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THE INFLUENCE OF TECHNOLOGICAL PARAMETERS ON OCCURRENCE OF RESIDUAL STRESSES IN IRON CASTINGS

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The paper establishes the present day state of knowledge on parameters influencing residual stresses in iron castings, based on writings on this subject. Furthermore, testing examined the influence of parameters, such as mold humidity, mold stiffness; pouring temperature and carbon equivalent (CE) on residual stresses. Tests have been carried out on standard grating test piece made of grey cast iron, poured in sand molds. The obtained measurements have been drawn in diagrams and the influence of each single parameter has been evaluated.

Key words: *iron castings, technological parameters, residual stresses*

Utjecaj tehnoloških parametra na pojavu zaostalih naprezanja u željeznim odljevcima. U radu je proučavanjem literature utvrđeno sadašnje stanje spoznaje o utjecajnim parametrima na zaostala naprezanja u odljevcima. Zatim je eksperimentalno ispitan utjecaj vlažnosti kalupa, tvrdoće kalupa, temperature ulijevanja, ugljikova ekvivalenta na zaostala naprezanja. Ispitivanja su provedena na standardnoj rešetkastoj probi od sivog lijeva koja je lijevana u pješčane kalupe. Na temelju mjernih rezultata nacrtani su dijagrami i analiziran je utjecaj svakog pojedinog parametra.

Ključne riječi: *željezni odljevci, tehnološki parametri, zaostala naprezanja*

INTRODUCTION

Residual stresses occur during process of formation of the casting, especially from the moment of building of sufficiently stable crust until attainment of the room temperature.

Depending on causes of residual stress appearance, we distinguish three kinds of stresses [1, 2]:

1. Thermal stresses σ_t. Originate from unequal changes of size within internally linked parts of the casting, caused by dissimilar intensity of heat removal during cooling off period.
2. Structural stresses σ_f. Result due to dissimilar phase and structural transformations in different parts of the casting, accompanied by change of volume.
3. Mechanical stresses σ_m. They arise because of mechanical resistance of the mold to casting shrinkage.

After completion of the cooling off period, the casting retains residual stresses, which equal the sum of stresses having different origin. If residual stresses surpass tensile strength, distortions and cracking of castings are to be expected in the process of manufacture or in stage of operation.

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THE INFLUENTIAL PARAMETERS

The residual stresses are frequent defect in production of castings, which is the reason that they are recurrently examined. The survey of influential parameters on residual stresses is shown in description of single research procedures. The residual stresses in castings depend on numerous parameters, some of them acting simultaneously.

The occurrence of residual stresses in iron castings depend on the influence of parameters such as [3 - 7]:

- casting design,
- mold humidity,
- mold hardness,
- pouring temperature,
- chemical composition (CE),
- cleaning of the castings.

However, the influence of only some of those parameters from available literature will be presented, such as:

Mold humidity

Some of the researches were conducted according to [3 - 6], and on Figure 1. [4] there is presentation of the influence of the mold humidity on residual stresses in the castings.

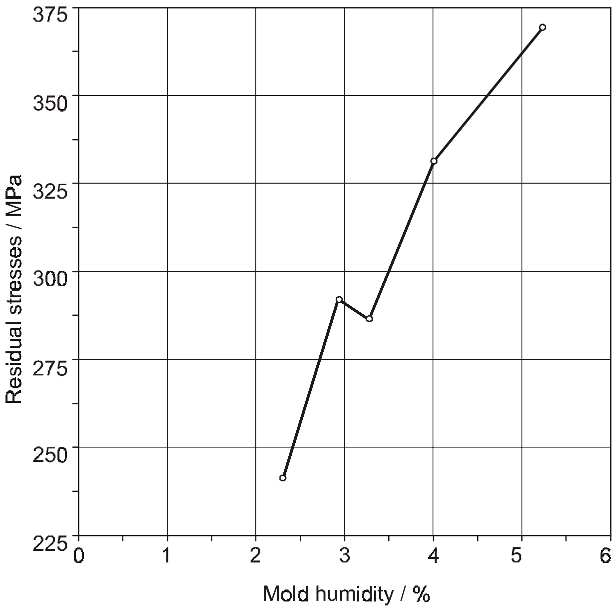

Figure 1. **Dependence of residual stresses on mold humidity [4]**
Slika 1. **Ovisnost zaostalih naprezanja o vlažnosti kalupa [4]**

The picture shows that increase in mold humidity leads to increase of residual stresses, which is explained by the fact that the more humid mold speeds up the cooling of the casting, then is the case with dry mold.

