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Manufacturing Methods of Alloy Layers on Casting Surfaces

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Abstract

In this paper, we presented the technology of layered castings based on the founding method of layer coating directly in the cast process known as the method of mold cavity preparation by monolithic or granular material of insert. Prepared castings consist of two fundamental parts: the base part and working part (layer). The base part of a layered casting is usually typical foundry material (i.e., pearlitic grey cast iron with flake graphite or ferritic-pearlitic carbon cast steel), whereas the dependence of an insert type (i.e., monolithic or granular) working part (layer) is suitably plated with ferritic and austenitic alloy steels or a layer from a Cr-base alloy. The ratio of thickness between the base and working part is between 8:1 and 10:1. The quality of the layered castings was evaluated on the basis of ultrasonic non-destructive testing, structure, and selected usable property research. According to work out technology, the prepared layered castings can work in conditions that require high heat resistance and/or corrosion resistance from the working surface layer of an element in a medium of industrial water, for example. Moreover, in the case of applying an insert based on Cr-base alloy powder on the working surface layer, it is possible to obtain high hardness and abrasive wear resistance.

Keywords:

cast steel, cast iron, monolithic and granular inserts, alloy layer, stainless steel

1. INTRODUCTION

The The technology of layered castings is gaining in importance, particularly when the criterion for highly usable properties concerns only the working surface layer, and the rest of the casting is only the base part that is not exposed to the direct influence of factors causing abrasive or corrosion wear. This technology is the most-economical way of enriching the surface of castings, as it allows for the production of layered elements directly in the casting process. Therefore, this technology can be significantly competitive for the commonly used technologies of surfacing by welding and thermal spraying because, in addition to its economic advantages, it does not generate opportunities for the development of cracks in the heat-affected zone that may arise as a result of making the layer by using the welding method. In general, the technology of cast bimetals containing a working layer and a base part is carried out based on two systems; i.e., liquid-liquid [1, 2] and liquid-solid [3–16]. An example of the former is a technology in which two independent gating systems are made, which guarantees a two-stage filling of the sand mold cavity. According to this manufacturing method, the bimetallic elements of hammer [1] or ball [2] mills are cast in material configurations of a resistant-to-abrasive-wear chromium cast iron working layer with a ductile low-carbon cast steel base. The basis technology of layered castings made in a liquid-solid system is the so-called method of mold cavity preparation. In this manufacturing method, the element enriching the surface of the casting is placed in the mold in the form of a granular [3–9] or monolithic [10–16] insert directly before the molten metal is poured. Therefore, this paper presents possibilities of using a Cr-base alloy as a granular insert and high-chromium and chromium-nickel alloy steels as monolithic inserts. In the case of the granular insert, the mold was poured by carbon cast steel, and in the case of the monolithic insert, the mold was poured by grey cast iron.

2. RANGE OF STUDIES

Within a framework of our studies, we made layered castings consisting of two fundamental parts; i.e., the base part and working part (layer). The base part of a layered casting is typical foundry material (i.e., pearlitic grey cast iron with flake graphite or ferritic-pearlitic carbon cast steel), whereas the dependence of an insert type (i.e., the monolithic or granular) working part (layer) is suitably plated with ferritic high-chromium steel and chromium-nickel austenitic alloy steel or a layer from a Cr-base alloy. The chemical compositions of the used materials are presented in Tables 1 and 2.

Table 1
Chemical compositions of materials used on base part of layered castings

Grey cast iron, mass contents in %								
C	Mn	Cr	Si	Cu	Al	P	S	Fe
3.10	0.60	0.80	1.00	0.20	0.20	0.03	0.03	rest
Carbon cast steel, mass contents, %								
0.60	0.60	0.09	0.18	0.28	–	0.03	0.02	rest

Table 2
Chemical compositions of materials used on working part (layer) of layered castings, from monolithic insert 5 mm thick plates of X6Cr 13 or X2CrNi 18-9 grade alloy steel and from granular insert powder of Cr-base alloy with granularity 0.32–0.64 mm

Alloy steel X6Cr 13, mass contents, %								
C	Cr	Ni	Mn	Si	Mo	P	S	Fe
0.08	13.50	0.50	0.90	0.88	0.01	0.02	0.01	rest
Alloy steel X2CrNi 18-9, mass contents, %								
0.03	19.20	9.80	1.45	0.90	0.20	0.03	0.01	rest
Cr-base alloy, mass contents in %								
7.92	62.53	–	–	0.75	–	0.026	0.02	28.75

In an aim to make a test of bimetallic layered castings in sand mold with no preheating, we placed monolithic inserts in the form of 5 mm-thick plates of alloy steels (Fig. 1) and in following variant granular insert in the form of 5 mm-thick mixtures of binder and powder of the Cr-base alloy (Fig. 2).

