Research of heat stresses in components of blast furnace tuyere

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Abstract. Using computer simulating in Deform 2D it was researched the effect of insert thickness and air gap size, separating it from the internal cylinder, on temperature pattern and stresses in the insert and the internal cylinder. It was shown, that with the increase a clearance between the insert and the internal cylinder and with increase the insert thickness, weight average values of voltage decrease in it. They have been more evenly spread with increases of insert thickness. In tuyere design it was offered increasing it thickness to 13 mm for hardening. Key words: tuyere, blast furnace, insulation insert, internal cylinder, temperature pattern, stress.

1 Introduction

Tuyeres are the essential elements of blast furnace in determining its performance; tuyere`s breakdown requires a furnace shutdown for destroyed tuyere`s replacement. For this reason furnace downtime leads to significantly reduce of iron smelting and increasing coke consumption. Besides, 30% of all heat loss happened in tuyeres in blast furnace [1]. That`s why the topical issue is tuyere hardening and reduction in heat losses through their surfaces.

At the present time the given issue is being solved by different ways: applying gas-flame sprayed coatings on working surface of tuyere [2–4], refractoriness of refractory products from the side of the air passage [5] and others. For identifying the ways to improve the tuyere design it is necessary modelling its thermal state, influencing the origin of thermoelectromotive forces in it.

In the previous works it was established the substantial impact of insulation insert in air passage and air gap, separating it from the internal cylinder, on tuyere temperature pattern (fig. 1) [6–9].

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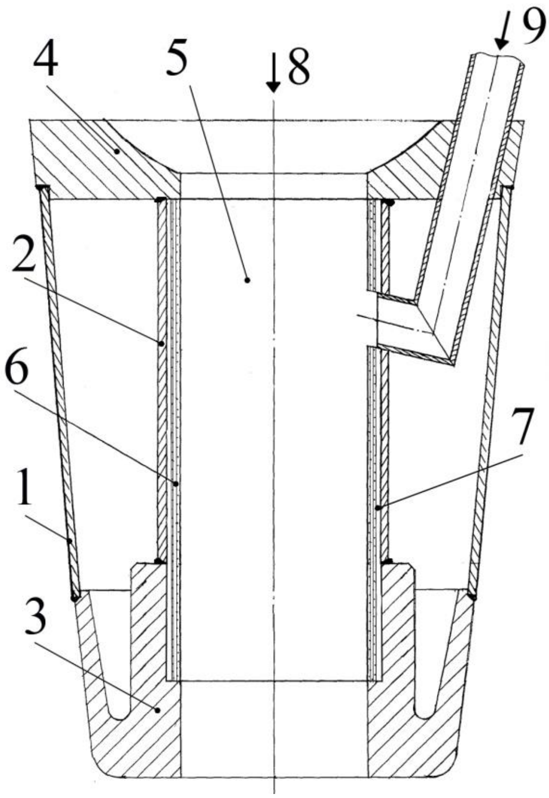

Fig. 1. The scheme of blast furnace tuyere (longitudinal section): 1- external cylinder, 2- internal cylinder, 3- tuyere nose, 4- flange, 5- air passage, 6- insert, 7-air gap, 8-hot blow, 9- natural gas

Estimation of thermal stresses is especially important for thermal insulation, the efficiency of which depends on its condition. Due to a large temperature change or the temperature variation rate along thickness the stresses arise in the insert and may lead to its premature failue during operation of the tuyere. Due to the temperature variation rate along thickness arising stresses can lead to deformation and the quality of welded joints in the internal cylinder.

Using modern software **the purpose of work** was researches of the influence of the insulation insert thickness in the air passage of tuyere and the size of air gap separating it from the internal cylinder, on the temperature pattern and the stresses in the insert and internal cylinder.

2 Research methodology and results

As we know, the cause of the occurrence of heat stresses in details is the presence of a temperature gradient in them [10]. Due to the relatively low thermal conductivity of the most ceramic materials (less than 10 W/ m·K) [11] with one-direction thermal action, a temperature gradient appears inside the thermal insulation. At the same time, thermal insulation materials have a relatively high coefficient of thermal expansion ($1\text{-}2\cdot10^{-5}$ K^{-1}) [12]. That leads to the fact that the more heated layers of the heat-insulating material are under compressive loads on the side of less heated layers and vice versa. In addition, in the absence of expansion space during heating, the heat insulating material is under additional compressive loads from the side of the internal cylinder.

