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Determining the Temperature Variation of the on the Wall of the Casting Mould during the casting of the Hadfield Steel

The present paper approaches the analysis of the metal temperature variation during the filling and solidification of steel in the casting mould. Furthermore we made determinations upon the heat transfer through the wall of the casting mould. The casting temperature, the casting speed and the heat transfer through the walls of the mould have a remarkable impact upon the shrinkage process for the prevention of casting defects (heat cavities and cracks). These cavities are also development cores for the heat cracks and the concentration of strains, which reduce the chemical, physical and mechanical properties of the cast parts. The shrinkage cavities represent one of the main defects of the cast product, and their reduction should be made up to the limits of technical possibilities.

Keywords: *casting, defects, shrinking cavity, acquisition, balls*

1. Introduction

One of the main consequences of the shrinkage process in the cast austenitic steel parts with high content of manganese is the development of shrinkage cavities. They are formed in each cast part, but their size, shape and location depend on a series of factors. [2], [3].

The shrinkage cavities may give relatively large dimension, and they are called “macro-cavities” concentrated in one or several cavities in the part of the cast part that solidifies the last. The macro-cavities may also be spread throughout the volume of the cast part. The small-sized shrinkage cavities are invisible with the naked eye and are called “micro-cavities”.

They are formed in the intervals between the axes of dendrites or on the edge of the primary crystallisation grains. These inter-crystalline pores form during the primary crystallisation process, are usually placed at the thermal core of the cast part. The shrinkage cavity represents one of the main defects of the cast products, and their reduction must be done to the limits of the technical capabilities. It is preferable to obtain an austenitic structure at the concentrations of 12-13% Mn and 0.8-1.4% C, which assure high abrasive resistance to wear and tear. The higher content of carbon assures the formation of cementite alloyed with manganese, situation that leads to the reduction of the manganese content in the austenite and to the modification of its stability. [5]. In order to avoid such situations one alloys the steel with chromium, which has a high affinity toward carbon and one avoid the dissolution of manganese into cementite. One recommends a chromium participation in proportion of 0.6-2.5%, i.e. one will correlate the chromium content with the carbon content, using the ratio Cr/C =0.8 – 1.92, when the manganese content is of 12 – 14% and the carbon content is 0.7 – 1.4% [1], [6] [8].

2. Experimental determinations

2.1. Experiment 1. One effected the analysis of the solidification of a ball with the diameter of 100 mm, cast from austenitic steel with high content of manganese, make T120CrMn130, in the mould, from casting mixture, without feeder.

One cast 2 sand moulds without feeder or cooler in order to see how the shrinkage cavity is formed in the parts made of austenitic steel with high content of manganese of the make T120CrMn130 and one determined theoretically and practically the solidification time of the part as well as the temperature variation in the mould wall.

In order to measure the variation of the metal temperature during the filling and solidification of steel in the casting mould, one introduced a platinum, platinum-rhodium thermo-couple in a quartz tube. Because of the large dimensions of the thermocouple (25 mm in diameter), in order to avoid influencing the cooling conditions, one introduced in the mould void only the active part of the device, which is 8-mm long. The position of the thermo – couple is shown in Figure 1.

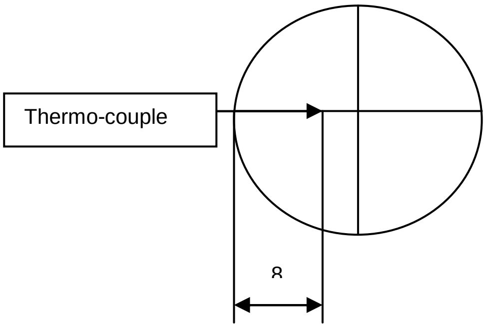

Figure 1. Position of the thermo-couple in the void of the casting mould.

In order to measure the heat gradient, one introduced three thermal resistances in the wall of the sand casting mould, noted in Figure 2 by TR1, TR2 and TR3, at distances of 5mm, 10mm, and 20 mm from the interior surface of the mould.

