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DESCRIPTION OF ALLOY LAYER FORMATION ON A CAST STEEL SUBSTRATE

CHARAKTERYSTYKA PROCESU KSZTAŁTOWANIA WARSTW STOPOWYCH NA ODLEWACH STALIWNYCH

A description of alloy layer formation on a steel substrate is presented. Two types of formation are considered: diffusion of carbon and chromium into the solid from the pad in the direction of the cast steel within the FeCrC (grains) and diffusion in a layer of liquid chromium cast iron formed in a preceding step. The influence of silicon in the pad on the pad's transformation into the liquid is also examined. Solidus and liquidus temperatures of high carbon ferrochromium are determined. The larger the content of Si is used in the experiment, the lower the solidus temperature of the FeCrC alloy is observed. This results from the higher intensity of the elements' diffusion and faster formation of the liquid.

Keywords: alloy layer, cast steel, FeCrC – alloy, diffusion

W pracy przedstawiono autorski opis procesu powstawania powierzchniowej warstwy stopowej, którego istota opiera się na dyfuzji w stanie stałym węgla i chromu z wkładki w stronę staliwa w obrębie ziaren FeCrC, jak również na dyfuzji w warstwie ciekłego żeliwa chromowego powstałego w wcześniejszych etapach tworzenia się warstwy w wyniku dyfuzji w stanie stałym. Zbadano również wpływ dodatku krzemu w materiale wkładki stopowej na proces przejścia jej w stan ciekły. Określono temperaturę likwidus i solidus żelazochromu wysokowęglowego mającą wpływ na ten proces. Stwierdzono, że zwiększona zawartość Si powoduje obniżenie temperatury solidus stopu FeCrC co jest powodem zwiększenia szybkości dyfundujących składników, co z kolei prowadzi do szybszego powstania fazy ciekłej.

1. Introduction

The aim of the alloy layer forming process on castings [1-6] is to obtain a considerable increase in the parameters of the effective surface area [7-10]. Many of the properties of such castings depend on the physical and chemical properties of surface layers, e.g. hardness, corrosion resistance or abrasion resistance [11,16]. The properties of these layers depend mostly on the cooling conditions and on the reaction on the surface metal/mould (i.e. the interaction between the mould's material and the surface layer of the casting) during its pouring and self-cooling [2,13-15]. These kinds of castings are produced according to technology that has been worked out at the Department of Foundry Engineering of the Silesian University of Technology. This technology allows to put armouring additions to the metallic matrix. Components giving a selective increase in the exploiting properties are mostly the armouring additions [3,4]. Materials which belong to the group of abrasion-resistant composites are the object of this research study. Graphite, molybdenum disulphide, the carbides: silicon, titanium, zirconium, vanadium, tungsten, etc. and the oxide of mainly silicon and aluminium could be the armouring additions in such applications. Ferroalloys, such as high carbon ferrochrome, can also be used [12]. These give the possibility to produce abrasion-resistant materials with a small or large friction coefficient or a corrosion resistance coefficient. The proven positive influence of the above-mentioned components on the exploiting properties allows to optimise the economic-technological process of producing such composites [5].

2. Aim of the research

The aim of the research was to create a composite material with different mechanical properties in the casting. We present a description of the mechanism for the surface layer forming process which makes it possible to change the properties of the

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casting. We describe, in particular, selected steps of forming the connection between alloy and non-alloy layers.

The research was conducted on the basis of cast steel with the use of grainy pads made of high carbon ferrochrome. Such a composite obtained good abrasion resistance and larger corrosion resistance. This material was produced with the use of casting technology of the surface alloy layer forming process. It is based on a diffusion connection which takes place directly in the mould.

3. Mechanism of alloy layer formation

The steps of the alloy layer forming process that were determined during the experimental research are the following:
1) pouring liquid cast steel into the mould and pad (Fig. 1a),
2) heat flow from the cast steel to the pad,
3) forming a thin clotted layer of cast steel (Fig. 1b),
4) diffusion in the solid state in the pad layer adjacent to the clotted layer of cast steel (Fig. 1c).