Arising under the temperature drop mechanical stresses can be calculated in accordance with Hooke's law:

$$\sigma_0=\Delta T\cdot\alpha\cdot E \qquad (1)$$

where σ_0 is a stress in material, ΔT is a change in the product temperature, α is the coefficient of linear thermal expansion of the material, E is the modulus of elasticity of the material.

We note that a slow change in temperature does not lead to the arising of significant mechanical stresses due to the phenomenon of stress relaxation [13]. With time arising stresses decrease in accordance with the following dependence [14]:

$$\sigma= \sigma_0\cdot e^{\tau\cdot E/K_1} \qquad (2)$$

where σ is the actual stress in the material, σ_0 is the stress in the material without relaxation (calculated by equation (1)), τ is the time since the beginning of the relaxation, E is the modulus of the material elasticity, K_1 is the constant characterizing the stress relaxation rate, depending on the viscous properties of the material.

For ceramic materials the constant K_1 varies in the range from 10^{15} at room temperature to 10^7–10^9 at a temperature of 1500-1700^{0}C [15].

Deform 2D program was used for the thermal state simulating of the tuyere. The initial data for the model creating was the tuyere for DP-5 designed by PJSC "Severstal". The thickness of the internal cylinder $h_{вн}$ = 6 mm, the external cylinder $h_{н}$ = 15 mm, the end of tuyere nose $h_{рт}$ = 30 mm, the average thickness of the lateral surface of the tuyere nose and the side of the air passage h_p = 18 mm (fig. 2)

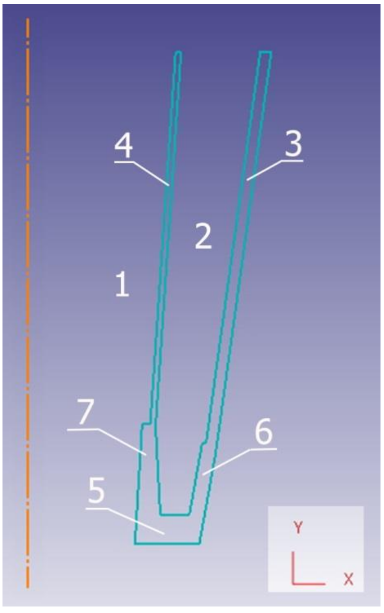

Fig. 2. The geometry of tuyere for simulating in Deform 2D: 1 – air passage, 2 - water-cooled hole, 3 – external cylinder, 4 – internal cylinder, 5 - the end of tyuere nose, 6 - the lateral surface of tyuere nose, 7 – tuyere nose from the side of the air passage

The elastic and thermal properties of used materials were set when simulating the temperature pattern and the stress in the insert and in the internal cylinder (table 1).

Table 1. The elastic and thermal properties of used materials

Indicator	Material		
	Cuprum M1	Ceramic	Air
Young's modulus, MPa	$1{,}32 \cdot 10^5$	$1{,}46 \cdot 10^4$	90
Poisson's ratio	0,33	0,17	0,01
Temperature coefficient of linear expansion, $^0C^{-1}$	$1{,}67 \cdot 10^{-5}$	$6{,}5 \cdot 10^{-6}$	10^{-7}
Coefficient of thermal conductivity, W/(m·K)	387	3	0,0362
Volume specific heat, J / (cm^3 · K)	3,49	2,7	0,0012

The simulation was carried out under the following initial and boundary conditions:

$t_{0\ tuyere}$= 30 ^{0}C; t_{blast} =1200 ^{0}C; t_{water} =30 ^{0}C; $t_{environment}$ =1600 ^{0}C; $\alpha_{blast\ –\ cuprum}$ = 375 W/(m^2·K); $\alpha_{cuprum\ –\ water}$ = 5815 W/(m^2·K); $\alpha_{environment\ –\ tuyere\ nose}$ = 268 W/(m^2·K); $\alpha_{environment\ –\ ex.\ cylinder}$ = 118 W/(m^2·K).

The insert thickness ($h_{вст.}$) was 10 and 13 mm, and the air gap value ($h_{воз.}$) was 0,1 and 2 mm (tables 2 and 3).

