

The quality of the joint between alloy steel and unalloyed cast steel in bimetallic layered castings

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Abstract

In paper is presented technology of bimetallic layered castings based on founding method of layer coating directly in cast process so-called method of mould cavity preparation. Prepared castings consist two fundamental parts i.e. bearing part and working part (layer). The bearing part of bimetallic layered casting is typical foundry material i.e. ferritic-pearlitic unalloyed cast steel, whereas working part (layer) is plate of austenitic alloy steel sort X2CrNi 18-9. The ratio of thickness between bearing and working part is 8:1. The aim of paper was assessed the quality of the joint between bearing and working part in dependence of pouring temperature and carbon concentration in cast steel. The quality of the joint in bimetallic layered castings was evaluated on the basis of ultrasonic non-destructive testing, structure and microhardness researches.

Keywords: Layered casting; Cast steel; Steel; Austenite; Ferrite; Pearlite

1. Introduction

The technology of layered castings is used in cases when the criterion of high usable properties concerns only working surface layer of casting and its remaining part is only bearing part, which is not directly exposed to the action of medium causes for example abrasive or corrosive wear.

The basic technology of layered castings is so-called method of mould cavity preparation in which the enriched element of the working surface layer of the casting is placed in mould in form of monolithic or granular insert directly before pouring molten metal [1÷7]. This technology is the most economical way of enrichment the surface of castings, as it allows the production of layer elements directly in the process of cast. Therefore, this technology can provide significant competition for the commonly used

technologies of surfacing by welding and thermal spraying [8], because in addition to economic advantages do not generate opportunities for the development of cracks in the heat affected zone, which arises as a result of making layer by welding method.

The idea of the proposed technology of layered casting was taken from the relevant mining industry method of manufacture of composite (alloy) surface layers based on granular inserts from Fe-Cr-C [1, 3, 4], Fe-Cr-C-Mo [2] oraz Ni-Cr-Fe-C [7] alloy, placed in mould directly before pouring molten metal. Obtained in this way working surface layers have a high hardness and metal-mineral wear resistance [1, 3 and 9].

Moreover in literature are present data about layered castings made on the basis of monolithic inserts, for example from unalloyed steel poured by liquid chromium alloy cast iron [5, 6] or from grey cast iron dipping into liquid hypoeutectic Al-Si alloy [9÷11]. Moreover using the method of mould cavity preparation

by monolithic insert was obtained bimetallic layered castings in material configuration grey cast iron – alloy steel sort X6Cr 13 or X39Cr 13 or X10CrNi 18-9 or X2CrNiMoN 22-5-3 [12, 13].

2. Range of studies

In range of studies were made bimetallic layered castings, which consist two fundamental parts i.e. bearing part and working part (layer) (Fig.1). The bearing part of bimetallic layered casting is typical foundry material i.e. ferritic-pearlitic unalloyed cast steel, whereas the working part (layer) is plate of austenitic alloy steel sort X2CrNi 18-9.

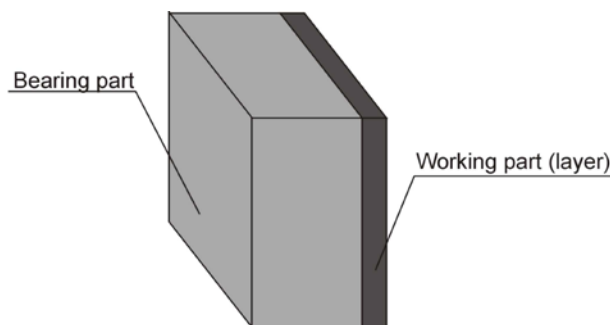


Fig. 1. Scheme of bimetallic layered casting

In aim of making a test bimetallic layered castings with dimensions 125 x 105 x 45mm, in sand mould with no preheating were placed plates of alloy steel X2CrNi 18-8 (Fig. 2), which then were poured by liquid unalloyed cast steel with carbon concentration changes in range from 0,2 to 0,6% from pouring temperature $T_{zal} = 1550, 1600$ and 1650°C .

The pouring temperature was measured by use of thermocouple Pt-PtRh10 directly before mould poured and carbon concentration of cast steel bearing part was measured by use of analyzer LECO CS-125. The experimental plan includes 16 test castings.

