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## BIMETALLIC CASTING: FERRITIC STAINLESS STEEL – GREY CAST IRON

## ODLEW BIMETALOWY: FERRYTYCZNA STAL NIERDZEWNA – ŻELIWO SZARE

The paper presents the problem of obtaining a permanent diffusional joint between the working surface layer and the base part in a bimetallic casting. The studied bimetallic casting was obtained as a result of using the founding method of layer coating directly in the cast process. The casting prepared using this method consists of two fundamental parts, i.e., the grey cast iron base and the working surface layer which constitutes of X6Cr 13 high-chromium stainless steels plate. Based on the obtained results it was confirmed that the decisive phenomena that are needed to create a permanent joint between the two components of the bimetallic casting are carbon and heat transport from the high-carbon and hot base material which was poured into the mould in the form of liquid metal to the low-carbon and cold material of the working layer which was placed in the mould cavity in the form of a monolithic insert.

*Keywords:* Bimetallic casting; Grey cast iron; Stainless steel;

W pracy przedstawiono problematykę uzyskiwania trwałego połączenia pomiędzy warstwą roboczą a częścią nośną w odlewie bimetalowym, który został wykonany przy użyciu metody nakładania warstw bezpośrednio w procesie odlewania. Wykonane tą metodą odlewy złożone są z dwóch zasadniczych elementów tj. części nośnej z żeliwa szarego oraz warstwy roboczej, którą stanowi blacha ze stali ferrytycznej odpornej na korozję gatunku X6Cr 13. Stwierdzono, że zjawiskami decydującymi o utworzeniu trwałego połączenia pomiędzy łączonymi tworzywami składowymi bimetalicznego odlewu warstwowego jest transport węgla i ciepła w kierunku od wysokowęglowego i gorącego materiału części nośnej wlewanego do formy w postaci ciekłego metalu do niskowęglowego i zimnego materiału warstwy roboczej umieszczanego w postaci wkładki monolitycznej we wnęce formy.

### 1. Introduction

In general, the technology of cast bimetals containing a working surface layer and a base part is carried out based on two systems, i.e. liquid-liquid [1, 2] and liquid-solid [3÷12]. An example of the first is a technology in which two independent gating systems are used in aim of two-stage filling of the sand mould 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 bimetallic castings made in the liquid-solid system is the so-called method of mould cavity preparation. In this manufacturing method the element enriching the surface of the casting is placed in the mould in the form of a granular [3÷7] or monolithic [8÷12] insert directly before the molten

metal is poured. Granular inserts are used to make bimetallic castings for the mining industry in material configurations with a hard working surface layer of Fe-Cr-C [4, 6], Fe-Cr-C-Mo [3] or Ni-Cr-Fe-C [7] alloys with an unalloyed cast steel base. An example of technology using the monolithic insert are bimetallic castings in a configuration of chromium cast iron connected with the weldable low-carbon steel plate [8]. However, a significant economic limitation of this manufacturing method is the need to preheat the steel plate (monolithic insert) that is placed in the mould.

Summarize the technologies of the bimetallic castings presented in the available literature have large limitations, e.g. decreased process economy due to the necessity of pouring two different alloys [1,2] and a decrease in yield resulting from the necessity of applying insert preheating [8,9] and complication of the cast process by applying two gating systems [1,2,8,9].

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Therefore, the aim of the paper is to describe a technology of bimetallic castings in a material configuration of high-chromium stainless steel – grey cast iron based on the liquid-solid method using a non-preheated monolithic insert. In the presented technology, preheating of the monolithic insert, which makes it easier to form a permanent joint between the working layer and the base part and also increases production costs as well as makes it difficult to place the steel plate in the mould cavity, was replaced by application of an activator covering the contact surface between both of the materials used. This technology constitutes the most economical way of enriching the surface of the castings as it allows the production of layered elements directly in the cast process. Therefore, this technology can be a significant competition for commonly used technologies of surfacing by welding and thermal spraying, because in addition to its economic advantages it does not allow cracks to develop in the heat affected zone, which arises as a result of making the layer by using the welding method.