A gradual increase of the temperature in the pad appears as a result of the heat flow from the cast steel in the direction of the mould. The higher the temperature that is obtained in the pad, the larger the activity of atoms is observed in the crystal lattices of C, Cr and Fe. The diffusion of atoms C and Cr from FeCrC to cast steel and Fe from cast steel into FeCrC in the solid state (Fig. 1c) appears as a result of large differences in the concentration of these elements (pad – cast steel). The research showed that the liquidus temperature for high carbon ferrochrome (Table 1) was higher than the temperature observed in the place of the connection between the pad and cast steel (Table 2). Thus the diffusion of elements takes place in the solid state. The diffusion of carbon (interstitial diffusion) and chromium (crucial diffusion) in the direction of cast steel and iron diffusion in the direction of the pad occur at this stage. The examined model of diffusion occurs between the porous material and the clotted layer of cast steel, so mass transport appears in particular grains of the pad and at the border of the grain of FeCrC and cast steel. The following steps are:
5) impoverishment of Cr and C and enriching in Fe the part of the pad as described above
6) transition into the liquid state by the part of the pad from the cast steel side (Fig. 1 d).
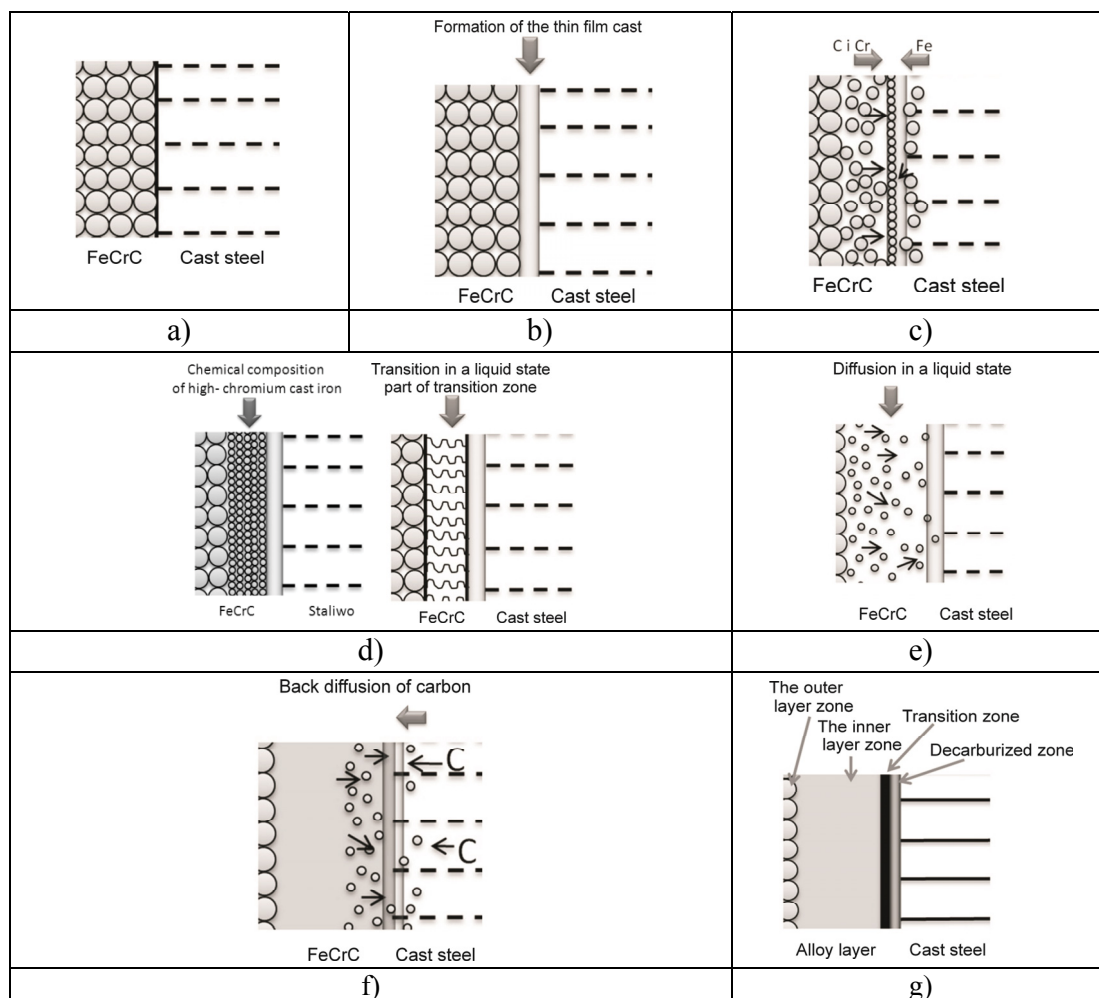

Fig. 1. Steps of the alloy layer formation: a) pouring the mould (with a pad) by liquid cast steel, b) forming a clotted cast steel layer, c) diffusion in a solid state, d) change of chemical composition of the "pad" and transition into a liquid state, e) diffusion in a liquid state, f) regressive diffusion of carbon, g) alloy layer formation

The chemical composition of the zone of contact of the two materials changes as a result of diffusion of C and Cr from the pad into the cast steel and Fe from cast steel into the pad. When the concentration of particular elements is similar to the chemical composition of chromium near eutectic cast iron, the transition of this zone into the liquid state is observed (Fig. 1 d). The obtained structure of the alloy layer shows that the surface alloy layer was formed from the liquid phase (Figs. 2, 3).

