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The Flexibility of Pusher Furnace Grate

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Abstract

The lifetime of guide grates in pusher furnaces for heat treatment could be increased by raising the flexibility of their structure through, for example, the replacement of straight ribs, parallel to the direction of grate movement, with more flexible segments. The deformability of grates with flexible segments arranged in two orientations, i.e. crosswise (perpendicular to the direction of compression) and lengthwise (parallel to the direction of compression), was examined. The compression process was simulated using SolidWorks Simulation program. Relevant regression equations were also derived describing the dependence of force inducing the grate deformation by 0.25 mm – modulus of grate elasticity – on the number of flexible segments in established orientations. These calculations were made in Statistica and Scilab programs. It has been demonstrated that, with the same number of segments, the crosswise orientation of flexible segments increases the grate structure flexibility in a more efficient way than the lengthwise orientation. It has also been proved that a crucial effect on the grate flexibility has only the quantity and orientation of segments (crosswise / lengthwise), while the exact position of segments changes the grate flexibility by less than 1%.

Keywords: Innovative foundry technologies and materials, Castings for heat treatment plants, Grates

1. Introduction

Stability of pusher furnace equipment is one of the main factors determining its efficiency. An essential element of this equipment is guide grate, on which the heat treated parts (charge) are resting. In pusher furnace, several grates arranged in row/rows are used simultaneously and are pushed through the furnace hearth from the charging door to the furnace outlet. The number of grates in a row does not exceed 25 pieces [1].

While operating, the grate is subjected to alternating process of simultaneous compression and heating followed by cooling. The compression of the grate is caused by its forced movement in the furnace. The result is deformation of the grate, and then cracking in long-term use [2, 3, 4].

Guide grate is typically a cast component of rectangular (Fig. 1) or square shape and is an example of the thin-wall openwork structure [2, 5]. It is designed using walls either straight or of simple shapes. In [6] it was demonstrated that replacing straight elements of the grate construction with other shapes of an equally simple geometry selected for analysis is an effective procedure leading to reduced stiffness of the whole structure.

The aim of this work was to develop quantitative and qualitative relationships describing the flexibility of grates with varying number and location of the flexible segments. The task of the flexible segment is to improve the grate ability to undergo elastic deformation under the effect of stress caused by its forced movement in the furnace.

2. Methodology and test result

To examine the efficiency of replacing the straight walls in a grate with flexible segments it was decided to carry out comparative studies. As a starting point for comparison was selected the grate design using straight walls (Fig. 1). It was assumed that this construction would be characterized by low flexibility (high stiffness). To modify its internal shape, flexible segments were incorporated into the grate design in crosswise (perpendicular to the direction of compression) and lengthwise (parallel go the direction of compression) orientation. For studies, the following assumptions have been made:

1. Initial model of the grate (Fig. 1).

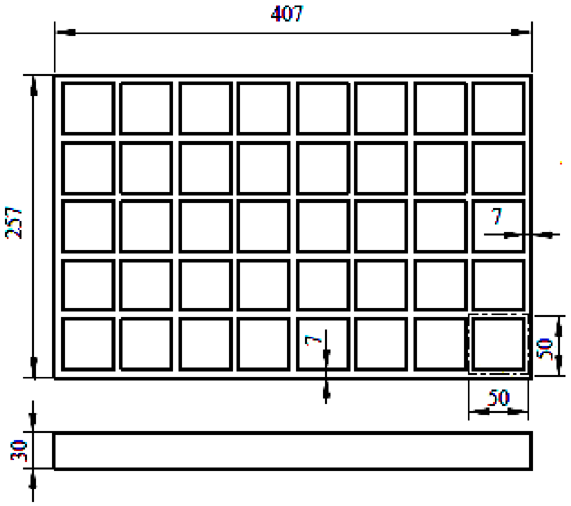

Fig. 1. The geometry of the initial grate adopted for research

2. The shape of the flexible segment [4] (Fig. 2.)

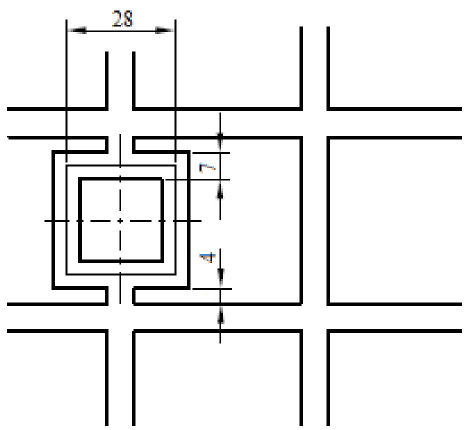

Fig. 2. The shape and dimensions of the flexible segment

When selecting the shape of a flexible segment it was important to make it symmetrical to the horizontal axis, otherwise deformation could occur not only in the direction of force but also in the direction perpendicular thereto. Then, adopting a constant value of deformation in the direction of force as a modulus of elasticity could raise some doubts regarding its interpretation.

