THE ANALYSIS OF THE EFFECTS OF HEAT AND MASS MOVEMENT DURING ALLOY LAYER FORMING PROCESS ON STEEL CAST

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Abstract

In this work there is presented the way how to improve the utility properties of steel cast by alloy layers application (on the base of alloy FeCrC) directly during the process of casting. The way how to forecast the thickness of the surface alloy layer on the cast with the use of simulation program Fluent was described. Computer simulation was conducted to forecast the distribution of particular elements on cross section of the cast. Thanks to it, it was possible to determine the thickness of obtained layer. The aim of the researches was also the analysis of conducted simulations of alloy layer forming process. There was the attempt to determine the influence of the geometry of the connection surface metal/pad and the grain size (of the pad from FeCrC) on their runs. Thanks to the analysis of obtained results, it was said that it was possible to forecast initially the distribution of the particular elements on the section cast- surface alloy layer and determine the virtual thickness of the layer with the use of Fluent program.

Keywords: Casting, cast steel, alloy layer, simulation

1. INTRODUCTION

Permanent improvement of quality of used materials is an important element of many technical branches during dynamic development of current industry. All tools and machines' elements are required to have good both strength properties (for example tensile strength) and ductile ones (for example hardness or shock resistance). In foundry obtaining such properties for one material is often very complicated and expensive, and even impossible. So that, composites are used in industry. They are modern engineering materials, which fulfil requirements [1, 2]. This kind of materials are mainly used in:

- car industry,
- aerospace (for example gliders),
- mining industry (for example embossed rolls, skids for coal combines),
- production of sports equipment (for example skies, poles),
- chips constructions (rudders, cylinders, traverses),
- electronic and electrical industry.

Layer casts are one kind of composites used in foundry, which are obtained by pouring properly prepared mould. A special pad is put in a place, where the layer characterized by different properties is expected to be formed. The pad is melted after pouring by liquid metal and forms alloy layer. Alloy material can be put inside the mould in several ways. The most often, properly done alloy pads are placed in the mould or on the core. They contain such elements like for example: Cr, Mn, Mo, Ni or C, which form diffusion layer rich in desired carbides after pouring the mould by metal [4-6].

High carbon ferrochrome was used to make pads during the research connected with alloy surface layer forming process. Implementing chrome and carbon to surface layer on the cast steel is profitable because of the possibility of obtaining bigger hardness. Nonalloy cast steel was used to do base casts. It is material commonly used in different branches of industry for the machines elements and devices, where surface layer can be used [3]. The chemical constitution of cast steel make intensive diffusion of elements from the pad into the cast and conversely possible. During the research, the computer simulation of alloy layer forming process on steel cast was conducted and the analysis of effects of heat and mass movement was done with the use of program Ansys CFD Fluent. The technology of alloy layers forming process consists in correct preparation of the mould by allocation the compacted pad made of high carbon ferroalloy in such place of mould, where alloy layer is expected and pouring it with liquid cast steel. The alloy layer is formed thanks to processes inside the mould between components of the pad and liquid metal [7-15].

2. OWN RESEARCH

The computer simulation was conducted to forecast the distribution of particular elements in cross section of the cast and determine the thickness of obtained layer. During the research, there was also the attempt to determine the influence of geometry of joint metal/pad surface on the alloy layer forming process. The research involved computer simulation of surface alloy layer forming process with the use of program Ansys CFD Fluent. To precise the simulation run, some main elements from used materials were highlighted (such like Fe, C, Cr, Si) and corresponding properties were collated for them. The simulation was conducted for three ranges of pad grain diameters (0.72 - 1.2; 0.36 - 0.72; 0.18 - 0.36 mm). Rectangular part containing the sample of the pad and niche of the mould presented on **Figure 1** with arrangement of measurement points was used in research. The net MES was put on obtained geometry after modelling the surface of contact between the pad and cast steel. Mapping of contact edge presented on **Figure 2** was used during calculations (ferrochromium used in research is grainy material **Figure 2d**, that is why such shape was used).