On the basis of results of previous studies [14] were used steel plates with thickness 5mm, which surfaces staying in direct contact with liquid metal were covered by activator in form of boron and sodium compounds. These compounds favour the formation of a permanent joint between both materials of layered casting. Obtained in this way the ratio of thickness between bearing and working part about 8:1 at solidification module 11,45mm.

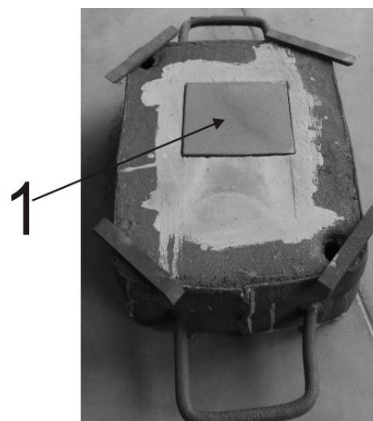
Therefore the aim of paper was assessed the quality of the joint between bearing and working part in dependence of pouring temperature and carbon concentration in cast steel.

The quality of the joint in bimetallic layered castings was evaluated on the basis of ultrasonic non-destructive testing made using the DIO 562 flaw detector by STARMANS ELEKTRONICS.

Next metallographic examination of macro-and microscopic was carried out. Metallographic specimens etched in the reagent Mi19Fe containing [15]: 3g of ferric chloride, 10cm^3 hydrochloric acid and 90cm^3 ethanol.

Moreover measurements of microhardness was made using FM 700's Future-Tech.

a)



b)



Fig. 2. View of sand mould with plate of austenitic steel (1) placed in its cavity: a – bottom half of mould, b – top half of mould

3. Results of studies

On the basis of non-destructive ultrasonic testing it was found, that in none of 16 test castings it does not occur the permanent joint on whole contact surface between the working part (layer) and the bearing part. The largest surface of permanent joint i.e. for which the bottom echo was larger than the echo of the transition zone (head placed on the side of the plate) was obtained at $T_{zal} = 1650^{\circ}\text{C}$ and concentration of carbon in cast steel $C = 0,6\%$ (Fig.3). This surface equals 80% of whole contact surface of both materials. In other cases were obtained permanent joint between alloy steel and unalloyed cast steel on surface less than 80%. Moreover was affirmed that application of pouring temperature 1550°C irrespective of carbon concentration in cast steel it does not allow for obtaining any kind of joint between the working part (layer) and the bearing part in bimetallic layered casting.

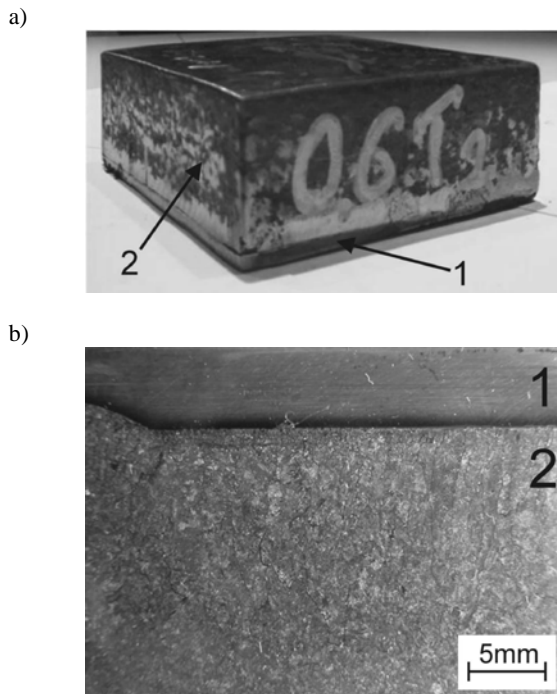


Fig. 3. View of test layered casting (a) and its example traverse section (b): 1 – working part (layer) in form of alloy steel X2CrNi 18-9 plate, 2 – bearing part from unalloyed cast steel at carbon concentration $C = 0,6\%$ and pouring temperature 1650°C

In table 1 is presented specification of non-destructive ultrasonic testing results of test bimetallic layered castings made in configuration alloy steel – unalloyed cast steel according to accepted experimental plan.

