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The determination of the thickness of composite layer

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ABSTRACT

Purpose: In this article the thermal simulation of formation composite layer on steel model casting and real casts were presented and described. There is also shown a computer program to determine the thickness of composite layers with the use of stochastic process. The main aim of researches was to prove the correctness of the method based on the calculus of probability thanks to the results of real casts.

Design/methodology/approach: Both the distribution of temperature in model casting and the course of temperature changes in the characteristic points of composite premould were determined for assumed changes of chosen technological parameters. The numerical calculations were done with the use of software NovaFlow&Solid 2.9 r81 and Preforma 1.1.

Findings: The desirable thickness of composite layer depends on the parameter ts of process and the level of pouring temperature during the casting process.

Research limitations/implications: Researches made possible to determine the thickness of composite layers and, thanks to it, to project the desirable composites.

Practical implications: Thanks to obtained results there is a possibility to project the thickness of composite layers in concrete places with the help of only a few data.

Keywords: Casting; Composite; Surfacing alloy layer; Computer simulation

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The production of cast with composite surface layer is not complicated for technological reasons. However, the process of forming these layers is complex and depends on many technological and material factors [1-4]. Up to now, the results of other researches show that the choice of process parameters, in order to determine technological conditions guaranteeing the desired thickness of composite layer, should be done each time for each size and shape of the cast. Because of great amount of factors, which influence the thickness, it is possible to use the theory of probability to calculate the thickness of composite layer in particular part of the cast [5-9].

The preform temperature (concretely the preform time of staying in the temperature between $T_S – T_L$) was assumed as a basic factor which influences the thickness of composite layer.

During the researches, both the computer simulation of the process of composite forming and the real casts were conducted in the same conditions [10-12]. The algorithm (to determine the thickness of composite layer with the use of stochastic process) was worked out, which was grounded on the obtained results [13-15].

The algorithm was used to build the computer program Preforma 1.1, which allows to calculate the thickness of composite layer for the given preform time (t_s) of staying in the temperature over the solidus temperature (T_S).

2. Researches

The aim of researches was to prove the correctness of the method based on the calculus of probability thanks to the results of real casts. The computer simulation of composite layer forming was conducted. Thanks to it, the algorithm was built and the thicknesses of composite layers were calculated. The real cast was conducted in the same conditions as well and the thickness of obtained layers were measured.

3. Researches range

The following stages were done:

- Working out the constructional assumptions for model casting and pouring system
- The simulation of composite layer formation process
- Determining the preform times of staying in the temperature over T_S
- Working out the algorithm, which allows to calculate the thickness of composite layer and its application to the computer program Preforma 1.1
- Determining the thickness of composite layers thanks to the results of simulation and program Preforma 1.1
- Conducting the real casts and the measurement of the thickness of obtained composite layers.

4. The real casts

The series of experimental casts, in the shape of the ball, was conducted during the researches. The balls at the 40, 60, 80, 100 [mm] diameters were cast in the crust moulds by the Cronin method. The characteristic values for ball casts are show on the Table 1

Table 1.
The characteristic values for ball casts

The characteristic values for ball casts				
Diameter of the ball ϕ [mm]	100	80	60	40
Modulus of the ball $M_K = d/60$ [mm]	1.67	1.34	1	0.67
Diameter of the neck [mm]	30	27	20	15
Calculated time of the solidification [min]	5.86	3.77	2.10	0.94
Weight of the cast [kg]	4.08	2.09	0.88	0.26

The ferrochromium (the size of grain 0.2-0.4[mm] and the chemical constitution shown in the table 2) was chosen as a main component of premould. 10% solution of polystyrene in ethyl acetate $C_4H_8O_2$ was used as a binder. The solidus and liquidus temperatures for premould material are the following:
T_S –solidus temperature for FeCr – 1300°C,
T_L –liquidus temperature for FeCr – 1545°C.

Table 2.
The chemical constitution of FeCr used for researches

FeCr	Fe	Cr	C	Al	Si
contents [%]	23.3	65.6	9.8	0.068	0.26

The model casts were conducted from cast low – carbon steel (the chemical constitution is presented in Table 3. The characteristic temperatures were the following: TL- 15050C, TS- 14500C.

