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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 2

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Abstract. The article solves the problem of determining thermoelastic stresses in calibrated strikers in a unit of combined casting and deformation during production of hollow steel billets using the calculation methodology developed by the authors. The authors substantiate the relevance of determining thermoelastic stresses in insulated strikers when compressing the wall of a hollow billet and at idle run when cooling the strikers with water, and describe the striker geometry to produce a hollow billet in one pass. 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 are given to calculate thermoelastic stresses in calibrated strikers using the finite element method with ANSYS package. The authors determined the magnitudes and patterns of distribution of thermoelastic stresses in a calibrated striker when compressing the wall of a hollow billet and at idle run when such a billet is produced in one pass in a unit of combined casting and deformation. Based on the calculated temperature values and the magnitude of the maximum compressive thermoelastic stresses on the contact surface of the strikers, it is proposed to use a pipe billet as a material for making strikers.

Keywords: unit, calibrated striker, casting, deformation, mold, hollow billet, temperature field, thermoelastic stresses, finite element

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Расчет температуры и термоупругих напряжений в бойках при получении стальных полых заготовок на установке совмещенного литья и деформации. Часть 2

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Аннотация. В статье решается задача определения термоупругих напряжений в калиброванных бойках установки совмещенного литья и деформации при получении стальных полых заготовок с использованием разработанной авторами методики расчета. Авторы обосновывают актуальность определения термоупругих напряжений в калиброванных бойках при обжатии стенки полой заготовки и на холостом ходу при охлаждении бойков водой и представляют геометрию бойка для получения полой заготовки за один проход. Представлены исходные данные для расчета термоупругих напряжений в калиброванных бойках установки совмещенного литья и деформации при получении полых заготовок и температурные граничные условия для их расчета. Для определения температуры бойка приводятся граничные условия и значения теплового потока и эффективного коэффициента теплоотдачи. Результатом расчета термоупругих напряжений в четырех сечениях являются характерные линии и точки, расположенные на контактной поверхности бойка и в приконтактном слое на глубине 5 мм от рабочей поверхности. Для расчета термоупругих напряжений в калиброванных бойках с использованием метода конечных элементов с применением пакета ANSYS приводятся размеры сетки конечных элементов. Авторы определили величины и закономерности распределения термоупругих напряжений в калиброванном бойке при обжатии стенки полой заготовки и на холостом ходу при получении за один проход такой заготовки на установке совмещенного литья и деформации. На основании расчетных значений температуры и величины максимальных сжимающих термоупругих напряжений на контактной поверхности в качестве материала для изготовления бойков предложено использовать трубную заготовку.

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

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Introduction

The main and most heavily loaded elements of a unit of combined casting and deformation are the strikers [1; 2]. During the working stroke, they simultaneously compress the wall of a steel hollow shell and move it in the casting direction. In this process, combined stresses arise in the strikers during the working stroke due to the compression force and the thermal load [3 – 5]. Therefore, a relevant problem is to substantiate the selection of the striker material that ensures the ability to withstand cyclic loading under the combined action of mechanical and thermoelastic stresses [6 – 8].

To calculate the stress state of the striker in the unit, its temperature field was first determined based on solving the unsteady thermal conductivity equation with the corresponding initial and boundary conditions [9 – 11].

The outer and inner diameters of the hollow billet made of 09G2S steel are 100 and 60 mm, respectively. The angular speed of the eccentric shafts was taken as 40 min^{-1}. At this speed, the contact time of the striker with the wall of the hollow billet during the working stroke is 0.375 s, and the pause time is 1.125 s. The temperature of the hollow billet in the striker entry zone is 1200 °C [12 – 14].

The geometry of the striker with dimensions is given in [9]. Iterative calculations showed that, to ensure a temperature of 350 °C on the striker contact surface at a heat transfer coefficient of 2000 W/(m^2·K), the heat flux density is 4.6 MW/m^2 [15].

It was established that, under the action of heat flow during compression of the hollow billet wall by the strikers, the temperature on the striker contact surface lies in the range of 370 – 451 °C. Subsequently, during idle operation with water cooling, the temperature of the striker contact surface decreases and falls within the range of 289 – 370 °C.