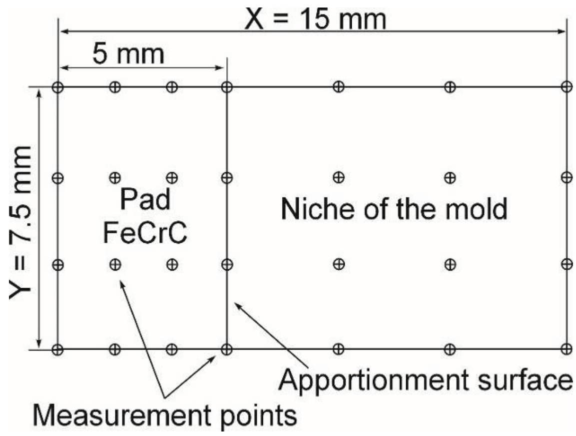

Figure 1 The scheme of assigned part of the mould with the arrangement of measurement points

Baseline parameters of simulation:

- pouring temperature - T_{zal} (1550, 1600 and 1650 °C),
- the speed of liquid metal raising - V_z (0.1, 0.3 and 0.5 m / s),
- grain diameter - Z_w (0.18 - 0.36; 0.36 - 0.72; 0.72 - 1.2 mm).

The influence of baseline factors on the thickness of obtained alloy layer was the main dependence being searched during simulation.

Alloy layer forming process finishes in fact when liquid metal is clotted. It was assumed that the proper temperature at the boarder of two phases would not be achieved because of disadvantageous choice of simulation parameters, in this way alloy layer would not be formed due to not enough pad heating. Real research [5] show that the temperature at the boarder of two centres must be higher than about 1300 °C for accepted materials. If the temperature is too high, the ferrochromium is leached by liquid metal. It is accepted (due to earlier attempts [5]) that borderline temperature is about 1500 °C, above this temperature material of the pad is totally leached.

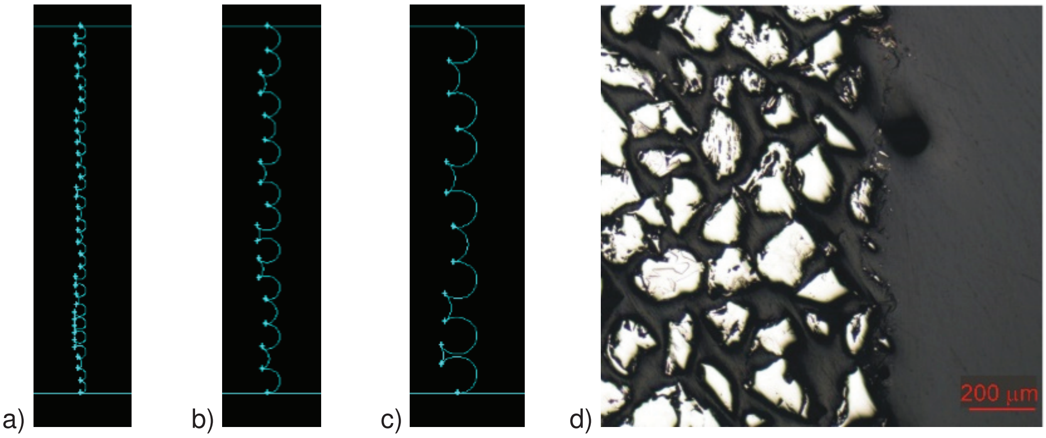

Figure 2 The edge of the pad FeCr done in program Gambit for alternative diameters of grains: a) 0.18 - 0.36 mm, b) 0.36 - 0.72 mm, c) 0.72 - 1.2 mm, d) real shape of the pad edge

Thanks to above assumptions, it possible to say, that alloy layer forms when the temperature at the boarder of two centres is between 1300 and 1500 °C. The width of alloy layer depends on the time of such a temperature at the pad edge, and it mainly depends on two baseline parameters of simulation - pouring temperature and the speed of mould fulfilling by liquid cast steel. **Figure 3a** presents the time of simulation durations. It is the time from the beginning of solidification till the temperature of 1300 °C at the control measurement point. In third case (simulation no 3) the proper pad heating was impossible because of too low cast steel temperature and shorter time of pouring. The alloy layer did not form. The results of simulations are presented in **Table 1**. In contract, during the fifth and sixth simulation, the baseline values caused too strong pad heating and the pad was melted (the temperature higher than 1500 °C).

