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Bimetallic layer castings

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ABSTRACT

Purpose: In paper is presented technology of bimetallic layer casting in configuration: working part (layer) from ferritic or austenitic alloy steel and bearing part from grey cast iron.

Design/methodology/approach: In applied technology surface layer on the basis of alloy steel at 2 or 5mm thickness was put directly in founding process of cast iron with use of preparation of mould cavity method. Quality of bimetallic layer castings was estimated on the base of ultrasonic non-destructive testing and examination of the structure and selected usable properties i.e. hardness.

Findings: The results of studies and their analysis show efficiency of new, innovative technology of heat-resisting layer castings.

Research limitations/implications: In further research, authors of this paper are going to application of different type of alloy steels on working part (layer) of bimetallic casting.

Practical implications: On the basis of research results was affirmed that application of thinner plates i.e. about thickness 2mm causes their deformation in time of pouring, what disqualify this layer casting for industrial application. Considerably best results was obtained with use thickness of plate 5mm.

Originality/value: The value of this paper resides in new effective method of manufacture of heat-resisting castings, mainly for lining of quenching car to coke production.

Keywords: Casting; Cast iron; Austenite; Ferrite

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1. Introduction

In the engineering industry noticeable is a growing demand for castings with special properties such as abrasive wear resistance, corrosion resistance at room or elevated temperature. Elements of this type often carried out entirely from expensive and hard to reach materials like of Ni, Co, Ti, or others. In many cases the requirements for high performance properties affect only the working surface of the casting. Especially if wear of an element leads to its destruction through exceeded the allowable main dimension decrease.

Among many methods for producing metallic coatings on materials for specific performance properties to be mentioned is casting technology called method of mould cavity preparation in which the element which is the working surface layer of the casting is placed in a form immediately before pouring molten metal. This technology is the most economical way of enrichment the surface of castings, both ferrous and nonferrous alloys, as it allows the production of layer elements directly in the process of casting [1-3]. Therefore, this technology can provide significant competition for the commonly used welding technologies and thermal spraying [4-9], 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 layer casting was taken from the relevant mining industry method of manufacture of composite layers of surface based on granularity inserts from Fe-Cr-C alloy and placed in mould immediately before pouring molten metal. Obtained in this way working surface layers have a high hardness and metal-mineral wear resistance [1-3].

Another, also has common features with the proposed technology is bimetallic layer castings in configuration: cast steel - chromium cast iron, in which bearing part of the casting is made of cast steel plate is designed to allow connection by welding to another part, and working part is made of chromium cast iron to ensure high hardness and abrasive wear resistance [10, 11]. However, a significant economic limitation of this method is the need to preheat the cast steel component placed in mould. This treatment is carried out by two-stage form pouring with the liquid cast iron (Fig. 1).

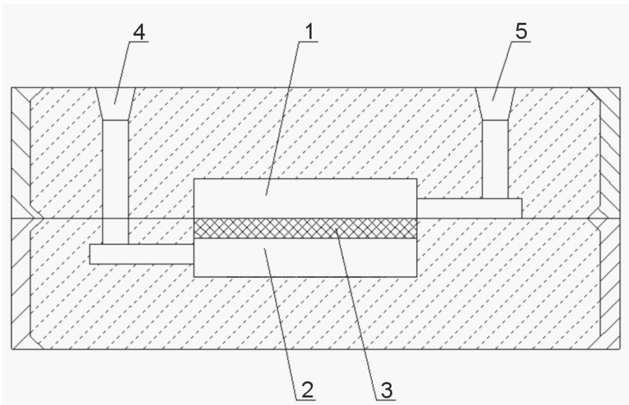


Fig. 1. Technology of bimetallic layer castings with use of two gating systems: 1 – cast iron layer, 2 – cavity (preheater) 3 – cast steel plate, 4, 5 – gating [10]

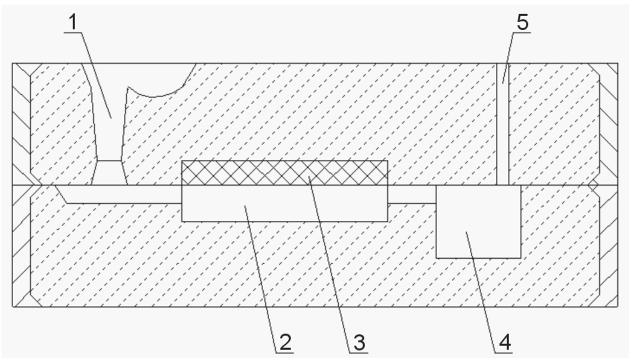


Fig. 2. Technology of bimetallic layer castings with use of one gating systems: 1 – gating, 2 – cast iron layer, 3 – cast steel plate, 4 – flow-off tank, 5 – flow-off [10]