3. Models of modified grates: on the axes of symmetry of the grates, straight ribs were replaced with flexible segments.

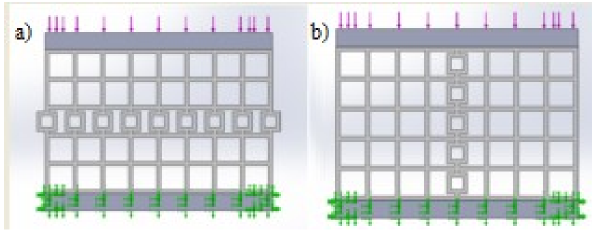

Fig. 3. Grates containing maximum number of flexible segments in orientations: crosswise (a) and lengthwise (b) [4]

Two collections of grates (with structure characterized by flexibility higher than the flexibility of the initial grate) were formed:

- Collection I; grates containing from 0 to 9 flexible segments in an orientation crosswise (Fig. 3a) and perpendicular to the compression force. The number of possible design solutions of the grate structure is 32 (Table 2).
- Collection II; grates containing from 0 to 5 flexible segments in an orientation lengthwise (Fig. 3b) and parallel to the compression force. The number of possible design solutions of the grate structure is 20 (Table 3).

All proposed models of the grates are symmetrical in respect of the vertical axis (parallel to the direction of force). The purpose of this restriction was to avoid non-parallelism of the lower and upper edge of the grate after load application, as this state would prevent an unambiguous measurement of strain in the whole grate structure.

4. Material of grate: cast steel GX40NiCrSiNb38-19– Table 1.

Table 1.
Material parameters of the examined grates

Property	Value
Elastic modulus; MPa	173000
Poisson's ratio	0.253
Transverse elastic modulus MPa	318.9
Density; kg/m^3	7800
Tensile strength; MPa	440
Yield strength; MPa	230
Coefficient of thermal expansion; K^{-1}	1.6
Thermal conductivity; W/(m·K)	14.6
Specific heat; J/(kg·K)	500

5. Loading conditions: the grate was placed between two stiff non-deformable beams. One of them was firmly secured, while to the other force was applied. The force causing grate deformation by 0.25 mm in the direction of compression was measured. The value of this force was adopted as a modulus of the grate elasticity. With the strain value of Δl = 0.25 mm adopted in the analysis, it has been assumed that under true performance conditions, this value will correspond to the increase of grate dimensions caused by an instantaneous temperature difference of 300° between the individual grate components, e.g. at the beginning of the heating process [6]. This assumption enables problem analysis using for calculation the properties of material at ambient temperature. It appears that such a procedure is sufficient for a preliminary assessment of the grate flexibility. Minor deviations from the real conditions can be accepted.

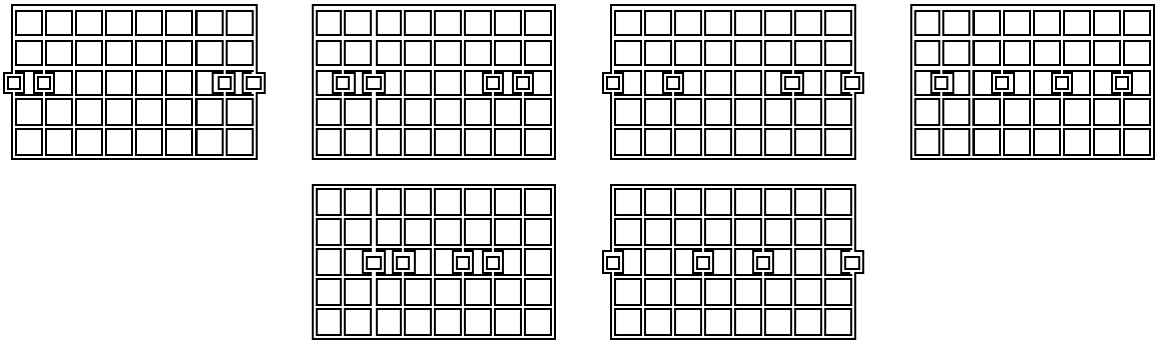

Fig. 4. Structures of grates comprising 4 flexible segments in crosswise orientation