## 2. Range of studies

The study encompassed bimetallic castings which consisted of two fundamental parts, i.e. a base and a working surface layer. The base part of the bimetallic casting was typical foundry material, i.e. grey cast iron with flake graphite, whereas the working layer was a plate of high-chromium stainless steels X6Cr 13 grade. The chemical composition of the component materials of bimetallic casting used here are presented in Table 1 and 2.

TABLE1

Chemical composition of the stainless steel X6Cr 13 grade working layer of the bimetallic casting

Elements content (%wt.)								
C	Cr	Ni	Si	Mn	Mo	P	S	Fe
0.080	13.500	0.500	0.880	0.900	0.010	0.020	0.002	rest

TABLE2

Chemical composition of the grey cast iron base part of the bimetallic casting

Elements content (%wt.)										
C	Mn	Si	Cr	Ni	Cu	Ti	V	P	S	Fe
3.10	0.50	1.70	0.10	0.05	0.15	0.01	0.01	0.12	0.06	rest

For the test bimetallic castings with the ratio of thickness between the base and working part being 8:1, plates of the stainless steels were placed in sand moulds with no preheating (Fig. 1). These were then poured with liquid cast iron at pouring temperature of 1450°C. On the basis of results of previous studies [10], steel plates with a thickness of 5 mm were used. Their surfaces, remaining in direct contact with the liquid metal, were covered by an activator in the form of boron and sodium compounds, i.e. an aqueous solution of  $\text{Na}_2\text{B}_4\text{O}_7 + \text{B}_2\text{O}_3$ . These compounds promote the formation of a permanent joint between

both materials of the layered casting by purification of the contact surface of the oxide layer, protection against the formation of a new oxide layer and by a decrease in the wetting angle on the insert, i.e. the liquid-metal boundary.

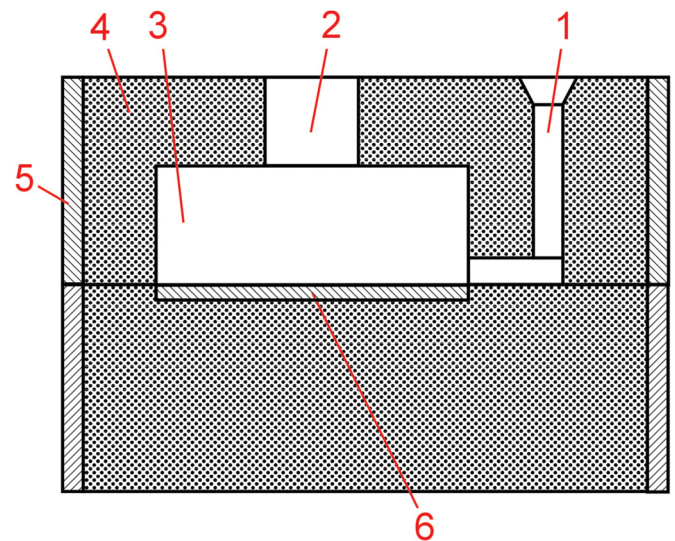


Fig. 1. Scheme of a sand mould technology for bimetallic casting: 1 – gating system, 2 – flow-off, 3 – mould cavity, 4 – moulding sand, 5 – moulding box and 6 – stainless steel plate

The quality of the joint in the bimetallic castings was evaluated on the basis of ultrasonic non-destructive testing done using the DIO 1000 flaw detector by STARMANS ELEKTRONICS. Then metallographic macro- and microscopic examinations were carried out. Metallographic samples etched in the reagent Mi19Fe contained: 3g of ferric chloride, 10cm<sup>3</sup> hydrochloric acid and 90cm<sup>3</sup> ethanol. For structure research a light microscope (LOM) NIKON and scanning electron microscope (SEM) INSPECT F with microanalysis of the chemical composition (EDS) were used. Measurements of microhardness were done using an FM 700 Future-Tech (HV0,01).