Table 3.
The chemical constitution of cast low – carbon steel

carbon steel	C	Mn	Si	P	S
contents [%]	0.3-0.4	0.4-0.9	0.2-0.5	≤0.04	≤0.04

The metal temperatures during the melt were the following:

- Heating temperature 1550, 1600, 1650^{0}C,
- pouring temperature 1510, 1550, 1600^{0}C.

In order to determine the solidification and self - cooling curves and the changes of temperature in the mould, the thermoelements were assembled. They were connected with analog to digital converter Crystaldigraph PC-T. The thermoelements were made of the wire at diameter 0,5 [mm]. In order to improve the precision and to minimize the inertia of measurement system, the thermoelements were placed inside the premould without additional protection. They were only covered by thin layer of zirconal.

The solidification curves for casts were obtained. Thanks to them, the characteristic thermal conditions for composite layer forming were specified (especially the preform time of staying in the temperatureover T_S).

5. Computer simulation

During designinig the geometry for simulation, the resurs of past researches were used. The three – dimensial geometry of experimental casts was modeled with SolidWorks program and imported to simulation program NovaFlow&Solid v2.9 r81. The thermophysical data of basic materials used in simulation are shown in Table 4.

Table 4.
The thermophysical data of basic materials used in simulation

T [°C]	λ [W/m/°C]	Cp [J/kg/°C]	ρ[kg/m^3]
Ferrochromium FeCr			
0	45	450	-
500	30.6	550	7343
1100	24	650	-
1200	-	-	7080
1500	-	750	-
Cast steel GS240 wg PN-EN 10027-1:1994			
T_{liq} = 1505,53, Q_{cr} = 250 [kJ/kg],	T_{sol} = 1451, Q_{eut} = 250 [kJ/kg]		
0	51,8	469	-
1400	-	-	7262.6
1525	-	-	6995
1550	-	740	6978.88
1600	30	740	6946.23
Moulding sand			
20	0.9	550	1550
500	0.6	600	1500
1000	0.5	800	1490
1500	0.5	900	1450

The obtained results from the simulation were the base for determination fundamental values needed for further analysis and to work out the algorytm and computer program Preforma 1.1. First of all - the time necessary for the metal to reach the temperature higher then solidus temperature (premould heating time).

6. Program Preforma 1.1

The thickness of surface composite layer depends on many factors. The process of the composite layer forming is very complex. So, it is impossible to unequivocally claim the thickness of composite layer. Because of it, it is assumed that the thickness is a random variable. The composite layer can be 1[mm] thick or 2[mm] thick and so on. So we can deal with the composite layer formation process as with the process of forming some partial layers. It is assumed that these layers appears in turn, of course – with a certain probability. It means, that the composite layer is formed by a random variable. Its thickness is a the expected value of this random variable. It is assumed, that the layers appears in turn and in this way form whole composite layer, so we can treat this process as a simply stochastic process of entries. The algorithm constructed on this assumption was used to build the computer program Preforma 1.1. The program is used to calculate the thickness of composite layer.

The basic steps for a given shape are the following:

- determinig the pouring temperature
- determining the time t_s In a place, where the composite layer forms.

The program was worked out in Borland Delphi and works under the control of operating system MS Windows. Self – cooling times (t_s) for a given pouring temperature (T_{zal}) are the input data.

7. Comparative analysis

To prove the correctness of the stochastic method of determination the thickness of composite layer, the real thickness of composite formed during the real experiment were compared with the thickness of composite obtained from the simulation (NovaFlow) and program Preforma 1.1.

In order to prove the correspondence between the preform times of staying in the temperature between T_S – T_L obtained from real experiment and simulation, the comparative analysis should be done in the same points of measurement. The goodness will allow to use the results of simulation and real cast to build and check the mathematical model and, as a final effect, computer Program Preforma 1.1.

The Fig. 1. shows the example of statement of measurement points for balls ϕ100 and ϕ60 [mm]. Fig. 2 and 3 show the comparison of self – cooling curves from simulation and experiment.

