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**DIFFUSION OF C AND Cr DURING CREATION OF SURFACE LAYER ON CAST STEEL CASTING****DYFUZJA C I Cr PODCZAS WYTWARZANIA WARSTWY WIERZCHNIEJ NA ODLEWIE STALIWNYM**

In paper a method of improvement in utility properties of unalloyed cast steel casting in result of diffusion of C and Cr in process of creation of surface layer is presented. The aim of paper was determination of diffusion range of basic elements of alloyed surface layer. Moreover a quantitative analysis of carbides phase strengthens alloyed surface layer of casting was carried out. The results of studies shown that important factors of surface layer creation are maximal temperature  $T_{max}$  on granular insert – cast steel boundary dependent of pouring temperature, granularity  $Z_w$  of Fe-Cr-C alloy insert and thickness of casting wall  $g_{\zeta_0}$ . On the basis of obtained results was affirmed that with increase of thickness of casting wall increases range of diffusion in solid state in Fe-Cr-C grains and in liquid state. Moreover the range of  $T_{max} = 1300 \div 1500^\circ\text{C}$  favours creation of the proper alloyed surface layers on cast steel.

*Keywords:* casting, cast steel, diffusion, alloyed surface layer, Fe-Cr-C alloy

W pracy przedstawiono metodę poprawy własności użytkowych odlewów ze staliwa niestopowego w wyniku dyfuzji C i Cr występującej w procesie wytwarzania warstwy wierzchniej. Zasadniczym celem badań było określenie zasięgu dyfuzji podstawowych składników wierzchniej warstwy stopowej. Badania obejmowały również analizę ilościową powstałej fazy węglkowej umacniającej warstwę wierzchnią odlewu. Wyniki badań oraz ich analiza wykazały, że istotnymi zmiennymi czynnikami procesu powstawania warstwy są maksymalna temperatura  $T_{max}$  osiągnięta na granicy ziarnista wkładka – staliwo zależna od temperatury zalewania, ziarnistość  $Z_w$  wkładki z stopu Fe-Cr-C i grubość ścianki odlewu  $g_{\zeta_0}$ . Na podstawie uzyskanych wyników stwierdzono, że wraz ze wzrostem grubości ścianki odlewu rośnie zasięg procesów dyfuzyjnych zarówno w stanie stałym w ziarnach Fe-Cr-C jak i w stanie ciekłym. Ponadto zakres  $T_{max} = 1300 \div 1500^\circ\text{C}$  sprzyja powstaniu prawidłowej powierzchniowej warstwy stopowej na staliwie.

**1. Introduction**

Idea of alloyed layer on castings concerns improvement in utility properties of surface, what results from increasing requirements for responsible elements of machines and devices.

On the wear of most elements of machinery and devices strongly influences life of cooperating surfaces [1-10]. However, preparation of such permanent surface with maintaining the suitable properties of casting core demands application of expensive treatments of surface engineering. Therefore, more economical is using, presented in paper, foundry technology of alloying surface layer, in which elements enriching surface of casting are placed in mould, in form of granular insert, directly before pouring the molten metal [2, 5, 11]. Alloyed surface layers on castings were created as a result of diffusion processes between unalloyed cast steel and granular insert of Fe-Cr-C alloy. As shown in the paper [11] with increase in the insert temperature, as result of its contact with liquid cast steel, mobility of C, Cr and Fe atoms in crystal lattice also

increases. Additionally, in result of large difference in elements concentration between insert and casting, diffusion of C and Cr proceeds in direction from Fe-Cr-C alloy to cast steel and Fe conversely. Considered model of diffusion occurs between solid granular material and solidifying metal, therefore mass transport takes place in the individual grains of insert and at the Fe-Cr-C grain – cast steel boundary. The result of diffusion process, mainly in solid state, is essential change of chemical composition in contact area between both materials. However, when concentration of mentioned elements is near to chemical composition of eutectic chromium cast iron, then micro area of insert placed near to contact area becomes liquid in result of decrease of its liquidus temperature. This temperature is lower than liquidus temperature of applied Fe-Cr-C alloy. Therefore diffusion of elements proceeds in liquid state. Moreover diffusion and transition to the liquid state of micro areas of insert occurs not only in one region, but extends into the insert in result of continuous heat flow activating elements motion. In result of presented diffusion processes takes place equalize the concentrations of the alloys components [5, 11].