A temperature of 1300°C (Figs. 4, 5) is the initial temperature of the surface alloy layer forming process for given conditions of the experiment. This temperature depends on the concentration of Si in the pad. This element reduces the temperature of the transition into the liquid state (Table 1). The following step is:

7) diffusion in the liquid state (Fig. 1e).

The transition of part of the pad into the liquid state is caused by the lower melting temperature of this material in comparison to high carbon ferrochrome (Table 1). Then diffusion of the components in the liquid state takes place (Fig. 1e). Diffusion of the elements and the transition into the liquid state do not occur only in one part but take place consecutively inside the pad (as a result of a permanent heat flow activating the diffusion processes) and in the direction of the cast steel, which makes the diffusion area larger (the pad used in the examination was 5 mm thick and the layer was 8 mm). Compensation for the components' concentration appears as a result of diffusion in the liquid state. Subsequent steps are the following:

8) retroactive diffusion of carbon from the transition zone and cast steel (Fig. 1f)

9) crystallisation and forming of the surface alloy layer (Fig. 1g).

4. Determining the *liquidus* and *solidus* temperatures

Determining the liquidus and solidus temperature for high carbon ferrochrome

The lying drop method was used to determine the solidus and liquidus temperature for FeCrC. The procedure of combined heating (CH – Contact Heating) was adapted. Images of the examined object were recorded during the research. A drop of metal was placed on a smooth and flat surface. The research was conducted in Ar protective gas. High carbon ferrochrome with a chemical composition as presented in Table 1 was used. The following parameters were used during the research:

• for sample 1: heating at a rate of ~9°C/min and cooling at a rate of ~13°C/min

• for sample 2: heating at a rate of ~8°C/min and cooling at a rate of ~15°C/min

• for sample 3: heating at a rate of ~8°C/min and cooling at a rate of ~14°C/min.

The obtained ranges of liquidus and solidus temperatures for particular samples show that small participation of silicon has an important influence on the decrease in temperature of the transition into the liquid state (Table 1).

TABLE 1

Chemical composition of ferrochrome; effect of silicon content on the *solidus*/*liquidus* temperatures

	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

5. Temperature changes at the cast steel-pad boundary

Thermocouples connected with the Analog-to-Digital converter, Crystaldigraph PC-T, were placed in the area of the connection between the two materials to determine the influence of the temperature on the alloy layer forming process. The results of measurements of temperature changes during casting solidification with an alloy pad are presented in Table 2.

The following measurements were observed in the place of contact of the two materials during the research. The lowest maximum temperature was 1303°C (Table 2) for the cast with T_{zal} = 1550°C, Z_w = 0.72-1.2 mm and $g_{śo}$ = 10 mm. The highest maximum temperature was 1536°C for the sample with T_{zal} = 1650°C, Z_w = 0.18-0.36 mm and $g_{śo}$ = 60 mm.

TABLE 2

Maximum temperature (T_{max}), as recorded at the cast steel-pad boundary

T_{zal}	1550°C				1600°C				1650°C			
Z_w	0,18÷0,36 mm											
$g_{śo}$	60 mm	40 mm	20 mm	10 mm	60 mm	40 mm	20 mm	10 mm	60 mm	40 mm	20 mm	10 mm
T_{max}	1473	1424	1329	1308	1480	1456	1422	1316	1536	1503	1444	1336
Z_w	0,36÷0,72 mm											
T_{max}	1455	1416	1355	1313	1460	1422	1405	1320	1489	1432	1413	1337
Z_w	0,72÷1,2 mm											
T_{max}	1425	1410	1349	1303	1446	1415	1398	1308	1492	1447	1330	1310
Average	1451	1417	1344	1308	1462	1431	1408	1315	1505	1461	1396	1328