In the first stage mould cavity beneath a cast steel plate is filled with liquid metal for preheat of cast steel element. Formed in this way, layer after cleaning cast iron is separated from the casting. In the second stage mould cavity over cast steel plate is filled, in which the liquid metal forms a layered connecting with the plate creating a bimetallic layer casting. The other method of preheating of cast steel plate is use one gating system with flow-off tank (Fig. 2).

Restrictions resulting from the application of preheating on the first reduce yield and the inability to make high mass and stiffness of the casting. According to the authors o this paper those problems can be eliminated by applying appropriate cover activation, applied on steel surface in contact directly with liquid metal.

Next method of bimetallic casting technology is based on a skeleton cast steel structure filled with cast iron. The advantages of this method include large surfaces of contact of both materials and the ability to carry out several connections anywhere in casting [12].

In addition, attention should be paid to the method of producing bimetallic castings in a continuous cast process. In this method, the casting process is carried out using two independent crucibles, from which two streams of molten metal is introduced to the crystallizer equipped with a special barrier that allows a combination of both materials connect in the bimetal (Fig. 3). However, this innovative technology is so far limited only to selected non-ferrous alloys such as Al-Zn, Al or Al-Sn-Pb [13].

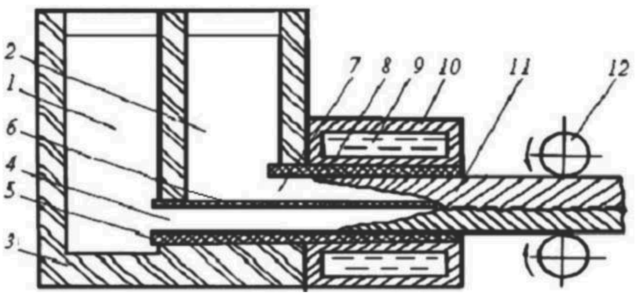


Fig. 3. Scheme of continuous cast process of bimetallic casting: 1 – liquid metal one, 2 – liquid metal two, 3 – crucible, 4 – the bottom channel, 5 – the bottom graphite plate, 6 – dividing plate, 7 – the top channel, 8 – the top graphite plate, 9 – cooling water, 10 – continuous casting mould, 11 – bimetallic casting, 12 – withdrawal device [13]

2. Range of studies

For the studies, the casting with a rectangular shape and dimensions of 125 x 105 x 40mm was used. In sand moulds steel plate of type X8Cr 13 or X10CrNi 18-8 of 2 and 5mm thick was placed with cover activation (Fig. 4). No procedure of preheating was applied. Then cast grey cast iron with temperature 1450^{o}C. In effect bimetallic layer casting in configuration: working part (layer) from ferritic or austenitic alloy steel and bearing part from grey cast iron was obtained (Fig. 5).

The quality of the bimetal layer casting was evaluated on ultrasonic NDT 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 [14]: 3 g of ferric chloride, $10 cm^3$ hydrochloric acid and $90 cm^3$ of ethanol. Qualitative microstructure research was conducted on the Nikon light microscope and electron scanning InspectF equipped with EDS system.

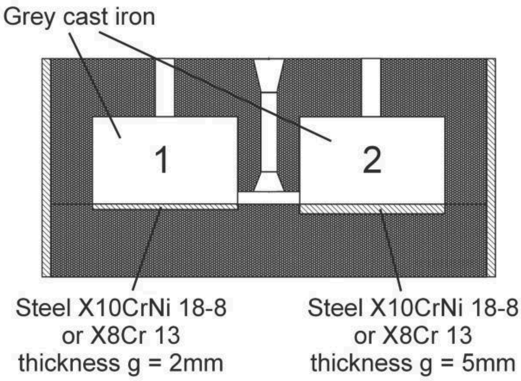


Fig. 4. Section of the sand mould ready to be poured by the liquid alloy (grey cast iron)

