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CALCULATION OF TEMPERATURE AND THERMOELASTIC STRESSES IN STRIKERS DURING PRODUCTION OF HOLLOW STEEL BILLETS IN A UNIT OF COMBINED CASTING AND DEFORMATION. PART 1

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Abstract. The article solves the problem of determining the temperature of calibrated strikers in a unit of combined casting and deformation during production of hollow steel billets. The authors substantiate the relevance of determining temperature fields and thermoelastic stresses in calibrated strikers when compressing the wall of a hollow billet and at full speed when cooling the strikers with water, and describe the strength and thermo-physical properties of the steel from which the strikers are made. Geometry of the striker for producing a hollow billet in one pass is shown. The paper considers the initial data and temperature boundary conditions for calculating the temperature field of the striker during production of hollow billets in a unit of combined casting and deformation. The boundary conditions are given to determine the striker temperature as well as the values of heat flow and effective heat transfer coefficient. The results of calculating the temperature fields are performed in four sections and are presented for characteristic lines and points located on the striker contact surface and in the contact layer at a depth of 5 mm from the working surface. Dimensions of the finite element grid were used in calculating the temperature field of the strikers. The temperature field of the strikers with collars was determined based on solution of the unsteady thermal conductivity equation with the corresponding initial and boundary conditions. The values and patterns of temperature distribution in a calibrated striker are presented when the wall of a hollow billet is compressed and when a hollow billet is produced in one pass in a unit of combined casting and deformation.

Keywords: installation, calibrated striker, casting, deformation, mold, hollow billet, temperature field, final element

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РАСЧЕТ ТЕМПЕРАТУРЫ И ТЕРМОУПРУГИХ НАПРЯЖЕНИЙ В БОЙКАХ ПРИ ПОЛУЧЕНИИ СТАЛЬНЫХ ПОЛЫХ ЗАГОТОВОК НА УСТАНОВКЕ СОВМЕЩЕННОГО ЛИТЬЯ И ДЕФОРМАЦИИ. ЧАСТЬ 1

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Аннотация. В статье решается задача определения температуры калиброванных бойков установки совмещенного литья и деформации при получении стальных полых заготовок. Авторы обосновывают актуальность определения температурных полей и термоупругих напряжений в калиброванных бойках при обжатии стенки поллой заготовки и на холостом ходу при охлаждении бойков водой, приводят прочностные и теплофизические свойства стали, из которой изготовлены бойки. Показана геометрия бойка для получения поллой заготовки за один проход. Приводятся исходные данные для расчета температурного поля бойка установки совмещенного литья и деформации при получении полых заготовок, а также представлены температурные граничные условия для расчета температурных полей бойков. Статья описывает граничные условия для определения температуры бойка и значения теплового потока и эффективного коэффициента теплоотдачи. Результаты расчета температурных полей были выполнены в четырех сечениях для характерных линий и точек, расположенных на контактной поверхности бойка и в приконтактном слое на глубине 5 мм от рабочей поверхности. Размеры сетки конечных элементов

приведены для использования при расчете температурного поля бойков. Температурное поле бойков с буртами определялось на основе решения уравнения нестационарной теплопроводности с соответствующими начальными и граничными условиями. Представлены величины и закономерности распределения температуры в калиброванном бойке при обжатии стенки полой заготовки и на холостом ходу при получении за один проход полой заготовки на установке совмещенного литья и деформации.

