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Bimetallic layered castings alloy steel – grey cast iron

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ABSTRACT

Purpose: 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.

Design/methodology/approach: Prepared bimetallic layered 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. pearlitic grey cast iron, whereas working part (layer) is depending on accepted variant plates of alloy steels sort X6Cr13, X12Cr13, X10CrNi18-8 and X2CrNiMoN22-5-3. The ratio of thickness between bearing and working part is 8:1. The verification of the bimetallic layered castings was evaluated on the basis of ultrasonic NDT (non-destructive testing), structure and macro- and microhardness researches. Moreover was made computer simulation of solidification of bimetallic layered casting in NovaFlow&Solid software.

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

Research limitations: In further research, authors of this paper are going to application of different material on bearing part of bimetallic layered casting.

Practical implications: Prepared bimetallic layered castings according to work out technology can work in conditions, which require from working surface layer of element a high heat resistance and/or corrosion resistance in medium for example of industrial water.

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; Steel; Bimetal

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MATERIALS MANUFACTURING AND PROCESSING

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 founding technology so-called method of mould cavity preparation in which the element which is the working surface layer of the casting is placed in mould in form of monolithic or granular insert (Fig. 1) directly before pouring molten metal [1-5]. 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 [6-10], 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 surface layers based on granular inserts from Fe-Cr-C alloy and placed in mould directly before pouring molten metal. Obtained in this way working surface layers have a high hardness and metal-mineral wear resistance [1,3,11].

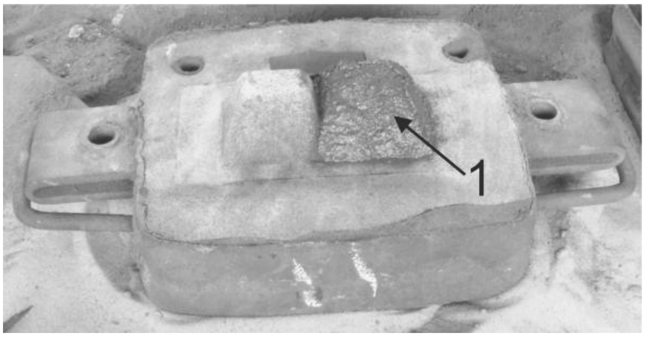

Fig. 1. View of mould cavity with granular insert - 1 [11]

Another, also has common features with the proposed technology is bimetallic layered 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 joint by welding to another part, and working part is made of chromium cast iron to ensure high hardness and abrasive wear resistance [4]. 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. 2). 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 layered casting.

Moreover in literature are present data about layered castings made on the basis of monolithic inserts, for example from grey cast iron dipping into liquid hypoeutectic Al-Si alloy [12].

In addition, attention should be paid to the method of producing bimetallic castings in a continuous cast process. In this method, the cast 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].

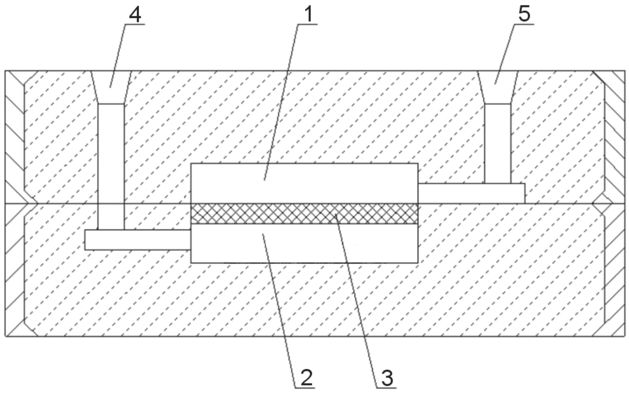

Fig. 2. Technology of bimetallic layered castings with use of two gating systems: 1 - cast iron layer, 2 - cavity (preheater) 3 - cast steel plate, 4, 5 - gating [4]