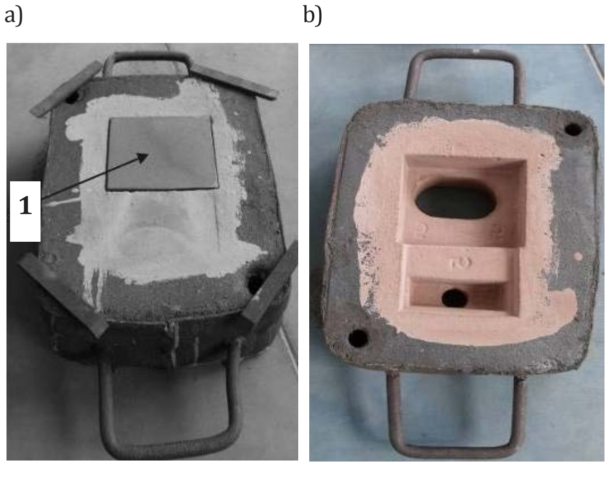

Fig. 1. View of sand mold with plate of alloy steel (1) placed in its cavity: a) bottom half of mold; b) top half of mold

Moreover, the plate's surface that stayed in direct contact with the liquid metal were covered by an activator in the form of boron and sodium compounds. These compounds favor the formation of a permanent joint between both materials in a layered casting.

The molds prepared in this way were poured by liquid grey cast iron from a pouring temperature of 1450°C in variants with monolithic inserts or in the variant with a granular insert by carbon cast steel from a pouring temperature of 1650°C. As a result, layered castings with a ratio of thickness between the bearing and working part between 8:1 and 20:1 were obtained. The quality of the layered casting was evaluated on the basis of ultrasonic NDT (non-destructive testing) using the DIO 562 flaw detector by STARMANS ELECTRONICS.

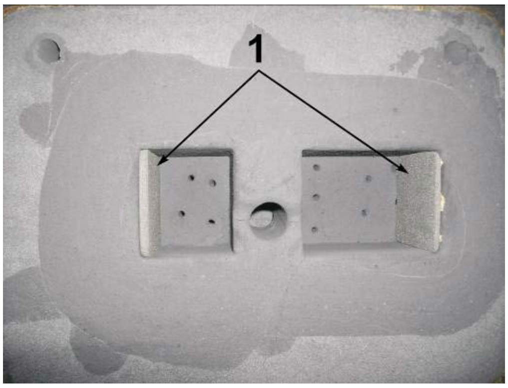

Fig. 2. View of sand mold with granular insert (1) placed in its cavity

Next, a metallographic macro- and microscopic examination was carried out using light and scanning electron microscopes. Metallographic specimens etched in the reagent Mi1Fe containing 3 cm^3 nitrous acid and 100 cm^3 ethanol and Mi19Fe containing 3 g of ferric chloride, 10 cm^3 hydrochloric acid, and 90 cm^3 ethanol. Moreover, the measurements of macro- and microhardness were made using the Vickers method.

3. RESULTS OF STUDIES

On the basis of non-destructive ultrasonic testing, it was found that a permanent joint between the working part (layer) and base part in the studied layered castings that were made in all variants was obtained, as the bottom echo was larger than the echo of the transition zone (head placed on the side of the working layer). These results are confirmed by the sample views of the cross-section of test layered castings presented in Figure 3. A sample microstructure of the obtained layered castings are presented in Figures 4–6. In the variants concerning the castings made with use of a monolithic insert and with the base part in the form of grey cast iron, as a result of the C diffusion phenomena in the direction from cast iron to steel plate, a transition zone was formed at the joint between the cast iron and steel. The shaped transition zone, which is structurally different from the used grey cast iron and steel plates, has the character of diffusion that determines the high quality of a joint between both bimetallic components. In addition, the formation of the microstructure of the transition zone and adjacent areas is affected by the heating temperature of steel, whose source is the liquid cast iron poured into the mold.

