Casting Technology Research on the Centrifugal Composite Roller of Three Layers Based on ANSYS

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ABSTRACT: In production process design for the centrifugal composite roller casting of three layers, temperature field of the solidification process is simulated by the finite element analysis software ANSYS. As the result shows, adopting a process of “three pouring and two combining” and adding graphitic steel as the transiting layer can promote combination between the working layer and the core, and save precious metal materials. The parameters, such as rotating speed of centrifuge machine, pouring moment of transiting layer, and molten steel temperature of the core, have a great effect on the casting quality. Based on the process design and numerical simulation, the roller obtains an excellent performance. Its surface hardness achieves HSD75 in the roller body and HSD39 in the roller neck, the working layer thickness ranger reaches 61mm, and the yield strength reaches 485 MPa.

1 FIRST PARAGRAPH

Composite casting technology can obtain a roller of high hardness and high toughness simultaneously. Two different materials are applied to the roller’s working layer and the core, to obtain a good wear-resisting property, high hardness and good thermal cracking resistance in the working layer, and a high strength, good toughness and high resistance to breakage performance in its core and roller neck. The technology solves the contradiction between the roller’s wear-resistance and toughness of one single material, saves a lot of precious materials, and reduces production cost [1-3].

The main technological difficulty for the centrifugal composite roller is the combination between the working layer and the core. Combination state and structure property of the bonding layer directly affect its performance. In order to improve the quality of the bonding layer, some transition metal is added as the transiting layer to ensure that the working layer little separates from the roller while working, and to achieve a good metallurgical bond between each layer [4-6]. This paper explores the temperature field of centrifugal composite roller during the pouring process to reveal complex mechanisms among different layers and provide the basis of the actual production.

2 PROCESS CHARACTERISTICS OF CENTRIFUGAL COMPOSITE ROLLER

In this paper, the roller, of which the size is φ1150 × 1250mm, adopts horizontal centrifugal casting process. In order to satisfy the demanding performance requirements, the working layer is made of high chromium cast steel, the transiting layer is made of graphitic steel, and the core is made of ductile cast iron. This roller’s major process characteristic is “three pouring and two combining”. The technology is pouring the working layer materials into centrifuge at first, and then pouring the transiting layer materials into centrifuge when the working layer’s metal solidifies to a certain thickness, waiting until the transiting layer is completely solidified, decelerating, and shutting down the centrifuge machine, and finally erecting the cold die and slowly pouring the core by top-filling. The key of this technology is seizing the right pouring moment in each layer in a proper pouring temperature. After testing many times, the following process parameters is adopted, see Table 1.

<table>
<thead>
<tr>
<th>Working layer</th>
<th>Die temperature /℃</th>
<th>pouring temperature /℃</th>
<th>liquid steel weight /kg</th>
<th>filling velocity/s</th>
<th>centrifuge rotating speed/ rpm</th>
<th>amount of flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>190±10</td>
<td>1480±5</td>
<td>4845</td>
<td>35-50</td>
<td>732</td>
<td>O-glass 35kg+ borax 4.35Kg</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Process parameters of centrifugal filling.
In addition, the roller adopts the method of filling core. Riser, of which the size is φ730mm×520mm, is set on the roller neck. Pouring time interval is the key factors, determining the metallurgical quality of bonding layer. Time interval too long, the combining region will have a poor strength. Time interval too short, the working layer will be mixed with other parts, so the thickness might be too thin to obtain enough strength. After repetitious tests, the time interval between closing centrifugal and pouring the core is determined within 180 ~ 240s, while the vertical pouring and pouring speed are ensured. The particular process parameters of filling core are shown in Table 2. After that, the riser needs a 25 kilogram addition of exothermic compound to avoid regional shrinkage defects.

Table 2. Process parameters of filling core.