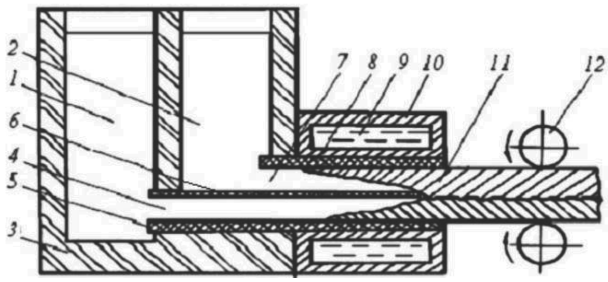

Fig. 3. Scheme of continuous cast process of bimetallic casting: 1 - liquid metal one, 2 - liquid metal two, 3 - crucible, 4 - the bottom channel, 5 - the bottom graphite plate, 6 - dividing plate, 7 - the top channel, 8 - the top graphite plate, 9 - cooling water, 10 - continuous casting mould, 11 -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

2. Range of studies

In range of studies were made bimetallic layered castings, which consist two fundamental parts i.e. bearing part and working part (layer) (Fig. 4).

The bearing part of bimetallic layered casting is typical foundry material i.e. pearlitic grey cast iron, whereas working part (layer) is depending on accepted variant plates of alloy steels sort X6Cr13, X12Cr13, X10CrNi18-8 and X2CrNiMoN22-5-3. In addition to its high corrosion resistance, some of these steels are also high heat resistance and/or hardness (wear resistance) (Fig. 5).

In aim of making a test bimetallic layered castings with dimensions 125×105×45 mm, in sand mould with no preheating were placed plates of alloy steels (Fig. 6), which then were poured by liquid grey cast iron from pouring temperature T_{zal} = 1450°C.

On the basis of results of previous studies [14] were used steel plates with thickness 5 mm, 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.

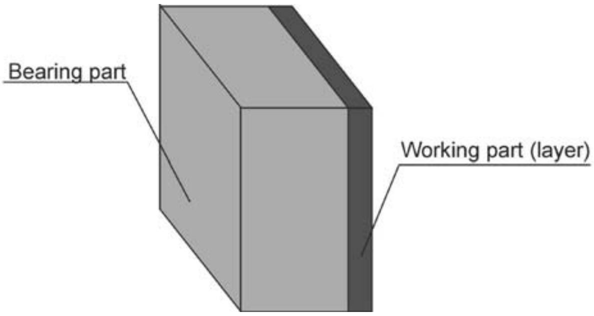

Fig. 4. Scheme of bimetallic layered casting

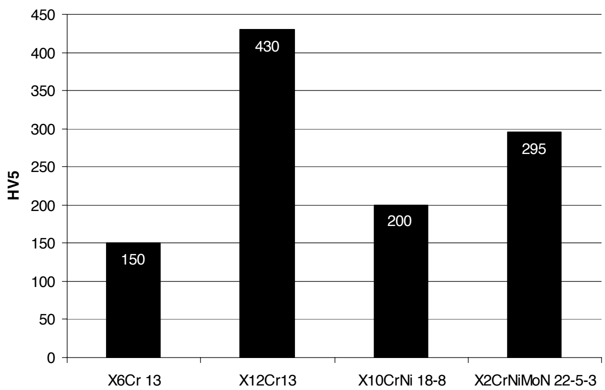

Fig. 5. Hardness of alloy steels plates applied to working part (layer) of bimetallic layered castings

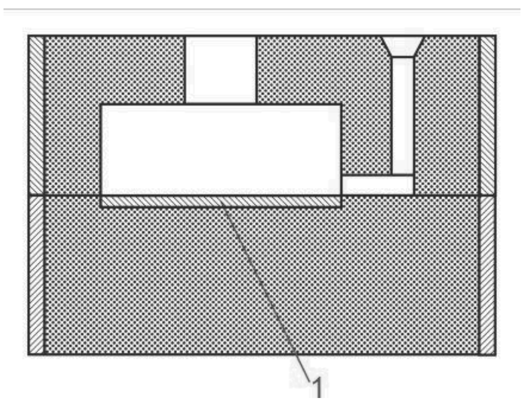

Fig. 6. Cross-section of sand mould with plate of alloy steel (1) placed in its cavity

