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Increase of Liquid Metal Utilization during Production of Bearing Circle Castings for Cement Furnaces

A. Zadera[a*], J. Senberger[a], Z. Carbol[b], J. Pluhaček[b]

[a]Department of Foundry, Institute of Engineering Technology, Brno University of Technology, Brno, Czech Republic
[b]Joint-stock company of Vítkovice Heavy Machinery a.s, Ostrava - Vítkovice, Czech Republic
*Corresponding author. E-mail address: zadera@fme.vutbr.cz

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Abstract

In manufacture of super heavy castings for cement furnaces a saving of liquid metal has been achieved by lowering the riser weight. By solidification modelling with the aid of the Niyama criterion a zone in the riser was designated where the occurrence of foundry defects (shrinkage porosity) can be expected. A plate of the material of dimensions ca 700*800*250 mm was taken from the riser. After thermal treatment the samples for making the bars for the static tensile test were taken from it. Based on done tests it has been found out that mechanical characteristics obtained from the static tensile test correlate, besides contraction, in the chosen level of statistical importance of p = 0.01 with carbon content. Neither in the zone of probable occurrence of defects designated by the Niyama criterion during solidification modelling the drop of strength characteristics was observed. Carbon content in a decisive extent influenced the strength characteristics. In case of ductility and contraction the convenient correlations with carbon content were observed from the riser height of 200 mm only. In the height of 400 mm there was already considerable variation of values and some values were lower ones than is demanded by standards.

Keywords: Heavy Castings, Modelling of Solidification, Breaking Strength, Yield Value, Ductility, Contraction

1. Introduction

Bearing circles of cement furnaces in the foundry of the joint-stock company of Vítkovice Heavy Machinery a.s. belong to heavy castings of the highest weight. Heavy castings are considered that ones of the wall thickness higher than 300 mm or the castings with a riser of diameter higher than 800 mm. The increase of liquid metal utilization in castings of the chosen type can be achieved both by decreasing the riser weight and by decreasing the dimension of technological allowances and working allowances. When checking a possibility of increasing the liquid metal utilization in circle castings the authors of the paper resulted from modelling the casting solidification with the aid of so called simulation programmes of cooling and solidification. In heavy steel castings the material quality under the riser is influenced in particular by segregation processes and further on by worsened conditions for metal feeding. Segregation processes are related to the change of element solubility in the melt and in the forming solid phase during solidification and they are strongly influenced by solidification time [1, 2]. The worsened conditions for feeding are meant the processes connected with filtration – penetration of the melt through the dendrite network. This phenomenon occurs already after separation of ca 20 – 30 % solid phase when the mechanical motion of the free melt level is interrupted and in such a way the conditions for feeding are worsened. Next feeding into the interdendritic spaces is then possible only with mentioned metal filtration through the dendrite

network [3]. It is usually expected that in the casting under the riser there are the highest segregations and service degradations of the material (shrinkage porosity, shrinkage microcavities). Defects caused by insufficient treatment of thermal nodes in the casting aren't taken into account here.

Quality demands on super heavy castings for cement furnaces are high and any change of their manufacturing technology need to be carefully prepared. In case of a new technology resulting from using the heavy weight chillers it was able to increase the controlled solidification extent. Based on the casting simulation it has been found out that the shrinkage porosity and shrinkage microcavities zone moved upwards in the riser and in the riser lower part the metal is without foundry defects of the shrinkage porosity and shrinkage microcavities types [4]. Under these conditions it is possible to lower the riser. Before changing the technology, with regard to demands made on the casting, the metal properties in the lower riser part were analysed. Bars for the static tensile test were made from samples taken from the riser and further on the strength was measured in individual sampling points. Chemical composition of metal was determined for all tensile test samples.

2. Description of done tests

The casting was moulded in the furan moulding mixture. A chromite layer was on the mould face. Altogether 260 t of liquid metal from 4 ladles were consumed for casting the mould according to the original technology. For the experimental casting the same amount of liquid steel as for the original technology was used for manufacture. A sample for determination of chemical composition was taken from each ladle. Metal composition from individual ladles ranged in an interval given in Table 1.

Steel in all ladles was treated on secondary metallurgy devices. All the ladles were marked by low sulphur and nitrogen contents that are from the point of view of service degradation of the material the most important for the reason of segregations. Aluminium content given in Table 1. represents total aluminium. Based on experience the content of aluminium dissolved in mentioned castings metal is by 0.002% up to 0.004% lower than total aluminium content. The casting shape and dimensions are given on Figure 1. Simulation of filling, cooling, and solidification was modelled in the Procast programme.

