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TRIBOLOGICAL AND CORROSIVE PROPERTIES OF THE PARTS OF MACHINES WITH SURFACE ALLOY LAYER

WŁASNOŚCI TRYBOLOGICZNE I KOROZYJNE CZĘŚCI MASZYN Z POWIERZCHNIOWĄ WARSTWĄ STOPOWĄ

There are presented the results of researches conducted on the steel cast with surface alloy layer in this work. The measurement of the thickness, hardness and abrasion wear resistance was conducted in accordance with norm ASTM G 65-00. The measurement of the corrosion resistance was conducted in accordance with the potentio – dynamical method. It is shown that it is possible to obtain the alloy surface layer of different thickness by control of some factors: pouring temperature T_{zal}, diameter of grain of FeCrC alloy Z_w and the thickness of the cast wall $g_{\acute{s}o}$. It is proved that the smaller diameter of ferrochromium grain, the thicker surface alloy layer. It is also said that the higher pouring temperature and thicker the cast wall, the thicker surface alloy layer. What is more – the smaller thickness of the cast wall, the bigger hardness and abrasion wear resistance.

Keywords: composite layer, ferrochromium, cast, abrasion wear resistance, corrosion resistance

W artykule przedstawiono wyniki badań odlewu staliwnego z powierzchniową warstwą stopową. Badania obejmowały pomiar grubości, twardości, odporności na zużycie ścierne wykonane zgodnie z normą ASTM G 65-00 oraz odporności na korozję metodą potencjo-dynamiczną. W wyniku przeprowadzonych badań stwierdzono, że sterując w zadanym zakresie zmiennymi czynnikami procesu takimi jak temperatura zalewania staliwa T_{zal}, średnica Z_w ziarna stopu Fe-Cr-C i grubość ścianki odlewu $g_{\acute{s}o}$ można uzyskać powierzchniową warstwę stopową o różnej grubości. Wyniki badań dowiodły również, że stosowanie na wkładkę stopową żelazochromu o mniejszej średnicy ziarna powoduje powstanie powierzchniowej warstwy stopowej o większej grubości, podobnie jak przy wzroście temperatury zalewania i grubości ścianki odlewu. Ponadto stwierdzono, że im mniejsza grubość ścianki odlewu tym uzyskuje się większą twardość warstwy i odporność na zużycie ścierne.

1. Introduction

The structure and properties of surface layers often have an influence on operating properties of many products and their elements. Surface layers are also desired because of economic factors where required operating properties are expected at possible low cost. They guarantee desired, usually not the biggest, operating properties of the core of the element and concurrently low cost because of inexpensive materials. As a result of proper choice of material of element, the process of shaping its structure and properties and the kind of surface layer with suitable technology the most advantageous matching of both core and surface layer properties are obtained [1,2,3,4]. This kind of researches has been conducting in Department of Foundry in Silesian University of Technology for several years [5,6]. The main object of the researches has become the layer casts for the sake of the requirement of both abrasive and corrosion resistance parts of machines for industry [12,14]. Non – alloy and low – alloy cast steel is used in foundry for the parts of machines where cast iron, especially high – alloy one, is not able to guarantee proper reliability of the product [15,18]. Unfortunately, the main disadvantage of this kind of material is deficit of desired properties in unfavourable conditions of work. Steel casting have to be modified by the change of chemical constitution or heat treatment to gain high abrasion wear resistance, what is not desirable because for the sake of economic analysis [10,11]. So, the foundry technology of surface alloy layers obtaining on the steel casting is an answer to requirements of present – day industry, such as: high hardness, strength and abrasion wear resistance of chosen surfaces with concurrently high plastic properties of the core. The process of forming of such layers is possible thanks to the technology of creation of the element with assumed properties of chosen surfaces instead of all cast. The mould is prepared by fixing suitably prepared composite pad on chosen surfaces of cavity and pouring it by liquid metal in this kind of technology [7,8,9,19].