## 3. Results and discussion of studies

Non-destructive ultrasonic testing showed that on the whole contact surface of both materials in the bimetallic casting a permanent joint was obtained, i.e. for which the bottom echo was larger than the echo of the transition zone (head placed on the side of the plate) between the working layer and the base part. These results were confirmed by a macroscopic visual quality assessment conducted on selected sections of test bimetallic castings (Fig. 2).

Figure 3 presents the microstructure of the obtained bimetallic casting. The joint obtained between the ferritic stainless steel and grey cast iron is durable and has a diffusional character. A decisive factor is the carbon diffusion from the cast iron to the steel plate. The proximate result of this diffusion is the creation of transition zones which are structurally different from the cast iron and the steel plate used.

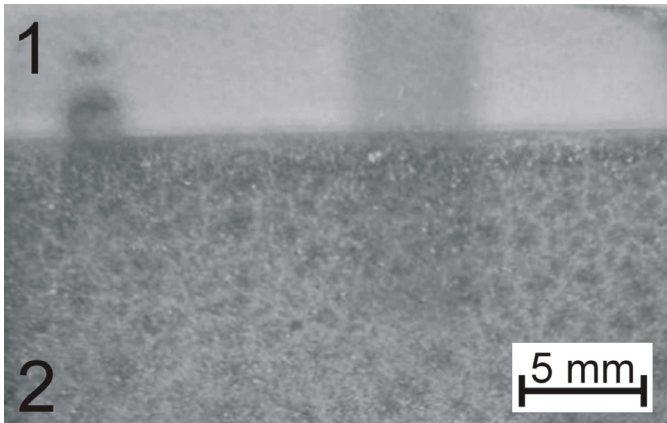


Fig. 2. Transverse section of the bimetallic casting: 1 – working layer in the form of a stainless steel X6Cr 13 plate, 2 – the base part of grey cast iron

Moreover, the heating temperature of stainless steel has an effect on the formation of the transition zones microstructure, and whose source is the liquid cast iron that was poured into the mould. For a pouring temperature of 1450°C of the cast iron and contact temperature  $T_s$  on the boundary of the liquid metal – the stainless steel X6Cr 13 plate is fixed on the basis of formulae presented in paper [13] equals about 870°C and then rises above 1200°C.

There are five zones present in the bimetallic casting microstructure, as is shown in Figure 3. The first and fifth zones have microstructures typical for alloys used adequately on the working layer and the base part of the bimetallic casting, i.e. ferrite in zone one and flake graphite in the pearlite matrix in zone five. The areas from 2 to 4 are transition zones. In zone 2, structural changes occurred in the solid state, i.e. as a result of carbonis-