<table>
<thead>
<tr>
<th>Interval</th>
<th>Pouring Temperature</th>
<th>Liquid Steel Weight</th>
<th>Filling Velocity</th>
<th>Inoculant</th>
</tr>
</thead>
<tbody>
<tr>
<td>/min</td>
<td>/°C</td>
<td>/kg</td>
<td>/min</td>
<td></td>
</tr>
<tr>
<td>≤8</td>
<td>1395±5</td>
<td>19750</td>
<td>5-6</td>
<td>75SiFe, 1Kgt/silicozirconiu m, 1Kgt/t</td>
</tr>
</tbody>
</table>

3 MODEL CONSTRUCTION OF THE CENTRIFUGAL COMPOSITE ROLLER

The numerical simulation of ANSYS is based on the temperature field in each layer of the roller, it reveals the temperature characteristics in the solidification process, helps to optimize the production process, and determines the proper pouring moment in each layer, thus ensuring the metallurgical bonding quality among each layer. In the complicated solidification process, the finite element model is the key part of the temperature field analysis. The temperature field is mainly based on three-dimensional unstable thermally partial differential equations derived from Fourier law. The latent heat of crystallization is deposed by the equivalent specific heat method. The mathematical equation is as follows:

\[
p_c \frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x} \left[ \lambda \frac{\partial T}{\partial x} \right] + \frac{\partial}{\partial y} \left[ \lambda \frac{\partial T}{\partial y} \right] + \frac{\partial}{\partial z} \left[ \lambda \frac{\partial T}{\partial z} \right] + Q
\]

In this formula, \( Q = \rho L \frac{\partial f_s}{\partial \tau} \); \( s \)—solid density; \( T \)—solidification temperature; \( C_p \)—heat capacity; \( t \)—coagulation time; \( L \)—latent heat.

In the meanwhile, the model should be simplified appropriately under the premise of not affecting the numerical simulation. The simplifying principles are as follows [7-8]:

(1) Authenticity. The simulation process must fully and truly reflect the heat transfer characteristics of the roller, for the local region that does not affect the numerical analysis can be simplified.

(2) Symmetry. Since the roller is an axis symmetric model, the finite element analysis could only intercept the roller body cross-section, see Figure 1.

(3) Consistency. Simulation parameters must be consistent with the practical process data.

4 SIMULATION OF TEMPERATURE FIELD OF ROLLER

Based on ANSYS software, the FEM (finite element model) analysis was carried out to study the centrifugal casting and filling core, the model is meshed and simulated, and analysis is made on temperature field in each layer. Figure 2 is a temperature-time curve, calculated at different positions of the working layer. According to the curve, thermal convection of the roller’s inner surface has a great impact on the solidification of the working layer. The impact gradually disappeared after cooling to a certain temperature. Since the massive crystallize latent heat releases and thermal radiation affects each other between the inner surface, the air temperature inside the roller increased gradually, while high-speed rotating centrifuge and metal-die cap limits the hot air motion. Once approaching a heat balance, air convection effect of the roller’s internal surface disappears. Therefore, the inner surface border cannot serve as adiabatic conditions in the calculation during the solidification process, but can serve as an adiabatic boundary at the end of solidification.

Manufacturing experience shows that moment of filling the core is a direct influencing factor to the bonding quality. As the solidus temperature of high-chromium steel in working layer is 1270 °C,
and the liquid steel comes close to complete solidification below the solidus temperature, the transiting layer can be filled at 1240~1260 °C, 10~30 °C below the steel solidus temperature. According to Fig.2, this interval is 13 to 14 minute after the working layer.

**Figure 2.** Temperature curve of different positions of working layer.

The temperature-time curve (after pouring the transiting layer) in different positions of the working layer is shown in figure 3. Red curve represents temperature change of the place 10mm away from the working layer surface. Its maximum temperature is 1337 °C above the solidus temperature of work layer, this indicates that the liquid steel from transiting layer has washed out the working layer over 10mm. Blue curve represents the temperature change of the place 20mm away from the working layer surface, its maximum temperature is 1243 °C, slightly lower than the solidus temperature of the working layer, this indicates that the liquid steel from transiting layer has not washed out the working layer to 20mm. That not only ensures a good metal fusion, but ensures an enough thickness of the working layer.

**Figure 3.** Temperature change curve of different positions after pouring the transiting layer.

After filling the transiting layer, the centrifuge machined should be shut down at the right moment, to make and assemble casting mould, and fill liquid ductile iron of the core. Shutting down earlier, the temperature of the transiting layer’s inner surface is higher, benefiting the combining. But if it’s too early to solidify completely, the casting will cave while decelerating. The excellent shut down moment is when the liquid metal of the transiting layer has just solidified. The solidus temperature of transiting layer is 1320 °C, based on the temperature simulation results on the liquid metal of transiting layer’s inner surface, (show as Figure 4), select the temperature 1290~1310 °C, 30 °C below the liquidus temperature, to shut down the centrifugal machine (the downtime interval is 33-34 minutes), and make the rotational casting mould stop in 3 minutes. Manufacturing experience shows that the process will keep the inner surface of the metal at a high temperature and ensure the metallurgical quality of the transiting layer, but will not emerge collapse accidents of liquid steel.