Table 1 Maximal temperature obtained at the place of the joint of two materials for each simulation (T_{zal} - pouring temperature, V_z - the speed of liquid metal raising, Z_w - alternative diameter of grains, t - time of being over the temperature of 1300 °C by the pad, T_{max} - Maximal temperature obtained at the place of the joint of the pad and cast steel)

No of simulation	Vz [m/s]	T_{zal} [°C]	Z_w [mm]	t [s]	T_{max} [°C]
1	0.1	1550	0.72-1.2	213.6	1481.1
2	0.3	1550	0.36-0.72	89.1	1360.6
3	0.5	1550	0.18-0.36	16.7	1277.5
4	0.3	1600	0.18-0.36	137.8	1411.7
5	0.1	1650	0.18-0.36	291	1570.1
6	0.1	1600	0.32-0.63	283	1549.3
7	0.3	1600	0.72-1.2	120.8	1390.1
8	0.5	1600	0.36-0.72	75.2	1347.8
9	0.5	1650	0.72-1.2	110	1379.7

The diagrams of surface distribution of carbon and chrome for particular moments and at the finish of each simulation were done for each simulation to compare obtained alloy layers (**Figure 4**).

The obtained results were used to forecast the virtual thickness of „formed" alloy layer mainly according to the range of carbon diffusion. It was posited that alloy layer was a part of model, where carbon concentration is between 0.6 and 7.9 %. The obtained virtual thickness was presented on **Figure 3b**.

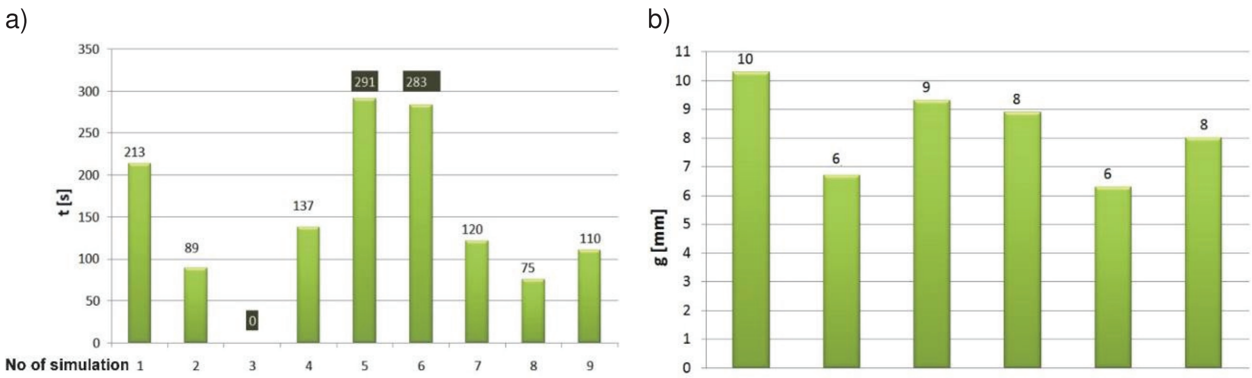

Figure 3 a) The collation of simulation times with start-up values,
b) Alloy layer thickness forecast based on the simulation