Ключевые слова: установка, калиброванные бойки, литье, деформация, кристаллизатор, полая заготовка, температурное поле, конечный элемент

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INTRODUCTION

The technology for producing hollow steel billets at pipe plants entails high capital, energy, and operating costs, since it includes casting solid round billets on horizontal continuous casting machines, heating them in furnaces, and piercing on presses or piercing rolling mills. Note that this equipment is predominantly of foreign manufacture, and under anti-Russian sanctions its supply may be halted. Accordingly, a domestic unit of combined casting and deformation has been developed that successfully replaces foreign equipment and can produce hollow steel billets in one pass [1 – 3]. The most heavily loaded elements of the unit during hollow-billet production are calibrated strikers, which, during the working stroke, simultaneously compress the wall of the hollow billet and draw it out of the mold. In this case, calibrated strikers experience combined stresses from the compression force and the temperature load, which reduce the service life of the strikers. To select the design parameters and material of the calibrated strikers on a sound basis, it is necessary to determine their stress state during the production of hollow billets on the unit of combined casting and deformation. To this end, the temperature field and thermoelastic stresses in the strikers during compression of the wall of the hollow billet must be determined [4 – 6].

This paper presents a procedure for calculating temperature fields and thermoelastic stresses in the strikers of a unit of combined casting and deformation. The pipe billet material is steel grade 09G2S; the inner and outer diameters of the pipe billet are 60 and 100 mm, respectively. The angular speed of the eccentric shafts is 40 rpm. At this speed, the striker contact time in the working stroke is 0.375 s, and the pause time is $0.375 \cdot 3 = 1.125$ s. The temperature of the pipe billet at the entry to the striker is 1200 °C, and after exiting the strikers it is 1000 °C.

The striker material is forged tool steel 4Kh4VMFS. For calculations for this steel in the temperature range from 20 to 700 °C, the following were adopted: modulus of elasticity E , density ρ , thermal conductivity λ , heat capacity c , coefficient of linear expansion α , and yield strength σ_y [2].

The geometry of the striker with dimensions is shown in Fig. 1.

By symmetry, the calculation was performed for one half of the striker (Fig. 2). A part of visible lines is shown, for which calculation results will be presented below.

The results of the temperature and stress calculations are given for three sections (1, 2 and 3), in each section, results are presented for five lines. The positions of the sections, the lines for each section, and the points

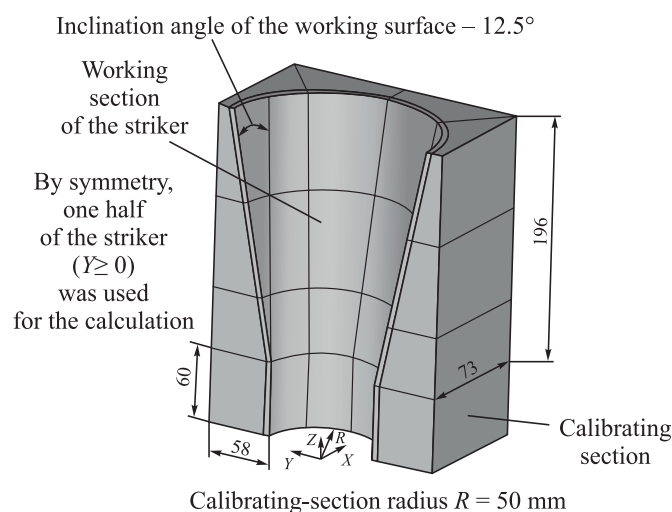


Fig. 1. Geometry of the striker with dimensions

Рис. 1. Геометрия бойка с размерами

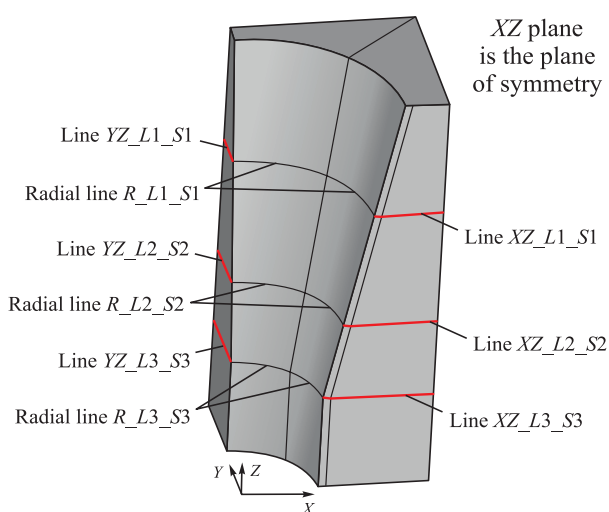


Fig. 2. Geometry of one half of the striker (part of the visible lines)