Table 2. Calculated values of temperature and stress in the insert

$h_{вст.}$, mm	$h_{воз.}$, mm*	Indicator	Minimum value	Maximum value	Weighted average value	Root-mean-square deviation
10	0	t,^{0}C	155	817	472	184
		σ, MPa	3,97	65,8	35,1	18,9
10	1	t,^{0}C	325	1020	909	85,1
		σ, MPa	29,8	91,7	73,5	11,0
10	2	t,^{0}C	351	1040	960	59,2
		σ, MPa	28,5	102	69,9	10,9
13	1	t,^{0}C	308	1020	813	93,0
		σ, MPa	15,1	97,7	58,2	14,4

* The air was set as an elastic body

Table 3. Calculated values of temperature and stress in the internal cylinder

$h_{вст.}$, mm	$h_{воз.}$, mm	Indicator	Minimum value	Maximum value	Weighted average value	Root-mean-square deviation
0	–	t,^{0}C	95,9	104	99,9	2,21
		σ, MPa	0,470	28,8	5,89	3,18
10	0	t,^{0}C	54,3	57,5	55,9	0,826
		σ, MPa	25,5	180	64,4	16,4
10	1	t,^{0}C	34,7	37,4	35,1	0,375
		σ, MPa	75,1	243	127	20,3
10	2	t,^{0}C	32,6	34,7	32,9	0,302
		σ, MPa	74,2	212	118	17,9
13	1	t,^{0}C	33,9	36,7	34,3	0,388
		σ, MPa	83,6	257	136	22,0

From tables 2 and 3 it can be seen that the weighted average insert temperature increase and the weighted average temperature of the internal cylinder decrease with an increase in the gap between the insert and the internal cylinder with the insert thickness of 10 mm. With an increase in the thickness of the insert with a gap of 1 mm, the weighted average temperature of the insert and internal cylinder decreases. As for the stresses, with increase in the gap with an insert thickness of 10 mm and with increase in the thickness of the insert with a gap of 1 mm, their weighted average values decrease, with an increase in the thickness of the insert, they are more evenly spread (fig.3-5).

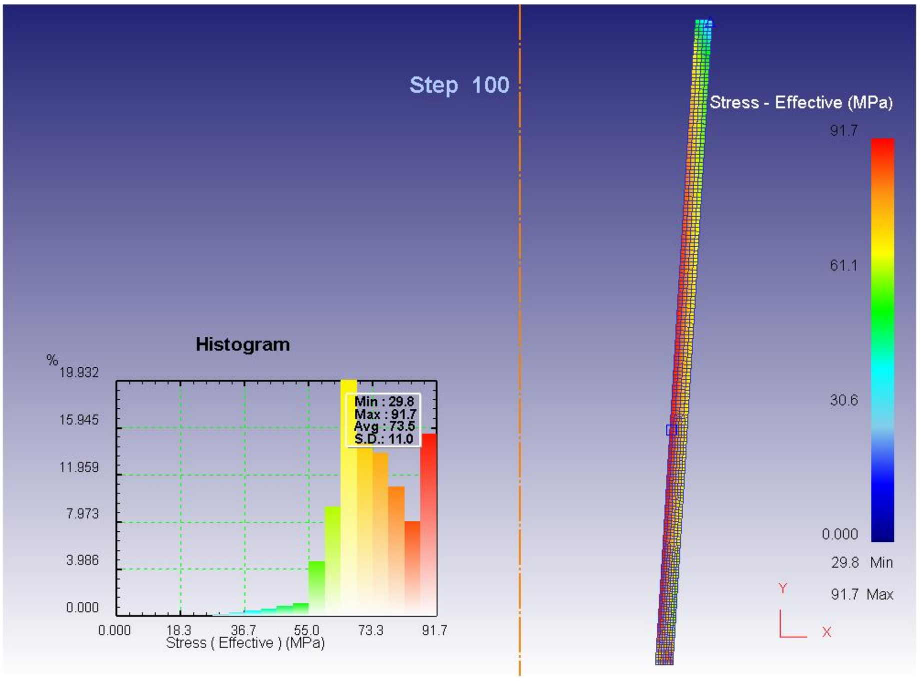

Fig. 3. Stresses in the insert in the stationary state (hвст.=10 mm, hвоз.=1,0 mm)