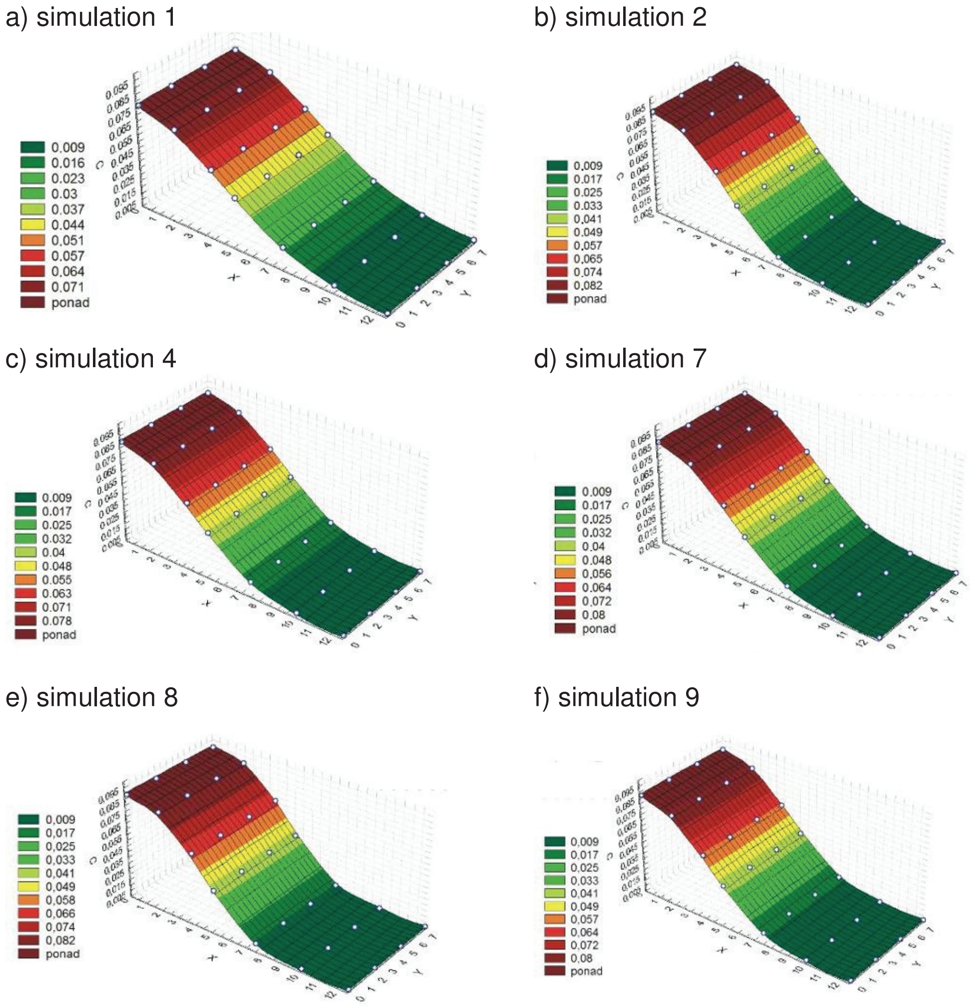

Figure 4 The distribution of carbon concentration in showcase area (after total finish of simulation); where: C - carbon concentration (%) x 10^2, X and Y - the size of model used in simulation (mm)

As a result of simulations number 5 and 6, one can think, that the alloy layer will not form (too high temperature at the place of the joint of materials - **Table 1** and too long time of being above 1300 °C - **Figure 3a**). The conclusions are similar to these based on many research conducted on real casts, which showed that layers formed at the range of temperature 1300 - 1500 °C [3, 5]. Layers did not form above

1500 °C because of overheating and melting the pad. This kind of situation is shown in simulation number 5 and 6, where maximal temperature was 1570 °C and 1549 °C respectively. Meanwhile, maximal temperature was 1277 °C in simulation number 3, what indicates the lack of suitable temperature conditions to form alloy layer.

3. CONCLUSIONS

The following conclusions were couched on the grounds of conducted research:

3.1. The speed of fulfilling the mould impacted the speed of diffusion by heating the pad during arising the level of liquid metal - in bottom, heated areas the elements diffused faster. However, the influence was so small, that it did not impact the width of layer in particular places. Very small speed of pouring could yet cause bigger uneven thickness of alloy layer.