2. The aim of researches

The aim of researches was to determine the suitable parameters for the production of casts strengthened by alloy composite layer on chosen surface of the element. There was examined the influence of pouring temperature, the thickness of

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the cast wall and the size of ferrochromium grains on the operating properties of given alloy layer. Steeling casts are used for example in extractive industry. The use of alloy layers in such elements cause considerable extension of working time. This kind of casts should be characterized by high hardness, abrasion wear resistance and corossion resistance and this group of properties were examined during the researches. The alloy layer forming process is concurrent with foundry part shaping one. It seems to be interesting for surface hardening and present researches are connected with optimal choice of parameters of the process to obtain strengthened cast with alloy layer.

3. The run of researches

The series of experimental casts with graduated thickness of the wall were conducted during the researches. The shape of the cast is presented on the picture 1. The alloy layer (thickness 5mm) was fixed on each grade in its central part (Fig. 1). The pad was made of high – carbon FeCrC 800 with the size of the grain 0,8÷0,64; 0,64÷0,32; 0,32÷0,16 mm and chemical constitution 62,53% Cr, 28,75% Fe, 7,92% C i 0,75% Si. The experimental casts were conducted from low – carbon steeling cast (0,28%C). The temperatures of pouring metal were the following: 1550, 1600, 1650°C. The thickness of surface alloy layer on the steeling cast was measured during the researches. The measurements were conducted at the section of the cast in the place of alloy layer forming. The results from the center part of the cast are presented at the Table 1.

It is observed on the basis of the researches that the thickest layer (12,97 mm) was obtained for the sample, where T_{zal} was 1600°C, Z_w =0,16÷0,32 mm and $g_{\check{s}o}$ =60 mm. Whereas, the smallest layer (0,63 mm) was obtained for the sample, where T_{zal} was 1600°C, Z_w =0,63÷0,8 mm and $g_{\check{s}o}$ =10 mm (Table 1). It is also observed that the grain size influences the thickness of the alloy layer. The researches show that the bigger size of the grain, the thicker alloy layer for the sizes of the grain less than 0,18 mm. The thickest alloy layer was obtained for the grain size 0,18÷0,36 mm. For bigger sizes of the grain the researches show that the bigger size of the grain, the thinner alloy layer. What is more, it was observed for pouring temperature T_{zal} =1550 and 1600°C. This phenomena was not marked for pouring temperature 1650°C. The differences of temperatures in the pad could be the reason of it [19].

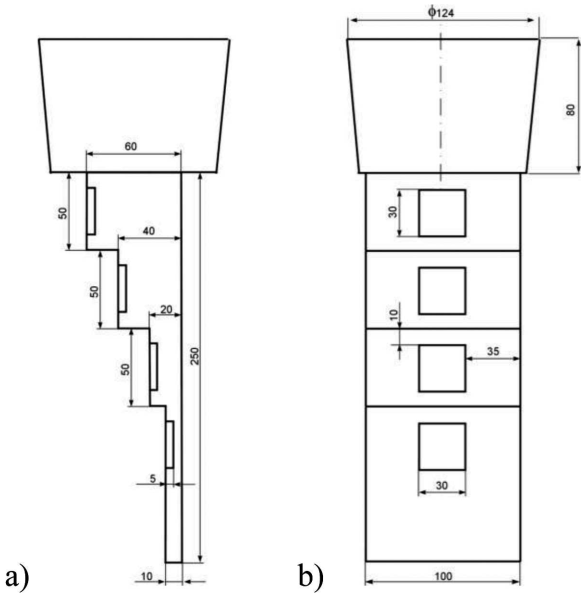

Fig. 1. The shape of experimental cast; a) section, b) sight

The hardness of obtained connection was also examined during the researches. The Vicker's method was used with standard PN-EN ISO 6507-1:1999 for the load 294,2 N. The measurements were conducted in random places in three areas: alloy layer, cast steel and transitory zone. The results of hardness for samples are gathered at the Table 2.