The formation of shrinkage porosity and shrinkage microcavities was evaluated in the model according to the Niyama criterion [1] and further on according to the thermal gradient size. It has been found out from results of cooling and solidification simulations that after changing the technology the foundry defects zone moved towards the riser centre and the lower riser part contains a metal free of foundry defects. Results of foundry defects modelling are given on Figure 2.

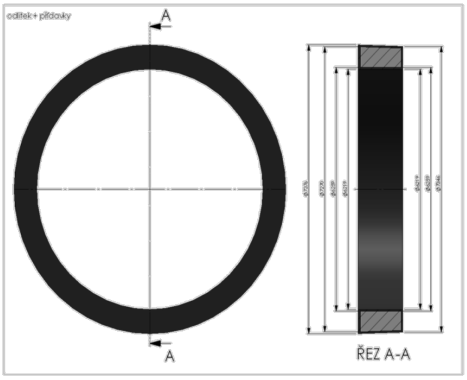

Fig. 1. Casting of the bearing circle of the cement furnace

Fig. 2. Occurrence of defects in the casting of a cement furnace circle

Results of foundry defects modelling ware subsequently compared with measurements of basic characteristics during the static tensile test. A plate of thickness of 250 mm was cut from the riser normal to it's axis and samples for making the bars for the static tensile test were taken from it. Before cutting the plate material was thermally treated by normalization (910°C/air). Chemical composition of steel was determined from each sampling point. Sampling points are given on Figure 3. The first series of samples was taken from a lower part of the riser neck and the next ones from the layers always by 200 mm. 5 samples were made and tested in each layer.

Table 1.
Interval of chosen elements of melts used for casting the circle in weight %

	C	Mn	Si	P	S	Al	N
min	0.22	1.37	0.41	0.006	0.001	0.025	0.0036
max	0.23	1.39	0.45	0.008	0.002	0.035	0.0061

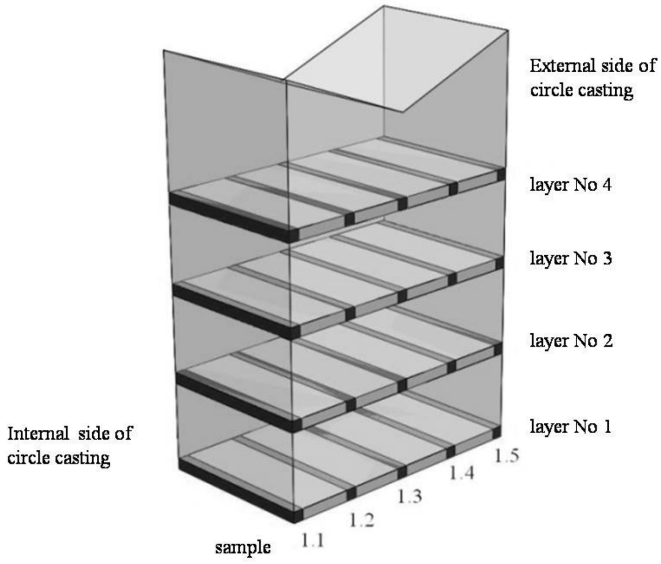

Fig. 3. Sampling scheme

3. Evaluation and interpretation of results

It has been found out by cooling and solidification simulation in the PROCAST programme that the probable point of forming the foundry defects (shrinkage microcavities) is situated in the riser thermal axis in distance of ca. 300 up to 400 mm from the upper riser edge. It has been expected in the experiment that the determined strength and plastic material characteristics during the static tensile test will be most influenced by the carbon segregation. Dependence of breaking strength (R_m), yield value ($R_{p0.2}$), and ductility (A) and contraction (Z) on the carbon content was expressed for the researched casting by a linear dependence in a form of (1) [5].

$$Y = a \cdot X + b \tag{1}$$

Y – the material characteristic value determined during the tensile test (R_m, $R_{p0.2}$, A, Z)
X – carbon content [weight %]
a, b – constants

Results of regression analysis for individual characteristics are given in Table. 2. Further on the Table 2 gives values of the correlation coefficient. In equation (1) the evaluated level of statistical importance of p = 0.01 for 19 freedom degrees the critical value is $r_{0.01} = 0.54$.