3.2. The influence of granulation (as a modelled edge) was found to be insignificant. The alloy layer had similar thickness on all length of modelled part of cast (**Figure 5**)

a) b)

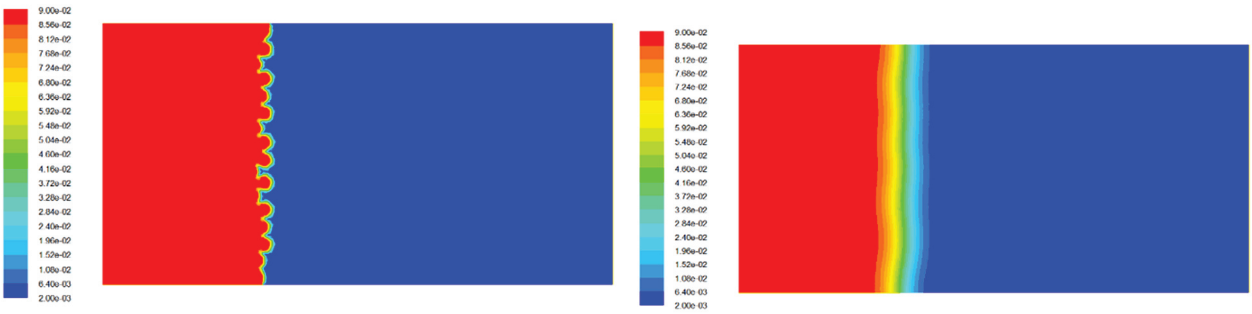

Figure 5 The shape of alloy layer a) at the moment of solidification and b) after 5 seconds from this moment

3.3. The analysis of concentration gradients for particular elements showed that the bigger diffusion coefficient (C), the wider diffusion layer noticeably. It is visible on the **Figure 6** where the carbon and chrome distributions in the end of the second simulation are presented.

a) b)

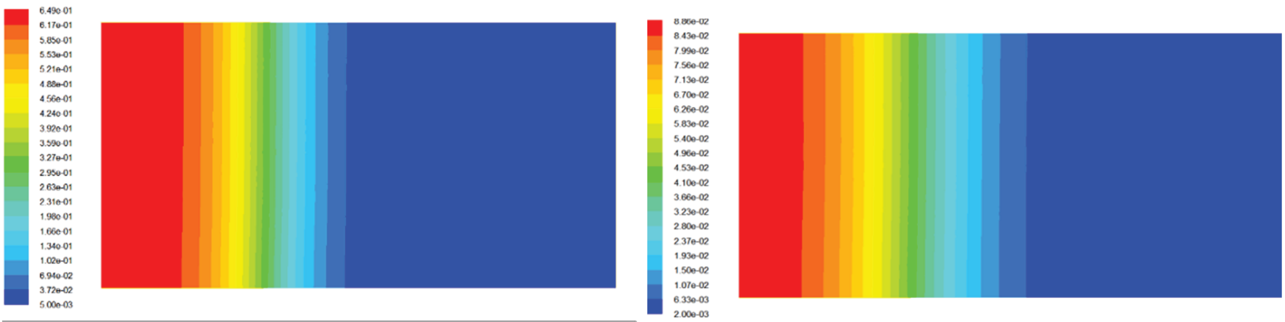

Figure 6 The distribution of a) chrome and b) carbon in a model at the moment of the end of the second simulation

3.4. The factor of the biggest importance, which influences the thickness of alloy layer is still pouring temperature. The higher temperature, the longer diffusion time in liquid phase. However, both the temperature and the speed of pouring must be properly adjusted. Too strong heating cause melting of ferrochromium and, as a result, the clearance of the pad material by convection motion of liquid cast steel. The temperature cannot be too low as well, because not enough heating of ferrochromium is possible when it meets with too fast fulfilling the niche of the mould. The cast steel would solidify before forming the alloy layer.

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