Based on the obtained temperature fields, thermoelastic stresses in the strikers of the unit were determined by the finite element method using the ANSYS package [16] (with elements of the calculation methodologies described in [16 – 18]). The finite element size in the deformation zone and in the calibrating sections of the strikers was taken as 1 mm. By symmetry, the calculation was performed for one half of the striker shown in Fig. 1 [9]. The calculation results for radial (*SR*), tangential (*S*θ), axial (*SZ*), and equivalent (*SEQV*) thermoelastic stresses are presented only for the characteristic lines *XZ_L2_S*2, *XYZ_L2_S*2, and *R_L2_S*2 and for the points of section *2* associated with the striker contact surface (Fig. 1).

The Table presents the values of thermoelastic stresses at the points of the characteristic lines of section *2* under the action of heat flow (HF) and during water cooling (WC).

Fig. 2 shows the patterns of thermoelastic stress distribution in the strikers along the characteristic line *R_L2_S*2.

Let us consider the distribution of thermoelastic stresses in the strikers along the characteristic lines of section *2* (Fig. 1), where the maximum compressive stresses arise during compression of the wall of the steel hollow billet. Thus, at point 1_*S*2 of the *XZ_L2_S*2 line, which passes along the axis of symmetry of the striker

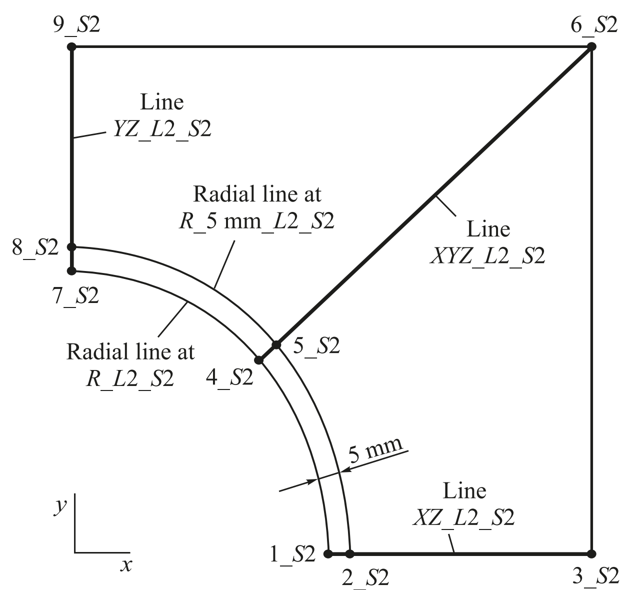

Fig. 1. Position of points and lines in section *2*

Рис. 1. Положение точек и линий в сечении *2*

Values of radial, tangential, axial and equivalent stresses at points of section *2* lines due to the effect of heat flow (HF) and cooling with water (WC) on the striker

Значения радиальных, тангенциальных, осевых и эквивалентных напряжений в точках линий сечения *2* от воздействия на боек теплового потока (HF) и охлаждения водой (WC)

Point	Stress, MPa							
	SR	*S*θ	*SZ*	*SEQV*	*SR*	*S*θ	*SZ*	*SEQV*
	At the end of the pause (WC)				At the end of contact (HF)			
1_*S*2	–9	–58	–191	178	–39	–589	–703	671
2_*S*2	–27	–243	–361	317	–33	–218	–348	297
3_*S*2	–56	–114	–62	56	–38	–113	–42	61
4_*S*2	–4	148	–142	258	–34	–381	–652	592
5_*S*2	–13	–91	–312	289	–18	–58	–295	278
6_*S*2	–542	–454	141	459	–561	–470	130	459
7_*S*2	21	25	341	342	–19	–59	–63	71
8_*S*2	53	–1	355	340	–32	–1	340	372
9_*S*2	0	1	857	856	0	1	859	858

caliber, at the contact surface, the maximum compressive axial stresses *SZ* reach −703 MPa (Fig. 2, Table).

During idle operation with water cooling, compressive thermoelastic stresses *S*θ and *SR* at the striker contact surface at point 1_*S*2 are significantly lower and amount to −58 and −191 MPa, respectively (Fig. 2, Table).

It should be noted that along the *XYZ_L*2_*S*2 line, the compressive thermoelastic stresses *S*θ and *SZ* at the striker contact surface during compression of the hollow billet wall are quite high; at point 4_*S*2, they are −381 and −652 MPa, respectively (Fig. 2, Table).