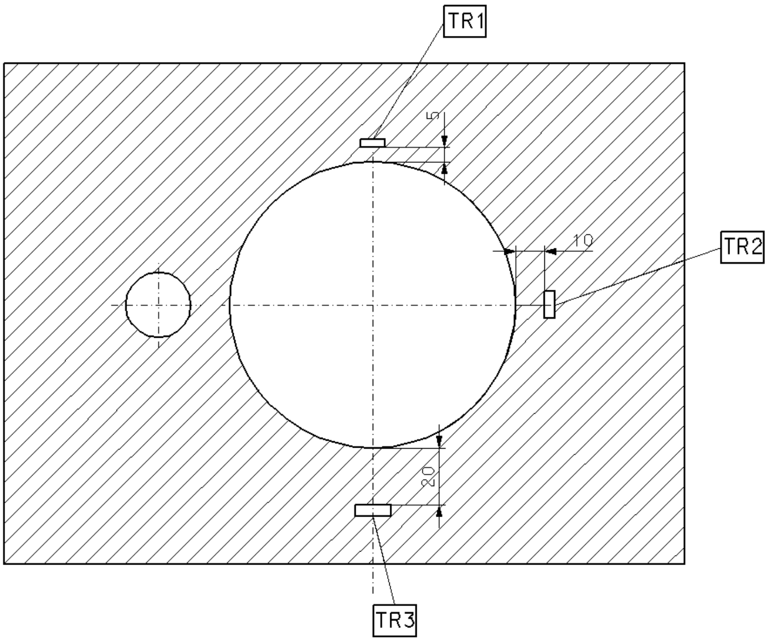

Figure 2. Position of the thermal resistance in the wall of the casting mould.

For the data acquisition one used a computer equipped with data acquisition board operating with the Lab VIEW software [3].

For the acquisition of the data from the thermal couples one used data collection modules of the type 5B37 [3] and for the thermal resistances on used modules of the type 5B34 RTD [3].

2.2. Diagram of the installation of data acquisition and interpretation.

The system is equipped with an acquisition board introduced into the computer. This acquisition board has the voltage inputs at voltages ranging between 0 – 10V. The signal from the temperature transducer (thermal resistance or thermocouple) must be converted by the signal conditioning module. The physical dimension varying on the terminals of the temperature transducer is the electrical resistance..

$$R_t = R_0(1+\alpha t) \tag{1}$$

R_t = resistance at the temperature t;

R_0 = resistance at the temperature 0^0C;

α = coefficient depending on the material of which the thermal resistance or the thermo-couple is made.

