

# Cooling Roller Steady-state Heat Flux and Temperature Analysis in Amorphous Ribbon Preparing Process



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**Abstract:** Temperature of cooling roller is a key issue affecting the quality of the amorphous ribbon. To this end, heat flux distribution acting on cooling roller outer wall was calculated by fluid dynamics software Fluent. Cooling roller steady temperature field was analyzed with a finite element method with heat flux boundary conditions. The cooling roller inner and outer wall temperature distribution was obtained and the temperature of cooling roller as a function of cooling roller thickness and water passage height was discussed. Results show that cooling roller outer wall temperature decreases with roller thickness and the cooling water passage height decrease; cooling roller inner wall temperature decreases with roller thickness increases and the cooling water passage height decreases. Meantime, the appropriate roller thickness and passage height were selected to keep both inner and outer wall temperature of cooling roller within the certain range. The study result provides theoretical support for cooling roller design and optimization.

**Key words:** amorphous ribbon; steady temperature field; heat flux; numerical simulation

Amorphous alloy has more excellent physical, chemical and mechanical properties than conventional crystalline alloy. Therefore, amorphous ribbon has very broad application prospects in electricity, aviation, aerospace and other fields. Planar flow casting (PFC) process is a major method for industrial preparation of amorphous ribbon owing to its capability of producing thin, wide and continuous amorphous ribbon<sup>[1]</sup>. Narasimhan<sup>[2]</sup> invented PFC process to produce amorphous ribbon, which can produce continuous amorphous ribbon at 20~30 m/s, and adjust the ribbon width with demands, especially in a Fe based magnetic ribbon preparation process<sup>[3]</sup>.

In PFC process, a large amount of high temperature melt conduct heat transfer to the cooling roller resulting in cooling roller outer wall temperature rising sharply, which can affect roller cooling capacity and amorphous ribbon quality. Thus, in order to produce high quality amorphous materials, it is necessary to analyze influencing factors of cooling roller temperature and select the suitable parameter to keep cooling roller temperature within a specified range<sup>[4-8]</sup>. One of the key boundary conditions acting on

cooling roller outer wall is heat flux. Pang<sup>[9]</sup> proposed an equivalent average heat flux method to simulate cooling roller temperature field distribution and conducted experiments to verify its correctness. Guo<sup>[10]</sup> simulated cooling roller steady-state temperature field in PFC process, got the cooling roller temperature field, and discussed the effect of roller diameter, thickness and speed on roller wall temperature. However, there is little information about the effect of heat flux distribution along cooling roller outer wall, cooling water passage height and roller thickness on cooling roller wall temperature.

The purpose of the present study is to discuss the heat flux distribution acting on cooling roller outer wall by a numerical simulation method. Steady thermal analysis was carried out to investigate the effect of parameter variables on cooling roller temperature distribution, and result will provide theoretical foundation for cooling roller design in PFC process.

## 1 Numerical Simulation

### 1.1 Physical model

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Presently, the PFC process is a major method for industrial preparation of amorphous ribbon. Schematic illustration of PFC process is shown in Fig.1. Melt in crucible flowing through the nozzle slit was sprayed onto cooling roller by argon pressure and its own weight, and then cooled rapidly at  $10^6$  K/s to form amorphous ribbon. These processes released lots of heat in a very short time, and raised cooling roller inner and outer wall temperature by heat conduction; then amorphous ribbon was detached from the cooling roller by peeling equipment at 1/4 circle of roller.

In the analysis above, there are two phases in amorphous preparation.

(1) From the position of melt injection to the position of ribbon detached from cooling roller (about 1/4 cir of roller), cooling roller outer wall mainly was subjected to heat flux from the melt and ribbon. So in this phase, cooling roller temperature analysis can use the equivalent heat flux  $q$ ;

(2) From the position of the ribbon detached from cooling roller to next melt inject position (remaining 3/4 cir of roller), cooling roller was mainly subjected to heat exchange with ambient air. Air heat transfer coefficient is much smaller than that of the cooling water, so in this study, cooling roller heat transfer with ambient air can be ignored.

## 1.2 Basic assumptions

So as to facilitate and simplify the analysis process, the following assumptions are proposed:

(1) Ignoring the flow disturbance, the melt flow is laminar.

(2) Amorphous ribbon contacts well with cooling roller, no slip occurs between cooling roller, melt and nozzle wall.

(3) Because the air heat transfer coefficient is much smaller than that of cooling water, we do not consider heat convection with ambient air<sup>[11]</sup>.

## 1.3 Mathematic model

The mathematic model of ribbon formation established according to corresponding physical model of PFC process and relevant calculation parameters are shown in Table 1<sup>[12]</sup>. In order to improve the accuracy and computational efficiency, local mesh refinement meshing was set in contact area between puddle and cooling roller outer wall as shown in Fig.2a.

Calculation accuracy is affected by model grid size. This study takes contact temperature between cooling roller outer wall and puddle as target verified grid independence by puddle grid size  $s=0.2, 0.1, 0.05, 0.02, 0.01$  mm, as shown in Fig.3. The contact temperature variation decreases with mesh size decreasing. When  $s=0.02$  mm, the curve has become approximately horizontal. Considering computational efficiency,  $s=0.02$  mm was chosen as a puddle model meshing standard.

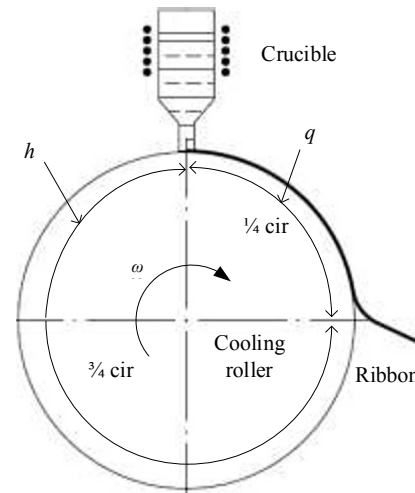


Fig.1 Schematic illustration of PFC

## 1.4 Boundary conditions

Boundary conditions are defined as shown in Fig.2b.

(1) Melt inlet: using pressure inlet boundary conditions, inlet temperature,  $T_{in} = 1533$  K; initial inlet pressure  $P_{in} = 20$  kPa.

(2) Crucible wall: here the heat exchange does not occur, and the adiabatic boundary conditions are set.

(3) Cooling roller inner wall: heat convection between cooling roller and cooling water, heat transfer coefficient is  $h$ , which changes with the cooling water passage height.

(4) Air inlet and outlet: pressure inlet boundary, relative pressure is 0.

(5) Cooling roller speed:  $v=30$  m/s.

## 1.5 Solution method

Discrete control equations are solved by the finite volume method. The SIMPLE algorithm are employed by solving Navier stoke equation to obtain the velocity and pressure distribution. An explicit time marching scheme is used to solve the VOF equation<sup>[11]</sup>.

## 1.6 Heat flux distribution

After simulation reached to steady state, cooling roller temperature and heat flux no longer changed as time. Steady state heat flux distribution, acting on the outer wall of the cooling roller, was extracted by the software Fluent, and post-processing module is shown in Fig.4.

It can be seen from the analysis result that cooling roller outer wall subjected to boundary condition can be divided into the following phases: L1-L5.

(1) Heat flux acting on cooling roller outer wall increased to maximum sharply at the front of alloy inlet position, where alloy has not been solidified, and cooling roller outer wall was subjected to the highest heat flux  $q_1 = 4 \times 10^8$  W/m<sup>2</sup>.

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