Abstract

In the work performed by the staff of Donetsk National Technical University (Ukraine), was set the complex problem providing on the one hand with the development of three-dimensional mathematical model, and on the other hand with the creation of the functional laboratory facility of the twin-roll strip casting process. Mathematical model connects nature of melt flow with temperature. It is implemented using the finite element method and allows to analyze the flow and heat transfer in solid-liquid zone during the process. Stationary three-dimensional flows, the effects of turbulence, coupled momentum equations and heat transfer are also taken into account. The project of the laboratory facility provides cast of a strip from the alloys of lead and tin. The design feature is that it is possible in a wide range to change technical data that affects the metal crystallization process and its subsequent rolling. This allows to verify the results of numerical modeling, make appropriate corrections, and thereby increase the accuracy of the numerical results, and also to optimize the control model of casting process. The results of calculation using the developed mathematical model show the speed, temperature and solidification nature in the bath area. Moreover, were obtained the velocity profiles of the melt in the bath facility of the twin-roll strip casting process in different planes depending on the supplying scheme of the liquid metal. Also was obtained the nature of the temperature distribution in the steel flow in the bath along the length of the rolls body.

Keywords: twin-roll strip casting, modeling, steel flow

1. PROBLEM STATEMENT

In a world of increased energy prices, priority must be given to metallurgy development, introducing innovative power saving technologies which will reduce production costs and increase competitiveness. The roll casting process uses the idea which was proposed by Henry Bessemer in 1856 [1].

Despite the fact that the technology of roll casting process has reached industrial realization [2], the relevance of research in this technology remains high because of its raises science linkage and, till today, insufficient optimization of some technological elements.

2. ANALYZE OF THE LAST RESEARCHES AND PUBLICATIONS

Confirmation of this can be found in the fact that the leading research centers in the field of metallurgy have in recent years created new laboratory facilities:

- Rhine-Westphalia the higher school, Aachen;
- Institute of iron studying of Max-Planck, Düsseldorf (Germany);
- The Oxford University (Great Britain);
- Technological Institute, Osaka (Japan);
- Industrial Materials Institute, Boucherville (Canada) and etc. [3].
The basic characteristics of the laboratory facilities available in the research centers are resulted in the table 1 [3].

**Table 1** The basic characteristics of existing experimental facility of roll casting process [3]

<table>
<thead>
<tr>
<th>The research centre</th>
<th>Casting direction</th>
<th>Rolls diameter , mm</th>
<th>Bandage material</th>
<th>Width of the roll working site, mm</th>
<th>Max speed of casting , m/min</th>
<th>Thickness of a cast strip, mm</th>
<th>Max weight of fusion, kg</th>
<th>Casting material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rhine-Westphalia high technical school, Aachen</td>
<td>vertically</td>
<td>580</td>
<td>Cu-Cr-Zr, with Ni covering</td>
<td>150</td>
<td>60</td>
<td>0,6-3</td>
<td>180</td>
<td>Steel</td>
</tr>
<tr>
<td>Institute of iron studying of Max-Planck, Düsseldorf</td>
<td>vertically</td>
<td>330</td>
<td>Elbodur NIB CH48</td>
<td>120</td>
<td>51,8</td>
<td>1-20</td>
<td>70</td>
<td>Steel</td>
</tr>
<tr>
<td>The Oxford university, Oxford</td>
<td>horizontally</td>
<td>400</td>
<td>Diestee</td>
<td>250</td>
<td>60</td>
<td>0,5-6,5</td>
<td>60</td>
<td>Al – alloy</td>
</tr>
<tr>
<td></td>
<td>vertically</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technological university, Osaka</td>
<td>vertically</td>
<td>1500</td>
<td>Cu</td>
<td>100</td>
<td>60</td>
<td>3</td>
<td>no data</td>
<td>Al – alloy</td>
</tr>
<tr>
<td></td>
<td>vertically</td>
<td>250-300</td>
<td></td>
<td>50...100</td>
<td>180</td>
<td>1-2,6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>horizontally</td>
<td>300</td>
<td></td>
<td>100</td>
<td>60</td>
<td>1,8-3,2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial Materials Institute, Boucherville</td>
<td>vertically</td>
<td>600</td>
<td>Cu-alloy</td>
<td>200</td>
<td>12</td>
<td>4-7,5</td>
<td>1000</td>
<td>Steel and nonferrous materials</td>
</tr>
</tbody>
</table>