The quality of the bimetallic layered casting was evaluated on the basis of ultrasonic NDT (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: 3 g of ferric chloride, 10 cm^3 hydrochloric acid and 90 cm^3 ethanol. Moreover measurements of macro- and microhardness 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 on entire contact surface of both materials in bimetallic layered castings (head placed on the side of the metal sheet) the bottom echo was larger than the echo of the transition zone, which indicates a good diffusion joint between working part (layer) and bearing part.

These results were confirmed by macroscopic visual quality assessment made on selected sections of test bimetallic layered castings. Example view of cross-section of test bimetallic layered casting is presented in Figure 7.

On the basis of results of microstructure researches, was affirmed that as a result of C diffusion phenomena in the direction from cast iron to steel plate and to much lesser range Cr in the opposite direction, transition zone has been formed at the junction of cast iron - steel. Shaped transition zone, structurally different from the cast iron and used steel plates, has the character of diffusion which determining the high quality of joint between both bimetallic components.

Moreover, the formation of microstructure of transition zone and adjacent areas is affected by the heating temperature of steel, whose source is the liquid cast iron poured into the mould. For the pouring temperature 1450°C of cast iron, the contact temperature T_s on the border of liquid metal - steel plate, fixed on the basis of dependence [15]:

$$T_s = \frac{\sqrt{\lambda_n \cdot c_n \cdot \rho_n} \cdot T_n + \sqrt{\lambda_r \cdot c_r \cdot \rho_r} \cdot T_r}{\sqrt{\lambda_n \cdot c_n \cdot \rho_n} + \sqrt{\lambda_r \cdot c_r \cdot \rho_r}} \tag{1}$$

where:

λ_n, λ_r - coefficient of thermal conductivity, suitably for the liquid cast iron (bearing part of casting) and steel plate (working part of casting), W/(m·K),

c_n, c_r - specific heat, suitably for the liquid cast iron (bearing part of casting) and steel plate (working part of casting), J/(kg·K),

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

T_n - temperature of the liquid cast iron, °C,

T_r - temperature of steel plate (working part of casting), °C,

is suitably for plate of alloy steel sort X6Cr13 and X12Cr13 about 870°C, for plate of alloy steel sort X10CrNi18-8 about 950°C and for plate of alloy steel sort X2CrNiMoN22-5-3 about 940°C. Moreover on the basis of results of computer simulation of solidification of bimetallic layered casting (Fig. 8), which was made with use of NovaFlow&Solid software, was affirmed that after about 100 seconds after pouring liquid cast iron into the mould, the contact temperature at the geometrical center of plate increases above 1200°C and then slowly decreases (Fig. 9).

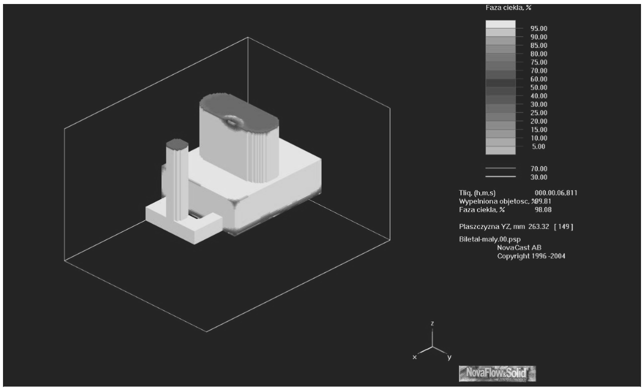

Fig. 8. View of computer simulation of solidification of bimetallic layered casting in NovaFlow&Solid software (colors represent amount of liquid phase)