Table 2.
Constants a, b for regression dependences R_m, $R_{p0.2}$, A, and Z expressed in the equation (1)

Y	A	B	R
R_m	652.5	383.4	0.70
$R_{p0.2}$	332.8	243.7	0.85
A	-31.2	29.1	0.56
Z	-81.8	70.0	0.53

For strength characteristics (R_m and $R_{p0.2}$) and ductility the linear dependence on carbon content is statistically important in the all studied range. According to work [6] the carbon content in the riser can be estimated on the base of carbon content in the melt sample and the total thermal gradient size (grad T) calculated in the simulation Procast programme. The work [6] studied the carbon segregation in a riser of a cone frustum shape where heat was removed in all directions. In case of a riser of an annular ring shape heat isn't removed in the direction of the riser axis. Therefore the conditions for segregation of elements during solidification are different than in the conic riser. Figure 4. shows a dependence of carbon content on a value of the total thermal gradient (grad T) in sections parallel with the riser section axis. Data marked in Figure 4. as V 3 represent the data obtained from the riser thermal axis; data marked as V 2, 4 were measured in distance of 165 mm from the riser wall and data marked V 1, 5 were measured 20 mm from the riser wall, see Figure 3. Correlations between carbon content and the total thermal gradient in the riser axis (V3) and in distance 20 mm from the riser wall (V1, 5) are statistically important at the chosen level of statistical importance of p = 0.05. Correlation between carbon content and the thermal gradient wasn't found out in samples taken from points nearest the riser surface (V1, 5).

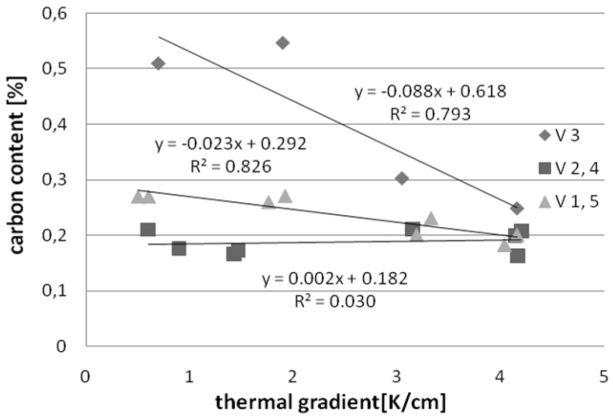

Fig. 4. Correlation between thermal gradient and the carbon content

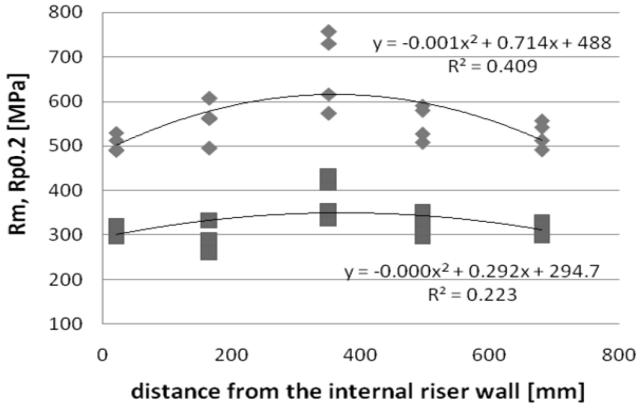

Fig. 5. Correlation between strength characteristics and a distance from the internal riser wall

Figure 5 shows dependence between strength characteristics in individual riser layers and a distance from the internal riser wall. A distance on the x axis = 20 corresponds to the internal riser wall on Figure 5. It is evident from results given on Figure 5. that strength characteristics in the given layer grow towards the riser centre with growing carbon content. In all layers the strength characteristics are convenient and the variance of R_m and $R_{p0.2}$ values is most of all influenced by carbon content.

Dependence of strength characteristics R_m and $R_{p0.2}$ is given on Figure 6. It is evident from Figure 6, that the dependence of strength and yield value on carbon content is statistically important. From the point of view of demands on the casting material the strength characteristics in the all studied riser zone are convenient.

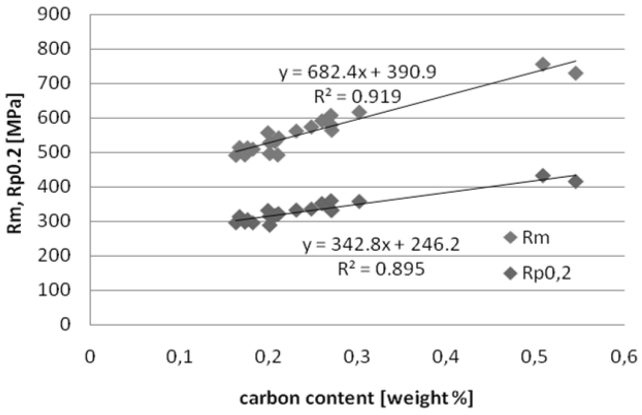

Fig. 6. Dependence of breaking strength and yield value on carbon content

Figure 7.gives dependence between plastic characteristics (A, Z) in individual riser layers and a distance from the internal riser wall. Dependences given on Figure 7 aren't statistically important. Ductility and contraction values show considerable variance and in many cases they are lower than demands made on the casting material of wall thickness more than 100 mm.