Also it’s necessary to note that, in parallel with the study of the roll casting process on physical models, intensive work as been carried out towards the creation of various kinds of mathematical models of the process [4-6], which give fairly large amounts of data about the process.

Analysis of existing publications, which reflect the results of research on the roll-casting, shows that currently the issues with the highest priority are of the following type:

- improving the quality of the final rolled metal;
- achieving uniform heat removal at speeds of rolls rotation > 0,5 rad/sec;
- questioning the optimization of metal supply to a crystallization bath;
- examining the process organization of getting a qualitative lateral strip edge;
- fine tuning the elements of the system start-up;
- questioning the optimization of depth bath with liquid metal between rolls etc.
In the light of the unresolved questions set forth above it is reasonably to use a comprehensive approach, based on parallel creation of a working physical model as well as mathematical one. Such an approach will result in the maximum reliability of the obtained data, in the shortest time possible.

3. **GOALS (OBJECTIVES) OF THE RESEARCH**

The aim is a comprehensive study of the roll casting process through the development of existing laboratory setup and mathematical model adapted to the laboratory setup conditions.

4. **THE BASIC STUDY MATERIAL**

In the designing of experimental facility the vertical scheme of conducting process has been used, when liquid metal moves from the furnace to casting bath, and after in the space between rolls (zone of metal crystallization) under the influence of gravity.

Results of executed 3D designing of model are shown in fig. 1.

![Fig. 1 Three-dimensional model of design laboratory facility of roll casting process: 1 - drive engine; 2 - spindles; 3 - rolls; 4 - a driving gear; 5 - a follower gear; 6 - a casting ladle.](image)

The rolls-crystallizers consist of a water-cooled copper bushing and two axial inserts, which provide required character of heat removal from an internal surface of bandages (fig. 2). Every roll has an individual drive of a direct current which provides realization of high twisting moments and possibility of conducting process with demanded plastic deformations [7].
Fig. 2 The scheme of junction of rolls-crystallizers (3-D model): 1 - a water-cooled bushing; 2 - a support-supply; 3 - an internal insert; 4 - a driving gear; 5 - a follower gear.

Besides that, there is the possibility of regulating the distance between rolls to expand to an investigated thickness of a strip: to a maximum of 4,0 mm.

Technical characteristics of the laboratory facility are presented in the table 2.

Table 2 The basic characteristics of projected experimental facility of roll casting process

<table>
<thead>
<tr>
<th>characteristic</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll’s diameter, mm</td>
<td>76</td>
</tr>
<tr>
<td>Wall thickness of the bandage, mm</td>
<td>10</td>
</tr>
<tr>
<td>The length of a roll’s working zone, mm</td>
<td>80</td>
</tr>
<tr>
<td>Distance between completely separated rolls, mm</td>
<td>37,5</td>
</tr>
<tr>
<td>Temperature of a water-cooled surface, °C</td>
<td>17-20</td>
</tr>
<tr>
<td>Frequency of rolls rotation, rad /sec</td>
<td>0-0,72</td>
</tr>
<tr>
<td>Temperature of modeling material crystallization, °C</td>
<td>80-210</td>
</tr>
<tr>
<td>Planned range of a thickness of a strip, mm</td>
<td>1-3,75</td>
</tr>
<tr>
<td>Planned materials for casting</td>
<td>Paraffin, Pb</td>
</tr>
</tbody>
</table>

In parallel with the creation of a physical model, there has been development in the mathematical model of the process which allows for research into the casting process of various materials in the above described equipment.

