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The Influence of Selected Cast Parameters on Quality of Joint in 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. unalloyed cast steel, whereas working part 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 and 4], Fe-Cr-C-Mo [2] and 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 4].

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 and 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 [12-14].

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. unalloyed cast steel, whereas the working part (layer) is plate of austenitic alloy steel sort X2CrNi 18-9.

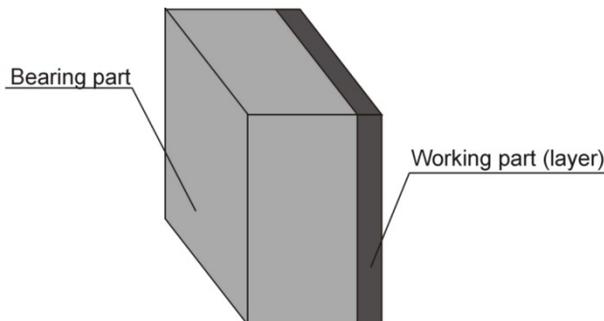


Fig. 1. Scheme of bimetallic layered casting

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 18-9, which then were poured by liquid unalloyed cast steel with carbon concentration changes in range from 0,2 to 0,6% (in first stage of studies) 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 basic 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 favor 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 of casting 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, 10cm³ hydrochloric acid and 90cm³ ethanol. Moreover measurements of microhardness was made using FM 700's Future-Tech.

3. Results of studies

On the basis of non-destructive ultrasonic testing it was found, that in none of 16 test castings from basic experimental plan 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), as show on Figure 2, was obtained at $T_{zal} = 1650^{\circ}\text{C}$ and concentration of carbon in cast steel $C = 0,6\%$. 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.

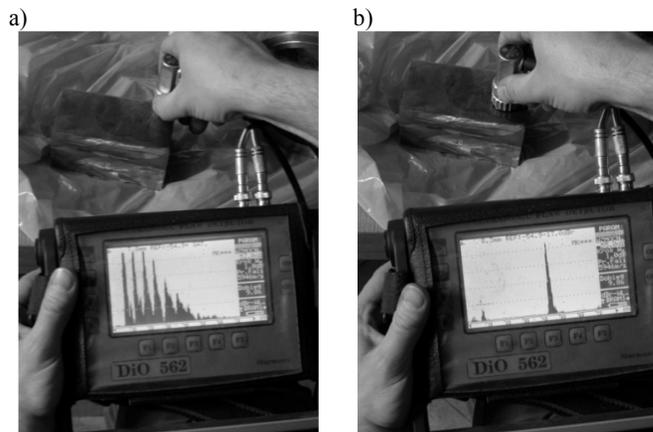


Fig. 2. View of example results of ultrasonic non-destructive testing of bimetallic layered castings: a – lack of joint between the working layer and the bearing part, b – permanent joint between the working layer and the bearing part

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 basic experimental plan.

These results were confirmed by macroscopic visual quality assessment made on selected sections of test bimetallic layered castings (Fig. 3). 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 bimetals 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:

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

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} , °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 | |
| 12 | | 0,52 | |
| 13 | 1550 | 0,43 | Complete lack of joint between the working layer and the bearing part |
| 14 | | 0,37 | |
| 15 | | 0,20 | |
| 16 | | 0,15 | |