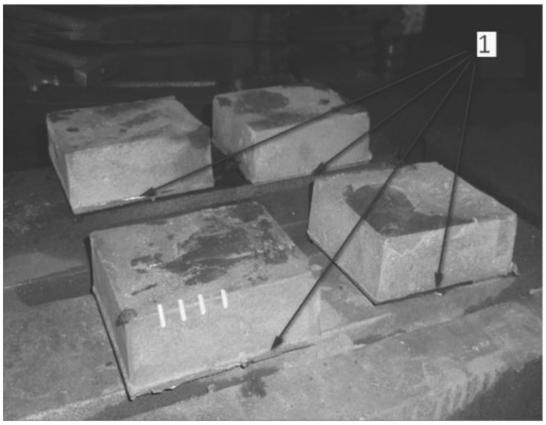


Fig. 5. View of cast iron test-castings with the surface enriched by alloy steel plate – 1

The study was extended to phase X-ray structure analysis carried out on the X-ray diffractometer XPertPro by Panalytical with the angular range 2θ from 35º to 125º in steps of 0.05º at the time of counting 5s. Using filtered X-rays from the lamp with a Co anode. Phase identification was based on data from the database International Centre for Diffraction Date ICDD. Samples for these studies were cut from the layer castings with surface enrichment of chromium-nickel steel plate after one cycle operation of abrasion of the metal - mineral according to the guidelines of ASTM G 65 - 00, to check whether there is a possibility of increasing the resistance to wear by plastic deformation induced transformation austenite to martensite ($\gamma \rightarrow \alpha'$).

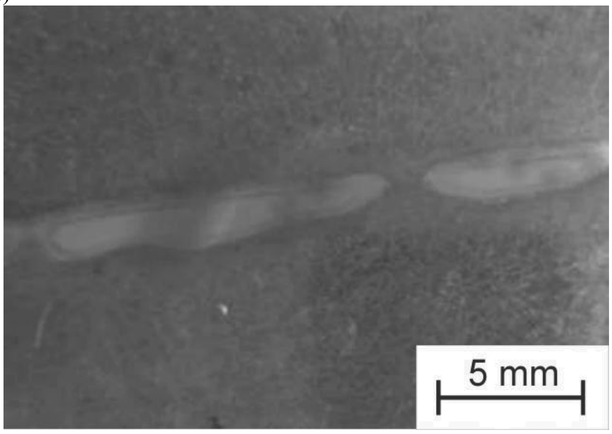
In addition, measurements of macro-and micro hardness test were made using appropriately MIC2 Krautrkramer-Branson's and FM 700's Future-Tech.

3. Results of studies

On the basis of non-destructive ultrasonic testing it was found that the entire sample bimetallic casting surface (head placed on the side of the steel plate) the bottom echo was larger than the echo of the transition zone, which indicates a good diffusion joint.

These results are confirmed in Figure 6, that shows an example of the cross-section of the bimetallic casting. Furthermore, it was found that in the case of thin plate that is 2 mm thick stainless steel, both X8Cr13 and X10CrNi18-8 a deformation occurs that is due to the low heat capacity that generates stress. As a result, a part of the liquid cast iron poured on the top of the plate, causes its partial dissolution (Fig. 6a) and determines the lack of usefulness of this type of castings for industrial applications. The described phenomenon does not apply to steel plates with a thickness of 5 mm (Fig. 6b), which allows to obtain the correct shape of the surface layer.

a)



b)

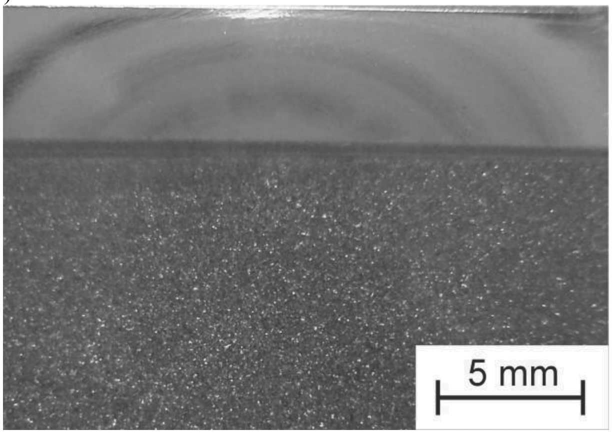


Fig. 6. View of cross-section of bimetallic grey cast iron casting with enriched surface by austenitic steel plate about thickness 2 mm (a) and 5 mm (b)