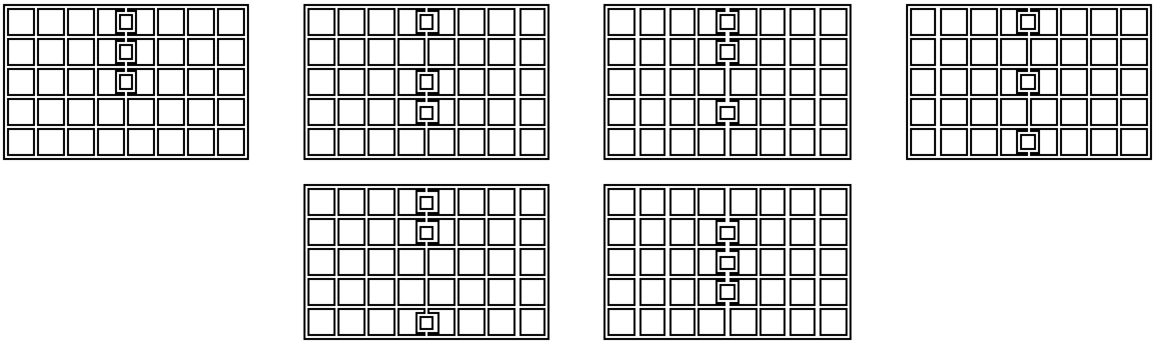

Fig. 5. Structures of grates comprising 3 flexible segments in lengthwise orientation

Table 2.
Number of flexible segments ($Nfs_{\perp}$) in an orientation crosswise and force F causing grate deformation $\Delta l = 0.25$ mm

No.	$Nfs_{\perp}$	F, N	No.	$Nfs_{\perp}$	F, N	No.	$Nfs_{\perp}$	F, N
1.	0	333200	12.	4	295600	23.	6	274900
2.	1	323800	13.	4	295600	24.	6	275400
3.	2	315000	14.	4	293600	25.	6	275300
4.	2	314000	15.	4	294300	26.	6	273300
5.	2	314000	16.	4	293600	27.	7	264700
6.	2	314000	17.	5	285200	28.	7	264800
7.	3	305500	18.	5	285700	29.	7	264700
8.	3	304100	19.	5	285200	30.	7	263000
9.	3	304100	20.	5	283800	31.	8	254800
10.	3	303600	21.	5	283800	32.	9	244300
11.	4	295200	22.	5	283300			

Table 3.
Number of flexible segments ($Nfs_{\parallel}$) in an orientation lengthwise and force F causing grate deformation $\Delta l = 0.25$ mm

No.	$Nfs_{\parallel}$	F, N	No.	$Nfs_{\parallel}$	F, N	No.	$Nfs_{\parallel}$	F, N
1.	0	333200	8.	2	318100	15.	3	314200
2.	1	324200	9.	2	318200	16.	3	314300
3.	1	323900	10.	2	318000	17.	4	311700
4.	1	323800	11.	3	314700	18.	4	311500
5.	2	318600	12.	3	314400	19.	4	311500
6.	2	318200	13.	3	314300	20.	5	309500
7.	2	318100	14.	3	314300			

Based on the obtained simulation results (Tables 2 and 3), relevant regression equations were derived to describe a relationship between the grate flexibility and the number of flexible segments in both orientations, i.e. crosswise and lengthwise. The equations and their graphic representations are shown in Figure 6. Points corresponding to all performed