Рис. 2. Геометрия половины бойка (часть видимых линий)

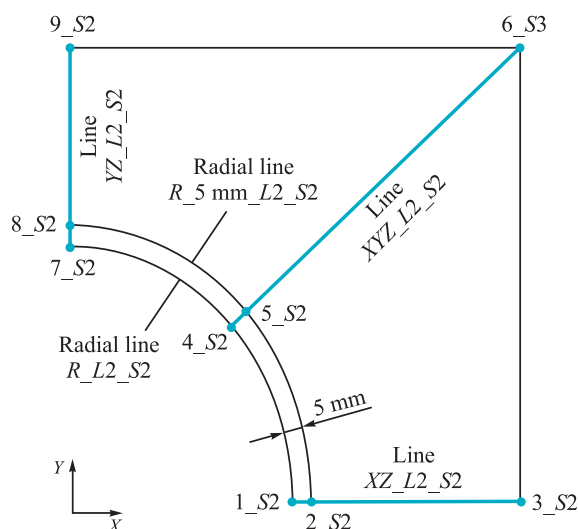


Fig. 3. Position of points and lines in section 2 (sections are shown in Fig. 2)

Рис. 3. Положение точек и линий в сечении 2 (сечения указаны на рис. 2)

through which the lines pass are shown in Fig. 3. Table 1 lists the names of all the lines and indicates the points through which these lines pass.

Calculations of the thermal and stress states of the strikers – for each thermal load (temperature boundary conditions), the specified thermo-physical and mechanical properties of the striker material, and the striker geometry – were performed as follows:

1. Using the thermal element SOLID 70, with the given temperature boundary conditions and thermophysical parameters (density, thermal conductivity, heat capacity) of the striker material, a quasi-steady-state (QSS) temperature field of the striker at the end of the working stroke and at the end of the pause [7 – 9].

2. Using the structural element SOLID 185, together with the modulus of elasticity and Poisson's ratio and the temperature field at the end of the working stroke (from step 1), the thermal stress state of the striker at the end of the working stroke was determined along the striker length [10 – 12].

The temperature field of the strikers is found by solving the unsteady thermal conductivity equation with the corresponding initial and temperature boundary conditions in the ANSYS package [10]:

$$c\rho \frac{dT}{dt} = \sum_{i=1}^3 \frac{\partial}{\partial x_i} \left(\lambda \frac{\partial T}{\partial x_i} \right), \quad (1)$$

All coefficients are taken as temperature-dependent for the strikers.

The initial condition for $T(\vec{X}, t)$ is:

$$T(\vec{X}, t) = T_0(\vec{X}). \quad (2)$$

The initial temperature of the strikers is 20 °C.

For the working surface of the striker, boundary conditions of the second kind have the form

$$\lambda \frac{\partial T}{\partial n} \Big|_S (t) = q, \quad (3)$$

where q is the density of heat flow from the metal in the deformation zone.

During the pause, the boundary conditions of the third kind for the working surface have the form

$$\lambda \frac{\partial T}{\partial n} = -\alpha_1 (T - T_k), \quad (4)$$

where α_1 is the effective heat transfer coefficient on the working surface during the pause; $T_k = 60$ °C is the temperature of the water supplied to the working surface of the strikers during the pause.