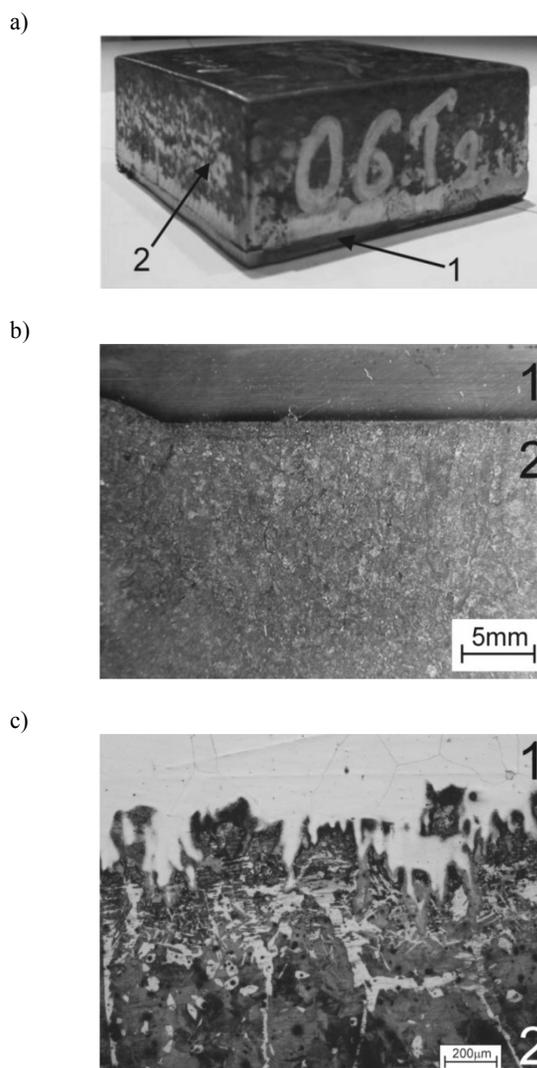


Fig. 3. View of test layered casting (a), its example traverse section (b) and microstructure of joint area (c): 1 – working part (layer) in form of alloy steel X2CrNi 18-9 plate, 2 – bearing part from unalloyed cast steel at carbon concentration $C = 0,6\%$ and pouring temperature 1650°C

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

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

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 bimetals 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).

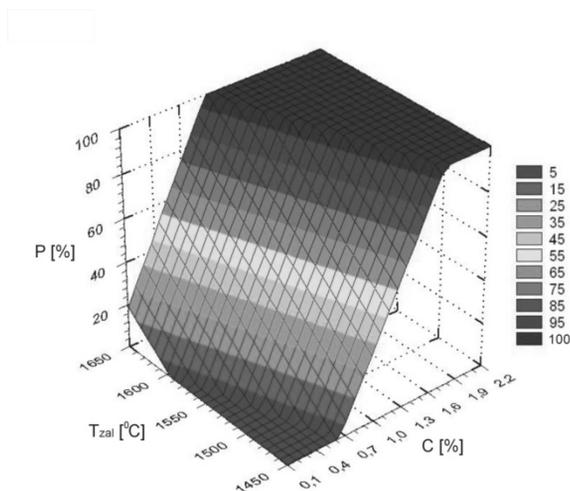


Fig. 4. The influence of pouring temperature and carbon concentration in bearing part on surface on which was obtained permanent joint between the working part (layer) in form of alloy steel X2CrNi 18-9 plate and cast steel in bimetallic layered casting at module 11,45mm

Therefore, based on the determined dependence can be argued that to obtain the permanent joint between both parts of bimetal on whole contact surface for fixed geometry of casting should be meet condition presented below:

$$C + 0,0037T_{zal} - 7,13 \geq 0 \quad (3)$$

On the bases of dependence (3) was affirmed that minimal carbon concentration in cast steel bearing part, which guarantees its permanent joint on whole contact surface with working part (layer) from alloy steel X2CrNi 18-9, equals about 1% at $T_{zal} = 1650^{\circ}\text{C}$ and additionally that any carbon concentration in cast iron bearing part i.e. $> 2\%$ guarantees its permanent joint with working part (layer) from alloy steel X2CrNi 18-9 at $T_{zal} = 1450^{\circ}\text{C}$ (Fig. 5).