These results were confirmed by macroscopic visual quality assessment made on selected sections of test bimetallic layered castings. Moreover in some cases was found that in place in which on the bases of non-destructive ultrasonic testing was affirmed lack of joint, in reality are present partial joints, which is characterized by the presence of so-called “bimetallic connecting bridges”. Presence of so-called “bimetallic connecting bridges” also provides stability of joint between working and bearing part of bimetal in conditions of small load. A more detailed characterization of the so-called “bimetallic connecting bridges” is shown in paper [16].

In aim of determination of considered cast parameters on quality of the joint between alloy steel and unalloyed cast steel in bimetallic layered castings was made statistical analysis of obtained results. Applying the method of stepwise regression looked for the following statistical relationship:

$$P = f(C, T_{\text{zal}}) \quad (1)$$

where:

P – surface on which was obtained permanent joint between the working part (layer) from alloy steel X2CrNi 18-9 and the bearing part from unalloyed cast steel in bimetallic layered casting, %,

C – carbon concentration in cast steel (bearing part of casting), % mas.,
 T_{zal} – pouring temperature, $^{\circ}\text{C}$;

Table 1.
 The results of non-destructive ultrasonic testing of test bimetallic layered casting in configuration alloy steel – unalloyed cast steel

No.	T_{zal} , $^{\circ}\text{C}$	C % mas.	Characteristic of joint between the working layer and the bearing part
1		0,60	Permanent joint on 80,0% of contact surface between the working layer and the bearing part
2		0,55	Permanent joint on 69,5% of contact surface between the working layer and the bearing part
3		0,43	Permanent joint on 65,0% of contact surface between the working layer and the bearing part
4	1650	0,34	Permanent joint on 9,2% of contact surface between the working layer and the bearing part
5		0,20	Permanent joint on 3,0% of contact surface between the working layer and the bearing part
6		0,18	Permanent joint on 1,0% of contact surface between working layer and bearing part
7		0,15	Permanent joint on 8,5% of contact surface between the working layer and the bearing part
8		0,55	Permanent joint on 10,0% of contact surface between the working layer and the bearing part
9	1600	0,43	Permanent joint on 48,9% of contact surface between working layer and bearing part
10		0,22	Permanent joint on 8,0% of contact surface between the working layer and the bearing part
11		0,60	Complete lack of joint between the working layer and the bearing part
12		0,52	
13		0,43	
14	1550	0,37	
15		0,20	
16		0,15	

On the basis of conducted calculations the following dependence was formulated:

$$P = 93,91C + 0,35T_{\text{zal}} - 568,06 \quad (2)$$

at correlation coefficient $R = 0,77$ i $R^2 = 0,59$.

On the basis of dependence (2) was affirmed, that with increases of pouring temperature and carbon concentration in material of bearing part of layered casting, increases of surface on which was obtained permanent joint between both bimetal parts is observed. Moreover was affirmed, that applicability of dependence (2) can be successfully extended to a higher concentration of carbon and lower pouring temperature i.e. proper for cast iron (Fig.4) as show in papers [7, 12÷14].

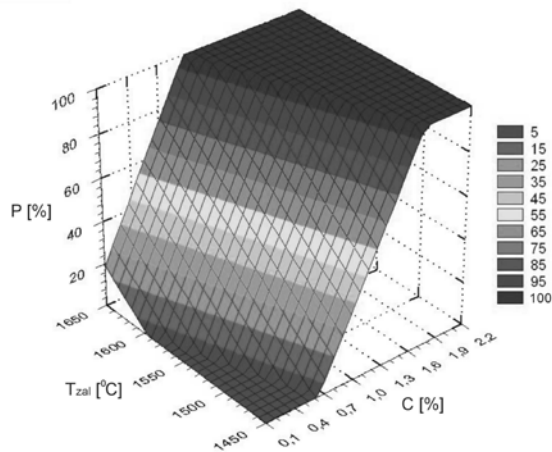


Fig. 4. The influence of pouring temperature and carbon concentration in bearing part of layered casting in configuration: alloy steel X2CrNi 18-9 – unalloyed cast steel at module of casting 11,45mm

Whereas on the basis of the analysis of results of microscopic metallographic examination was affirmed, that the pouring temperature influences on degree of nonlinearity of boundary between the working part (layer) and the bearing part, which determines high strength of joint between both materials in bimetallic layered casting (Fig.5 and 6). Increases in nonlinearity of boundary in result from increase in pouring temperature of cast steel is observed.

