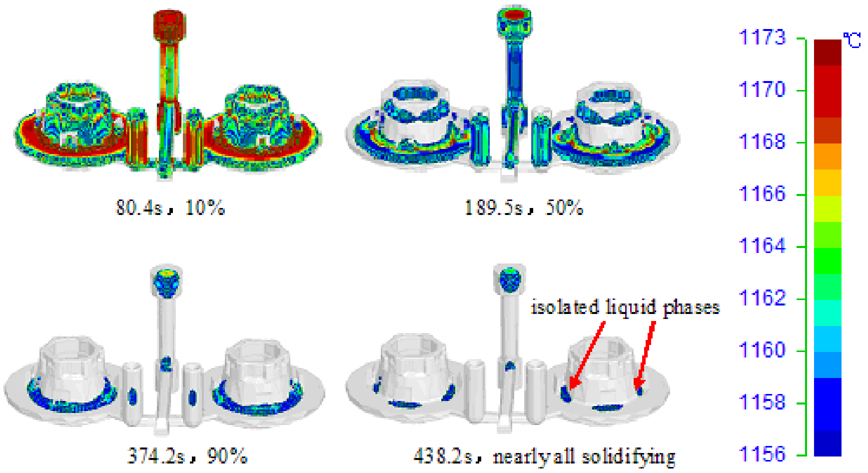

Figure 4. Solidification simulation result of the first modified project.

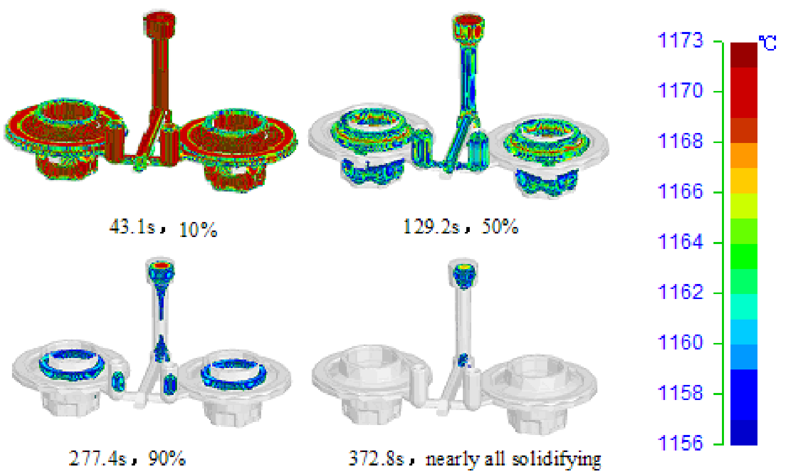

Figure 5. Solidification simulation result of the second modified project.

4.3 Production confirmation

To verify the above simulation results and analyses, the second modified project has been employed as the optimized project to batch production of the hub. The production shows that shrinkage defect during the trial period has been effectively controlled, and hence the result of numerical simulation is reliable and reasonable.

5 Conclusions

To solve shrinkage defects of automobile wheel hub during the trial production, the original casting project and two kinds of the modified projects were conducted to do solidification simulation of wheel hub casting by means of commercial InteCAST software. An optimized casting process was selected for the mass production of the wheel hub. The following conclusions can be drawn from the results:

1) The original casting project indicated that the ingate place and rims solidified earlier than hot spot positions, therefore, the feeding channels were jammed, the riser had no effect on the hot spot positions, and shrinkage defect easily occurred in the places due to the lack of feeding molten iron.
2) The first modified project showed that solidification characteristics and defect distribution were similar to those of the original project, shrinkage easily occurred in the circumference of the four rims.
3) The second modified project indicated that the solidifying sequence was greatly changed and isolated liquid phases were nearly completely removed. Consequently, shrinkage defect of the wheel hub was effectively eliminated, and the development recycle of the wheel hub was significantly shortened.

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