TABLE 1

The results of measurements of the thickness of the layer (T_L)

T_{zal} [°C]	**1550**				**1600**				**1650**			
Z_w [mm]	**0,16÷0,32**											
$g_{\check{s}o}$ [mm]	**60**	**40**	**20**	**10**	**60**	**40**	**20**	**10**	**60**	**40**	**20**	**10**
T_L [mm]	8,25	10,26	7,07	1,53	12,97	11,23	9,02	4,32	No layer	No layer	4,21	0,52
T_{zal} [°C]	**1550**				**1600**				**1650**			
Z_w [mm]	**0,32÷0,64**											
$g_{\check{s}o}$ [mm]	**60**	**40**	**20**	**10**	**60**	**40**	**20**	**10**	**60**	**40**	**20**	**10**
T_L [mm]	7,79	8,23	4,25	0,97	9,4	6	4,82	0,65	11,07	8,9	8,2	3,41
T_{zal} [°C]	**1550**				**1600**				**1650**			
Z_w [mm]	**0,63÷0,8**											
$g_{\check{s}o}$ [mm]	**60**	**40**	**20**	**10**	**60**	**40**	**20**	**10**	**60**	**40**	**20**	**10**
T_L [mm]	6,17	6,42	6,14	2,27	10,18	8,88	9,08	0,63	8,18	8,17	7,39	2,31

TABLE 2

The results of hardness of all samples

T_{zal} [°C]		1550				1600				1650			
Z_w [mm]		0,16 ÷ 0,32											
$g_{śo}$ [mm]		60	40	20	10	60	40	20	10	60	40	20	10
No measurement	1w	476	434,5	496	839	618,5	637	725,5	760,5	No layer	No layer	499	549
	2w	403	543,5	352	466	540	483	610	556,5			477	559
	3w	387,5	391	368	404	525	661,5	454	542,5			475,5	401
	p	275	234	233,5	288	373,5	231,5	255	164,5			358	374
	7s	139,5	140	127	137	122,5	126	133	134	129	129	254	230
	8s	138	146	130	138	120	138	129	187	175	210	253	198
	9s	140	142	129	140	124	135	120	154	210	149	198	220
T_{zal} [°C]		1550				1600				1650			
Z_w [mm]		0,32 ÷ 0,63											
$g_{śo}$ [mm]		60	40	20	10	60	40	20	10	60	40	20	10
No measurement	1w	372,5	337,5	472	432	346	573	680	479,5	476	444	479,5	536,5
	2w	347	448,5	350,5	410	341	468,5	479,5	752	398,5	410	439	507
	3w	377	344,5	415,5	429	379	499	451,5	669,5	392,5	429,5	419	323,5
	p	209,5	193,5	198	290	270,5	267,5	298	240	209	198,5	182,5	227
	7s	132	129	130	134	185,5	167,5	180,5	182	147	132,5	131	133
	8s	128	129	129	139	190	170	186	186	139	139	139	129
	9s	1239	130	134	120	185	181	187	182	198	125	128	130
T_{zal} [°C]		1550				1600				1650			
Z_w [mm]		0,63 ÷ 0,8											
$g_{śo}$ [mm]		60	40	20	10	60	40	20	10	60	40	20	10
No measurement	1w	450,5	413,5	538,5	415,5	312,5	329,5	415,5	721,5	389,5	393,5	390	437
	2w	397,5	423,5	378	522,5	405	437,5	447,5	516,5	392	382	342,5	372,5
	3w	380	400	552	577	372,5	403	513,5	394,5	380	422	368	582
	p	284	279	293	326	225,5	249,5	219,5	208,5	244,5	240	232,5	284
	7s	326	309,5	317	293	209,5	223	217,5	221	211	242,5	215	220
	8s	129	148	289	279	198	221	228	231	217	199	212	187
	9s	139	289	298	249	187	198	123	284	231	129	178	198

s – cast steel
p – transitory zone
w – alloy layer

The average hardness was the following: 409 HV for the wall thickness of 60 mm, 446 HV for the wall thickness of 40 mm, 466 HV for the wall thickness of 20 mm, 524 HV for the wall thickness of 10 mm. It is observed that the smaller thickness of the cast wall, the bigger hardness of the layer. The obtained layer was characterized by much bigger hardness than cast steel where it was 177 HV at the average.