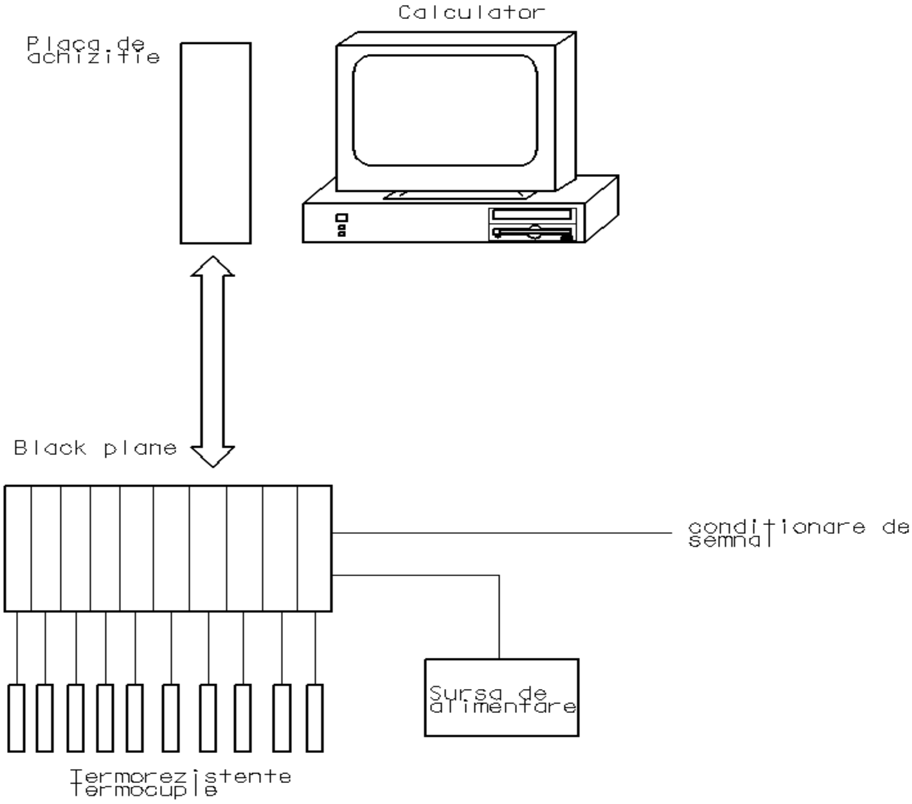

Figure 3. Diagram of the installation of data acquisition and interpretation.

Legend:
Placa de achiziţie = acquisition board
Calculator = Computer
Condiţionare de semnal = signal conditioning

The module converts the physical dimension, i.e. electrical resistance obtained at the output of the thermal resistance or thermal coupe into electrical voltage measurable by the acquisition board.

2.3. Presentation of the measurements.

The practical casting conditions were identical with those under which the casting simulated was effected. The temperature measured before the discharge was of 1460^0C. The ladle was permanently heated with flame, because of the low temperature in the casting hall (approximately 3^0C).

The casting temperature measured in the ladle was of 1410^0C. The casting time was of 2 seconds, the filling of the mould was done through a siphon casting network. The interval of solidification, according to the equilibrium diagram for the considered steel, is :

$t_{lic} = 1380^0C$; $t_{sold} = 1330^0C$.

$_{ts} = t_{lic} – t_{sol} = 1380 – 1330 = 50^0C$.

The results of the measurements of the liquid metal temperature during the filling of the mould, solidification and cooling of the part, acquired from thermo-couple T1, the closest to the part (Figure 1), are shown in the plot (Figure 4).

The first registered signal is approximately 1 – 2 seconds after the time 01:55.2 seconds when the temperature reaches 1400^0C, when the liquid steel came in contact with the thermo-couple. A decrease of temperature occurs from 1400 to 1390^0C, in approximately 10 – 15 seconds.

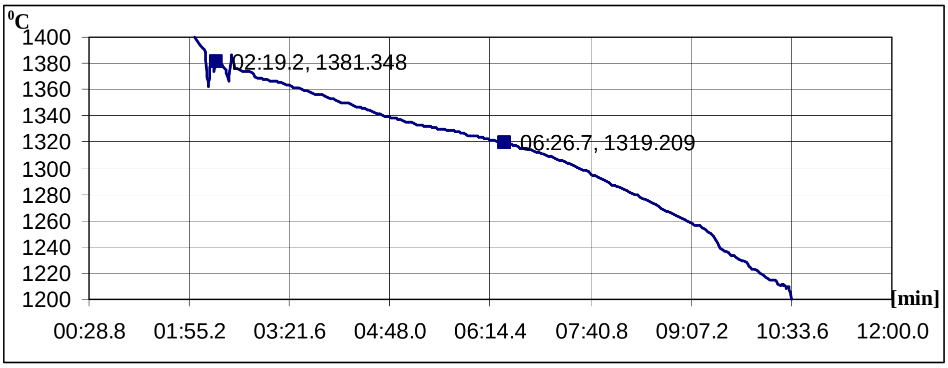

Figure 4. Study of the solidification of a ball cast form austenitic manganese steel make T120CrMn130.

During the following period of time two sudden variations of temperature occur, from 1390 to 1360^0C, and then a recovery of temperature to the value of 1390^0C. This phenomenon is produced because of the variation of the steel heat, until the filling is done and to the fact that the thermo-coupe is covered in a quartz tube, which in a first phase thermally insulates the thermo-couple. The inflection on the curve appears somewhere around the temperature of 1330^0C, which is considered to be the end of solidification temperature. The solidification begins at the moment marked on the plot with the value 2 min, 19 seconds corresponding to the temperature of 1380^0C and ends at 1330^0C, the moment 6 minutes, the total duration of solidification being of around 210 seconds, i.e. 3.5 minutes.

On the basis of the data obtained practically one could also perform a theoretical calculus of the solidification time.