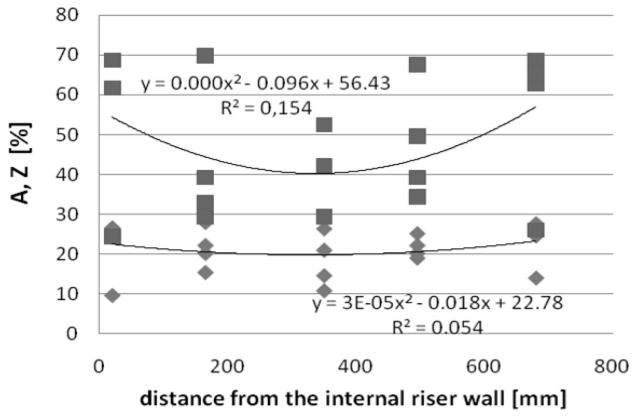

Fig. 7. Dependence between plastic characteristics (A, Z) and a distance from the internal riser wall

Change of ductility in individual layers in dependence on the sample position is given on Figure 8. From the point of view of demands on the material the ductility values in first two layers are convenient (more than 20%). In next layers the ductility values even lower than 15% already occur. The ductility change tendency in these layers no more corresponds neither to carbon content nor a distance from the internal riser wall.

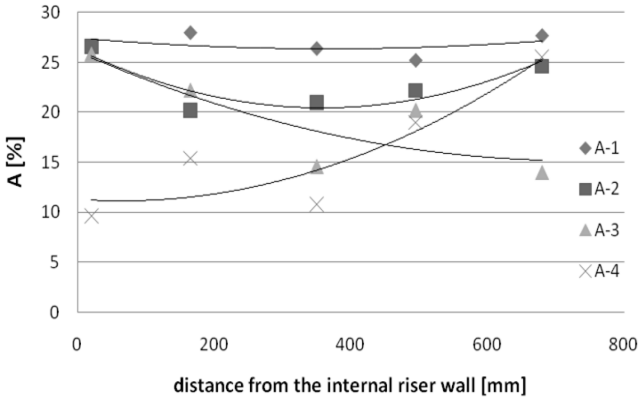

Fig. 8. Course of ductility values in dependence on a distance on the x axis

It can be expected that foundry defects will influence the values of yield point and partly of strength too only in such cases when they are of a macroscopic size and in such a way they considerably decrease the test bar diameter. In case of ductility and contraction the defects of microscopic size, segregation zones, and structure defects can already be effective.

4. Summarization and conclusion

The work presented by this paper was aimed at reducing the liquid metal consumption in manufacture of circle castings for cement furnaces. In the first phase the simulation of mould filling and subsequent cooling and solidification was done in several variants in the Procast programme. Based on results of individual variants a technology ensuring both the lowest defect occurrence, and at the same time the maximum utilization of liquid metal has been proposed. During solidification modelling a zone of occurrence of foundry defects was determined in the riser. In the riser point, where the highest influence by those defects was expected, the samples for the tensile test were taken. Mechanical properties during the tensile test were determined on 20 samples taken along the all riser cross section and chemical composition was analysed. Based on simulations the total solidification times and values of the total thermal gradient were further on determined in the studied points. Based on the experiment results the following conclusions were determined:

a) In the casting and riser thermal axis the most extensive manufacturing degradation of the material takes place as a result of element segregation with the formation of foundry defects. It followed from results of done tensile tests that the material of the casting of the cement furnace circle in all points of the riser neck and in the first studied layer meets the standard demands and thus the wall thickness (700 mm) doesn't influence the material properties in this zone.
b) Strength characteristics of steel correlate with carbon content and from the point of view of the standard demands on the given material in the studied zone they are convenient.
c) Convenient correlation between the value of total thermal coefficient and carbon content has been determined for the studied casting. Based on calculated total gradient the carbon content in the riser can be predicted with sufficient reliability.
d) With solidification modelling a zone of all probable occurrence of foundry defects in a distance of ca 400 mm above the section between the riser and the casting was marked out in the riser. In these places the defects can be formed that can cause a breach of strength or plastic properties in the given riser place.
e) Ductility values correlate on the chosen level of statistical importance with carbon content but they don't correlate with the sample position in the riser place. The ductile value variance is highest in layers of 400 and 600 mm above the section point. The highest variance of ductility values was found out in the place of defect occurrence predicted by the simulation programme. Some ductility values don't meet the standard demands on the given material.
f) Contraction on the chosen p level of statistical importance doesn't correlate both with carbon content and with the position in the riser point too. Similarly as in case of ductility the high variance of contraction values occurs in the riser zone above 400 mm from the section between the riser and the casting. The deviation of measured values from the functional dependence of plastic characteristics on carbon content can be explained by the presence of foundry defects of microscopic size (shrinkage microcavities) the influence of which will appear in the static tensile test during deformation.
g) Based on modelling and done testing it has been recommended under the studied conditions to decrease the riser height by 200 mm.

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