

Chapter 9

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DIFFUSION PROCESSES OCCURRING DURING PRODUCTION OF ALLOY LAYER ON STEEL CAST MOULDS

Abstract: The paper presents the results of simulation tests with the use of the Thermo-Calc software. The effect of adding silicon to the alloy insert material on the process of its liquefaction was tested. The liquidus and solidus temperature of high carbon ferrochromium affecting the process was also determined. It has been found that the increased Si content causes reduction of the solidus temperature of FeCrC which causes the increase of the diffusing components and further leads to faster liquefaction directly related to production of the alloy surface layer.

Keywords: diffusion, alloy layers, ferrochromium, cast steel

9.1. Introduction

Fast development of materials with an alloy layer has been observed since the 1980's. The production of such materials was the result of search for new materials that would meet the expectations of designers and engineers, impossible to be achieved by traditional materials. The possibility to design the properties and structure of the materials with an alloy layer is an important prerequisite opting for their use (SZAJNAR J. 2013a).

Layered moulds represent such group of moulds in which two different materials are joined into one element (mould). High carbon

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ferrochromium was assumed for the production of surface alloy layers and the inserts were produced. The addition of chromium and carbon to the surface layer on the steel cast is beneficial as it enables obtaining higher hardness of the layer. Non-alloy casting steel was used for the production of the base moulds. The material for the layer support part of the layered mould was selected in virtue of its wide use for elements of machines in various industrial branches, where most frequently the surface layers may be used (SZAJNAR J. 2013b, WRÓBEL T. 2011).

One of the production stages of the alloy surface layer on casting steel moulds is solid-state diffusion. This stage results from the flow of heat from the casting steel towards the mould, which causes a gradual temperature growth in the insert. Along with the temperature growth in the insert, an increase atom mobility takes place (the diffusion process rapidly grows) in the C, Cr and Fe crystalline lattice. As a result of high difference of the elements concentration (insert – casting steel) and the temperature growth in the insert, there is a diffusion in the solid state of C and Cr atoms with FeCrC800 to casting steel. At this stage the carbon diffusion (interstitial diffusion) and chromium diffusion (nodal diffusion) towards casting steel take place. The diffusion model in question occurs between the porous material and the hardened casting steel layer, so the mass transportation takes place in the particular insert grains and on the borderline between FeCrC800 grain and casting steel. The diffusion continues (on the borderline between the two materials) until the particular components reach the concentration of a chemical compound approximate to the peri-eutectic chromium cast iron and then the zone liquefies and the given components diffuse (WALASEK A. 2012, SZAJNAR J. 2014).

9.2. Own research

The purpose of the research was to watch the diffusion phenomena during the production of the alloy layer on the casting steel mould surface. The essence of the cognitive process was an attempt to describe complex diffusion phenomena during the production of the surface alloy layer (made from the high carbon iron chromium and non-alloy casting

steel). Several simplifying assumptions have been made in the calculations, including, without limitation the number of components of the structure in question (C, Cr, Fe i Si).

The research included, without limitation: determination of the characteristic temperatures and phases in the casting steel and alloy insert, as well as in the transition zone, and carrying out simulation of producing a liquid phase on the borderline between the two materials, by means of the Thermo-Calc software.

Furthermore, the research included the liquidus and solidus temperature of high carbon ferrochromium with the method of large (lying) drop, applying the CH (Contact Heating) procedure. The ferrochromium used in the tests has a chemical composition as presented in Table 9.1. While carrying out the tests, the heating rate applied was 8°/min. and cooling rate - 14 °C/min.

The liquidus-solidus temperature ranges obtained for particular samples indicate that the low silicon share significantly reduces the liquefaction temperature of the material (table 9.2).

Table 9.1. Ferrochromium chemical composition

	Cr [%]	C [%]	Si [%]	P [%]	S [%]	Fe [%]
Sample 1	63,6	7,1	0,38	-	-	28,92
Sample 2	62,53	7,92	0,75	0,026	0,02	28,754
Sample 3	61,1	6,82	2,09	-	-	26,99

Table 9.2. The liquidus-solidus temperature for ferrochromium depending on the silicon content

	Cr [%]	C [%]	Si [%]	Fe [%]	T _L [°C]	T _S [°C]
Sample 1	63,6	7,1	0,38	28,92	1638	1527
Sample 2	62,53	7,92	0,75	28,754	1637	1508
Sample 3	61,1	6,82	2,09	26,99	1597	1505

The model used for the simulation was presented in Fig. 9.1. The tests were carried out on two types of inserts, which differed by silicon content (0,85%). The result of the simulation was the course of the components' diffusion in the materials tested. The tests were made for the following temperatures: 1230, 1250, 1280, 1300, 1330, 1350, 1380, 1400, 1430 °C.