In aim to verify the determined dependence were cast layered castings at keeping its geometry and in configuration working part (layer) from alloy steel X2CrNi 18-9 - bearing part from unalloyed cast steel at carbon concentration $C = 0,96\%$ (Fig. 6) and from grey cast iron at carbon concentration $C = 3,1\%$ [12-14]. On the of results of non-destructive ultrasonic testing it was found, that in both cases occurred permanent joint between the working part (layer) and the bearing part on whole contact surface, what confirms the rightness of the presented dependences (2) and (3).

Moreover as show in paper [17] 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. Increases in nonlinearity of boundary in result from increase in pouring temperature of cast steel is observed.

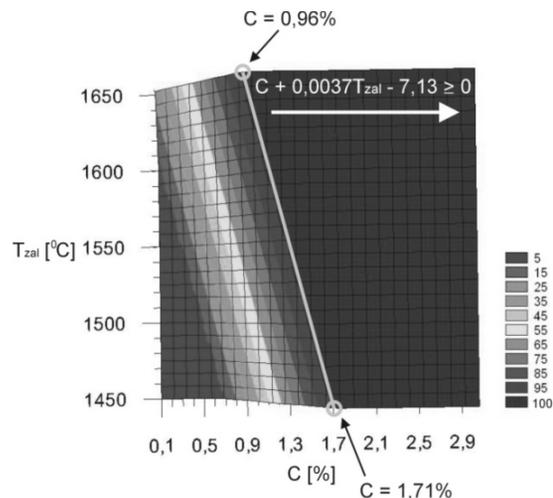


Fig. 5. Graphical interpretation of necessary condition to obtaining the permanent joint on whole contact surface between working part (layer) from alloy steel X2CrNi 18-9 and bearing part from unalloyed cast steel or cast iron in bimetallic layered casting at module 11,45mm

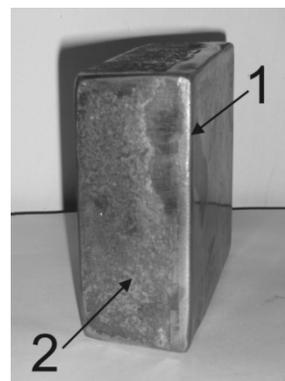


Fig. 6. View of layered casting in configuration: 1 - working part (layer) in form of alloy steel X2CrNi 18-9, 2 - bearing part from unalloyed cast steel at carbon concentration $C = 0,96\%$ and pouring temperature 1650°C

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

Moreover, the result of the C diffusion phenomenon next to creation of pearlitic transition zone is decarbonizing of cast steel in near boundary area and in consequence of this is creation in this zone ferritic microstructure with small amount of pearlite, considerably smaller than in the rest of bearing part of casting (Fig. 7).

