

# Solidification of heavy castings

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## Abstract

Quality of the casting material is influenced by great numbers of material properties, metallurgical treatment, and particular solidification conditions too. In the case of solidification of heavy castings the properties and quality of the casting material are considerably changed in consequence of running segregation phenomena, worsen metal feeding conditions, and microporosity formation etc. It can even result in defaulting the required strengths and plasticity of the casting material. The work deals with changes of chemical composition and changes of mechanical properties in places with a long solidification time corresponding to them.

**Keywords:** Heavy castings; Segregation; Temperature gradient

## 1. Introduction

In manufacture of heavy castings the foundry defects always occur that cause the higher costs of finishing operations and that can also cause the increased costs resulting from complaints by customers. Further on it is necessary all the time to decrease the consumption of liquid metal for individual castings and thus to decrease the costs of casting manufacture [1, 2]. One of ways of the cost reduction is decreasing the liquid metal consumption and the decrease of machining allowances. The decrease of liquid metal consumption is conditioned partly on the solidification modelling, partly on knowledge of the segregation method and the formation of shrinkage microporosity on the riser/casting interface and in lower riser parts. While professional programmes cope with solidification modelling, the models aren't sufficiently tested in operation for determination of segregations and zones with shrinkage microporosity. Some works are aimed at the field of segregation simulations [3] and their consequences, e.g. in a form of conchoidal fractures [4, 5]. The work was aimed at experimental obtaining the data about the segregation and shrinkage microporosity zones in a massive riser and on the basis of this information in the future to suggest the criteria for prediction of chemical composition and the segregation extent in heavy castings.

## 2. Description of the experiment and used testing methods

The formation of segregations and shrinkage microporosity was analyzed on a riser of diameter 1600 mm from a steel casting. A plate ca. 100 mm thick was cut out from the riser in its thermal axis. The plate was machined and it served for manufacture of mechanical test samples. At the same time the chemical composition was determined in chosen places of the riser (fig. 1.). As results from fig. 1., the chemical composition was determined in chosen places of the riser, and namely in three layers from casting surface in distances of 200, 400 and 600 mm. Chemical composition was determined 3 times in every place. Mean values of chemical composition (average from tree measurements) are given in table 1.

Table 1. gives chemical composition of steel in layers (distances from the casting) as follows: under the C letter – 600 mm, under the B letter – 400 mm, and under the A letter A – 200 mm from the casting surface. The first column under the given letters further on gives the distances (50 up to 600 mm) from the riser surface (side wall). To the riser places where chemical composition was determined the calculated temperature gradients were adjoined. Temperature gradients  $T$  were calculated in the PROCAST programme. Heat is removed in all three directions.

From the temperature field shape it can be expected that the most intensive heat removal has the vertical component in the riser axis direction. Fig. 2. shows the course of total temperature gradient. In one riser half it can be also described by a polynomial of the

2<sup>nd</sup> degree. A correlation between carbon content in individual layers and temperature gradient values from the surface towards the riser centre can be expected.

Table 1.  
Mean values of element concentration in the given place of the riser [weight %]