In case of bimetallic layered casting in configuration bearing part from pearlitic grey cast iron - working (layer) part from alloy steel plate sort X6Cr13 (Fig. 10), in surface layer of this type of casting a single-phase ferritic microstructure was obtained (zone no. 1). In result of carbon diffusion in the direction from cast iron to steel in the outer area of plate (zone no. 2), the concentrations of this element increases above 0.1%, which combined with the high heating temperature of this area leads to the microstructure of the solid solution γ, which during cooling of the casting with a small rate, transforms in martensite. The ratio of martensite of hardness 365μHV to the amount of ferrite increases in direction to joint border of bimetal. In the last zone (no. 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 of hardness 410 μHV occurs with iron and chromium carbides of hardness 900 μHV. The first zone (no. 4) on the side of cast iron creates pearlite of hardness 300 μHV. This zone is connected with the previous, no. 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 typical for cast iron high-carbon phases i.e. graphite or cementite. Then, in zone no. 5, as a result of high-speed solidification of molten metal at a concentration of carbon proper for cast iron, hard spot areas are present. The last zone no. 6 consists of a typical microstructure for the grey cast iron poured into moulds, such as flake graphite in a pearlitic matrix of hardness 270 μHV.

In case of bimetallic layered casting in configuration bearing part from pearlitic grey cast iron - working (layer) part from alloy steel plate sort X12Cr13 (Fig. 11), in surface layer of this type of casting was obtained microstructure with dominant amount of martensite (zone no. 1). Next in result of carbonizing and heating of the outer area of plate whose source is the liquid cast iron poured into the mould, in zone no. 2 was obtained microstructure of hardness 650 μHV contains martensite with iron and chromium carbides. Amount of carbides increases in direction to joint border of bimetal (zone no. 3). Similarly to previous variant the first zone (no. 4) on the side of cast iron creates pearlite. This zone is connected with former no. 3 by non-linear border too, which guarantees high quality of joint between both bimetallic components. In result of slower cooling rate of casting, than in previous variant, is present fluent transition from pearlitic zone no. 4 to zone no. 5 i.e. flake graphite in pearlitic matrix, without presence of hard spot areas.

In case of bimetallic layered casting in configuration bearing part from pearlitic grey cast iron - working (layer) part from alloy steel plate sort X10CrNi18-8 (Fig. 12), in surface layer of this type of casting a single-phase austenitic microstructure was obtained (zone no. 1). In result of heating the outer area of steel plate from molten cast iron to a temperature above 1200°C, in this area (zone no. 2) followed by carbon interstitial diffusion in austenite, which migrates from the whole volume of γ phase to the grain boundaries and in connection with chromium vacancy 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. Next, zone no. 3 is characterized by a microstructure of hardness 550 μHV consisting of austenite and ferrite with small amount of iron and chromium carbides. High quality of both materials joint in this type of bimetallic layered casting provides the diffuse nature, which illustrates the phenomenon of penetration in the transition zone (zone no. 3) of martensite strips of hardness 400 μHV, which were formed in the impoverished in carbon cast iron layer (zone no. 4). Furthermore, it was found that depending on local cooling rate in zone no 4, in place of martensite, pearlite occurs. Then, in zone no. 5, as a result of high-speed solidification of molten metal at a concentration of carbon proper for cast iron, hard spot area are present. The last zone no. 6 consists of a typical microstructure for the grey cast iron poured into molds, such as flake graphite in a pearlitic matrix.

In case of bimetallic layered casting in configuration bearing part from pearlitic grey cast iron - working (layer) part from alloy steel plate sort X2CrNiMoN22-5-3 (Fig. 13), in surface layer of this type of casting was obtained diphase (duplex) ferritic-austenitic microstructure (zone no. 1). In result of zone no. 2 heating to high temperature in this area was obtained coarse-grained austenite. Whereas in result of carbonizing and heating of the outer area of plate whose source is the liquid cast iron poured into the mould, in zone no. 3 was obtained martensitic microstructure of hardness 400 μHV. In next zones besides martensite are present large amount of iron and chromium carbides, which guarantee increase of hardness from 550 μHV (zone no. 4) to about 1000 μHV (zone no 5). Similarly to previous variants the first zone (no. 6) on the side of cast iron creates pearlite. In result of slower cooling rate of casting, than in previous third variant, is present fluent transition from pearlitic zone no. 5 to zone no. 6 i.e. flake graphite in pearlitic matrix, without presence of hard spot areas.