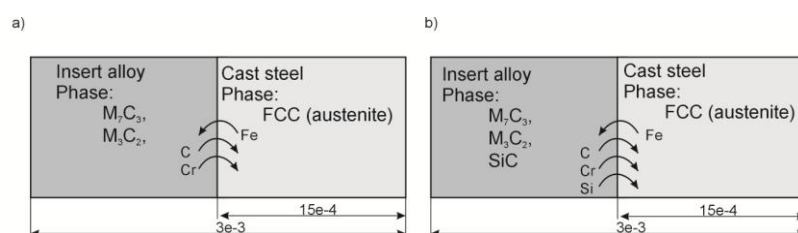


Fig. 9.1. Diagram of cells for calculations of diffusion between casting steel and insert: a) without silicon, b) with silicon

9.3. Test results

Based on the tests, the mass share for particular phases occurring between the liquidus and solidus temperature was established for the alloy insert without silicon (Fig. 9.2a), with silicon content (Fig. 9.2b), the transition layer (Fig. 1.3a,b) and non-alloy casting steel (Fig. 9.4).

The test result was the decomposition of the particular elements in the virtual alloy layer produced. Examples results were presented in fig. 9.5-8 for the temperature 1300 °C. In table 9.3 the weight concentration of C, Cr, Fe i Si was presented on occurrence of the liquid phase.

Table 9.3. Concentration of elements in the material tested during liquefied phase production

Element	With application of insert containing no Si addition	With application of Si containing insert
C	0,88 %	1,17 %
Cr	2,24%	0,2 %
Fe	96,88%	98,29 %
Si		0,29 %

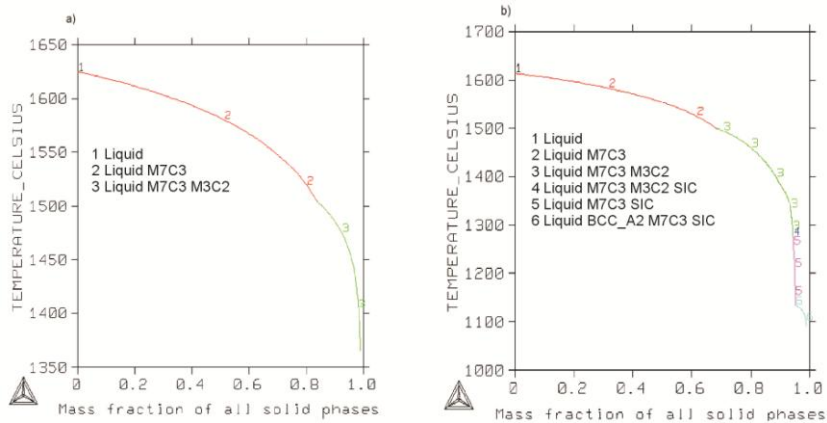


Fig. 9.2. Curve presenting the mass share of particular phases occurring between the liquidus and solidus temperature for the alloy insert a) without Si, b) with Si; FCC- austenite, M_7C_3 , M_3C_2 , SIC-carbides, BCC- ferrite

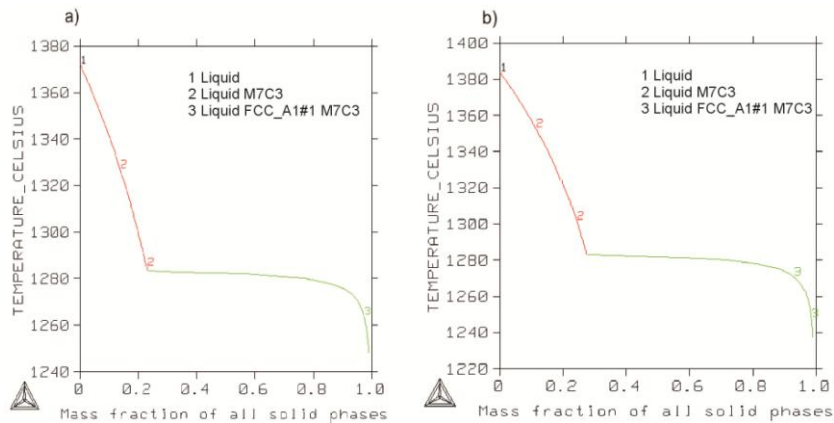


Fig. 9.3. Curve presenting the mass share of particular phases occurring between the liquidus and solidus temperature for the transition layer: a) without Si, b) with Si; FCC- austenite, M_7C_3 , M_3C_2 , SIC-carbides, BCC- ferrite