The abrasion wear resistance of obtained alloy layer was also examined during the researches. There was used the machine constructed with standard ASTM G 65-00. This kind of machine is used to examine the abrasion wear resistance metal – mineral. The researches were conducted on the samples obtained after normalizing heat treatment. The loss of mass was measured with an accuracy of 0,001 g. These researches made the discovery of the loss of mass (Δm) for each layer possible. The results of measurements are presented at the Table 3. The examination of abrasion wear resistance of chosen materials of high abrasion wear resistance (Table 4) was conducted and related to material to make a comparison.

The smallest loss of mass and concurrently the biggest abrasive resistance was obtained for chromium cast iron (about 0,016 g), whereas it was about 0,029 g for layers on steel casting. The relative wear in relation to cast steel of these two materials was rightly 0,115 and 0,218 g. Austenitic cast steel had the smallest abrasive resistance determined by the biggest mass loss. The relative wear was 0,854 g. The obtained results prove the high abrasive resistance of surface alloy layers on the steel castings. It is worth to say that the steel castings of the same shape are cheaper three times than uniform casts made of chromium cast iron.

TABLE 3

The results of abrasion wear resistance examinations

T_{zal} [°C]	**1550**			**1600**			**1650**		
Z_w [mm]	**0,16÷0,32**	**0,32÷0,64**	**0,64÷0,8**	**0,16÷0,32**	**0,32÷0,64**	**0,64÷0,8**	**0,16÷0,32**	**0,32÷0,64**	**0,64÷0,8**
$g_{śo}$[mm]	**60**	**40**	**20**	**60**	**40**	**20**	**60**	**40**	**20**
Loss of mass [Δm]	0,046	0,036	0,025	0,040	0,036	0,021	0,151	0,041	0,025
	0,036	0,028	0,021	0,039	0,034	0,017	0,126	0,034	0,023
	0,030	0,024	0,021	0,025	0,023	0,014	0,041	0,024	0,022

TABLE 4

The results of abrasive resistance examination

Material **Lp.**	**1**	**2**	**3**	**4**	**5**	**Average mass loss**
Austenitic steel: 00H18N10 (X2CrNi19-11)	0,167	0,133	0,095	0,106	0,075	0,115
Martensitic steel: 4H13 (X12Cr13)	0,049	0,044	0,044	0,039	0,034	0,042
Chromium cast iron	0,013	0,019	0,016	0,015	0,015	0,016
Low – alloyed, ferritic - pearlite cast steel	0,145	0,119	0,170	0,117	0,122	0,135