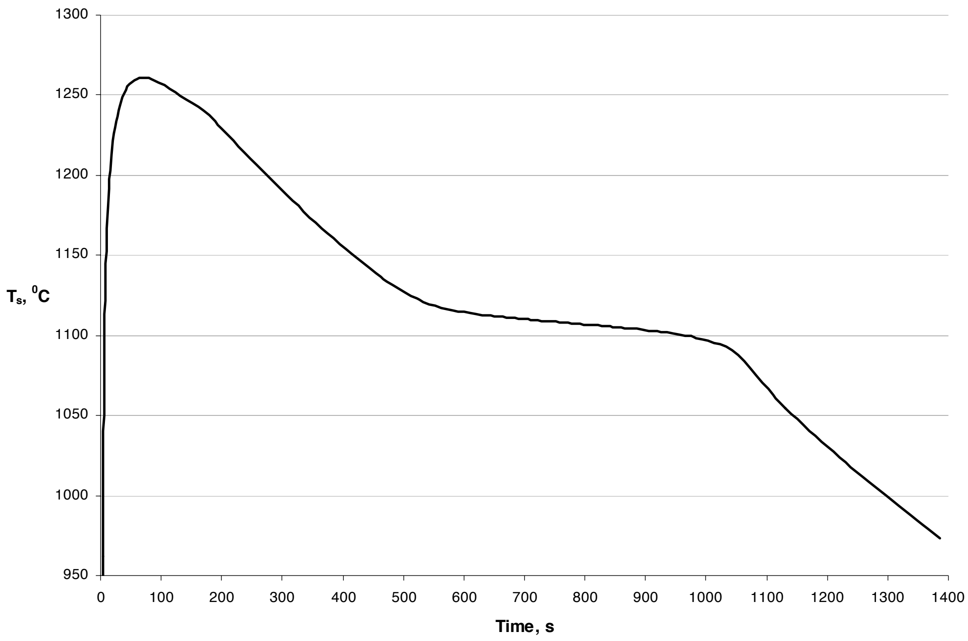

Fig. 9. Distribution in time of contact temperature T_s at the geometrical center of steel plate in bimetallic layered casting in configuration: bearing part from pearlitic grey cast iron - working part (layer) from alloy steel sort X10CrNi18-8