On the striker end face, the back wall, and the top and bottom of the striker, the boundary conditions of the third kind have the form

$$\lambda \frac{\partial T}{\partial n} = -\alpha_2 (T - T_a), \quad (5)$$

where α_2 is the heat transfer coefficient for cooling the back wall and the top and bottom with water or air,

Table 1. Names of the lines for three sections, the points through which these lines pass

Таблица 1. Наименования линий для трех сечений, точки, через которые проходят эти линии

Line	Points	Line	Points	Line	Points
Section 1		Section 2		Section 3	
XZ_L1_S1	1_S1, 2_S1, 3_S1	XZ_L2_S2	1_S2, 2_S2, 3_S2	XZ_L3_S3	1_S3, 2_S3, 3_S3
XYZ_L1_S1	4_S1, 5_S1, 6_S1	XYZ_L2_S2	4_S2, 5_S2, 6_S2	XYZ_L3_S3	4_S3, 5_S3, 6_S3
YZ_L1_S1	7_S1, 8_S1, 9_S1	YZ_L2_S2	7_S2, 8_S2, 9_S2	YZ_L3_S3	7_S3, 8_S3, 9_S3
R_L1_S1	1_S1, 4_S1, 7_S1	R_L2_S2	1_S2, 4_S2, 7_S2	R_L3_S3	3_S3, 4_S3, 7_S3
R_5mm_L1_S1	2_S1, 5_S1, 8_S1	R_5mm_L2_S2	2_S2, 5_S2, 8_S2	R_5mm_L3_S3	2_S3, 5_S3, 8_S3

depending on the calculation case; $T_a = 60\text{ }^{\circ}\text{C}$ is the ambient temperature at the end face, back wall, and top and bottom.

In this formulation, one assumption is that the radiative heat flow from the metal is neglected in calculating the striker temperature fields [13 – 15].

Equations (1) – (5) constitute an initial boundary-value problem for the unsteady temperature field of the strikers in the unit of combined casting and deformation [16 – 18].

This scheme for determining temperature and thermoelastic stresses in the strikers by the finite element method is implemented in one of the modules of the ANSYS package [19; 20].

Temperature values at all points along the lines are given in Table 2.

ANALYSIS OF CALCULATION RESULTS

Under heat flow during wall reduction, the contact surface of the striker reaches 370 – 451 $^{\circ}\text{C}$ (results shown only for the portion between sections 1 – 3; Table 1, points 7_S3 and 1_S1). The maximum temperature occurs in section 1 on the plane of symmetry of the striker. During idle operation with water cooling, the contact-surface temperature decreases to 289 – 370 $^{\circ}\text{C}$ (points 7_S3 and 1_S1) while the maximum remains in section 1 on the plane of symmetry.

At a depth of 5 mm, the temperatures at the end of contact and at the end of the pause in the QSS mode coincide and depend only on location; they lie within 295 – 392 $^{\circ}\text{C}$ (points 8_S3 and 2_S1). The maximum is again in section 1 on the plane of symmetry.

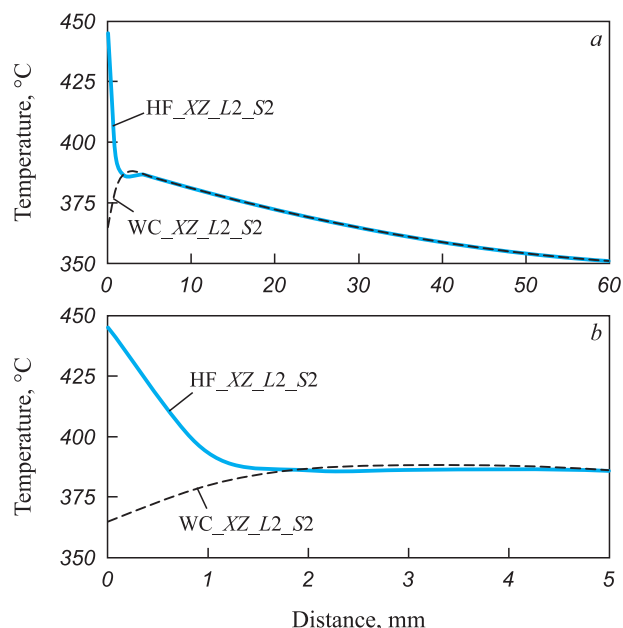


Fig. 4. Nature of temperatures along the XZ_L2_S2 line due to the effect of heat flow (HF) and cooling with water (WC) on the striker along its thickness (a) and from the contact surface to a depth of 5 mm (b)