Figures 7 and 8 presents the results of metallographic microscopic examination. As a result of C diffusion phenomena in the direction from cast iron to steel plate and to a lesser extent Cr in the opposite direction, transition zone has been formed at the joint of cast iron - steel. Shaped transition zone, structurally different from the cast iron and steel plates used, has the character of diffusion in determining the quality of a joint of both bimetallic components. In addition, the formation of microstructure of transition zone and adjacent areas is affected by the heating temperature of steel, because of the cast iron poured to mould. For the temperature of pouring iron 1450°C, the temperature T_s at the border of the contact liquid metal - steel plate was fixed on the basis of dependence [15]:

$$T_s = \frac{\sqrt{\lambda_z \cdot c_z \cdot \rho_z} \cdot T_z + \sqrt{\lambda_s \cdot c_s \cdot \rho_s} \cdot T_s}{\sqrt{\lambda_z \cdot c_z \cdot \rho_z} + \sqrt{\lambda_s \cdot c_s \cdot \rho_s}} \tag{1}$$

where:
λ_z, λ_s – coefficient of thermal conductivity, respectively for the liquid grey cast iron and steel plate, W/(m·K),
c_z, c_s – appropriately for the heat of liquid grey cast iron and steel plate, J/(kg·K),
ρ_z, ρ_s – mass density, adequate for the liquid grey cast iron and steel plate, kg/m^3,
T_z – the temperature of molten grey cast iron, °C,
T_s – temperature of the steel plate, °C,
which is for the ferrite stainless steel X8Cr 13 about 870°C and for austenitic stainless steel X10CrNi 18-8 about 950°C.

Influence of diffusion of the basic elements of alloys in combination with a high temperature of heating of steel plate, and its effects an cast iron during its solidification like chill, decide on the formation of diversified microstructure in the joint area of both materials.

In the case of bimetallic layer casting in configuration: working part (layer) from high chromium steel X8Cr 13 and bearing part from grey cast iron, the analysis carried out on the surface layer (steel plate) side allows to distinguish the zones shown in Figure 7 and in Table 1.

Table 1.
Microstructure characteristic of bimetallic layer casting in configuration: working part (layer) from alloy steel X8Cr 13 and bearing part from grey cast iron

Zone number*	Microstructure component	Microhardness μHV
1	Ferrite (α)	205
2	Martensite (α`)	365
3	Martensite with carbides (Fe, Cr)$_x$C$_y$	α` = 410, (Fe, Cr)$_x$C$_y$ = 1000
4	Pearlite	300
5	Hard spots – pearlite, ledeburite with carbides (Fe, Cr)$_3$C	Matrix = 420, (Fe, Cr)$_3$C = 800
6	Flake graphite in pearlite matrix	Matrix (pearlite)= 300

* - zone designation according to Fig. 7

In the surface layer of this type of bimetallic layer casting a single-phase ferritic structure was obtained, which provides high corrosion resistance also at elevated temperatures.

As a result of carbon diffusion in the direction from cast iron to steel in the outer area of the plate (zone number 2), the concentrations of carbon increases above 0.1%, which combined with the high temperature of heating of this area leads to the structure of the solid solution γ, which during cooling of the casting with a small rate, transforms in martensite. The ratio of martensite to the amount of ferrite increases in direction to joint border of bimetal.

In the last zone (number 3) on the side of steel plate, as evidenced by preserved the original orientation of crystal grains, as a result of intensive carburizing from cast iron, martensite occurs with iron and chromium carbides.

The first zone (number 4) on the side of cast iron creates perlite. This zone is connected with the previous one, number 3 by non-linear border, which guarantees high quality of joint between both bimetallic components. The presence of pearlite results from the improverishment of this zone in the carbon, which precludes creating of high-carbon phases i.e. graphite or cementite, typical for cast iron.

Then, in zone number 5, as a result of high-speed solidification of molten metal at a concentration of carbon proper for cast iron, hard spot area is consisted of iron and chromium carbides, probably in the form of cementite (Fe, Cr)$_3$C.

The last zone number 6 consists of a typical structure for the grey cast iron poured into moulds, such as flake graphite in a pearlitic matrix.