T_{zal} – pouring temperature, Z_w – grain size of FeCrC, $g_{śo}$ – thickness of the casting wall
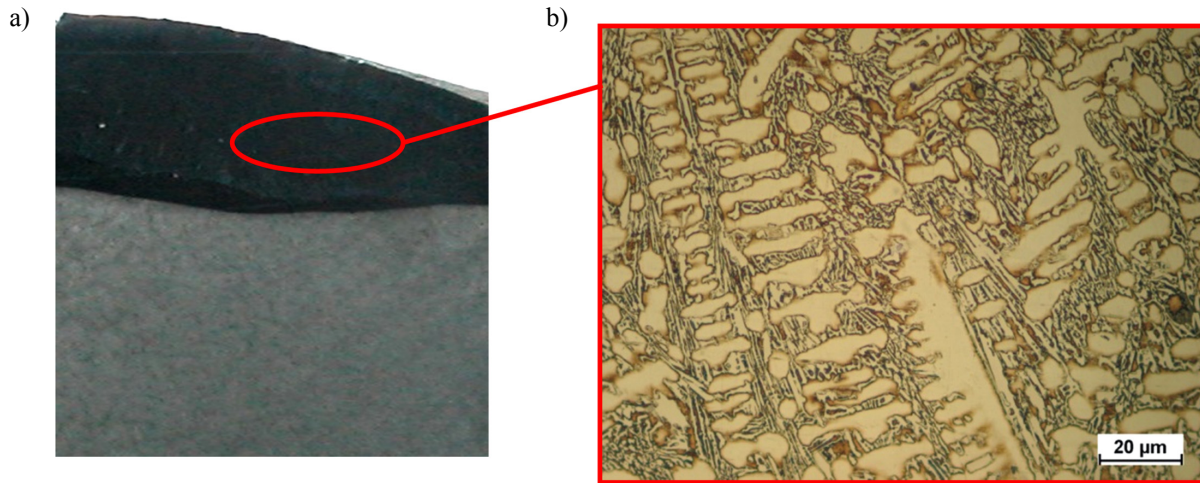
a)

b)

Fig. 2. Structure of the alloy layer produced by using the TIG method: a) macro structure; b) micro structure

6. Partial transition of melted FeCrC into the liquid state

The examination of weld overlay put on the non-alloy cast steel with the use of the TIG method (Tungsten Inert Gas) was conducted to observe the obtained structure after total FeCrC melting. The aim of this research was to compare the obtained structure of melted FeCrC with the alloy layer formed by using the casting method. The TIG method takes place in the following way: with additional material melting (FeCrC) and ground metal (cast steel) over-melting by the heat of an arc between the electrode (W+ThO$_2$ (5%)) and the filling ground in the shield of neutral gas (Ar). The macro and micro metallographic examinations were conducted to evaluate the quality of the obtained overlay weld (Fig. 3).

An analogy could be noticed during the comparison of the structure for the connection obtained by using the TIG method (Fig. 2) and the casting method (Fig. 3). It showed that an alloy layer formed directly during the casting process is produced, among others, from the liquid phase. The structure obtained in both cases is identical.
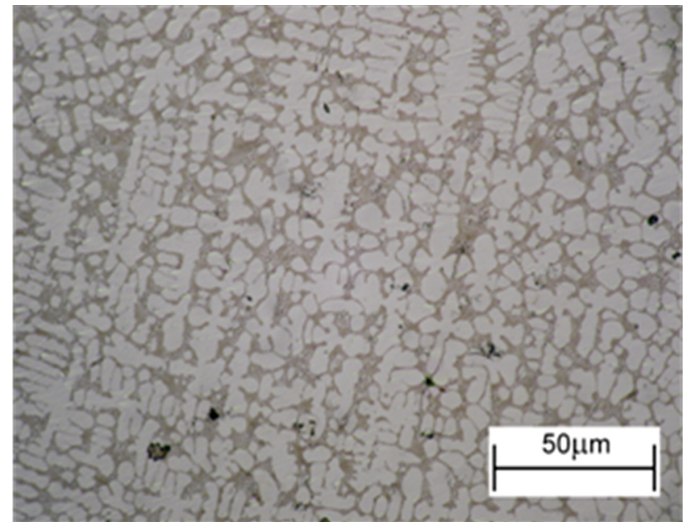

Fig. 3. Microstructure of the layer; T_{heat} = 1600°C, Z_w = 0.18÷0.36 mm, Z_w = 20 mm