While the carbon concentration in cast steel bearing part influence on thickness of pearlitic transition zone (δ) with hardness $230\mu\text{HV}$, which connects austenitic steel with ferritic-pearlitic cast steel (Fig.7÷9). Increases in thickness of pearlitic transition zone (δ) in result from increase in carbon concentration in cast steel is observed (Fig.10). Increase of pearlitic transition zone thickness with carbon concentration also positively influences on strength of joint between both materials in bimetallic layered casting.

More details about forming of transition zone in this type of layered castings is presented in paper [16].

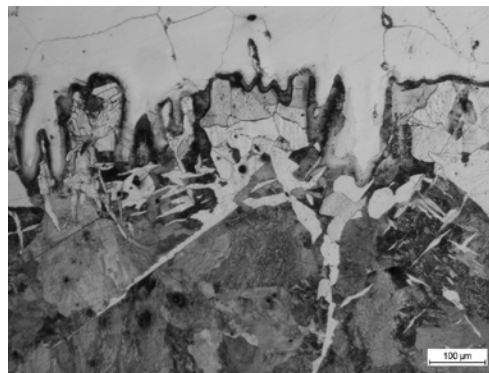


Fig. 5. Microstructure of joint area between austenitic alloy steel and ferritic-pearlitic unalloyed cast steel C = 0,55% at $T_{zal} = 1650^{\circ}\text{C}$ – etching Mi19Fe



Fig. 6. Microstructure of joint area between austenitic alloy steel and ferritic-pearlitic unalloyed cast steel C = 0,55% at $T_{zal} = 1600^{\circ}\text{C}$ – etching Mi19Fe

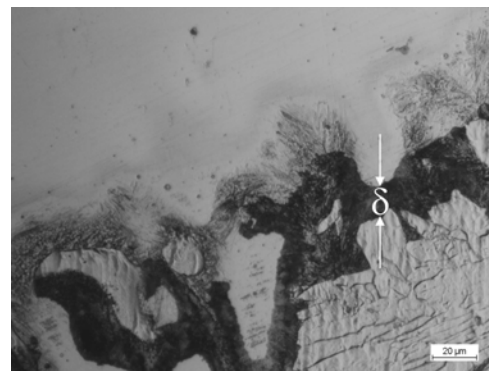


Fig. 7. Microstructure of joint area between austenitic alloy steel and ferritic-pearlitic unalloyed cast steel at C = 0,60% and $T_{zal} = 1650^{\circ}\text{C}$ – etching Mi19Fe

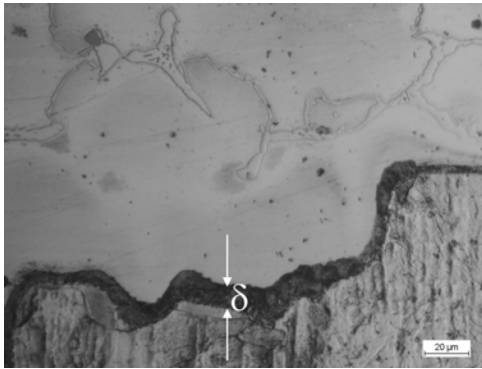


Fig. 8. Microstructure of joint area between austenitic alloy steel and ferritic-pearlitic unalloyed cast steel at $C = 0,43\%$ and $T_{zal} = 1650^{\circ}\text{C}$ – etching Mi19Fe

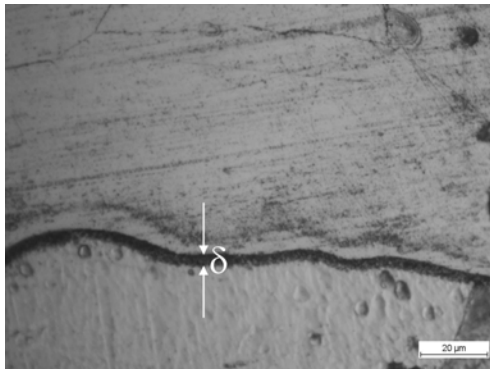


Fig. 9. Microstructure of joint area between austenitic alloy steel and ferritic-pearlitic unalloyed cast steel at $C = 0,20\%$ and $T_{zal} = 1650^{\circ}\text{C}$ – etching Mi19Fe