In the case of bimetal layer casting in configuration: working part (layer) from chromium-nickel steel X10CrNi 18-8 and bearing part from grey cast iron, the analysis carried out on the side of surface layer (steel plate) allows to distinguish the zones shown in Figure 8 and in Table 2.

Table 2.
Microstructure characteristic of bimetallic layer casting in configuration: working part (layer) from alloy steel X10CrNi 18-8 and bearing part from grey cast iron

Zone number*	Microstructure component	Microhardness μHV
1	Austenite (γ)	220
2	Austenite with carbides Cr$_{23}$C$_6$	330
3	Ferrite (α) and austenite (γ) with small amount of carbides Cr$_7$C$_3$ and Cr$_{23}$C$_6$	Matrix (α+γ) = 275
4	Martensite (α`)	350
5	Hard spots – pearlite, ledeburite with carbides (Fe, Cr)$_7$C$_3$	Matrix = 430, (Fe, Cr)$_7$C$_3$ = 1100
6	Flake graphite in pearlite matrix	Matrix (pearlite)= 300

* - zone designation according to Fig. 8

The surface layer of this type of bimetal layer casting obtained single-phase austenitic structure, which is similar like the ferritic layer provides high resistance to corrosion, also at elevated temperatures.

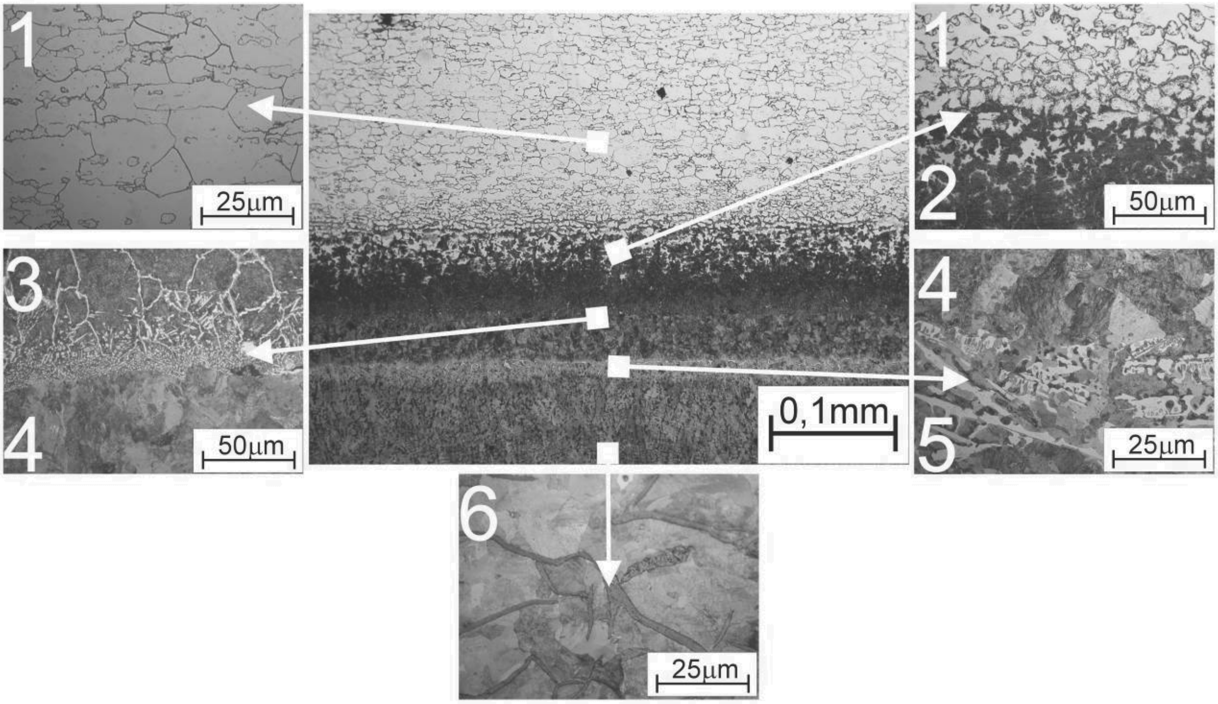


Fig. 7. Microstructure of bimetallic layer casting in configuration: working part (layer) from alloy steel X8Cr 13 (plate of the thickness about 5 mm) and bearing part from grey cast iron.– etching Mi19Fe