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## 2. Aim and range of studies

The aim of studies was to determine the influence of thickness of casting wall, pouring temperature of unalloyed cast steel and granularity of Fe-Cr-C alloy insert on alloyed surface layer creation process. The experimental plan includes made unalloyed cast steel castings ( $C = 0,3\%wt.$ ) with alloyed surface layer on the basis of Fe-Cr-C ( $C = 8\%wt.$ ,  $Cr = 63\%wt.$ ) alloy in sand moulds, with three levels of variability of thickness of casting wall ( $g_{\zeta_0}$ ) in range from 20 to 60 mm, pouring temperature ( $T_{zal}$ ) in range from 1550 to 1650°C and granularity of Fe-Cr-C alloy insert ( $Z_w$ ) in range from 0,16 to 0,8 mm.

The range of studies contains temperature measurements with use of thermocouple Pt-PtRh10 on contact area between insert and cast steel and determination of a maximal temperature ( $T_{max}$ ). To measure the diffusion range, the scanning electron microscope Inspect F equipped with EDS spectrometer, was used. Moreover quantity of carbides in alloyed surface layer was measured on the basis of metallographic microscopic studies with use of NIKON NIS-elements BR software.

## 3. Results of studies

In Figures 1-3 and Table 1 results of point wise and linear microanalysis of chemical composition (mainly C and Cr content) of area of joint between alloyed surface layer and cast steel are presented. On the basis of obtained results was affirmed that the depth of penetration of analyzed elements is depending of thickness of casting wall. The range of diffusion of Cr is larger for 60 mm thickness of casting wall than for 20 mm. Moreover casting with larger solidification module creates the conditions for a more intensive course of diffusion phenomena what results from longer lasting process and achievement of higher temperature by contact area between Fe-Cr-C insert and cast steel.

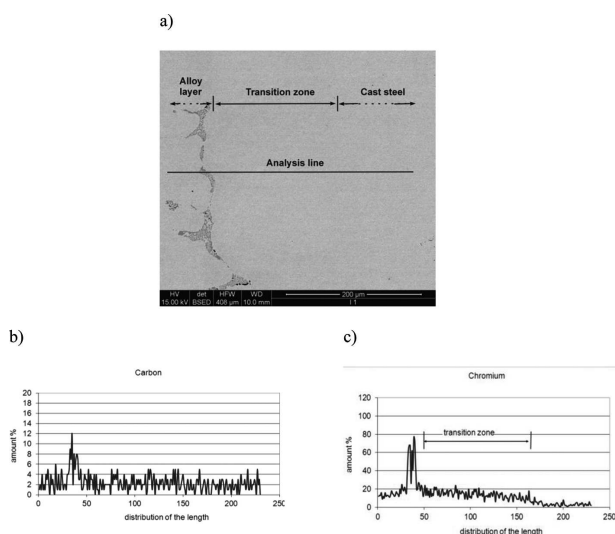


Fig. 1. The result of linear microanalysis in area of joint between alloyed layer and cast steel:  $T_{zal} = 1600^\circ C$ ,  $g_{\zeta_0} = 60$  mm,  $Z_w = 0,16 \div 0,32$  mm (a – SEM image showing structure of analysed area, b – linear distribution of C concentration, c – linear distribution of Cr concentration)

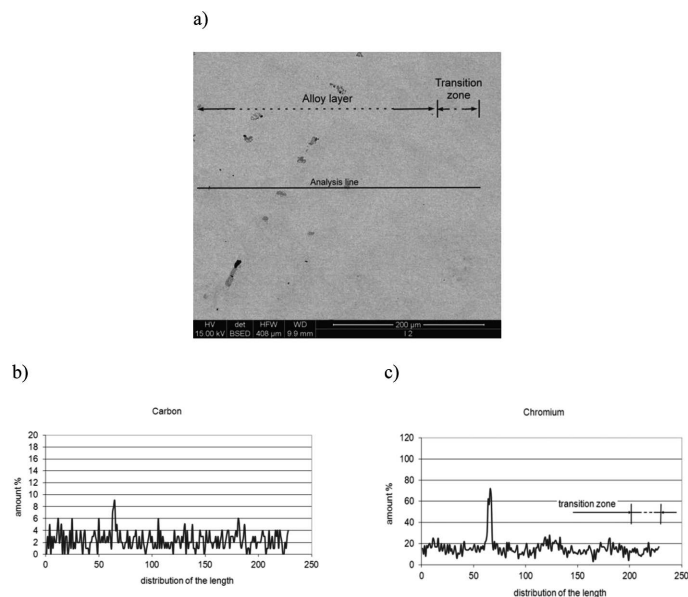


Fig. 2. The result of linear microanalysis in area of joint between alloyed layer and cast steel:  $T_{zal} = 1600^\circ C$ ,  $g_{\zeta_0} = 40$  mm,  $Z_w = 0,16 \div 0,32$  mm (a – SEM image showing structure of analysed area, b – linear distribution of C concentration, c – linear distribution of Cr concentration)