Mold hardness

Some experiments were conducted according to [3 - 6], and the Figure 2. [4] and they show the influence of mold hardness on the height of residual stresses in the castings.

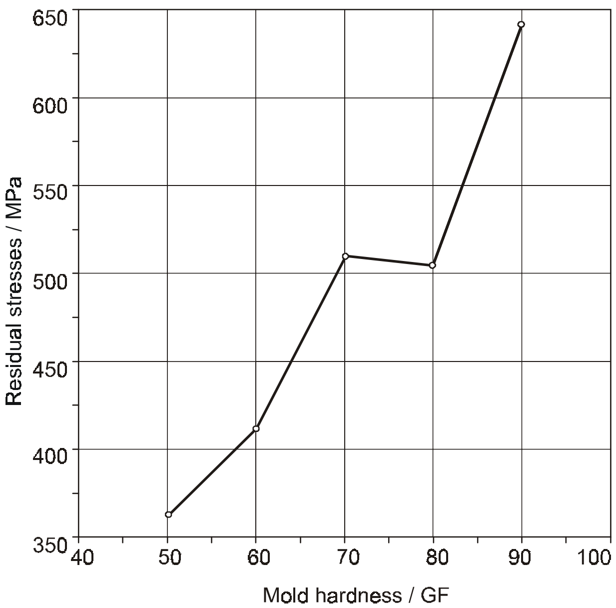

Figure 2. **Dependence of residual stresses on mold hardness [4]**
Slika 2. **Ovisnost zaostalih naprezanja o tvrdoći kalupa [4]**

The picture shows that increase in mold stiffness leads to increase of residual stresses, which is explained by the fact that the hard mold gives bigger resistance to casting shrinkage during process of cooling off in the mold.

Pouring temperature

Some experiments were conducted according to [3 - 6], and the Figure 3. [4] shows the influence of pouring temperature on the height of residual stresses in the castings.

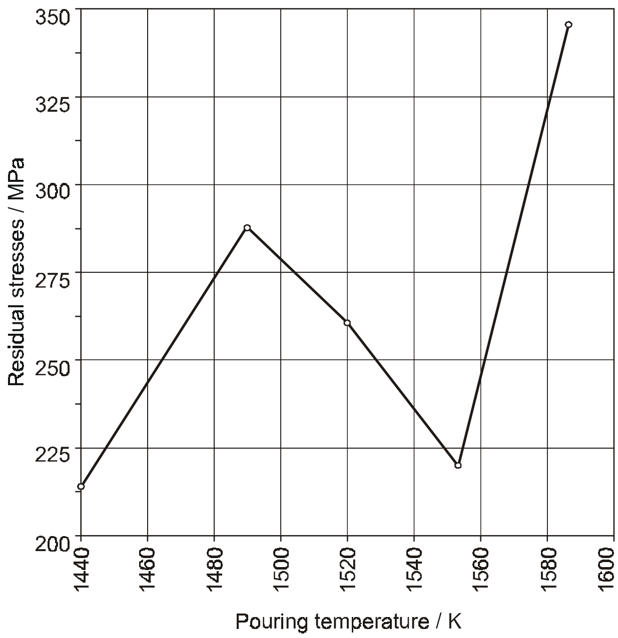

Figure 3. **Dependence of residual stresses on pouring temperature [4]**
Slika 3. **Ovisnost zaostalih naprezanja o temperaturi ulijevanja [4]**

The figure shows the smallest values of residual stresses at pouring temperature of 1500 K, while further increase in pouring temperature leads to increase of residual stresses in the casting.

Chemical composition - Carbon equivalent (CE)

Chemical composition of the casting also exerts significant influence on the height of residual stresses, i.e. CE. CE influence is shown in Figure 4. [5].

The figure shows that increase of CE leads to decrease of residual stresses in castings. This phenomenon is explained by reduction of tensile strength and the hardness of the grey casting.

Therefore, the greater CE results with lower hardness of materials, which enables local plastic deformations and reduces residual stresses.