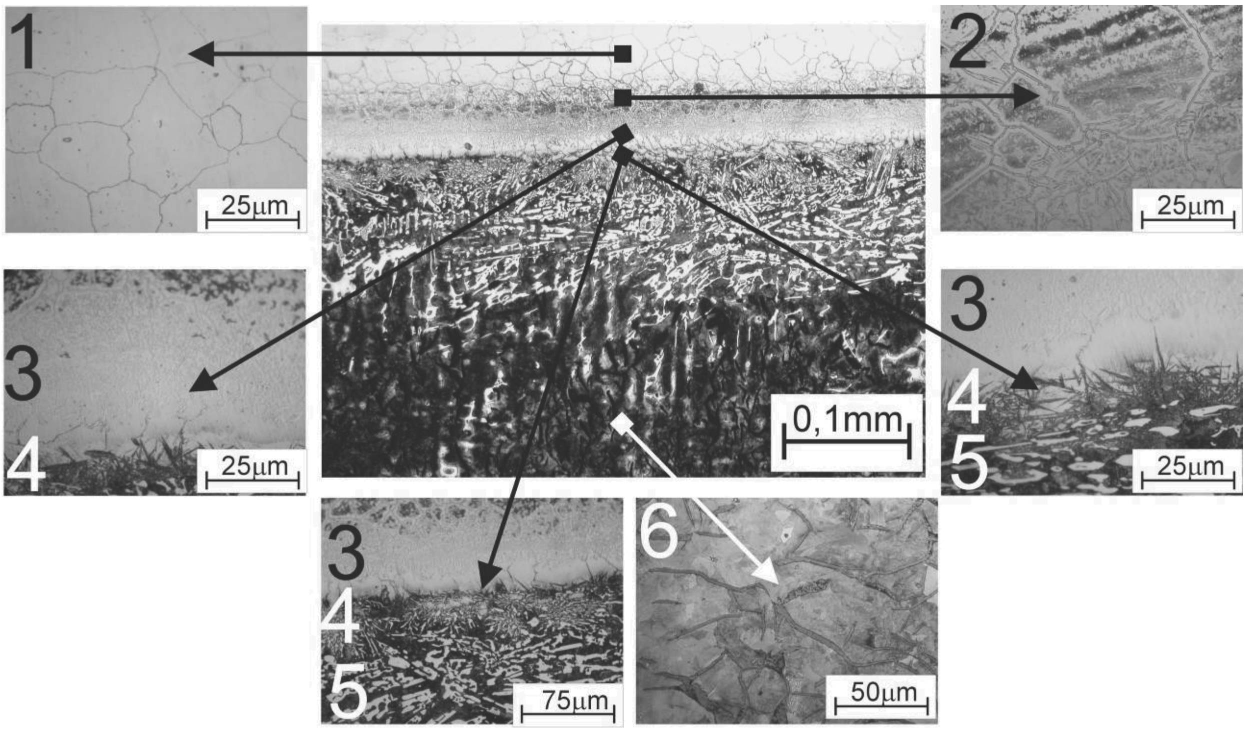


Fig. 8. Microstructure of bimetallic layer casting in configuration: working part (layer) from alloy steel X10CrNi 18-8 (plate of the thickness about 5 mm) and bearing part from grey cast iron.– etching Mi19Fe

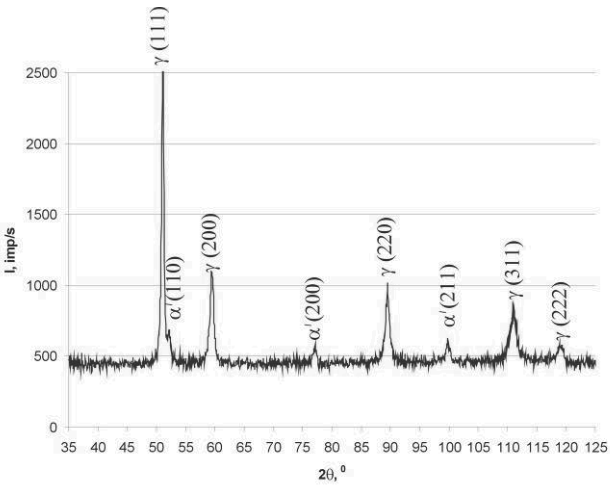


Fig. 9. X-ray diffraction of bimetallic layer casting with working part (layer) from austenitic steel X10CrNi 18-8 after one cycle exploitation in conditions of abrasive action of type metal-mineral

However, compared to ferritic (150HV), austenitic structure has a greater resistance to abrasive wear. The increase in hardness of austenite (from 220HV to 400HV) in operating conditions occurs as a result of inducted of plastic deformation martensitic transformation $\gamma \rightarrow \alpha'$.