During idle operation, at the striker contact surface at point 4_*S*2, the tangential stresses *S*θ are tensile, with a maximum value of 148 MPa, while the axial stresses *SZ* are compressive, with a value of –142 MPa. However, through the striker thickness, the axial stresses initially increase to –312 MPa, then decrease, change sign, and become tensile, reaching a maximum value of 141 MPa (see Table).

Let us consider the distribution of thermoelastic stresses along the radius of the striker contact surface (line *R_L*2_*S*2, Fig. 1).

During compression of the hollow billet wall, at point 1_*S*2 of the striker contact surface, the thermoelastic stresses *S*θ and *SZ* are compressive, amounting to –589 and –703 MPa, respectively. Along the radius, they decrease and at point 4_*S*2 become –381 and –652 MPa, while at point 7_*S*2 they are –59 and –63 MPa, respectively (Fig. 2, Table).

During idle operation, at point 1_*S*2 of the striker contact surface, compressive thermoelastic stresses *S*θ and *SZ* arise with values of –58 and –191 MPa, respec-

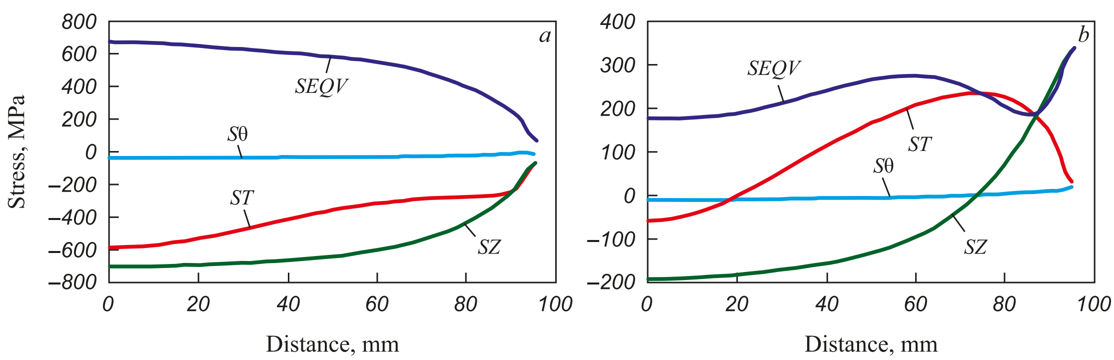

Fig. 2. Nature of thermoelastic stresses along the *R_L*2_*S*2 line:
a – due the effect of heat flow (TP) on the striker (at the end of the contact);
b – due to the effect of cooling with water (ОХЛ) (at the end of the pause)

Рис. 2. Характер термоупругих напряжений вдоль линии *R_L*2_*S*2:
а – от воздействия на боек теплового потока (ТР) (в конце контакта);
b – от охлаждения водой (ОХЛ) (в конце паузы)

tively. Further along the radius of the striker contact surface, at point 7_*S*2, they become tensile, reaching 25 and 341 MPa, respectively (Fig. 1, Table).

As a result of the study, it was established that the temperature of the striker contact surface during compression of the steel hollow billet wall can reach 451 °C. At this temperature, the compressive thermoelastic stresses at the striker contact surface reach 703 MPa.

The calculated values of thermoelastic stresses correlate well with the results obtained in similar studies using the QForm analysis software system [19].

Considering the above, the strikers of the unit of combined casting and deformation for producing steel hollow billets should be manufactured from 4Kh4VMFS steel. This is a die steel with increased resistance to heat checking and high wear resistance. The conditional yield strength of the steel at a temperature of 500 °C is 1309 MPa, which significantly exceeds the maximum thermoelastic stresses caused by the thermal load [20]. This steel is also used for manufacturing tooling for high-speed machine forging and upsetting on horizontal forging machines.

Conclusions

A procedure has been developed for calculating thermoelastic stresses in calibrated strikers of a unit of combined casting and deformation during the production of steel hollow pipe billets. The magnitudes and patterns of thermoelastic stress distribution in three sections of the calibrated striker during the production of steel hollow billets in a unit of combined casting and deformation have been determined. It has been established that the maximum compressive thermoelastic stresses at the striker contact surface reach 703 MPa. It is proposed that the strikers of the unit of combined casting and deformation for producing steel hollow billets be manufactured from 4Kh4VMFS steel, whose yield strength at a temperature of 500 °C is 1309 MPa.

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