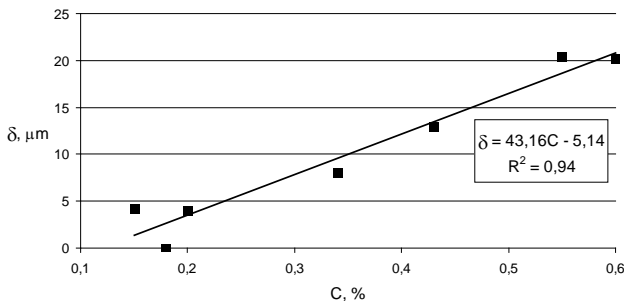


Fig. 10. The influence of carbon concentration in cast steel on thickness of pearlitic transition zone (δ) in bimetallic layered casting at $T_{zal} = 1650^{\circ}\text{C}$

4. Summary

On the basis of obtained results was affirmed that obtaining necessary, permanent joint between plate of alloy steel sort X2CrNi 18-9 and unalloyed cast steel in bimetallic layered

casting at assumed solidification module, demands simultaneously of two conditions i.e. suitable, high pouring temperature of liquid cast steel poured into the mould in which is placed 5mm thick plate of austenitic alloy steel and also suitable, minimal difference in carbon concentration between the both joined materials. Fulfilment of only one of these conditions result in obtaining of defective casting, which has no application characteristics.

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References

- [1] J. Marcinkowska, B. Kuszniar: Cast coatings on machine elements, Proceedings Materiale of Scientific Conference "Cast Form of Machine Elements", Olsztyn (1979), 1-11 (in polish).
- [2] T. Heijkoop, I. Sare: Cast-bonding – a new process for manufacturing composite wear products, Cast Metals, 3 (1989), 160-168.
- [3] J. Gawroński, J. Szajnar, P. Wróbel: Study on theoretical bases of receiving composite alloy layers on surface of cast steel castings, Journal of Materials Processing Technology, 157–158 (2004), 679-682.
- [4] J. Szajnar, P. Wróbel, T. Wróbel: Model castings with composite surface layer - application, Archives of Foundry Engineering, 3 (2008), 105-110.
- [5] D. Bartocha, J. Suchoń, S. Jura: Layer castings, Solidification of Metals and Alloys, 38 (1998), 151-156 (in polish).
- [6] M. Cholewa, S. Tenerowicz, T. Wróbel: Quality of the joint between cast steel and cast iron in bimetallic castings, Archives of Foundry Engineering, 3 (2008), 37-40.
- [7] T. Wróbel: Ni and Cr base layers in bimetallic castings, Proceedings of 20th Anniversary International Conference on Metallurgy and Materials METAL 2011, (2011), 91.
- [8] A. Klimpel: Surfacing and thermal spraying. Technologies, WNT, Warsaw (2000) (in polish).
- [9] J. Viala, M. Peronnet, F. Barbeau, F. Bosselet, J. Bouix: Interface chemistry in aluminium alloy castings reinforced with iron base inserts, Composites: Part A, 33 (2002), 1417-1420.
- [10] S. Pietrowski, T. Szymczak: Model of the alphinising coating crystallization on iron alloys, Archives of Foundry Engineering, 3 (2007), 123-128.
- [11] S. Pietrowski: Structure of alifinising layer on the gray cast iron, Archives of Foundry, 11 (2004), 95-104.
- [12] T. Wróbel: Bimetallic layered castings alloy steel – grey cast iron, Archives of Materials Science and Engineering, 2 (2011) 118-125.
- [13] T. Wróbel, M. Cholewa, S. Tenerowicz: Examples of material solutions in bimetallic layered castings, Archives of Foundry Engineering, 3 (2011), 11-16.

- [14] M. Cholewa, T. Wróbel, S. Tenerowicz: Bimetallic layer castings, *Journal of Achievements in Materials and Manufacturing Engineering*, 43/1 (2010), 385-392.
- [15] K. Sękowski, J. Piaskowski, Z. Wojtowicz: Atlas of structures of founding alloys, WNT, Warszawa 1972, (in polish).
- [16] T. Wróbel, M. Cholewa, S. Tenerowicz: Bimetallic layered castings alloy steel – carbon cast steel, *Archives of Foundry Engineering*, Nr 1, vol. 11, 2011, s. 105-107.