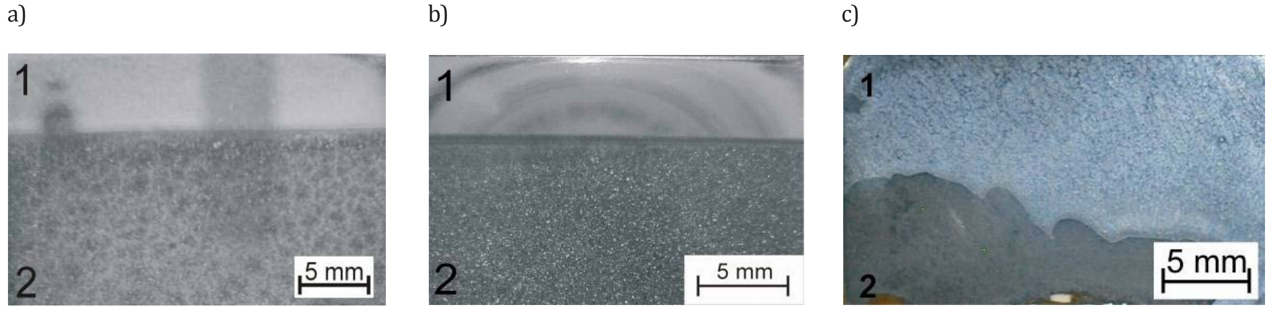

Fig. 3. Views of sample cross-section of layered castings in configuration: a) 1 – working layer in the form of a stainless steel X6Cr 13 grade plate, 2 – base part of grey cast iron; b) 1 – working layer in the form of a stainless steel X2CrNi 18-9 grade plate, 2 – base part of grey cast iron; c) 1 – base part of carbon cast steel, 2 – working part in the form of Cr-base layer

In the case of using alloy stainless steel X6Cr 13 grade as a monolithic insert, five zones are present in the casting microstructure (as shown in Figure 4). The first and fifth zones have microstructures typical of alloys used adequately on the working layer and the base part of the layered casting; i.e., ferrite in Zone 1 and flake graphite in the pearlite matrix in Zone 5, while the Zones 2 through 4 are transition zones). In Zone 2, structural changes occurred in the solid state; i.e., as a result of the carbonizing connected with heating whose source was liquid cast iron poured into the mold. Solid solution γ was created in this zone (which undergoes the martensite transformation during casting cooling at a low cooling rate). The ratio of martensite content (with a microhardness of about 380 μHV) to ferrite content (with a microhardness of about 170 μHV) increases in the direction of the border steel – cast iron. The carbonization of Zone 3, which is placed closer to the liquid cast iron poured into the mold than Zone 2, decreases the liquidus and solidus temperature. As a result, the third zone is remelted due to a temperature higher than that of the solidus. Then, Zone 3 crystallizes at a specified chemical composition, which results in a microstructure with a microhardness of 530 μHV containing Cr carbides in the pearlitic matrix. On the side of the base part is a decarbonized Zone 4. In this zone, a microstructure of pearlite is present (with a microhardness of about 300 μHV). Next, deep inside the base part, a smooth transition takes place to high-carbon Zone 5 containing flake graphite in the pearlite matrix.

Similarly, there are also five zones in the microstructure of the layered casting in an X2CrNi 18-9 stainless steel working surface layer configuration with a grey cast iron base (as shown in Figure 5). The first and fifth zones have microstructures that are typical of alloys used adequately on the working layer and the base part of the layered casting; i.e., austenite in Zone 1 and flake graphite in the pearlite matrix in Zone 5. The areas from 2 to 4 are transitions zones. In Zone 2, structural changes occurred in the solid state; i.e., as a result of the carbonizing connected with the diffusion of chromium induced by heating whose source was liquid cast iron poured into the mold.