Рис. 4. Характер температур вдоль линии XZ_L2_S2 в зависимости от воздействия на боек теплового потока (HF) и охлаждения водой (WC) по толщине бойка (a) и от поверхности контакта на глубине 5 мм (b)

Temperature variation is similar through the thickness and along the radius. The maximum temperature – at the end of contact and at the end of the pause – at the working surface of the striker and at a depth of 5 mm occurs in the part of the striker located closer to the mold; toward the calibrating section the tempera-

Table 2. Temperature values at all points of the lines

Таблица 2. Значения температур во всех точках линий

Section 1			Section 2			Section 3		
Point	Temperature, $^{\circ}\text{C}$		Point	Temperature, $^{\circ}\text{C}$		Point	Temperature, $^{\circ}\text{C}$	
	WC	HF		WC	HF		WC	HF
1_S1	370	451	1_S2	365	445	1_S3	354	435
2_S1	392	392	2_S2	386	386	2_S3	373	373
3_S1	370	370	3_S2	350	350	3_S3	310	310
4_S1	368	448	4_S2	360	441	4_S3	348	429
5_S1	389	389	5_S2	381	381	5_S3	366	366
6_S1	344	344	6_S2	330	330	6_S3	285	285
7_S1	304	385	7_S2	294	375	7_S3	289	370
8_S1	314	314	8_S2	302	302	8_S3	295	295
9_S1	286	286	9_S2	252	252	9_S3	221	221

Note. WC and HF denote the temperature at the end of the pause and at the end of the working stroke (end of contact), respectively.

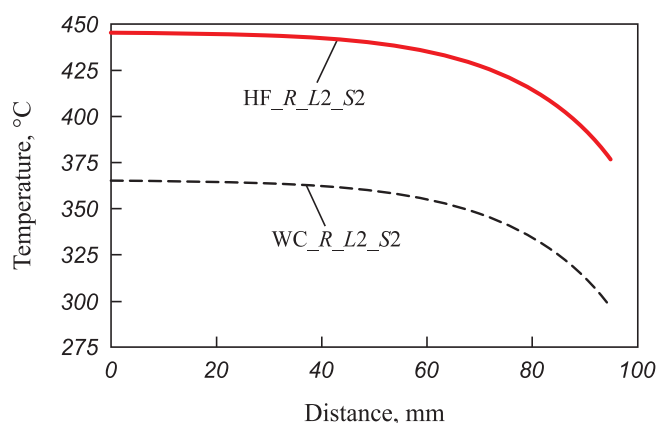


Fig. 5. Nature of temperatures along the R_L2_S2 line due to the effect of heat flow (HF) and cooling with water (WC) on the striker

Рис. 5. Характер температур вдоль линии R_L2_S2 в зависимости от воздействия на боек теплового потока (HF) и охлаждения водой (WC)

ture decreases. Radially, the temperature is highest on the plane of symmetry and decreases toward the lateral surface of the striker.

Through the thickness, the striker temperature decreases: on the support side surface it is 285 – 370 °C (points 6_S3 and 3_S1); on the lateral surface side it is 221 – 286 °C (points 9_S3 and 9_S1).

Temperature equalization occurs at a depth of 2 mm from the contact surface, both through the thickness and along the radius.

Figs. 4 and 5 show the temperature distribution along characteristic lines of the calibrated striker in section 2 during wall reduction and during idle operation with water cooling. Temperatures at characteristic points in sections 1 and 2 differ only slightly (Table 2).

CONCLUSIONS

A procedure has been developed for calculating temperature fields and thermoelastic stresses in calibrated strikers of a unit of combined casting and deformation during the production of steel pipe billets. The temperature distribution along characteristic lines has been determined for both wall reduction and idle operation with water cooling. It has been established that, under heat flow during wall reduction, the temperature of the contact surface of the striker is 370 – 451 °C.

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