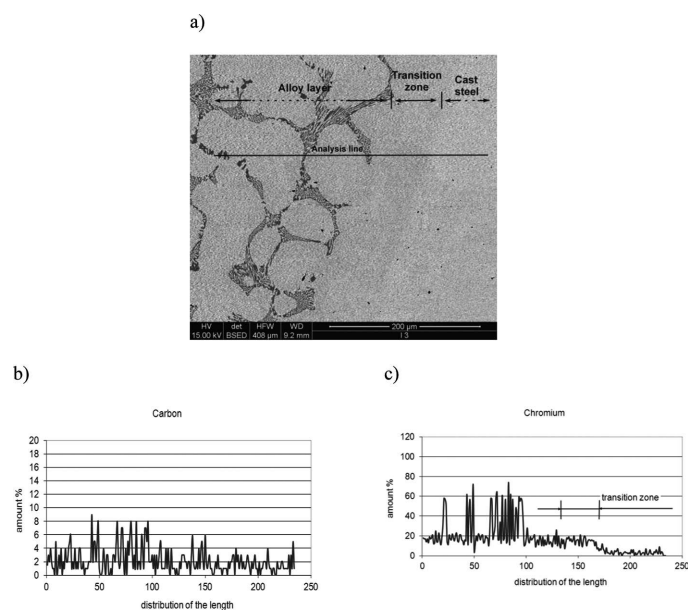


Fig. 3. The result of linear microanalysis in area of joint between alloyed layer and cast steel:  $T_{zal} = 1600^\circ C$ ,  $g_{\zeta_0} = 20$  mm,  $Z_w = 0,16 \div 0,32$  mm (a – SEM image showing structure of analysed area, b – linear distribution of C concentration, c – linear distribution of Cr concentration)

Moreover thickness of casting wall together with pouring temperature and granularity of insert strongly influence on quantity of Cr, Fe carbides in alloyed surface layer (Tab.2). On the basis of obtained results was affirmed that with decrease of  $g_{\zeta_0}$  and  $T_{zal}$  with simultaneously increase of  $Z_w$  increases quantity of Cr, Fe carbides in alloyed layer. This results from lower degree of C and Cr loss by diffusion from the alloyed layer to cast steel. Measurement of carbides quantity in alloyed surface layer is important because this phase strongly

influences on utility properties i.e. hardness and resistance on abrasive wear of layered casting.

TABLE 1

Changes in elements content (%wt.) from alloyed layer through transition zone to cast steel

Element	Distance, $\mu\text{m}$									
	0	50	100	150	200	250	300	350	400	450
T <sub>zal</sub> = 1600°C, g <sub>śo</sub> = 60 mm, Z <sub>w</sub> = 0.64-0.8 mm										
C	1.4	1.2	1.2	1.0	1.0	1.1	0.7	0.8	0.9	0.7
Si	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Cr	5.9	4.6	4.2	3.9	3.1	2.3	1.3	0.6	0.6	0.6
Fe	92.1	93.6	94.1	94.4	95.3	95.9	97.5	98.0	97.9	98.1
T <sub>zal</sub> = 1600°C, g <sub>śo</sub> = 40 mm, Z <sub>w</sub> = 0.64-0.8 mm										
C	1.0	1.0	1.0	1.5	1.5	1.4	0.7	1.0	0.8	0.6
Si	0.7	0.8	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5
Cr	5.7	4.9	3.9	3.6	2.8	2.4	1.4	0.5	0.6	0.6
Fe	92.6	93.3	94.5	94.3	95.0	95.6	97.3	97.9	98.1	98.3
T <sub>zal</sub> = 1600°C, g <sub>śo</sub> = 20 mm, Z <sub>w</sub> = 0.64-0.8 mm										
C	2.2	1.9	1.9	1.7	1.8	1.4	0.8	0.4	0.2	0.2
Si	0.8	0.8	0.6	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Cr	7.6	8.0	4.4	1.7	0.7	0.6	0.6	0.5	0.2	0.1
Fe	89.4	89.3	93.1	96.1	97.0	97.4	98.0	98.5	99.0	99.1