7. Temperature determination for the initial stage of layer formation

Recording of temperature changes in the place of contact of the two materials (cast steel/FeCrC) was conducted to determine the beginning of the alloy surface layer forming process (Fig. 4b).
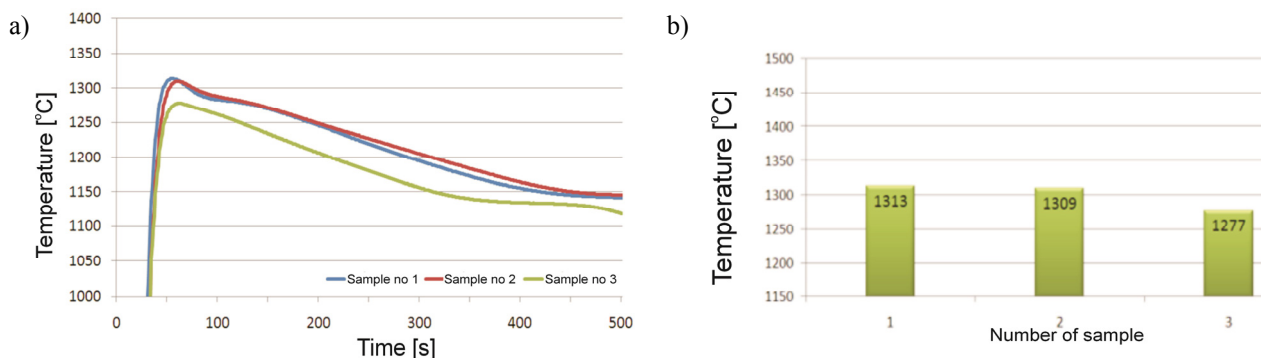
a)

b)

Fig. 4. Registered: (a) temperature curves for particular samples, (b) maximal temperatures

Both the methodology of composite forming and the place of temperature recording have been presented in the literature [1]. The obtained curves of heating with maximal temperatures are presented in Fig. 4a. The obtained temperature (Fig. 4b) caused the alloy surface layer to not form in sample 3. A visible non-carbon layer could be noticed in the structure of samples 1 and 2 with the largest heat capacity (Fig. 5). It shows the beginning of carbon diffusion.
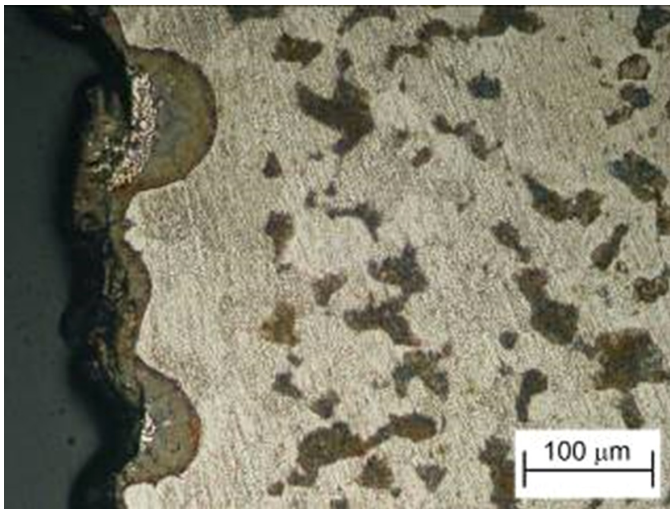

Fig. 5. Structure of the sample 2; inc. 200×

The research conducted here confirmed the information that was provided in the literature [6] regarding the temperature which initiates the beginning of the diffusion processes and then the alloy surface layer forming process. This temperature is equal to 1300°C for the analysed conditions of the experiment.

8. Conclusions

The temperature of the initial alloy surface layer forming process was equal to 1300°C for the analysed conditions of the experiment. The silicon content in the pad material had an influence on this temperature and, more importantly, on the temperature of the liquid phase in the place of contact between pad and casting. The larger the participation of silicon, the lower the T_L and the shorter the time of liquid phase forming. The research study allowed us to work out the mechanism of the alloy layer forming process on steel casting. The mechanism consists of the following steps: pouring the mould (with a pad) by liquid cast steel; heat flow from the cast steel into the pad; forming a thin, clotted layer of cast steel; diffusion in a solid state from the pad layer adjacent to the clotted layer of cast steel; decrease of Cr and C and increase of Fe in the zone of the pad as mentioned above; transition into the liquid state by the part of the pad on the cast steel side; diffusion in a liquid state; reverse carbon diffusion from the transition zone and cast steel; crystallisation and alloy surface-layer forming.

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