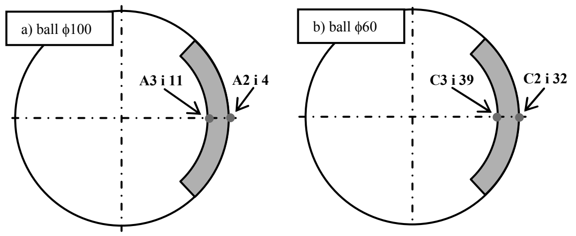

Fig. 1. The position of measurement points: A3, A2, C3, C2 –thermoelements in experiment; 1, 4, 39, 32 – thermoelements in simulation

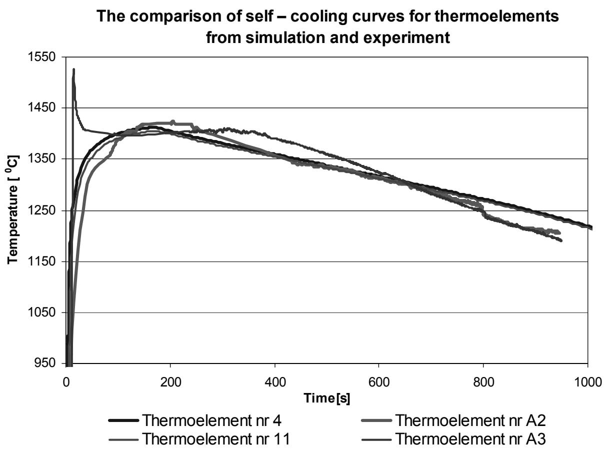

Fig. 2. Self - cooling curves for ball ϕ100 in measurement points of the premould surface placed on the outer side (nr 4 and A 2), on the inner side (nr 11 and A 3), $T_{zal} = 1550^0$C

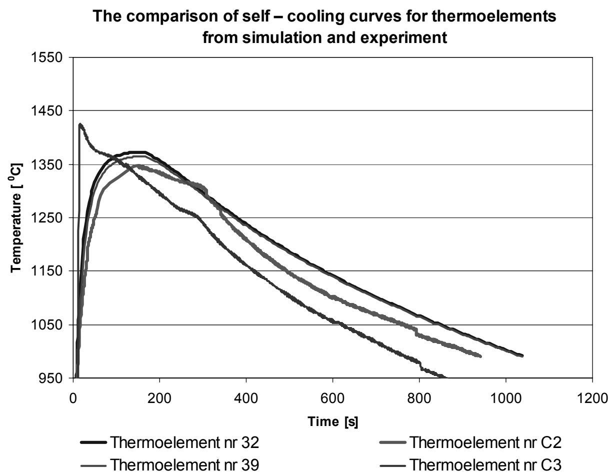

Fig. 3. Self - cooling curves for ball ϕ60 in measurement points of the premould surface placed on the outer side (nr 32 and C 2), on the inner side (nr 39 and C 3), $T_{zal} = 1550^0$C

Thanks to the analysis of these diagrams, it is evident, that times t_s from simulation and experiment are compatible.

The determined thickness of composite layer, with the use of program Preforma 1.1, are compatible with the thickness of composite layers measured during the experiment.

The thickness of composite layer was determined for ball cast at the pouring temperature 1550^0C. The calculations were done for 5 [mm] thick premould. The average outcomes of measured thickness of surface composite layers of real casts and the outcomes obtained with the use of Preforma 1.1 are shown in Table 5.

Table 5.
The average thickness of surface composite layers for ball casts

Diameter of balls [mm]	Pouring temperature 1550^0C Avarage thickness of composite layers of real cast [mm]	Pouring temperature 1550^0C Avarage thickness of composite layers calculated by program Preforma 1.1 [mm]
100	8.1	7.8
80	6.0	6.4
60	4.6	4.8

The results are compatible and prove the rightness of the stochastic method and computer program Preforma 1.1.

8. Conclusions

- The obtained thickness of composite layers of real casts are similar to thickness of composite layers calculated by program Preforma 1.1. This program is a useful tool to project the thickness of composite layers.
- The main advantage of the stochastic method presented in this work is simplicity. You need only a few data (preform time of staying over the solidus temperature (t_s) and the pouring temperature) to forecast the thickness of composite layer. The method enables to avoid the description of complex diffusion process.
- Parameters t_s and pouring temperature are enough to determine the thickness of composite layer with the use of stochastic process.

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