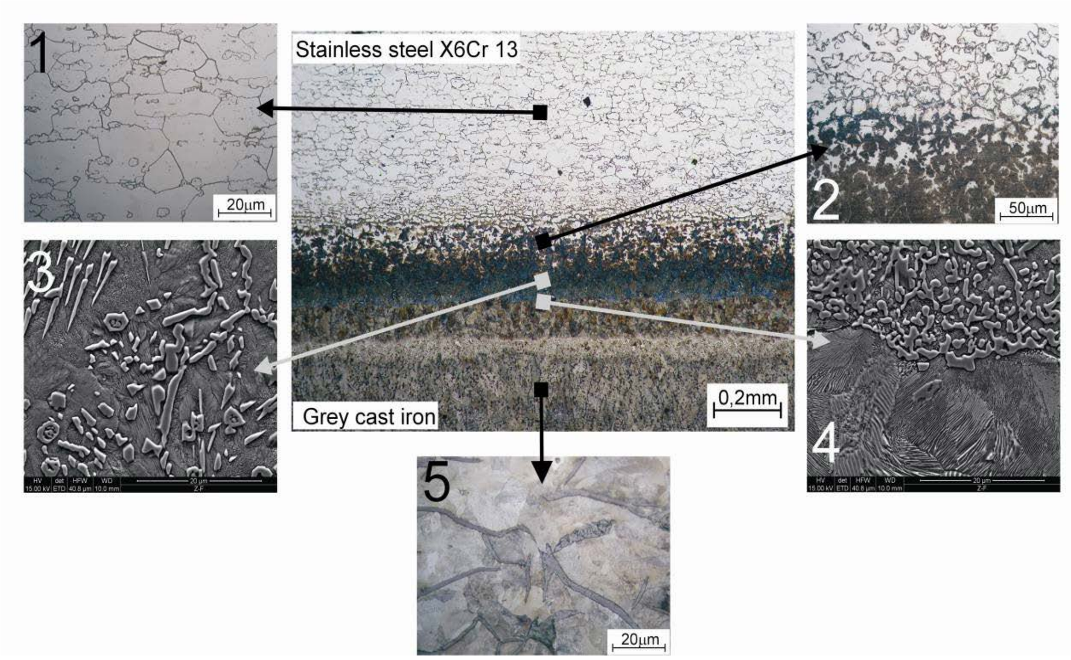

Fig. 4. Microstructure of a layered casting in a configuration of the working layer in the form of a stainless steel X6Cr 13 grade plate and the base part from grey cast iron

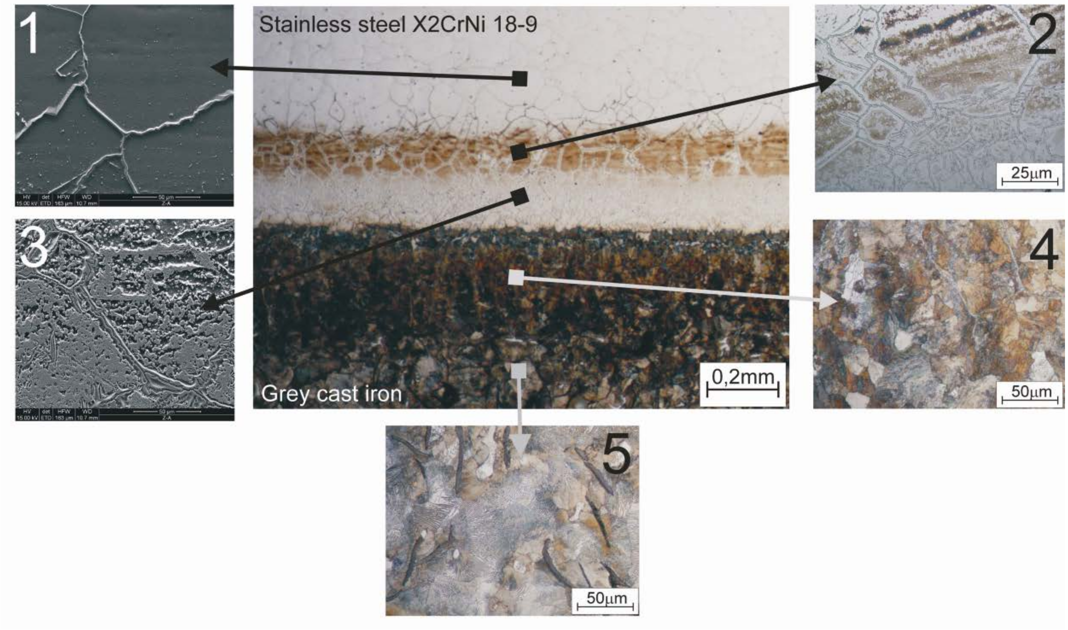

Fig. 5. Microstructure of a layered casting in a configuration of the working layer in the form of a stainless steel X2CrNi 18-9 grade plate and the base part from grey cast iron