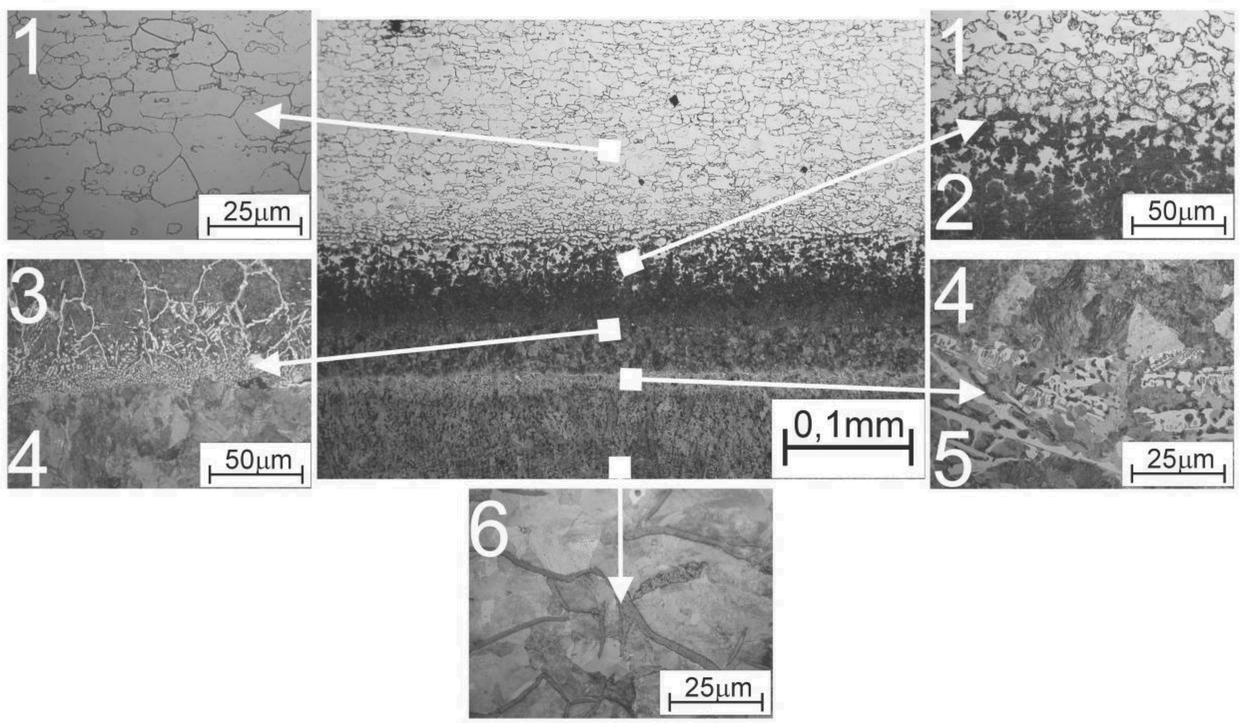

Fig. 10. Microstructure of bimetallic layered casting in configuration: bearing part from pearlitic grey cast iron - working part (layer) from alloy steel plate sort X6Cr13 - etching Mi19Fe