TABLE 2

Influence of g<sub>śo</sub>, T<sub>zal</sub>, and Z<sub>w</sub> on quantity of Cr, Fe carbides

T <sub>zal</sub> , °C	g <sub>śo</sub> , mm	Z <sub>w</sub> , mm		
		0,16-0,32	0,32-0,64	0,64-0,8
1550	60	138	474	224
	40	237	410	621
	20	332	875	820
1600	60	97	175	108
	40	99	349	350
	20	166	385	401
1650	60	–	106	112
	40	–	299	13
	20	–	294	592

In Table 3 measurements of T<sub>max</sub> on contact area between insert and cast steel is presented. On the basis of results was affirmed that in all cases T<sub>max</sub> exceeded about 1300°C. Moreover for T<sub>zal</sub> = 1650°C and Z<sub>w</sub> = 0.16-0.32 mm independently of value of g<sub>śo</sub> the T<sub>max</sub> exceeded 1500°C. For this three cases not observed creation of alloyed layer.

#### 4. Conclusions

Based on the conducted studies the following conclusions have been formulated:

TABLE 3

Influence of g<sub>śo</sub>, T<sub>zal</sub>, and Z<sub>w</sub> on value of T<sub>max</sub> on contact area between insert and cast steel

T <sub>zal</sub>	1550 °C			1600 °C			1650 °C		
Z <sub>w</sub>	0.16÷0.32 mm								
g <sub>śo</sub> , mm	60	40	20	60	40	20	60	40	20
T <sub>max</sub> , °C	1473	1424	1329	1480	1456	1422	1536	1503	1524
Z <sub>w</sub>	0.32÷0.64 mm								
T <sub>max</sub> , °C	1455	1416	1355	1460	1422	1405	1489	1432	1413
Z <sub>w</sub>	0.64÷0.8 mm								
T <sub>max</sub> , °C	1425	1410	1349	1446	1415	1398	1492	1447	1330

1. Increase in thickness of casting wall and in pouring temperature of cast steel with simultaneous decreases in granularity of Fe-Cr-C alloy insert cause an decrease in quantity of Cr, Fe carbides in surface layer, what results from increased degree of C and Cr loss by diffusion in direction from the alloyed layer to cast steel.

2. The range of maximal temperature on contact area between insert and casting equals T<sub>max</sub> = 1300÷1500°C favours the creation of the proper alloyed surface layers on cast steel. Exceeding of 1500°C results in melting and mixing of insert with liquid cast steel. Therefore in this case is not to possible creation of alloyed surface layer.

#### REFERENCES

- [1] T. Wróbel, 20<sup>th</sup> Anniversary International Conference on Metallurgy and Materials, May 18-20, 2011, Brno, Czech Republic, 758-764.
- [2] J. Szajnar, D. Bartocha, C. Baron, A. Walasek, Archives of Foundry Engineering **8**, 139-143 (2008).
- [3] C. Cingi, V. Rauta, E. Niani, J. Orkas, Materials Science Forum **654-656**, 2712-2715 (2010).
- [4] M. Cholewa, T. Wróbel, S. Ternerowicz, T. Szuter, Archives of Metallurgy and Materials **55**, 771-777 (2010).
- [5] J. Szajnar, A. Walasek, C. Baron, Archives of Metallurgy and Materials **58**, 931-936 (2013).
- [6] T. Heijkoop, I. Sare, Cast Metals **2**, 160-168 (1989).
- [7] M. Stawarz, 22<sup>nd</sup> International Conference on Metallurgy and Materials, Metal 2013, May 15-17.2013, Brno, Czech Republic, 92-96.
- [8] A. Studnicki, J. Jezierski, 21<sup>st</sup> International Conference on Metallurgy and Materials, Metal 2012, May 23-25.2012, Brno, Czech Republic, 795-802.
- [9] B. Arnold, T. Heijkoop, P. Lloyd, G. Rubens, I. Sare, Wear **203-204**, 663-670 (1997).
- [10] K. Janerka, D. Bartocha, J. Szajnar, J. Jezierski, Archives of Metallurgy and Materials **55**, 851-859 (2010).
- [11] J. Szajnar, A. Walasek, C. Baron, 22<sup>nd</sup> International Conference on Metallurgy and Materials, Metal 2013, May 15-17.2013, Brno, Czech Republic, 134-139.