In this zone, microstructures with carbides Cr23C6 in the γ (austenite) phase matrix were created. The result of the presence of carbides in Zone 2 is an increase in microhardness from about 200 µHV in the austenitic Zone 1 to 340 µHV and a decrease in corrosion resistance, as evidenced by the effects of microsection etching (pits), which clearly appear in the zone. The carbonization of Zone 3, which is placed closer to the liquid cast iron poured into the mold than Zone 2, decreases the liquidus and solidus temperatures. As a result, Zone 3 is melted by a high heating temperature. Then, Zone 3 crystallizes at a specified chemical composition, which decides about the microstructure containing Cr carbides in the α + γ (ferrite + austenite) matrix. On the side of the base part is decarbonizing Zone 4. Depending on the local cooling rate and chemical composition, a microstructure of pearite is present in this zone, with a microhardness of about 280 µHV or less a pearlitic-martensitic microstructure with a microhardness of about 370 µHV. Next, deep inside the base part, a smooth transition takes place to high-carbon Zone 5 containing flake graphite in the pearlite matrix. More details about the mechanism of creating a permanent joint in these material configurations of layered castings is shown in the paper [16]. Whereas, the application on the insert of the Cr-base alloy allows us to obtain high hardness (about 450 HV) and abrasive wear resistance on the working surface of the layered casting with carbon cast steel base.

The transition zone and alloy layer, which is possible to divide into outside (original) and inside (secondary), were obtained as a result of joining the two materials (Fig. 6). The outside alloy layer (original) is an area of incomplete dissolved grains of ferrochromium joined by an eutectic mixture. This area consists of big grains with high content of chromium. The inside alloy layer (secondary) is the fundamental part of the layer formed as a result of the diffusion of basic elements, and it is built mainly from carbide emition.

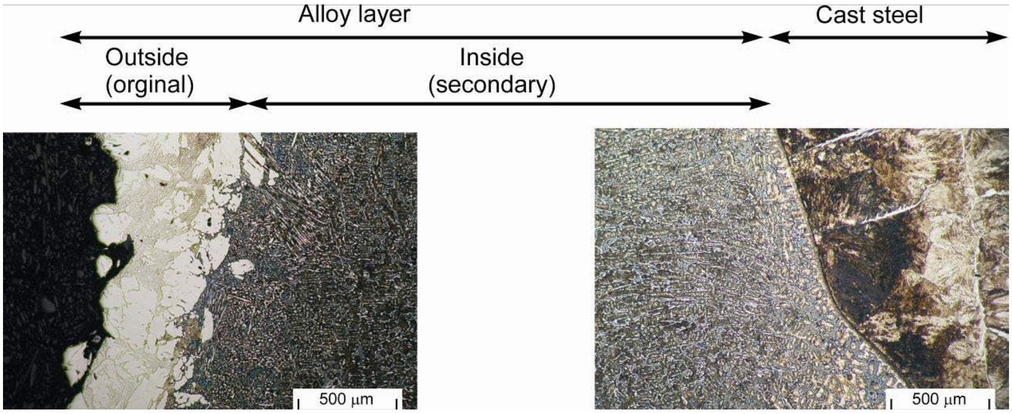

Fig. 6. The structure of surface alloy layer with FeCrC

During the formation of the surface layer on the alloy, a few stages were specified:

- pouring the mold and premold with liquid metal,
- formation of the thin film cast,
- diffusion in a solid state,
- transition in a liquid state,
- diffusion in a liquid state,
- back diffusion of carbon from of transition zone and steel cast,
- crystallization and formation surface layer of alloy.

4. SUMMARY

Prepared layered castings according to work out technology including the use of monolithic and granular inserts possess high quality and a permanent joint between both component materials and can work in conditions that require high heat resistance and/or corrosion resistance from the working surface layer of the element in a medium of industrial water, for example. Moreover, in the case of applying the insert on the basis of Cr-base alloy powder on the working surface layer, it is possible to obtain high hardness and abrasive wear resistance.

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