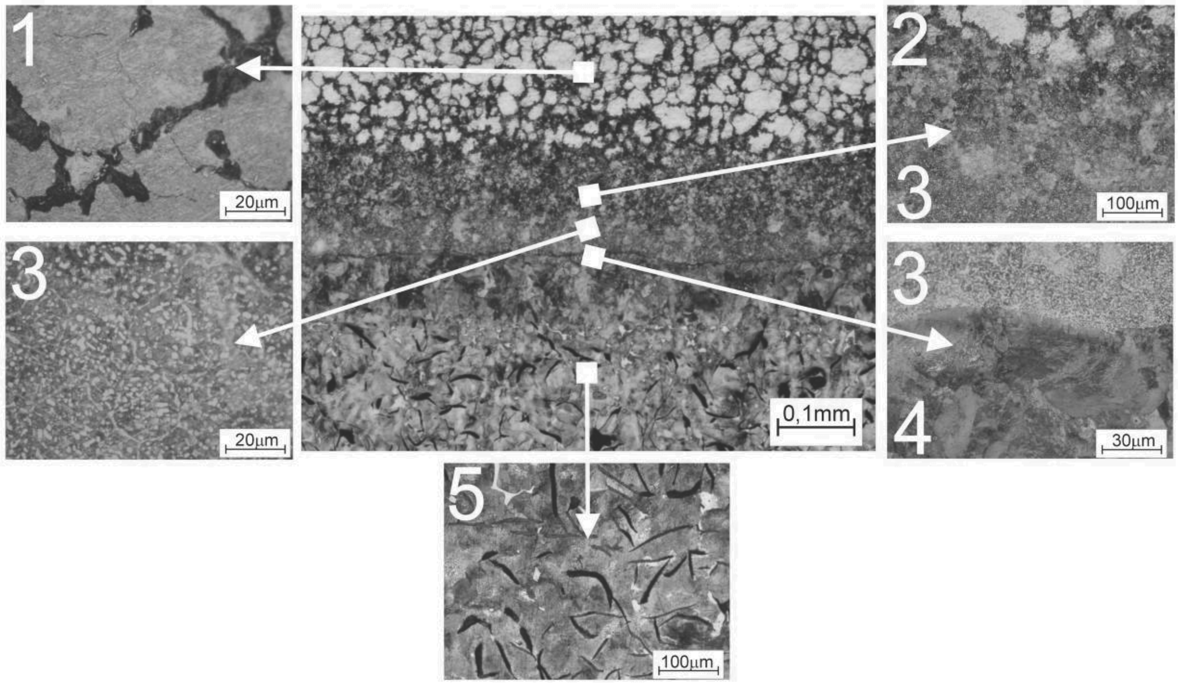

Fig. 11. Microstructure of bimetallic layered casting in configuration: bearing part from pearlitic grey cast iron - working part (layer) from alloy steel plate sort X12Cr13 - etching Mi19Fe

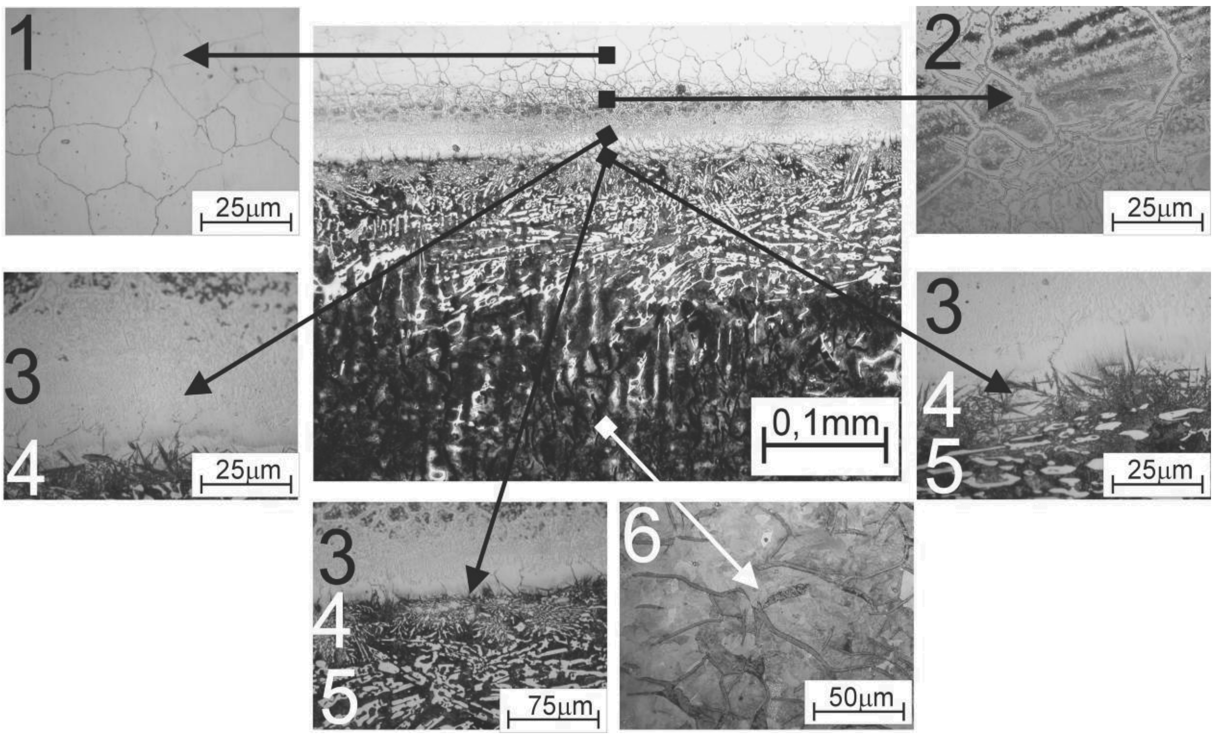

Fig. 12. Microstructure of bimetallic layered casting in configuration: bearing part from pearlitic grey cast iron - working part (layer) from alloy steel plate sort X10CrNi18-8 - etching Mi19Fe