2.4. Determining the temperature variation in the wall of the casting mould without feeder.

According to Figure 2, in the casting mould one mounted three thermal resistances for measuring the temperature variation in the mould wall. For the data acquisition one used the same installation as above.

The three thermal resistances were marked TR1, TR2, TR3, and placed to different distances in the mould wall..

The results of the temperature variation in the mould wall measured with the three thermal resistances are shown in Figure 5.

The thermal resistance TR1 is the closest to the cat part, at a distance of 5 mm. AS expected, this curve has the steepest slope, reaching somewhere near 850^0C after around 7 minutes.

The second curve represents the variation of the temperature measured with the thermal resistance TR2, placed at 10 mm from the interior surface of the part. The increase of temperature is slower, it reaches approximately 650^0C after around 8-9 minutes. The difference between the two curves is the fact that whereas curve TR1 starts to decrease after about 10 minutes, the corresponding TR2 curve remains constant for about 23-24 minutes, after which it relatively suddenly decreases to 600^0C.

The curve afferent to thermal resistance TR3 situated at 20 mm from the interior surface, has an even slower increase, after about 5 minutes reaching the value of 100^0C, and the value of 500^0C about 15 minutes; it remains constant for 15 minutes, after which it starts to decrease slightly.

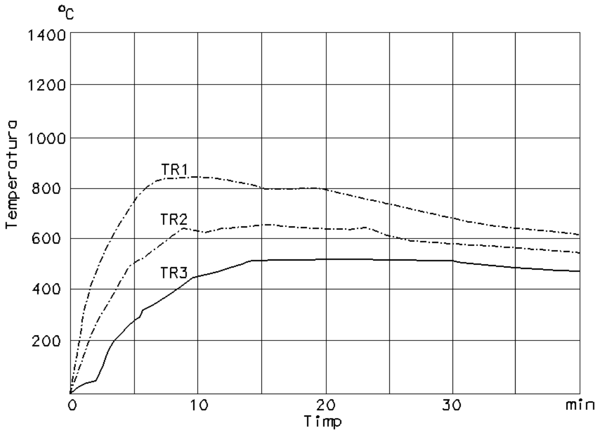

Figure 5. Temperature variation in the wall of the casing mould without cooler.

2.4. Theoretical calculation of the solidification time of a ball with the diameter of 100 mm cast in a sand mould, without feeder, from the steel make T120CrMn130. Initial conditions.

The calculation of the solidification of a part cast in a mould made of casting mixture can be done with the help of the formulas proposed by de A. L .Veinik [6]. These formulas were deducted for the case when, due to a smaller thermal conductivity of the mould material compared to the thermal conductivity of the metal that solidifies, the temperature on the interior surface of the mould instantly reaches the temperature of the metal, and the different of temperatures in the metal itself, between the surface and the core of the cast part, is negligible.

A.I.Veinik [6] divides the process into four periods:

- the period of mould filling;
- the period of overheating heat transfer;
- the period of solidification of the cast part;
- the period of cooling of the cast part after solidification.

The decrease of the metal temperature during the mould filling depends on factors that are rather difficult to take into consideration: section and configuration of the casting network, length of the casting channels, duration of casting etc.

The calculus will be made only for the first two periods of the process; for that we shall consider that we know the average temperature of the metal after the casting into the mould, especially because during the casing of steel parts the overheating of the metal over the temperature where solidification begins is usually reduced.

The initial temperature of the metal in the mould before solidification may be considered with sufficient precision as being equal to the average value between the casting temperature and the temperature where solidification starts. In order to determine the duration of the firs two periods, A.I.Veinik [6] gives the following formulas:

a) Transfer of the overheating heat:

$$\sqrt{t_1} = \frac{\sqrt{\pi}}{2}\frac{v}{A}\frac{\gamma_1 cl}{b_0}\ln\frac{t_{lich}}{t_{cr}} \quad \text{in h}^{0,5} \qquad (2)$$

b) Transfer of the overheating heat and of the solidification and crystallisation temperature

$$\sqrt{t_2} = \frac{\sqrt{\pi}}{2}\frac{v}{A}\frac{\gamma_1 q_{cr}}{b_0 t_{cr}} + \sqrt{t_1} \quad \text{in h}^{0,5} \qquad (3)$$

where:

t_1 = duration of the period of overheating heat transfer, [hours];

t_2 = duration of the process of solidification and crystallisation (considering the transfer of the overheating heat) [hours];