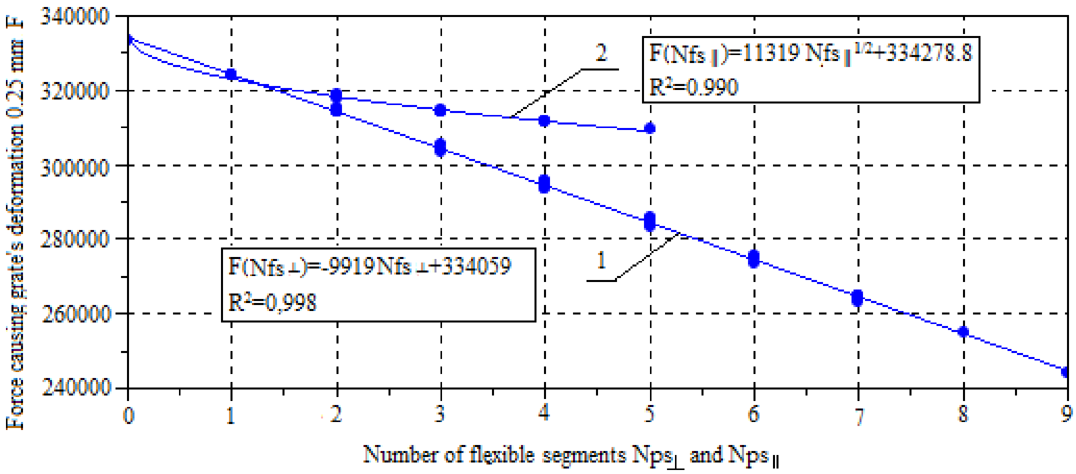

Fig. 6. The results of measurements and calculations for grates with flexible segments in orientation crosswise (1) and lengthwise (2)

simulations are marked on the drawing. The approximate value of F corresponds many times to one value of Nfs⊥ (similarly, the approximate value of F corresponds to one value of $Nfs_{\|}$) – the difference between forces causing the grate deformation by 0.25 mm is small, irrespective of how the flexible segments are arranged in respect of each other (e.g. see Figs 4 and 5). Therefore an analysis was performed to see the magnitude of scatter of the force values causing the grate deformation by 0.25 mm, using grates with the highest and lowest flexibility and the same number of flexible segments arranged in crosswise and lengthwise orientation (Table 4). Analysis of the data suggests that the layout of flexible segments in orientation crosswise or lengthwise has no significant effect on the grate deformability – the value of P% does not exceed 1%.

Table 4.
Impact of the layout of flexible segments (Nfs) in crosswise and lengthwise orientation on the percent scatter of force values (P%) causing 0.25 mm deformation in the most and least flexible grates

Nfs	P%	
	Orientation of flexible segments	
	Crosswise	Lengthwise
1	—	0,09%
2	0,32%	0,19%
3	0,63%	0,16%
4	0,68%	0,06%
5	0,85%	—
6	0,77%	—
7	0,68%	—

3. Discussion of results

Based on the results of simulations it was found that flexibility of the guide grate can be increased by incorporating flexible segments in orientation crosswise or lengthwise. It was also proved that the flexible segments in crosswise orientation increased the grate flexibility more effectively that in the orientation lengthwise (Fig. 6).

Analysis of the value of force F(Nfs⊥) and $F(Nfs_{\|})$ (Tables 2 and 3, respectively) shows that the designer can predict the flexibility of the designed grate in a wide range of values by incorporating the flexible segments instead of straight ribs.

The comparative analysis used in this study is sufficient for a preliminary assessment of the flexibility – elasticity of the structure of guide grates despite the adoption of a few simplifications. It has to be remembered, however, that under real conditions the stress state is different because of the physical and mechanical properties of the grate material changing as a function of temperature.

References

[1] Bajwoluk, A. & Gutowski, P. (2015). The Effect of Pallet Component Geometry on Temperature Gradient During Cooling. *Archives of Foundy Engineering*. 15(1), 5-8.

[2] Piekarski, B. (2012). *Casting from high temperature alloys in furnaces for heat treatment*. Szczecin: Wydawnictwo Uczelniane Zachodniopomorskiego Uniwersytetu Technologicznego w Szczecinie. (in Polish).

[3] Piekarski, B. & Drotlew, A. (2008). Constructing casts working in the conditions of cyclic temperature changes. *Archiwum Technologii Maszyn i Automatyzacji*. 28(3), 95-102. (in Polish).

[4] Słowik, J. (2015). *Strength analysis of elements openwork.* Master thesis. Zachodniopomorski Uniwersytet Technologiczny w Szczecinie. (in Polish).

[5] Piekarski, B. & Drotlew, A. (2010). Cast functional accessories for heat treatment furnaces. *Archives of Foundry Enginnering*. 10(4), 183-190.

[6] Drotlew, A., Garbiak, M., Kubicki, J., Piekarski, B. & Siluk, P. (2013). The construction of the pallet to the basic technological equipment for heat treatment. *Prace Instytutu Odlewnictwa vol. LIII nr 3;* 59-7. (in Polish).