| layer | distance [mm] | %C   | %Mn  | %Si  | %P    | %S     | %Al   | %N     |
|-------|---------------|------|------|------|-------|--------|-------|--------|
| C     | 600           | 0.52 | 1.69 | 0.57 | 0.026 | 0.0189 | 0.016 | 0.0230 |
|       | 400           | 0.46 | 1.66 | 0.53 | 0.024 | 0.0126 | 0.016 | 0.0214 |
|       | 250           | 0.40 | 1.53 | 0.49 | 0.017 | 0.0091 | 0.016 | 0.0190 |
|       | 150           | 0.22 | 1.38 | 0.46 | 0.011 | 0.0048 | 0.017 | 0.0137 |
|       | 50            | 0.16 | 1.27 | 0.41 | 0.008 | 0.0045 | 0.018 | 0.0099 |
| B     | 600           | 0.40 | 1.6  | 0.52 | 0.021 | 0.0096 | 0.016 | 0.0194 |
|       | 400           | 0.35 | 1.52 | 0.50 | 0.015 | 0.0081 | 0.016 | 0.0149 |
|       | 250           | 0.33 | 1.47 | 0.47 | 0.013 | 0.0070 | 0.016 | 0.0170 |
|       | 150           | 0.23 | 1.43 | 0.47 | 0.011 | 0.0038 | 0.017 | 0.0088 |
|       | 50            | 0.17 | 1.32 | 0.42 | 0.009 | 0.0033 | 0.018 | 0.0101 |
| A     | 600           | 0.32 | 1.45 | 0.47 | 0.014 | 0.0073 | 0.016 | 0.0167 |
|       | 400           | 0.33 | 1.46 | 0.47 | 0.015 | 0.0073 | 0.017 | 0.0166 |
|       | 250           | 0.28 | 1.41 | 0.46 | 0.013 | 0.0061 | 0.017 | 0.0152 |
|       | 150           | 0.20 | 1.36 | 0.45 | 0.011 | 0.0039 | 0.018 | 0.0116 |
|       | 50            | 0.16 | 1.27 | 0.41 | 0.008 | 0.0045 | 0.018 | 0.0099 |

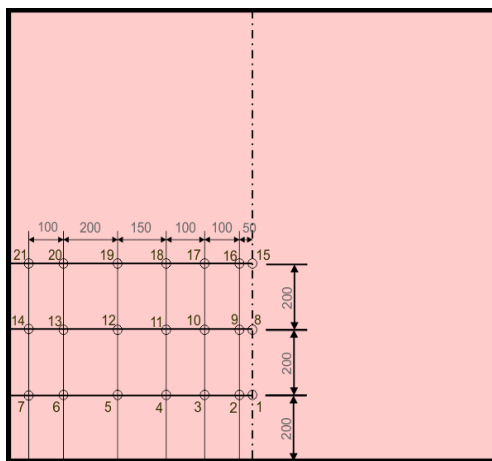


Fig. 1. Schematic depicting of places where steel composition was determined

### 3. Segregation of carbon during steel cooling in the riser

From all present elements the carbon segregation has the highest influence on mechanical values determined with tensile test and on steel hardness. Carbon concentration in the riser in the measured layers is given on fig. 3.

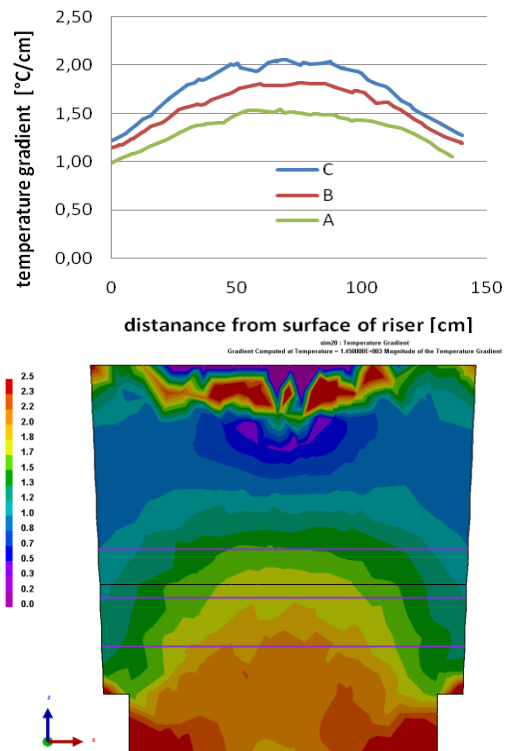


Fig. 2. Graphic depiction of temperature gradient values in dependence on position in the riser