V = volume of the cast part [m^3];
A = surface of the cast part in contact with the mould [m^2] ;

$\gamma_1;\gamma_{sol}$ = Apparent specific weight of the solidified and solid metal respectively [kg/m^3];

cl = caloric capacity of the liquid metal [j/kg^{0}C];

q_{cr} = solidification and crystallisation heat [J/kg^{0}C];

t_{cr} = temperature of solidification and crystallisation (as steel crystallisation takes place within a small range of temperatures; in calculations this temperature is considered constant) [°C];

t_{lichid} = Initial temperature of metal after casting into the mould, in °C. As mentioned before, one may consider s $t_{liquid} = \frac{t_{cast} + t_{cr}}{2}$ [^{0}C] where t_{cast} is the metal temperature in [°C] measured at the casting into the mould;

$b_0 = \sqrt{\lambda_0 c_0 \gamma_0}$, [J/m^2 h^{0,5} ^{0}C]; (3) is the "accumulation" coefficient or the coefficient of "thermal inertia" of the mould wall , where:

- λ_0 is the thermal conductivity [J/m^2 h ^{0}C];
- c_o specific heat [J/kg ^{0}C];
- γ_0 apparent specific weight of the material of the mould [kg/m^3].

From the plot, Figure 4, one remarks that the main temperature plateau during solidification was at a value of approximately 1330^{0}C. This so-called "temperature of the solidus plateau" was considered the solidification temperature, t$_{cr}$ in the calculation with the following formulas, as these formulas are given for the case of metal solidification at a certain constant temperature.

a. the period of overheating temperature transfer (reduction of temperature from the t$_{liquid}$ = 1400^{0}C down to t$_{cr}$ = 1330^{0}C (one uses Formula 2)

$$\sqrt{t_1} = \frac{\sqrt{\pi}}{2} 0{,}0166 \frac{7100 * 0{,}0451}{5{,}736} \ln \frac{1400}{1330} = 0{,}041$$

$$t_1 = 0{,}041^2 = 0{,}00168h \approx 0.1\min \approx 6.0\sec where$$

$\frac{v}{A} = 0{,}0166$; [m]

from the literature [4] one adopted the following value :

γ^{ℓ} = 7100kg/m^3;

c$^{\ell}$ = 0.0451J/kg^{0}C;

t_{lichid} = 1400 [^{o}C] (in fact the metal temperature during the mould filling) ;

t_{cr} = solidification temperature according to Formulas (1) and (2) was considered starting from the constant solidification temperature. Conventionally for the calculation one adopted the value t_{cr} = 1330^o C.

For the sand mould one adopted from the literature [71]:

$$b_0 = \sqrt{\lambda_0 \cdot c_0} \cdot \gamma = \sqrt{1,37 \cdot 0,275 \cdot 1500} \approx 24.0 kcal / m^2 h^{0,50} C$$

where:

- coefficient of thermal conductivity λ_o = 0.237 [J/m^2 h^o C];
- specific heat c_o = 0.275 [J/kg^{o}C];
- volume weight γ_0 = 1500[kg/m^3];
- b_o = 4.2 – 5.736 [J/m^2 h^{0,5} ^{o}C].

b. period of overheating heat transfer and of the solidification and crystallisation temperature (using Formula 3) :

$$\sqrt{t_2} = \frac{\sqrt{\pi}}{2} 0.0166 \frac{7350 * 16,535}{5,736 * 1330} + 0.041 = 0.261$$

$$t_2 = 0.261^2 = 0.0681 h = 4.09 \min = 245 \sec where$$

besides the known dimensions one adopted form the literature[63] :

γ_1 = 7350 [kg/m^3];

q_{cr} = 15.53 [J/kg^{0}C].

4. Conclusions

By comparing the solidification duration of 4.09 minutes, i.e. 245 seconds, obtained from the calculation with the duration obtained experimentally of 3.5 min i.e. 210 seconds, we remark that these calculations give results which are in accordance with the experiment. These determinations are very useful as they allow the correction of the thermal transfer coefficients used in the simulation software.

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