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Calculation of Temperature and Thermoelastic Stresses in the Backups with Unit Collars of Combined Continuous Casting and Deformation during Steel Billet Production. Report 1

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Abstract—The article describes the main loads affecting shaped backups of the combined process unit of continuous casting and deformation during billet production. The importance of determining the temperature fields and thermoelastic stresses in shaped backups with collars is provided during the formation of several billets, at slab compression, as well as during idling water cooling of backups. The authors describe strength and thermophysical properties of steel from which the backups are made. Geometry of backups with collars used for obtaining billets of three different shapes in one pass is shown. Initial data of the temperature field calculation are given for backups with collars of the combined unit. Temperature boundary conditions are considered for the temperature field calculation of backups with collars. Boundary conditions determining temperature of such backups are described and the values of the heat flow and effective heat transfer coefficient are given. The calculation results of temperature fields are performed in four sections and are given for typical lines and points located on the contact surface of backups with collars and in contact layer at 5-mm depth from the working surface. The sizes of the finite element grid, which is used for the temperature field calculation of backups with collars, are provided. The temperature field of backups with collars is determined based on the solution regarding the unsteady thermal conductivity equation corresponding to initial and boundary conditions. When obtaining billets of three shapes in one pass at the unit of combined continuous casting and deformation, values and regularities of temperature distribution in the bases and tops of the middle and extreme edges of the shaped backups are presented during slab compression and at idle.

Keywords: unit of combined process, crystallizer, slab, shaped billet, separation, temperature field, finite element

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INTRODUCTION

The unit of the combined process of continuous casting and deformation can be effectively used to obtain three or more billets in one pass [1, 2]. The most loaded elements of the combined process unit when obtaining billets are backups with separating collars, which simultaneously form several billets and pull the steel slab out of the mold during the working operation. In this case, in the shaped backups, total stresses arise from the compression force and temperature load, which reduce their resistance.

For a reasonable choice of design parameters and material of shaped backups, it is necessary to determine their stress state when receiving several billets on a continuous casting and deformation unit. Thus, it is important to determine the temperature field and thermoelastic stresses in the backups with collars during the billet formation and at idling.

STATEMENT OF THE PROBLEM, INITIAL DATA AND BOUNDARY CONDITIONS

The calculation of the temperature and thermoelastic stresses in the backups with collars was carried out when three billets with dimensions of 70.7 × 70.7 mm were obtained from grade St3 steel on a unit using a combined process of continuous casting and deformation.

The backup material is tool die steel of the grade 4X4VMFS. The geometry of the backup with collars and the accepted dimensions is shown in Fig. 1.

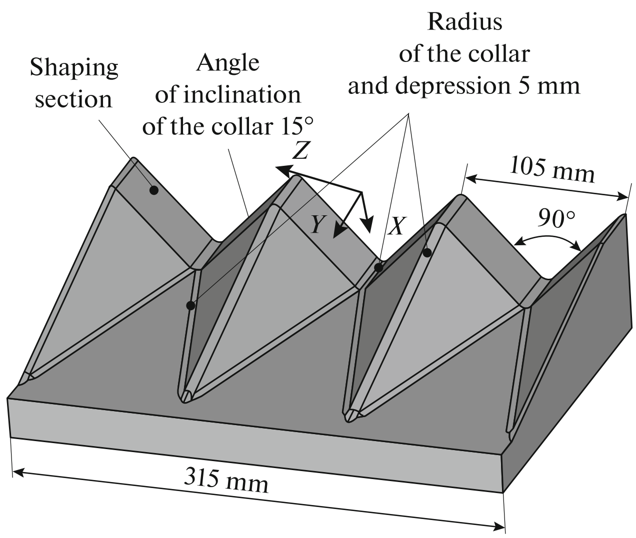

Fig. 1. Geometry of the backup with dimensions.

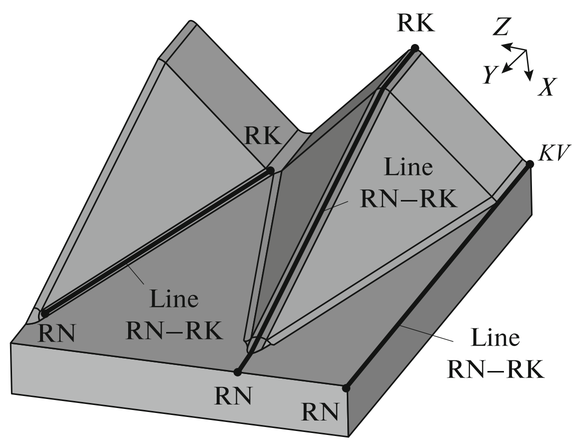

Fig. 2. Position of lines along the backup height in cavity, on the collar and in the radius zone.