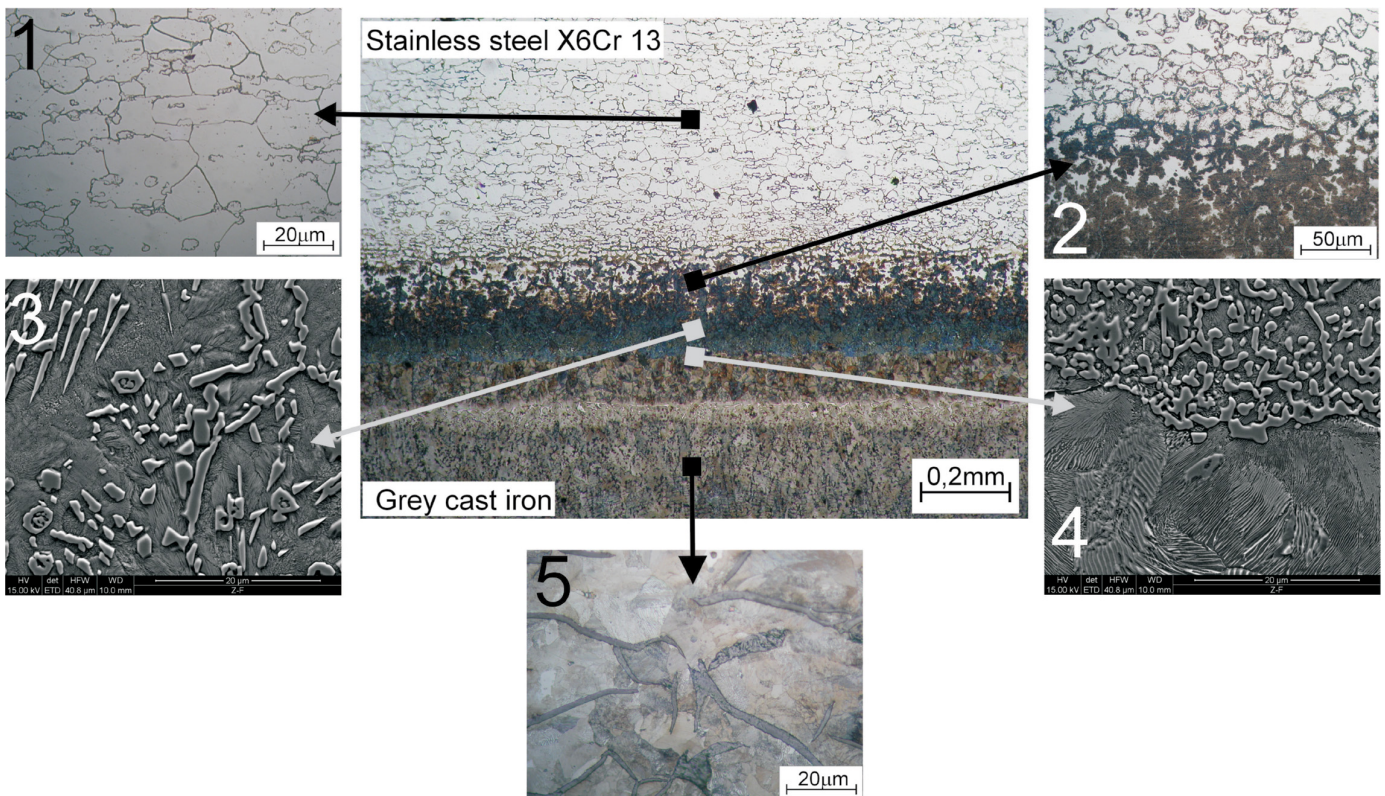


Fig. 3. Microstructure of a bimetallic casting in a configuration of the working layer in the form of a stainless steel X6Cr 13 plate and the base part from grey cast iron

ing connected with heating whose source was liquid cast iron poured into the mould, in this zone was created solid solution  $\gamma$ , which during casting cooling with low cooling rate undergoes the martensite transformation. The ratio of martensite content with a microhardness of about 370mHV to ferrite content with a microhardness of about 180mHV increases in direction of the border steel – cast iron. Carbonising of zone 3, which is placed closer to the liquid cast iron poured into the mould than zone 2, decreases the liquidus and solidus temperature. As a result, the third zone is remelted due to temperature higher than the  $T_s$ . Then

zone 3 crystallises at a specified chemical composition, which results in the microstructure containing Cr carbides (mainly  $M_{23}C_6$  and  $M_7C_3$ ) with a microhardness of about 850 mHV, in the martensite matrix with a microhardness of about 410 mHV (Figs. 4 and 5).

On the side of the base part is the decarbonised zone 4. In this zone a microstructure of pearlite is present with a microhardness of about 220 mHV (Fig. 6). Next, deep inside the base part a smooth transition takes place to high-carbon zone 5 containing flake graphite in the pearlite matrix.