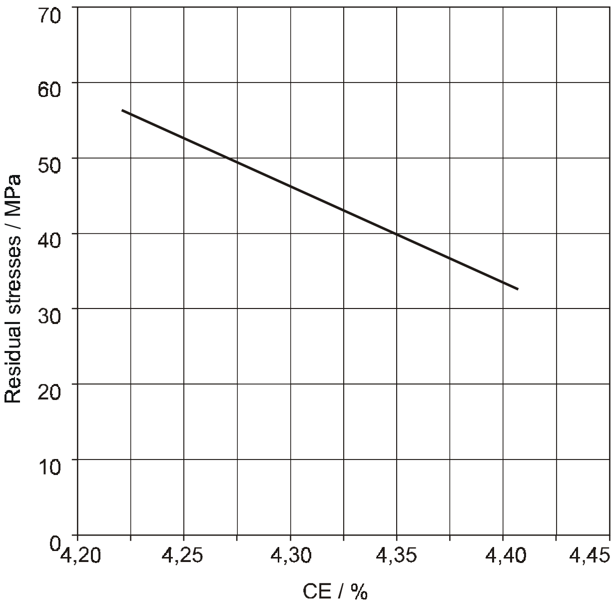

Figure 4. **Dependence of residual stresses on CE [5]**
Slika 4. **Ovisnost zaostalih naprezanja o CE [5]**

RESULTS AND DISCUSSION

To extend the scope of previous knowledge on residual stresses in iron castings, tests were conducted on standard grating poured out of grey cast iron in single sand mold having size 210 × 370 × 55/55 mm.

Tests were conducted in accordance with the test schedule 2^4, which means that four influential parameters were examined on two levels.

The influential parameters during testing had the following range:
- mold humidity, V = 4 and 8 %,
- mold hardness, GF = 60 and 90,
- pouring temperature, t_u = 1350 and 1400 °C,
- chemical composition (CE) = 4, 27 and 4, 4 %.

Calculation of residual stresses

Residual stresses were calculated according to the following equation:

$$\sigma = \varepsilon \cdot E \quad (1)$$

$$\varepsilon = \varepsilon_2 - \varepsilon_1 \quad (2)$$

where:

σ - residual stresses / MPa,
ε - real distortion / (μm/m),
E - module of elasticity, in calculation taken to be 105 000 / MPa,
ε_1 - initial (Referential) distortion value /(μm/m),
ε_2 - distortion of grating probe after removal of loading / (μm/m).

Distortions were measured by application of electric resistant strain gages of the type 1,5/120 LY 11, by the manufacturer Hottinger Baldwin Technik GMBH. The strain gage tape is glued on the grating probe and connected by wires to digital device for measurement of distortion DMD 20 of the same company.

Firstly, the initial (referential) distortion ε_1 is being measured on the grating probe containing residual stresses. After that the outer bars of the grating probe are cut by hand saw. No increase of heat of the grating probe is allowed during process of cutting, which might exert influence on measuring results. Cutting of external bars leads to removal of residual stress of the grating probe. After cutting of the bars distortion of the grating probe ε_2 after removal of load is being measured. Finally, the real distortion ε is being measured according to (1).

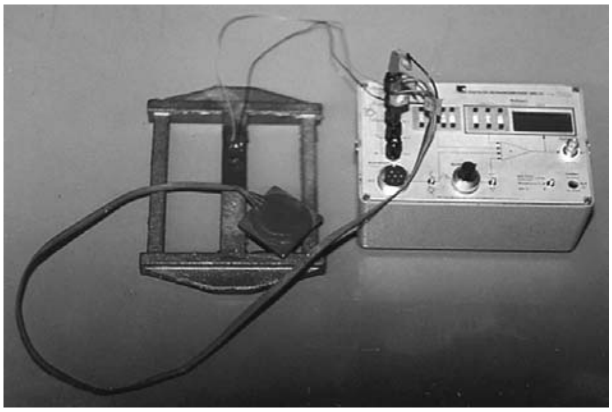

Figure 5. **Measurement of distortion on grating probe**
Slika 5. **Mjerenje deformacija na rešetkastoj probi**

Measurement of distortion on grating probe has been shown on Figure 5.

TEST RESULTS

Test results have been shown in (Table 1.).
On the basis of obtained values given in Table 1., diagrams of dependency of residual stresses on four influential parameters have been drawn as given below.

Mold humidity

The influence of mold humidity on residual stresses has been shown in Figure 6.