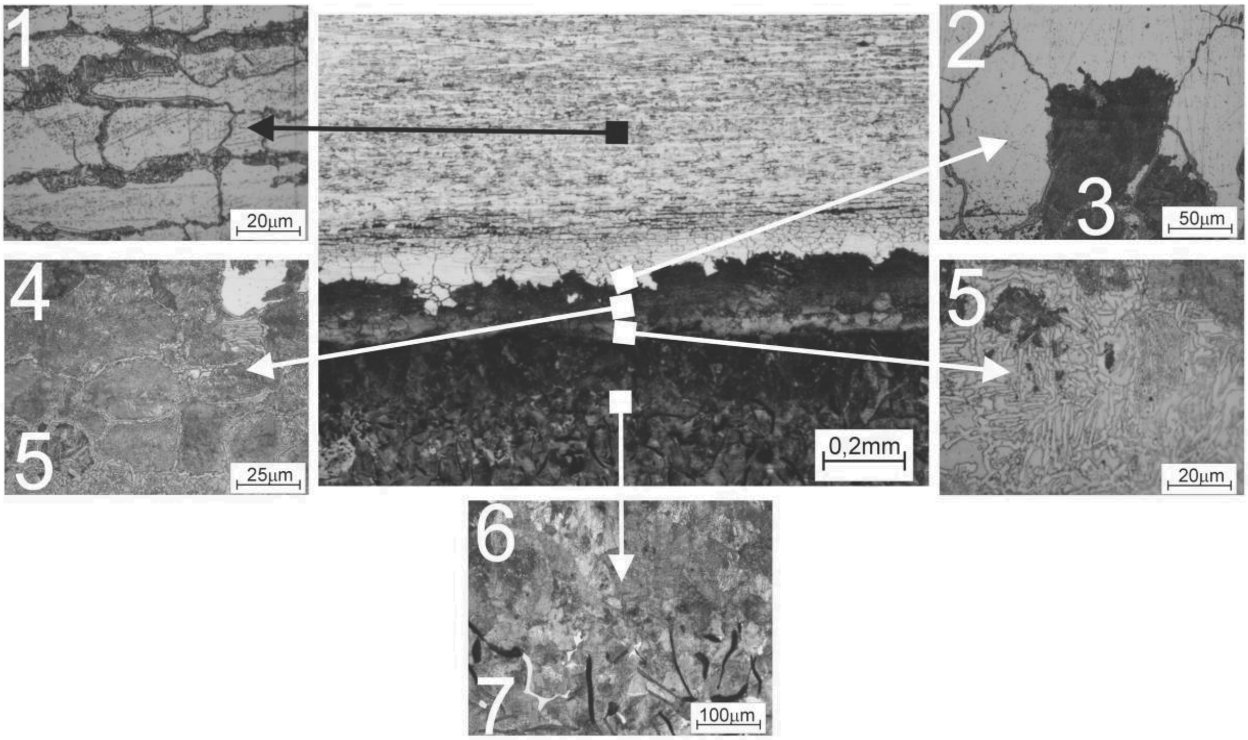

Fig. 13. Microstructure of bimetallic layered casting in configuration: bearing part from pearlitic grey cast iron - working part (layer) from alloy steel plate sort X2CrNiMoN22-5-3 - etching Mi19Fe

4. Summary

Founding technology based on mould cavity preparation method allows to obtain a bimetallic layered castings in configuration: bearing part from pearlitic grey cast iron - working part (layer) from alloy steel sort high chromium ferritic or martensitic, chromium-nickel austenitic or duplex ferritic-austenitic, 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.

Prepared bimetallic layered castings according to work out technology can work in conditions, which require from working surface layer of element a high heat resistance and/or corrosion resistance in medium for example of industrial water. Moreover in case of application on working part (layer) the martensitic high chromium or austenitic chromium-nickel steels is possible to obtain high abrasive wear resistance. In case of chromium-nickel steel this is result of increase in hardness of austenite from about 200 HV to about 400 HV. This increase of hardness following in operating conditions results from induced of plastic deformation martensitic transformation $\gamma \rightarrow \alpha'$ [14].

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