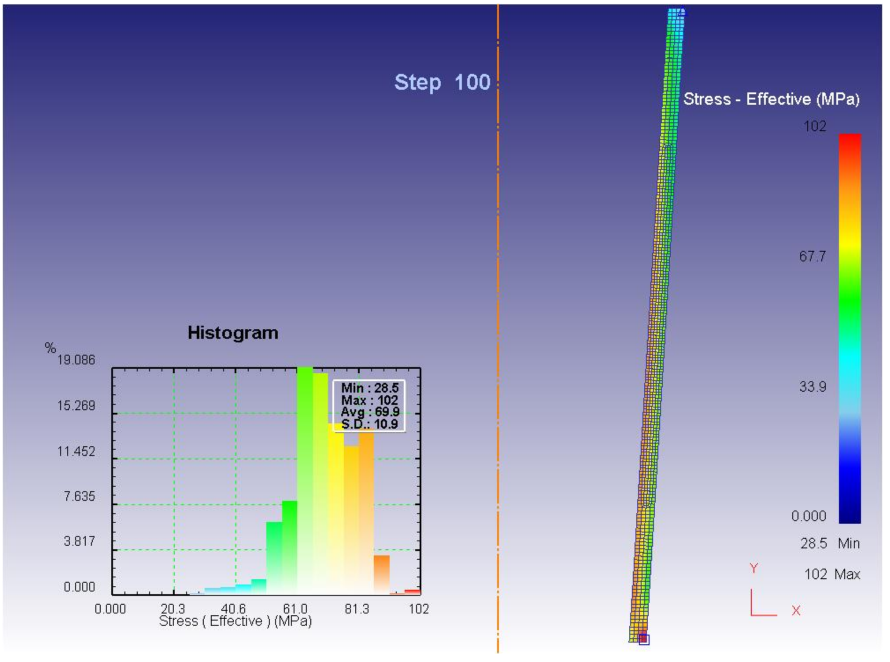

Fig. 4. Stresses in the insert in the stationary state (hвст.=10 mm, hвоз.=2,0 mm)

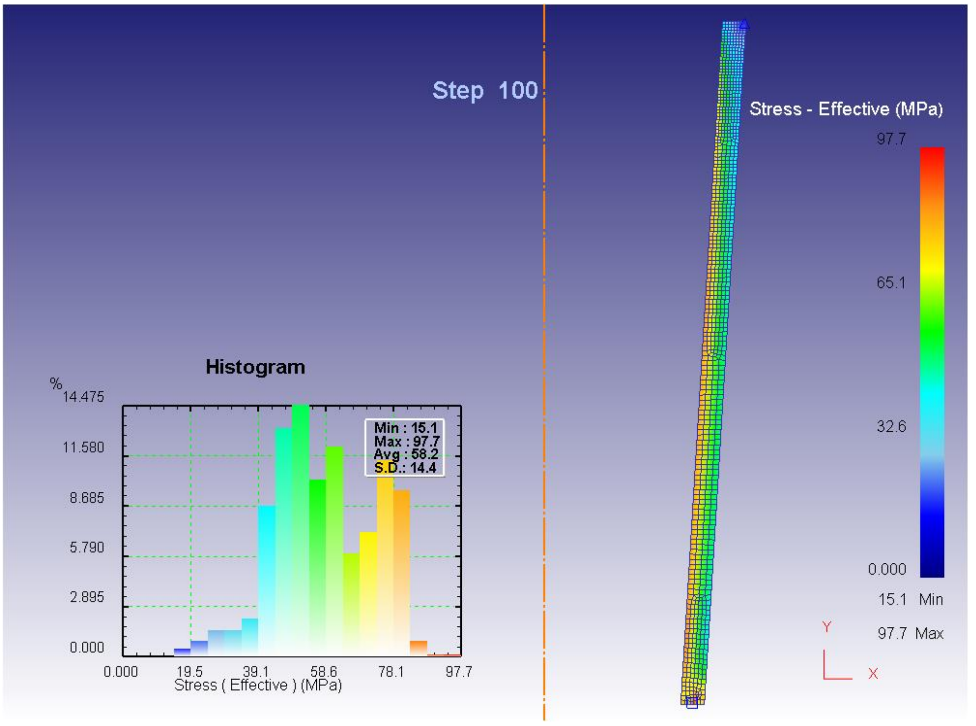

Fig. 5. Stresses in the insert in the stationary state ($h_{вст.}$=13 mm, $h_{воз.}$=1,0 mm)

In any case, in the insert the maximum values of stresses do not exceed the experimental values of the ceramic compressive resistance - 111.7-117.0 MPa. In fact, in the insert the maximum stresses are smaller because of the relaxation phenomenon [13].

Similarly, in the internal cylinder the maximum stress values do not exceed the yield stress of cuprum M1, under tension the hard alloy is σ_T=300-450 MPa.

3 Conclusion

The analysis of the temperature and stresses of the insert and internal cylinder of blast furnace tuyere with using computer simulating in Deform 2D, shows that increasing of the insert thickness to 13 mm increases its durability.

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