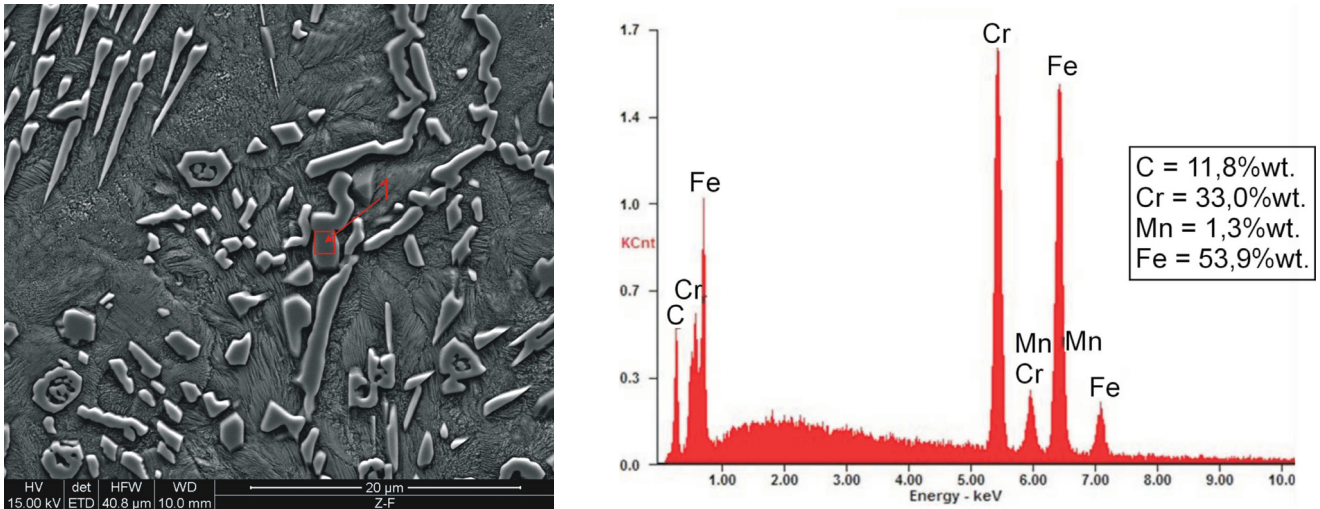


Fig. 4. Microanalysis of the chemical composition: a) microstructure of the studied area in zone 3 from Fig. 3, SEM and b) the result of EDS in point 1 (carbide)

#### 4. Concluding remarks

On the basis of the obtained results it can be confirmed that decisive phenomena needed for creation of a permanent joint between the two components of the bimetallic casting, i.e. X6Cr 13 stainless steels and grey cast iron, are carbon and heat transport from the high-carbon, hot material of the base part, which was poured into the mould in the form of liquid metal

to low-carbon, cold material of the working layer, which was placed in the mould cavity in the form of a 5 mm thick monolithic insert. The decisive influence of carbon on forming the joint between the working layer and the base part results from its readily transport with the interstitial mechanism from one material to another, as distinguished from Fe, Cr or Ni transport with the vacancy mechanism.