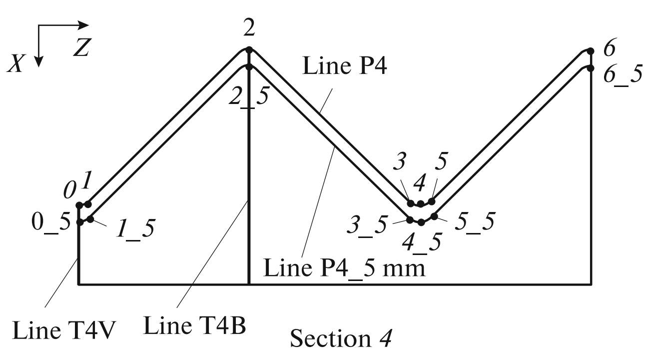

Fig. 3. Position of lines in section *4*.

By virtue of symmetry, for calculating the stress state of the backup, its half is taken (Fig. 2) in the *XYZ* coordinate system.

The results of calculating temperatures are given for two lines of four sections (*1*–*4*). The position of the feature lines and points for each section is shown in Fig. 3 (designations *0*–*6*—points on the working surface of the backup; *0_5*, *1_5*, *2_5*, *3_5*, *4_5*, *5_5* and *6_5*—points at a 5-mm depth from the working surface of the backup).

In addition, the calculation results are additionally shown along three more lines throughout the height of the backup, the position of which is shown in Fig. 2.

The angular speed of the eccentric shafts is assumed to be 40 rpm. At this speed of the eccentric shaft, the contact time of the backup during the working operation is 0.375 s, and the cooling time is 1.125 s.

The temperature of the slab before the backups was 1200°C, and after the backups—1000°C.

The temperature field calculation of the backup is performed for the following variant:

—the impact of a heat flow with a density of 4 MW/m^2 on the working surface of the backup during the working operation for 0.375 s; during the cooling, the effective heat transfer coefficient is 2000 W/(m^2 K);

—the top and bottom of the backup, as well as the lateral surfaces of the backup, are cooled with water with a heat transfer coefficient of 500 W/(m^2 K);

—from the side of the saddle, there is air cooling with a heat transfer coefficient of 20 W/(m^2 K) and an ambient temperature of 60°C [2–8].

CALCULATION METHOD

When calculating the temperature field of the backup, an eight-node thermal solid-state finite element SOLID 70 was used, and for calculating the stress state—an eight-node structural solid-state finite element SOLID 185. The size of the finite element grid was assumed to be variable—0.25–2.50 mm. The minimum size was taken on the working surface of the near-contact layer to a 5-mm depth of the deformation zone. As a result, the number of elements and nodes is 2887542 and 2827400 in the simulation.

The temperature field of the backups with collars is determined based on the solution of the nonstationary heat conduction equation with the corresponding initial and boundary conditions [9–20].

CALCULATION RESULTS

The results of calculating the temperatures of the collar on the working surface of the backup, at a 5-mm depth from the working surface and from the side of the saddle in four sections are given in Tables 1, 2.

The collar at point 2 at the end of the slab compression is heated to a temperature of 539–543°C, and at

Table 1. Temperature values at the points of collar along the T1B–T4B lines

Point position and moment of contact or cooling	Temperature value, °C, in points along the lines			
	T1B	T2B	T3B	T4B
W. s. contact (point *2*, Fig. 3)	539	543	539	542
W. s. cooling (point *2*, Fig. 3)	359	364	359	351
At a depth of 5 mm contact (point *2_5*, Fig. 3)	403	410	406	400
At a depth of 5 mm cooling (point *2_5*, Fig. 3)	411	416	413	408
Saddle-contact Saddle-cooling	395	401	378	355

W. s. Contact and W. s. cooling—temperatures on the working surface at the end of contact and at the end of cooling along the lines T1B–T4B; saddle-contact and saddle-cooling—temperature on the back surface at the end of contact and at the end of cooling along the T1B–T4B lines.

Table 2. Temperature values at the end of contact/cooling at points of sections *1–4*

Point	Temperature, °C, at the points of sections			
	1	2	3	4
0	527/362	531/367	519/354	499/345
1	520/368	525/371	512/358	502/344
2	539/359	543/364	539/359	542/351
3	519/367	521/368	502/348	489/331
4	518/353	519/354	503/338	483/329
5	463/309	484/330	487/332	483/325
6	456/276	457/277	455/275	463/272

idling, when the shaped backup is cooled with water, its temperature drops to 351–364°C (Table 1). At a 5-mm depth from the contact surface, the temperature of the collar at the end of compression and idling differ insignificantly (400–406 and 408–416°C).

From the above results, it follows that the temperature field of the backup during slab compression and idling changes at a 3-mm depth for the depressions between the middle collars and 3.5 mm for the tops of the middle collars.