Table 1. **Test results**
Tablica 1. **Rezultati ispitivanja**

No	V / %	GF	t_u / °C	CE	σ_m N/mm^2	No	V / %	GF	t_u / °C	CE	σ_m N/mm^2
1	4	60	1350	4,27	56,28	17	4	60	1350	4,4	47,3
2	8	60	1350	4,27	78,74	18	8	60	1350	4,4	73,96
3	4	90	1350	4,27	67,42	19	4	90	1350	4,4	58,3
4	8	90	1350	4,27	84,41	20	8	90	1350	4,4	77,92
5	4	60	1400	4,27	66,18	21	4	60	1400	4,4	56,2
6	8	60	1400	4,27	86,65	22	8	60	1400	4,4	80,16
7	4	90	1400	4,27	71,32	23	4	90	1400	4,4	64,6
8	8	90	1400	4,27	87,4	24	8	90	1400	4,4	83,36
9	4	60	1350	4,27	50,2	25	4	60	1350	4,4	43,15
10	8	60	1350	4,27	75,04	26	8	60	1350	4,4	64,64
11	4	90	1350	4,27	63,5	27	4	90	1350	4,4	50,2
12	8	90	1350	4,27	80,68	28	8	90	1350	4,4	72,24
13	4	60	1400	4,27	56,25	29	4	60	1400	4,4	46,8
14	8	60	1400	4,27	81,92	30	8	60	1400	4,4	75,84
15	4	90	1400	4,27	65,21	31	4	90	1400	4,4	57,3
16	8	90	1400	4,27	84,25	32	8	90	1400	4,4	79,96

Following the points in the diagram a line can be drawn showing dependency of residual stresses for different values of influential parameters. The line is drawn approximately, and it shows how the increase in mold humidity leads to increase of residual stresses. This can be explained by the fact that higher mold humidity results in faster cooling and solidification of the grating probe, then with molds having lower humidity content.

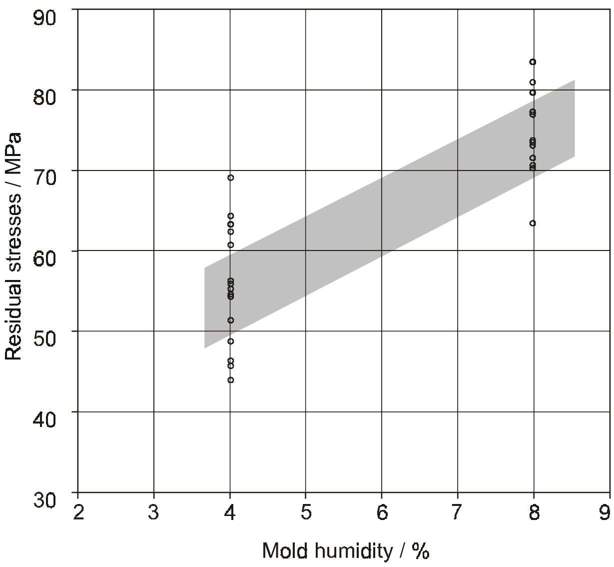

Figure 6. **Change of residual stresses depending on mold humidity**
Slika 6. **Promjena zaostalih naprezanja u ovisnosti od vlažnosti kalupa**

Mold hardness

The influence of mold hardness on the height of residual stresses has been shown in Figure 7.

Following the points in the diagram a dependency line of residual stresses and mold hardness can be approximately drawn. It shows that residual stresses increase with increase of mold hardness. This can be explained by the fact that higher mold hardness gives greater resistance to casting shrinkage, which has been confirmed in already published referential works.

Pouring temperature

The influence of pouring temperature on the height of residual stresses is shown in Figure 8.

The line following diagram points shows dependency of residual stresses on pouring temperature. The figure shows the increase of residual stresses depending on pouring temperature, which has also been confirmed in the published accessible literature (for temperatures over 1500 K).