The presence of martensite $Fe_{\alpha'}$ confirms carried out a qualitative X-ray phase analysis (Fig. 9). Martensite is increasing hardness and wear resistance of surface from Fe_{γ} austenitic steel in bimetallic layer casting.

The result of heating the external area of the steel plate from molten cast iron to a temperature above 900°C, in this area (zone number 2) is dissolved carbon interstitial diffusion in austenite, which migrates from the whole volume of γ phase to the grain boundaries and in connection with vacancy chromium diffusion from near border grains areas, $Cr_{23}C_6$ chromium carbides are formed.

In addition besides presence of this type of carbides on the borders, they occur in the central areas of austenite grains. The presence of carbides $Cr_{23}C_6$ result in a decrease of corrosion resistance in this area, as illustrated by the effects of etching (corrosion pits) metallographic specimens appear explicitly in those areas.

Another, different in structural terms is transition zone connecting the areas typical of steel on one side and cast iron on the other. Taking into account the complexity of the microstructure in this zone, the phase composition was based on the microanalysis of chemical composition (Fig. 10) and predicting the presence of elements based on the analysis done in THERMOCALC (Fig. 11). On this basis, the area marked as number 3 is characterized by a microstructure consisting of austenite and ferrite with small amount of Cr carbides.

High quality of both materials joint in this type of bimetallic layer casting provides the diffuse nature, which illustrates the phenomenon of penetration in the transition zone (zone number 3) of martensite strips, which were formed in the impoverished in carbon cast iron layer (zone number 4). Furthermore, it was found that depending on local concentrations of carbon and other elements, as well as local cooling rate in zone number 4, in place of martensite, perlite occurs (Fig. 12). However, this does not affect the reduction of joint quality in bimetallic layer casting.