The contact surface of the backup heats up from the effect of the heat flow during the compression of the workpiece (the results are presented only for the part of the backup between sections *1–4*):

—at the base of the middle collar up to a temperature of 489–525°C (points *1* and *3*, Table 2);

—at the top of the middle collar up to a temperature of 539–543°C (point *2*, Tables 1, 2);

—at the base of the extreme collar up to a temperature of 463–487°C (point *5*, Table 2);

—at the top of the extreme collar up to a temperature of 455–463°C (point *6*, Table 2).

Then at idling while cooling the backup with water, the contact surface temperature of the backup decreases:

—at the base of the middle collar up to a temperature of 331–371°C (points *1* and *3*, Table 2);

—at the top of the middle collar up to a temperature of 351–364°C (point 2, Tables 1, 2);

—at the base of the extreme collar up to a temperature of 309–332°C (point *5*, Table 2);

—at the top of the extreme collar up to a temperature of 272–277° C (point *6*, Table 2).

From this, it can be seen that the top of the extreme collar has a lower temperature compared to the temperature of the middle collar. The difference is no more than 92°C.

Figure 4 shows the temperature distribution graphs in the separating shoulder along the T4B line during slab compression and at idling.

From Fig. 4, which characterizes the temperature distribution over the thickness of the collar and along the length of the deformation zone, it follows that the temperature of the collar at the end of the slab compression is 542°C, and at the end of the idling at a

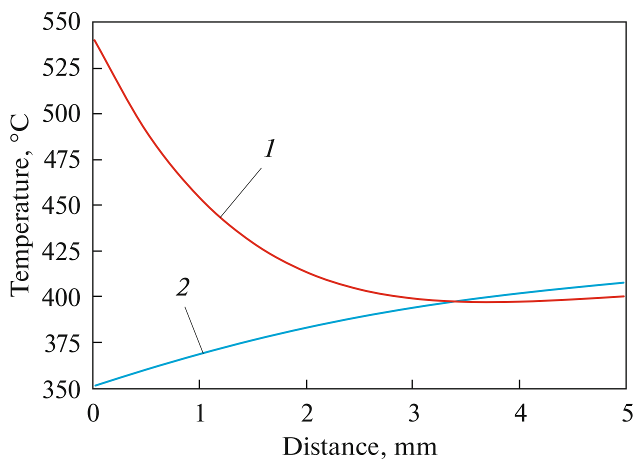

Fig. 4. Nature of temperatures along the T4B line due to the heat flow (*1*) and water cooling (*2*) impact on the backup (5 mm deep from the contact surface).

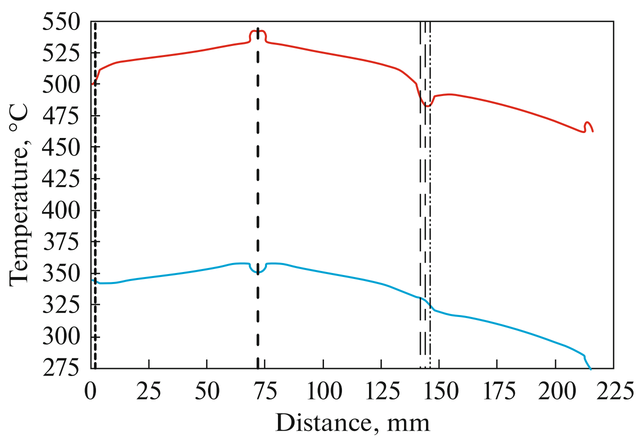

Fig. 5. Nature of temperatures along the P4 line from heat flow (HF) and water cooling (WC) impact on the backup (vertical lines *1*–*5* correspond to the position of the points of section 4 in Fig. 3): ----—*1*; - - - —*2*; ——— —*3*; — — — —*4*; ---- —*5*; red line —HF; blue line —WC.

depth of 3 mm from the contact surface, it decreases to 400°C.

Figure 5 shows the results of calculating the temperature on the contact surface of the shaped backup along the P4 line.

The P4 line is the sweep lines. The beginning of each line P1–P4 is at point *0*, and the end of the line is at point *6* (Fig. 3). Vertical lines *1*–*5* on the graphs correspond to the position of the characteristic points on the contact surface of the shaped backup. These graphs clearly show the temperature distribution over the width and length of the deformation zone due to the impact on the backup of the heat flow and water cooling during the formation of three billets from the slab on the unit of the combined process of continuous casting and deformation.

CONCLUSIONS

The problem of determining the temperature fields in the shaped backups of the combined process of continuous casting and deformation during the production of three steel billets has been presented and solved. The values have been determined and the regularities of the temperature distribution in backups with collars along the width and length of the deformation zone from the impact on the shaped backup of the heat flow during slab compression and idling during the formation of three steel billets from the slab have been established.

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