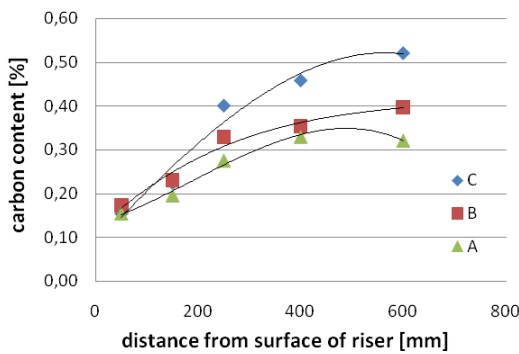


Fig. 3. Segregation of carbon in A, B, C layers as a function of distance from surface of riser

Up to the distance of 150 mm from the riser surface the carbon content in steel is lower than that one in steel in the ladle. The variance of carbon content values within the riser height (up to 600 mm) is only small too. Up to the distance of ca. 2/3 from the riser surface the carbon content grows. In the last third (in the riser centre) the change of carbon content is already small.

Based on statistical evaluation of temperature gradient values and carbon content the equation (1) has been formulated expressing the dependence of carbon content in the riser material on temperature gradient in all studied riser zone, i.e. 200 mm from the casting surface up to the distance of 600 mm from the casting surface.

$$\%C = 1,41 \cdot V \cdot \text{grad}T - 0,068 \cdot \text{grad}T - 1,321 \cdot V + 0,127 \quad (1)$$

V – Distance from the casting surface [m]

Equation (1) was then used for comparison of calculated and measured values of carbon content in studied part of the riser on the basis of real values of temperature gradient and the distance from the casting surface. 15 pairing values of measured and calculated carbon concentration were compared in such a way (fig. 4.). The dependence given on fig. 4. is with 15 measurements on the importance level  $p = 0.05$  statistically important.

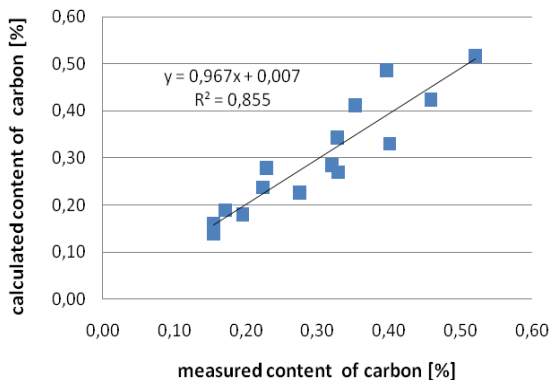


Fig. 4. Correlation between measured and calculated values of carbon content in the studied riser zone

Segregation of carbon in the riser for the studied riser can be described with the above mentioned equation (1). The given method expresses a way how the segregation processes in massive casting cross-sections can be described on the basis of statistical analysis and how they can be then used for predicting the concentration of carbon or other arbitrary chosen element. Knowledge of carbon concentration in chosen casting or riser cross-sections is important as its value strongly influences mechanical properties too. Values of mechanical properties in dependence on carbon content can be expressed with the aid of equations (2) up to (4). They were obtained by regression analysis of chemical composition values and mechanical values measured during operational melts. The values are valid for cast-on test samples of non-alloy steel in after normalizing state.

$$R_m = 249,9 + 1069 \cdot C \quad [\text{MPa}] \quad (2)$$

$$R_e = 147,0 + 6365 \cdot C \quad [\text{MPa}] \quad (3)$$

$$A_5 = 44,2 - 61,1 \cdot C \quad [\%] \quad (4)$$

If the relations (2) and (3) are used for carbon contents in the riser given on fig. 3., then it is possible to predict the strength values in different riser places (fig. 4.). Fig. 5. shows graphical dependence of the distance in the riser (carbon content) on elongation to fracture values.

Calculated course of breaking strength and yield point of steel is similar as the course of carbon content concentration in the riser. Up to the distance from the riser surface of ca. 200 mm the differences of calculated breaking strength and yield point for individual layers are small. The strength values grow up to the distance of 300 up to 400 mm from the riser surface. In distance from the riser surface more than 400 mm the calculated changes of breaking strength and yield point towards the riser centre are already small but differences between individual layers are great. The greatest change of carbon concentration and consequently the change of strength properties too run up to the distance of ca. 400 mm from the riser surface. Changes of carbon concentration and strength properties in the casting centre are then small.