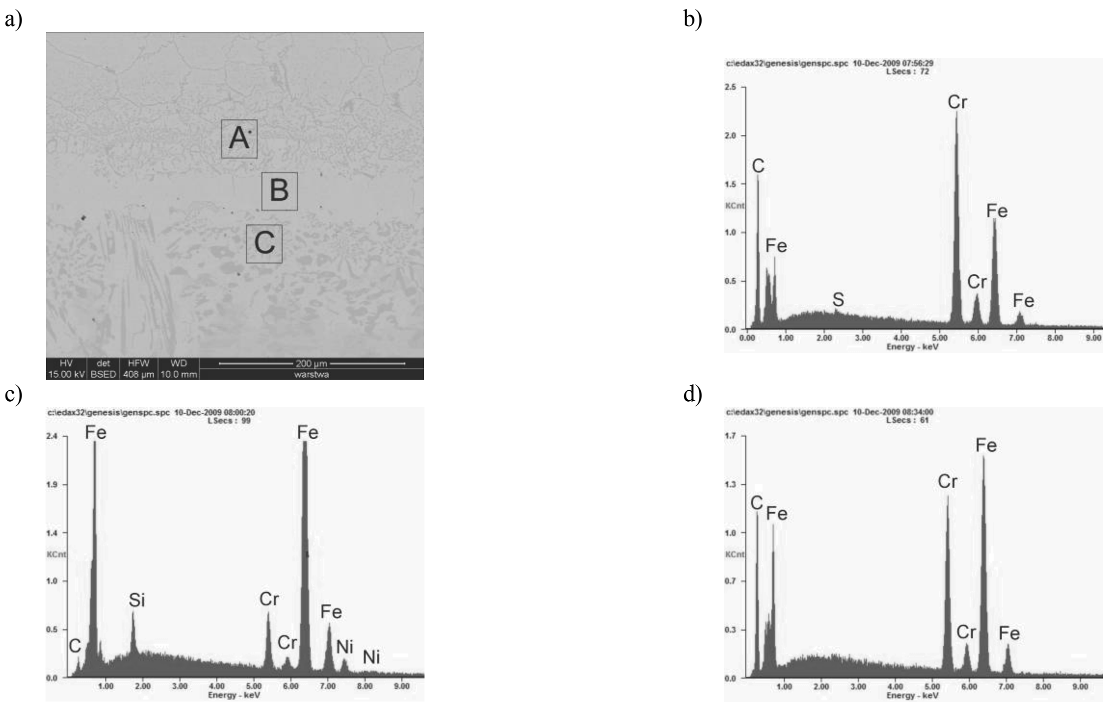


Fig. 10. Distribution of C, Fe, Si, Cr and Ni in transition zone between austenitic alloy steel and cast iron in bimetallic layer casting: a) structure of research area, b) pointwise microanalysis of chemical composition in point „A", c) pointwise microanalysis of chemical composition in point „B", d) pointwise microanalysis of chemical composition in point „C"

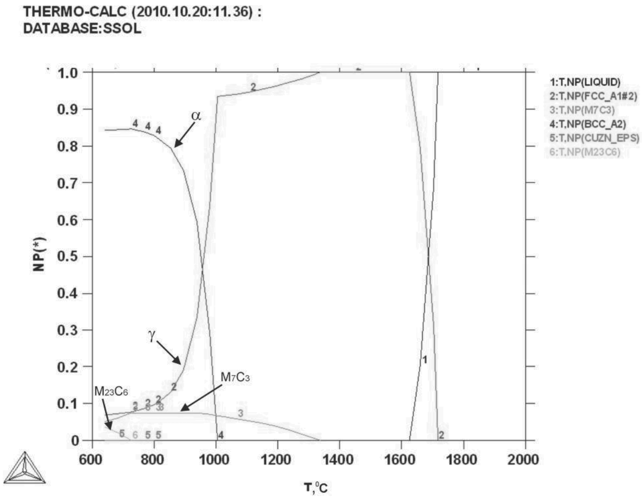


Fig. 11. Simulation of phase compositions in microstructure of zone number 3 (see Fig. 8 and Table 2) according to THERMOCALC

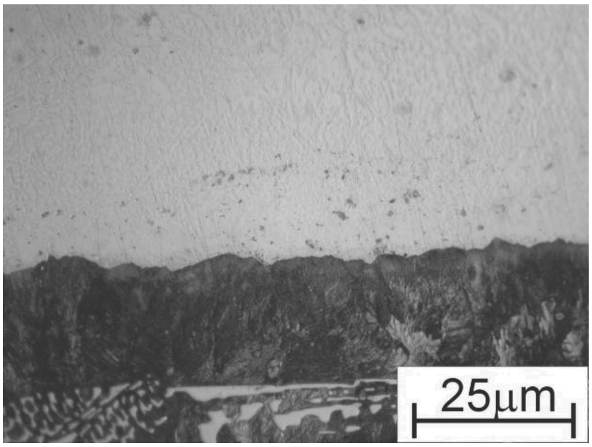


Fig. 12. Microstructure of joint zone in bimetallic layer casting in configuration: austenitic steel plate – grey cast iron. In direction from surface is visible following: $\alpha + \gamma$ with Cr carbides, pearlite, ledeburite + pearlite - etching Mi19Fe

Then, in zone number 5, as a result of high-speed solidification of molten metal at a concentration of carbon proper for cast iron, hard spot area with iron and chromium carbides are present.

The last zone number 6 consists of a typical structure for the grey cast iron poured into molds, such as flake graphite in a pearlitic matrix.

4. Conclusions

Based on conducted studies following conclusions have been formulated:

1. Cast technology based on mould cavity preparation method allows to obtain a bimetallic layer casting in configuration: working part (layer) from high chromium steel X8Cr 13 or chromium-nickel steel X10CrNi 18-8 and bearing part from grey cast iron, free from defects especially in the sensitive area of a joint of both materials. Obtained permanent joint between steel plate and grey cast iron is characterized with diffusion, which is determined primarily by diffusion of carbon in the direction from cast iron to steel.
2. Application of thin plates 2 mm thick, resulting in their deformation during the pouring, which disqualifies a layer casting for industrial applications. Much better results were obtained as a result of the application plates with greater thickness, i.e. 5 mm.
3. Made of bimetallic layer casting can work in conditions demanding from the surface layer of high heat resistance and/or resistance to corrosion in environments such as industrial water. In addition, if the configuration with the austenitic steel is possible to obtain high resistance to abrasive wear.
4. This type of bimetallic layer castings are mainly assigned for lining of quenching car to coke production.

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