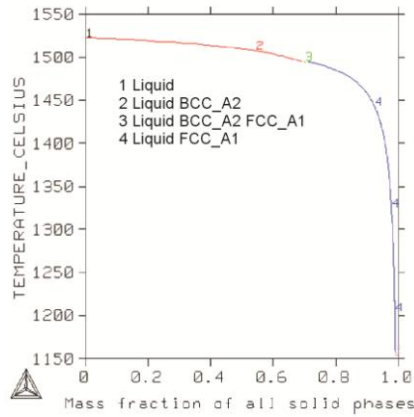


Fig. 9.4. Curve presenting the mass share of particular phases occurring between the liquidus and solidus temperature for low carbon casting steel: FCC-austenite, BCC-ferrite

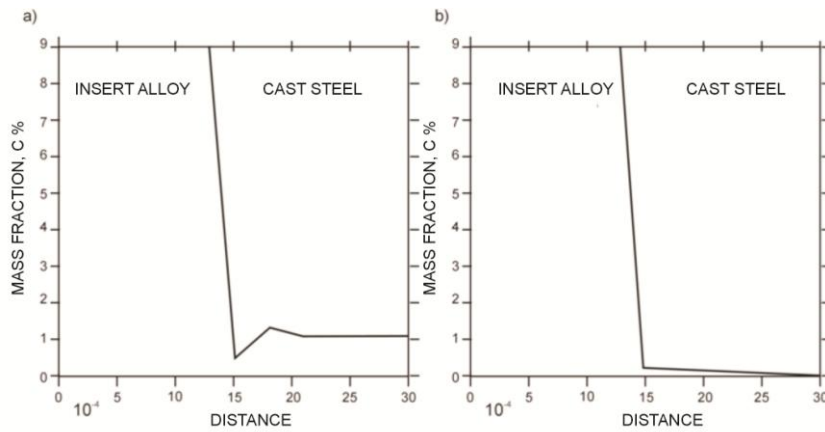


Fig. 9.5. Decomposition of carbon between casting steel in temperature 130°C: a) without silicon, b) with silicon

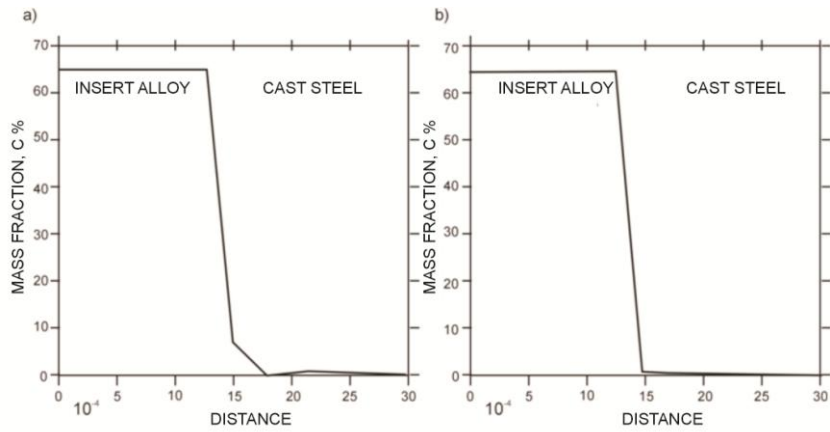


Fig. 9.6. Decomposition of chromium between casting steel and insert in temperature 1300 °C: a) without silicon, b) with silicon