**Figure 4.** Temperature curve of the transiting layer’s inner surface.

To remelt the solidified metal’s inner surface of the transiting layer, the pouring temperature of the core must be higher than the solidus temperature of the transiting layer. And because of the large amount of core liquid metal, large heat capacity, the pouring metal temperature of the core could not be too high, otherwise the transiting layer would be washed mixed severely, and the amount of chromium in the core’s ductile iron would increase, which degrades the performance of the core. Therefore, it is appropriate to determine the pouring temperature of the core 1395 °C.

**Figure 5.** Temperature curve of different positions in the transiting layer after filling the core at 1240 °C temperature. According to the blue temperature curve, the highest temperature is 1280 °C at 20 millimeters away from the inner surface of the transiting layer. It is supposed that the core’s liquid steel can remelt the transiting layer to a dozen millimeters.
Figure 5. Temperature curve of different positions of transiting layer after filling core.

5 ACTUAL CASTING AND PERFORMANCE

According to the results of numerical simulation, the centrifugal composite roller of high chromium cast steel was produced, and machined afterwards, as is shown in Figure 6. An ultrasonic detection on the roller is carried out. The test report shows that the roller is in accordance with relevant requirements of GB/T1503-2008 appendix B, satisfying the use requirements. The chemical composition of the working layer, the transiting layer and the core of the casting is detected, and the results are shown in Table 3.

Figure 7 shows the Microscopic metallographic. It can be seen from the diagram that the micro-structure of the working layer is mainly the sorbite(troostite) and martensite, carbide and micro-scale residual austenite. The micro-structure of the core’s working layer is spherical graphite, pearlite, a small amount of ferrite and carbide. The actual micro-structure of roller meets the corresponding index and requirement completely.

Figure 6. Cast of the centrifugal composite roller.

Figure 7. Microstructure of roller There-into, (a) is the microstructure of working layer, (b) is the microstructure of the core.

Table 3. Practical composition of the centrifugal composite rolle.

<table>
<thead>
<tr>
<th>element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>W</th>
<th>Nb</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working layer</td>
<td>1.5</td>
<td>0.7</td>
<td>0.7</td>
<td>≤0.03</td>
<td>≤0.02</td>
<td>12.5</td>
<td>1.4</td>
<td>1.65</td>
<td>0.45</td>
<td>---</td>
<td>0.15</td>
<td>/</td>
</tr>
<tr>
<td>Transiting layer</td>
<td>1.2</td>
<td>2.5</td>
<td>0.6</td>
<td>≤0.03</td>
<td>≤0.02</td>
<td>≤0.2</td>
<td>≤0.2</td>
<td>≤0.2</td>
<td>≤0.2</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>core</td>
<td>3.3</td>
<td>2.5</td>
<td>0.5</td>
<td>≤0.03</td>
<td>≤0.015</td>
<td>≤0.2</td>
<td>0.7</td>
<td>0.15</td>
<td>≤0.03</td>
<td>/</td>
<td>/</td>
<td>0.06</td>
</tr>
</tbody>
</table>
6 CONCLUSION

Through time-temperature curve, the temperature field changes of centrifugal composite roller can be observed directly in the casting process, which can be put into actual production, say, selecting production process of centrifugal composite roller, scientifically setting parameters, and improving the quality of products. The research results show that through the "three pouring and two composite", the middle layer would be graphite steel, which can promote the combination between the working layer (high chromium cast steel) and the core (ductile iron). During the pouring process, the metal liquid of working layer is poured first, and after 13~14 minutes, when the inside surface metal temperature of the working layer reaches 1240 ~ 1260 ℃, the liquid steel of the transiting layer is poured, after 33 ~ 34 minutes, the centrifuge machine is decelerated and shut down, wait a few minutes until the metal temperature of inside surface reaches 1290 ~ 1310 ℃, the core is poured. Through the casting process, the mechanical performance and micro-structure meet the use requirements.

7 AKNOWLEDGEMENT

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