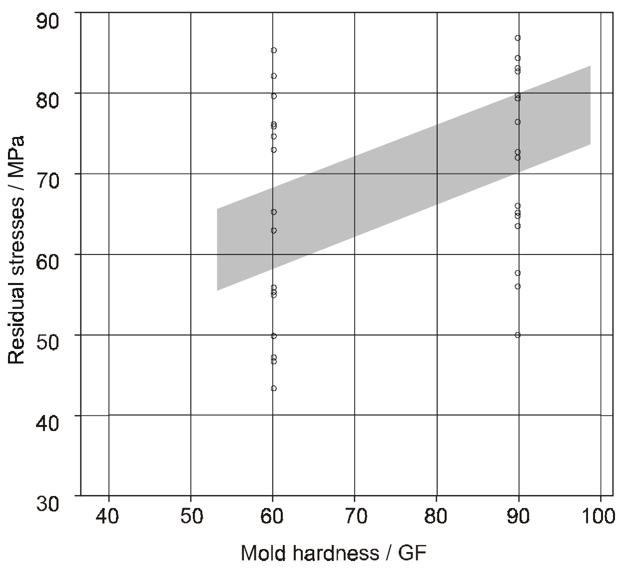

Figure 7. **Change of residual stresses depending on mold hardness**
Slika 7. **Ovisnost zaostalih naprezanja o tvrdoći kalupa**

Chemical composition (CE)

The influence of chemical composition (CE) on height of residual stresses has been shown in Figure 9.

Following the points in diagram we obtain approximate line leading to conclusion that greater CE values correspond

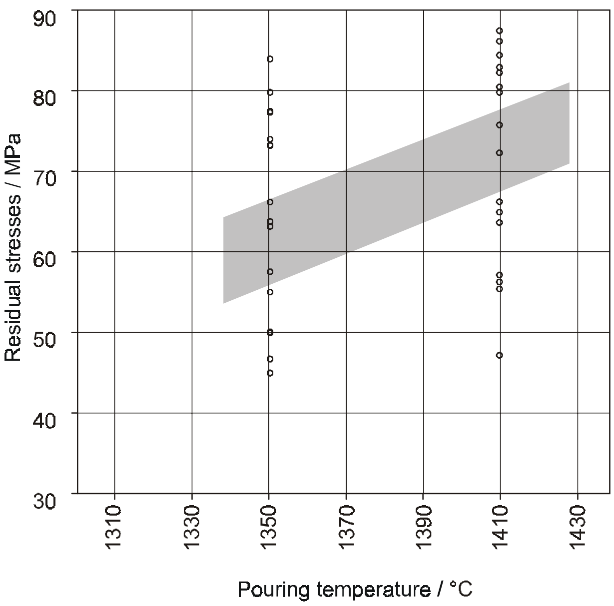

Figure 8. **Dependence of residual stresses on pouring temperature**
Slika 8. **Ovisnost zaostalih naprezanja o temperaturi ulijevanja**

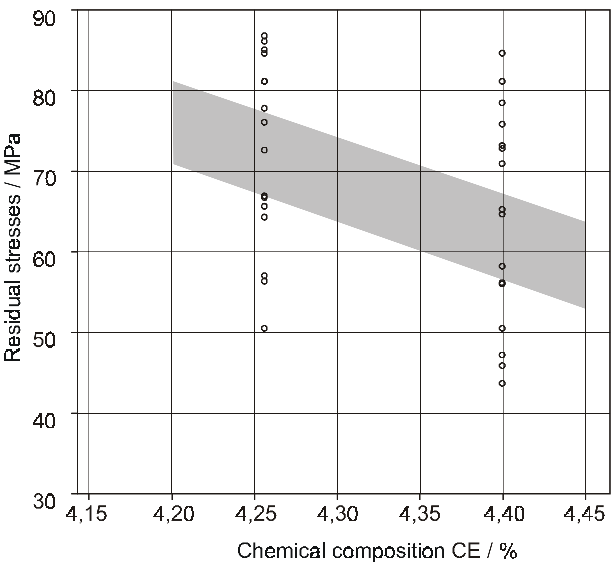

Figure 9. **Dependence of residual stresses on chemical composition (CE)**
Slika 9. **Ovisnost zaostalih naprezanja o kemijskom sastavu (CE)**

to lower values of residual stresses. This phenomenon explains the fact that increase of CE reduces strength and hardness (enabling local plastic distortions), so that also residual stresses are being reduced. These results are also being confirmed in previously published referential works.

CONCLUSION

This paper presents the influence of some parameters on residual stresses in castings on the basis of available referential data. Further it examines the influence of

- mold humidity,
- mold hardness,
- pouring temperature,
- chemical composition (CE)

on residual stresses occurring during casting of standard grating probe (test piece) made of grey cast iron in a single sand mold. Test results are given in Table 1. and are confirmed by previous research.

Further studies and statistical processing of data with more technologically influential parameters are to be expected, as well as publishing of obtained results on other kinds of castings.

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