The creation of mathematical model for research into the processes of hashing metal alloy and strip hardenings during roll casting process was carried out in the environment of ANSYS CFX, possessing the following possibilities:

- Modeling of inviscid, laminar and turbulent streams;
Modeling of heat transfer, including various kinds of convection, the conjugated heat exchange, radiation and etc [5].

The decision of tasks in view of hydrodynamics and solidification was realized in three-dimensional interpretation, with following admissions: rolls are not deformed; stream of melting is turbulent; at the contact between the roll and metal condition of permanent adhesion.

Lead was chosen as metal for casting. Boundary conditions: heat conductivity - 23.2 W / (m·K), a specific thermal capacity of metal for casting - 138.84 J / (kg·K), density of metal for casting - 10641 kg/m³. Technical characteristics are taken as much as possible approached to possibilities of laboratory facility: external diameter of rolls - 76 mm, length of the crystallization-deformation zone - 40 mm, a thickness of a strip - 3.25 mm, the temperature of cast metal is constant, frequency of rolls rotation - 0.033÷0.15 sec⁻¹. In the first stage of modeling the problem of the method of supplying the melt into the mold was solved. Various schemes of submerged nozzles were considered. Here we considered ½ of studied area of geometrical model because of its symmetry relative to vertical-longitudinal plane.

Studies have shown a significant influence of character of melt flow distribution at the crystallizer on the solidification processes (Fig. 3).

The data shows that the usage of slotted submerged nozzle, with a width almost equal to the width of the roll body, can solve the problem of averaging the temperature along the length of the crystallization zone. In turn, this ensures a stable crystallized component. However, usage of the slotted submerged nozzle didn't solve the problem of heating of the meniscus of the liquid bath. In this regard, a new design of submerged nozzle - T-shape was created. Numerical modeling of the casting roll process with use of submerged nozzle T-shape (Fig. 4) showed that ruptures of the crystallized strip are absent until speed of rolls rotation < 0.1 sec⁻¹. Large speeds of rolls rotation are undesirable for two reasons:

- Firstly, the crystallized strip might be ruptured;
- Secondly, so-called "dead spaces" of metal mixing arise on the surfaces in the contact zone of the melt with a roll, which is extremely undesirable.

Experimental testing of new design of submerged nozzle T-shape in the laboratory facility showed its good operability, as well as the possibility to calibrate the developed mathematical model.
Using the calibrated mathematical model, studies were implemented in order to assess the influence of frequency of the rolls rotation on the character of the temperature fields, which generated in the melt, and crystallized component within the crystallization-deformation zone (fig. 5). Analysis of the data shows that in the studied range of rotation speeds of rolls-crystallizers, in contact with the roll, the character of formation process of solid crust is stable. However, with the growth of the rolls speed from the minimum (0,033 sec\(^{-1}\)) to the maximum value (0,083 sec\(^{-1}\)) its thickness is reduced by an average of 65%. At the same time, increasing the speed of the rolls-crystallizers rotation minimizes the volume of the metal zone with a low temperature.

5. CONCLUSION

On the basis of systematization of the published data, the laboratory facility of the roll casting process and three-dimensional mathematical model of the process which was implemented by finite-element method in commercial package ANSYS has been designed. An integrated approach permitted the calibrated design mathematical model based on the results of data obtained in the physical model. Also a new design of the submerged nozzle T-shape has been proposed. It is shown that the usage of submerged nozzle T-shape stabilizes the roll casting process in interval of the speed rotation of the rolls 0,033 ... 0,083 sec\(^{-1}\).
Fig. 4 The temperature distribution of the melt in the longitudinal symmetry plane, depending on the rolls-crystallizers rotation speed
Fig. 5 Change of temperature fields within the height of the crystallization-deformation zone, depending on the rolls-crystallizers rotation speed: a - 0.033 sec⁻¹; b - 0.05 sec⁻¹; c - 0.066 sec⁻¹; d - 0.083 sec⁻¹

REFERENCES