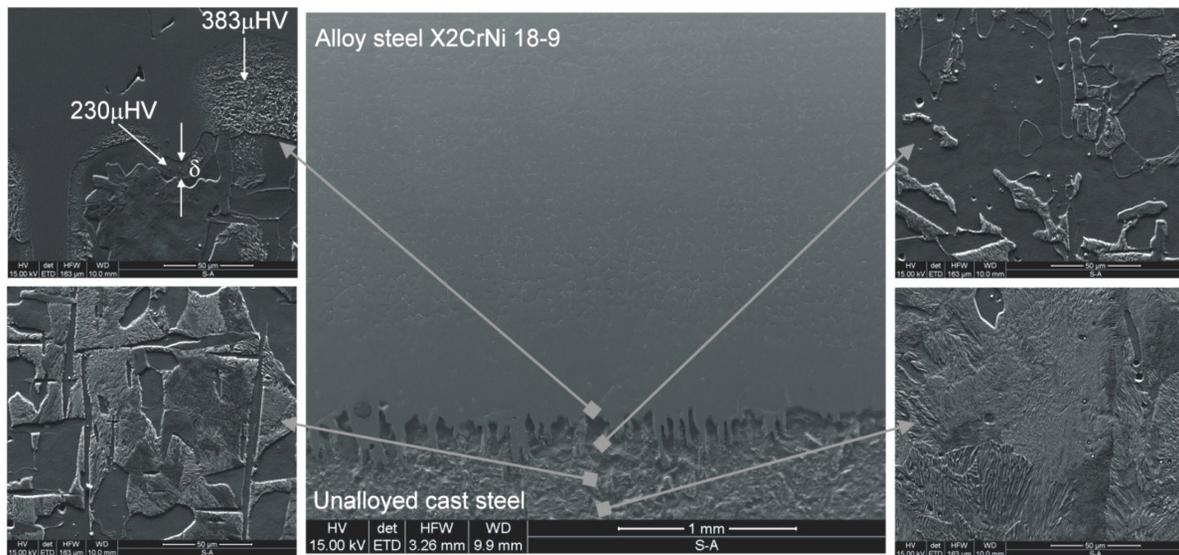


Fig. 7. Microstructure of bimetallic layered casting in configuration working part (layer) in form of alloy steel X2CrNi 18-9 plate - bearing part from unalloyed cast steel

Additionally, the near boundary area of plate of alloy steel sort X2CrNi 18-9 is carbonizing by cast steel and in result of this is obtained in this zone microstructure of martensite with hardness about $380\mu\text{HV}$ (Fig. 7). Besides carbonizing of the near boundary area of austenitic steel, also favors the creation of martensite cooling from high temperature to which the plate is heated, and whose source is the liquid cast steel poured into the mould. For the pouring temperature 1650°C of cast steel, the contact temperature T_s on the border of liquid metal - steel plate, fixed on the basis of dependence [18]:

$$T_s = \frac{\sqrt{\lambda_n \cdot c_n \cdot \rho_n \cdot T_n} + \sqrt{\lambda_r \cdot c_r \cdot \rho_r \cdot T_r}}{\sqrt{\lambda_n \cdot c_n \cdot \rho_n} + \sqrt{\lambda_r \cdot c_r \cdot \rho_r}} \quad (4)$$

where:

λ_n, λ_r – coefficient of thermal conductivity, suitably for the liquid cast steel (bearing part of casting) and steel plate (working part of casting), $\text{W}/(\text{m}\cdot\text{K})$,

c_n, c_r – specific heat, suitably for the liquid cast steel (bearing part of casting) and steel plate (working part of casting), $\text{J}/(\text{kg}\cdot\text{K})$,

ρ_n, ρ_r – mass density, suitably for the liquid cast steel (bearing part of casting) and steel plate (working part of casting), kg/m^3 ,

T_n – temperature of the liquid cast steel, $^\circ\text{C}$,

T_r – temperature of steel plate (working part of casting), $^\circ\text{C}$, is about 1100°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. Fulfillment of only one of these conditions result in obtaining of defective casting, which has no application characteristics.

Moreover on the basis of guidelines to presented technology was made bimetallic sleeve in configuration internal working part (layer) in form of alloy steel X2CrNi 18-9 – external bearing part from unalloyed cast steel (Fig. 8) predicted to application as element of mechanical coal miner.

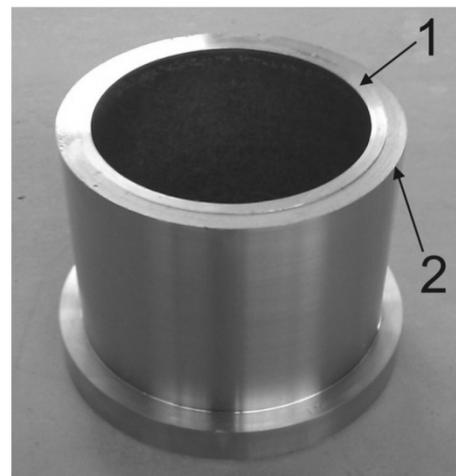


Fig. 8. View of bimetallic sleeve in configuration: 1 – internal working part (layer) in form of alloy steel X2CrNi 18-9, 2 – external bearing part from unalloyed cast steel

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