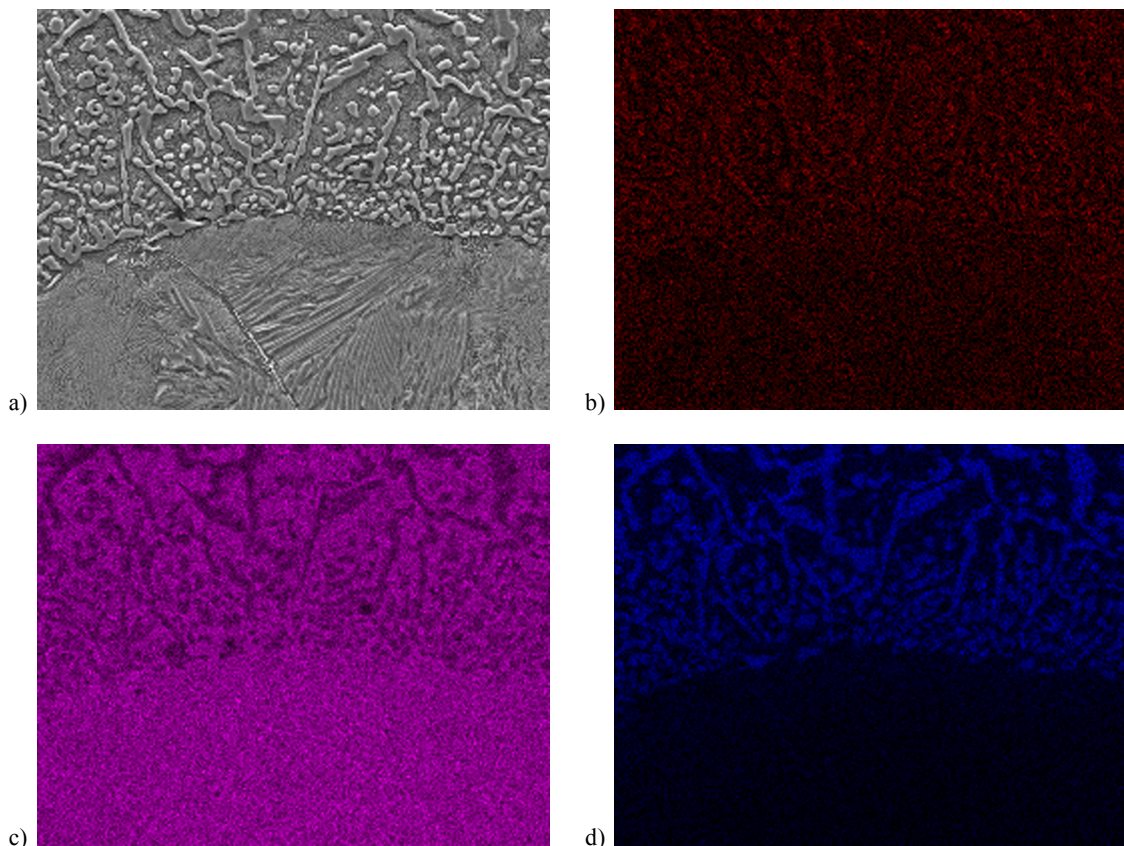


Fig. 5. Map of selected elements distribution: a) microstructure of the studied area in zone 3 and 4 from Fig. 3, SEM, b) distribution of C, c) distribution of Fe and d) distribution of Cr

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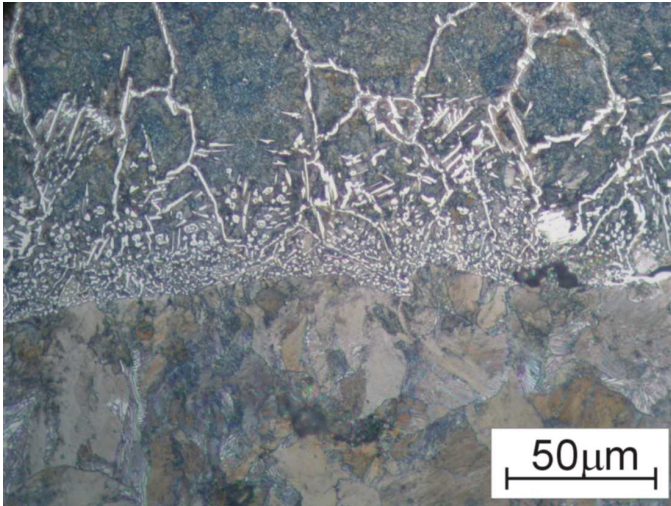


Fig. 6. Microstructure of the joint area between stainless steel X6Cr 13 (zone 3) and grey cast iron (zone 4), LOM, etching Mi19Fe

Therefore, as result of this phenomena in the microstructure of bimetallic casting three transition zones were created which were situated between the microstructure proper for the working layer, i.e. ferritic for stainless steel and the microstructure proper for the base part, i.e. flake graphite in the pearlite matrix. On the side of the base part of the bimetallic casting is the first transition zone containing pearlite without graphite, which was created as a result of decarbonising connected with carbon transport in the direction to this element lower concentration, i.e. to the working layer. Then there is the transition zone created from the liquid phase as a result of carbonising which decreases both the liquidus and solidus temperature in this border area of the steel plate and next melts under the influence of high temperature resulting from heat transport in the direction from the liquid cast iron to the monolithic insert. The chemical composition obtained in this zone determines the crystallisation of the microstructure consisting of carbides, mainly Cr, in the solid solution matrix. On the side of the working layer the transition zone created in the solid phase is present as a result of carbonising (insufficient to significantly reduce the melting point) and cooling from a high temperature (insufficient to melt this area). This zone with diphasic microstructure contains martensite and ferrite.

Received: 20 April 2015.

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