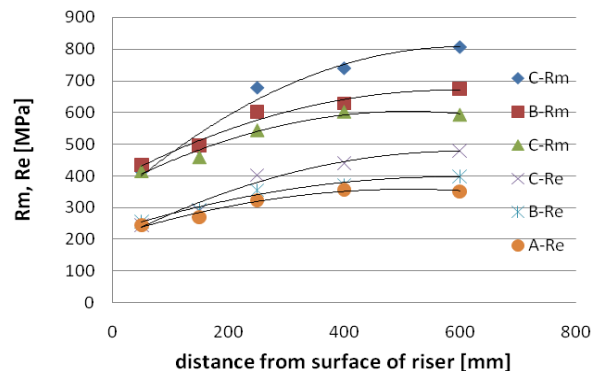


Fig. 5. The  $R_m$  and  $R_e$  values calculated for given carbon contents according to equations (2) and (3)

Prescribed mechanical values for the material of the studied casting are given in table 2. According to table 2 the strength values on the riser surface would be lower than that ones given in the prescription. The riser material achieves the prescribed strength values only in distance of ca. 250 mm from the riser

surface in height of 400 mm in the riser. Differences in the yield points on the riser surface and in its centre form 40 up to 90 %. Hardening and tempering used to be prescribed for castings from this material. Under these conditions the strength values can be achieved on the casting surface too.

Table 2.

Prescribed mechanical values for the casting material

| $R_{eH}$ [MPa] | $R_m$ [MPa] | $A_5$ [%] | Z[%]    | HBW       |
|----------------|-------------|-----------|---------|-----------|
| min. 350       | 550 - 700   | min. 20   | min. 50 | 163 - 207 |

Change of elongation as a function of distance from the casting surface is given on fig. 6. In calculated values of elongation near the casting surface the differences for samples taken in the height are small. With growing carbon content the elongation falls down. With the lowest carbon contents in the „A“ layer, i.e. 200 mm above the casting surface, the calculated elongation values are not changed in practical terms. The calculated elongation values are convenient. In „B“ and „C“ layers the elongation value falls down into the thermal axis zone.

Prediction of strength properties and elongation doesn't consider the occurrence of foundry defects. These defects as shrinkage microporosity can occur in studied riser zones and they can influence real mechanical properties.

solidification were determined. These values were then compared with chemical composition and a statistically important connection between temperature gradient and the change of carbon content in riser cross-section was found out. It made possible to express this connection also mathematically with good agreement between real and calculated carbon content.

If it will be able to determine carbon content then it will be possible to predict fairly well the values of mechanical properties during tensile test too. But for improving the model accuracy it is necessary to do further measurements for being possible to verify the given process more.

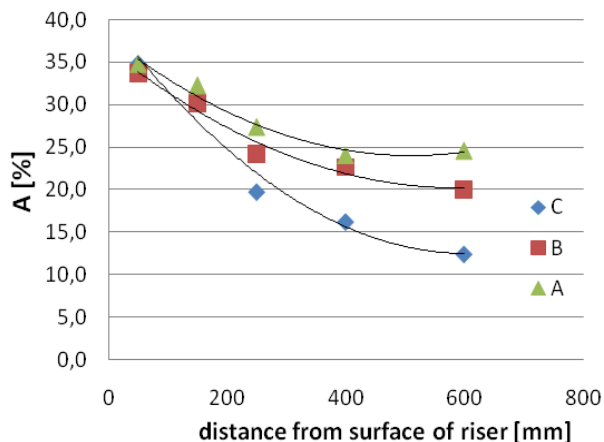


Fig. 6. The  $A_5$  values calculated from carbon contents according to the equation (4)

## 4. Conclusions

The contribution deals with problems of solidification of heavy casting and their risers. Based on numerical simulations the values of temperature gradient in the riser during riser

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