TABLE 5

The results of the examination of corrosion resistance

T_{zal} [°C]	**1550**			**1600**			**1650**		
Z_w [mm]	**0,16÷0,32**								
$g_{śo}$[mm]	**60**	**40**	**20**	**60**	**40**	**20**	**60**	**40**	**20**
Corrosion potential, E_{corr}, mV	-614	-597	-596	-589	-586	-583	No layer	No layer	-586
Breakdown potential, E_b, mV	-623	-600	-603	-603	-599	-581			-528
Anode current intensity, i_{corr}, nA/cm^2	5,3	6,3	18,7	12,4	10,0	7,7			6,6
Polarization resistance, R_p, kΩcm^2	4,9	4,1	1,4	2,1	2,6	3,4			3,9
Z_w [mm]	**0,32÷0,63**								
Corrosion potential, E_{corr}, mV	-596	-593	-581	-598	-582	-579	-577	-565	-541
Breakdown potential, E_b, mV	-608	-610	-585	-604	-582	-592	-587	-576	-559
Anode current intensity, i_{corr}, nA/cm^2	8,0	8,7	13,4	4,8	8,7	12,9	9	7,7	7,1
Polarization resistance, R_p, kΩcm^2	3,4	3,0	1,9	5,5	3,0	2,0	2,9	3,4	3,7
Z_w [mm]	**0,63÷0,8**								
Corrosion potential, E_{corr}, mV	-608	-582	-581	-631	-604	-592	-569	-564	-543
Breakdown potential, E_b, mV	-615	-600	-590	-626	-593	589	-570	-584	-553
Anode current intensity, i_{corr}, nA/cm^2	6,9	6,9	10,6	8,4	9,8	7,9	6,4	5,4	13,1
Polarization resistance, R_p, kΩcm^2	3,8	3,8	2,5	3,1	2,6	3,3	4,1	4,8	2
	Chromium cast iron			**Austenitic steel**			**Martensitic steel**		
Corrosion potential, E_{corr}, mV	-474			-478			-612		
Breakdown potential, E_b, mV	-497			-490			-620		
Anode current intensity, i_{corr}, nA/cm^2	21,7			4,9			5,7		
Polarization resistance, R_p, kΩcm^2	1,2			5,4			5,4		

Corrosion researches were also conducted to estimate corrosion resistance of alloy layer formed on the steel casting. The examination was conducted with the use of potentio-dynamical method. The potentiostat PGP201 of Radiometer was used. Saturated calomel electrode (NEK) was used as reference electrode, platinum wire was used as supporting electrode. Corrosion resistance examination with the use of potentio – dynamical method was started for potential E_{pocz} =E_{OCP}-100 mV. The change of potential moved in direction of anode with the speed 1mv/s. When maximum value of measurement range or anode current density of 1 mA/cm^2 were reached, polarized sample was kept by obtained potential for 1 minute, then the direction of polarization was changed. The measurements were conducted in electrolyte simulating environment of mine water [11] at the room temperature. Corrosion resistance examination was started with determining the opening potential E_{OCP}. The samples were mechanically polished to get flat surfaces, examinations were conducted on the area of 1 cm^2, the rest of surfaces were protected against corrosive acting of the factor. Corrosive potential for all samples was established after 30 minutes. The examination was started with determining the corrosion potential, next the curves of anode polarization were recorded. Characteristic parameters for corrosion resistance were determined on the base of curves: corrosion potential $E_{corr,}$ breakdown potential E_b, polarization resistance $R_{p.}$ Polarization resistance was determined with the use of Stern's method. The range ±10 mV in relation to corrosion potential was analyzed for the sake of necessity of inhibition of linear dependence between current intensity and sample's potential. The results of examination of pit corrosion resistance for samples is presented at the Table 5.

The researches showed that the casts with pouring temperature 1650°C had the best corrosion resistance. The biggest corrosion resistance gained the layers where the diameters of the grain were from the range 0,32÷0,63 mm. The results of potentio – dynamical examination do not indicate the meaningful differences among the corrosion potentials for examined connections. Chromium cast iron had the best corrosion resistance for examined parameters of variability (Table 5). However, the differences in corrosion resistance and abrasive resistance are small, what fosters the employment of steel castings with surface layers in industry.

4. Conclusions

The thickness of surface alloy layer depends on the thickness of the cast wall ($g_{śo}$) and pouring temperature. The bigger cast, the bigger cast module, longer time of cooling and, what is connected with it, thicker alloy layer. The average hardness of surface alloy layer was about 460 HV and depended on heat capacity of the cast. The thinner cast wall, the bigger hardness of the alloy layer and it probably depends on penetration distance of C and Cr and appearing of carbides M_7C_3. The obtained average hardness was much bigger than the hardness of cast steel equaled 177 HV. The researches showed that alloy layers on the steeling casts were characterized by the hardness bigger twice than cast steel. The bigger hardness, the bigger abrasion wear resistance of surface alloy layer. The abrasion wear resistance was expressed by the mass loss equal 0,029 g for the layer. This value is much smaller than for steeling cast where the mass loss was about 0,135 g. The difference between the mass loss for alloy layer and chromium cast iron, which has got similar properties to examined material of the layer, is big and equal about 50% (0,014 g). In spite of the mass loss, steeling casts with surface alloy layer are much cheaper than uniform casts from chromium cast iron, what is important for industry in terms of economic aspect. The following conclusions were reached on the base of conducted researches:

1. Higher pouring temperature and thicker cast wall causes thicker surface alloy layer.
2. The thickness of the cast wall, the size of the pad grain and pouring temperature influence the hardness of the alloy layer. The thinner cast wall, the bigger hardness of the layer. The smaller diameter of the FeCrC grain of the pad, the bigger hardness of the layer. The higher pouring temperature, the bigger hardness of the layer as well.
3. The thicker cast wall, the bigger mass loss what testifies the decrease of abrasion wear resistance.
4. Synergetic action of analyzed factors of the process: pouring temperature, thickness of the cast. Wall and diameter of the grain allows to reach corrosion resistance of alloy layer similar to materials characterized by high resistance.

REFERENCES

[1] J. Szajnar, D. Bartocha, C. Baron, A. Walasek, Archives of Foundry Engineering **8**, 3, 139-143 (2008).

[2] M. Brožek, Manufacturing Technology **5**, 5-9 (2005).

[3] I. Kovač, J. Žarnovsky, R. Drlička, J. Ružbarsky, Manufacturing Technology **10**, 78-80 (2010).

[4] A. Studnicki, J. Jezierski, Metal 2012, Internatinal Conderence on Metallurgy and Materials, Brno (2012).

[5] T. Wróbel, Archives of Materials Science and Engineering **48**, 2, 118-125 (2011).

[6] T. Wróbel, Metal 2011: International Conference on Metallurgy and Materials. Brno, 758-764 (2011).

[7] M. Cholewa, T. Wróbel, S. Ternerowicz, T. Szuter, Archives of Metallurgy and Materials **55**, 3, 771-777 (2010).

[8] W. Wołczyński, T. Okane, C. Senderowski, B. Kania, D. Zasada, J. Janczak-Rusch, Archives of Metallurgy and Materials **56**, 2, 311-324 (2011).

[9] P. Wróble, Doctor's thesis, Improvement of the cast steel castings surface by creating the alloy composite layer in casting process, Silesian University of Technology, Gliwice, (2004).

[10] C. Baron, Doctor's thesis, The surface composite layer on the steel cast, Silesian University of Technology, Gliwice, (2007).

[11] A. Walasek, Doctor's thesis, Designing of the structure and properties of the alloyed surface layer on the cast steel castings, Silesian University of Technology, Gliwice, (2012).

[12] K. Janerka, D. Bartocha, J. Jezierski, J. Szajnar, Metal 2012; International Conference on Metallurgy and Materials, Brno, (2012).

[13] D. Bartocha, J. Kilarski, J. Suchoń, C. Baron, J. Szajnar, K. Janerka, Archives of Foundry Engineering **11**, SI 3, 265-271 (2011).

[14] D. Bartocha, J. Suchoń, Archives of Foundry Engineering **11**, SI 3, 5-14 (2011).

[15] D. Bartocha, K. Janerka, J. Suchoń, Archives of Metallurgy and Materials **162**, SI, 465-470 (2005).

[16] K. Janerka, D. Bartocha, J. Szajnar, J. Jezierski, Archives of Metallurgy and Materials **55**, 3, 851-859 (2010).

[17] K. Janerka, J. Jezierski, D. Bartocha, J. Szajnar, Advanced Materials Research **622-623**, 685-689 (2013).

[18] M. Stawarz, Eksploatacja i Niezawodność, ISSN 1507-2711, **2**, 22, 55-58 (2004).

[19] J. Szajnar, A. Walasek, C. Baron, Manufacturing Technology **13**, 1, 103-108 (2013).

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