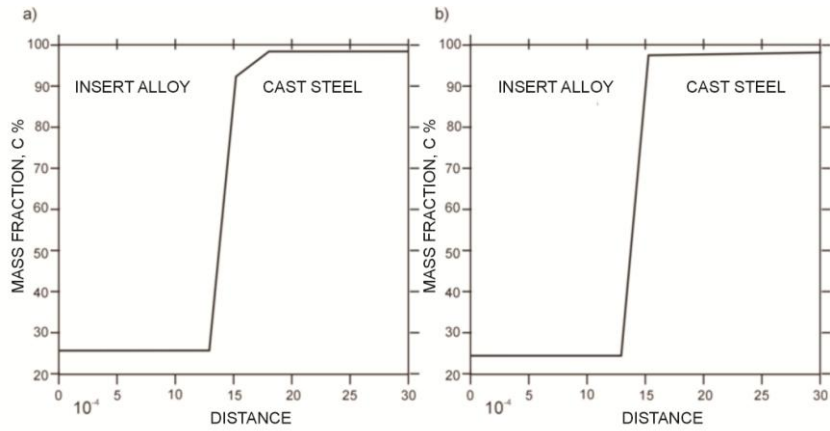


Fig. 9.7. Decomposition of iron between casting steel and insert in temperature 1300 °C: a) without silicon, b) with silicon

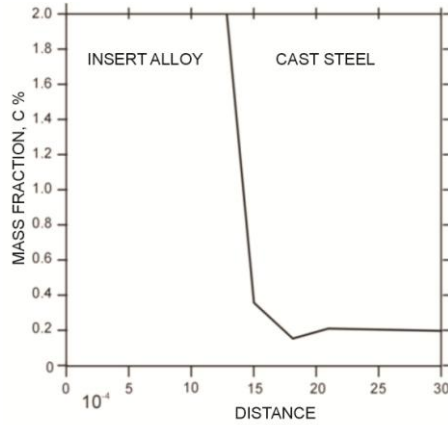


Fig. 9.8. Decomposition of silicon between casting steel and insert with silicon in temperature 1300 °C

Tables 9.4 and 9.5 present a list of percentage concentration of particular element during liquefaction and periods of time after which the liquefied phase is produced in the casting steel zone.

Table 9.4. Set of results obtained in simulation; with the use of insert without addition of silicon

With application of insert containing no Si addition				
Temperature °C	C%	Cr%	Fe%	Time (s)
1230	1,51	2,74	95,74	476502
1250	1,30	2,90	95,81	351751
1280	1,23	2,85	95,92	250000
1300	0,88	2,24	96,88	112001
1330	0,66	0,25	99,09	1252
1350	0,51	0,25	99,24	751
1380	0,37	0,23	99,41	252
1400	0,33	0,22	99,45	251
1430	0,24	0,20	99,56	2

Table 9.5. Set of results obtained in simulation; with the use of insert with addition of silicon

With application of Si containing insert					
Temperature °C	C%	Cr%	Si%	Fe%	Time (s)
1230	1,58	0,28	0,40	97,76	26440
1250	1,45	0,27	0,39	97,88	19530
1280	1,31	0,27	0,28	98,17	9131
1300	1,17	0,25	0,29	98,29	6581
1330	0,47	0,20	0,20	99,15	252
1350	0,45	0,20	0,20	99,15	251
1380	0,20	0,20	0,20	99,40	7
1400	0,20	0,20	0,20	99,40	2
1430	0,20	0,20	0,20	99,40	0,008

Thanks to the simulation it was possible to determine the time of liquefied phase production between the alloy insert and non-alloy casting steel. Substantial differences during the liquefaction depending on the temperature and the chemical composition of the insert tested. The time of producing the liquefied phase between the non-alloy casting steel and the alloy insert with addition of silicon is on average 19 times shorter, compared to the time of producing the same phase for insert without silicon addition.

Based on simulation it was determined that the alloy layer is produced from the liquefied phase as a result of diffusion of C, Cr, Fe and Si (for insert with addition of silicon) between the alloy insert and the non-alloy casting steel being in its solid phase.

9.4. Summary and conclusion

From the test analysis we may draw a conclusion that the production of the liquid phase in the transition zone is caused by diffusion of carbon, chromium and silicon from the alloy insert to the casting steel and diffusion of iron in the opposite direction. The main factors affecting the production of the alloy layer with growth kinetics closely connected with the production of the liquid phase, include temperature, liquid phase

production time and the chemical composition of the materials tested. It has been found that the increased Si content causes the reduction of solidus temperature in non-alloy casting steel and in the alloy insert, which causes the increased rate of diffusing components (especially carbon), which leads the production of liquid phase in the transition zone.

It has been found that the production process of the surface alloy layer is largely influenced by the silicon content in the alloy insert. The silicon addition reduces the liquidus temperature of high carbon ferrochromium and the temperature of the insert's liquefaction, which causes the acceleration of the diffusion processes taking place during the alloy layer production.

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