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Self-hardening of X46Cr13 Steel Integrated with Base from Grey Cast Iron in Bimetallic System

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Abstract

The paper presents the technology of manufacturing layered castings, consisting of grey cast iron (base part) and high-chromium stainless steel (working part/layer). The aim of researches was an attempt of integration of heat treatment of steel X46Cr13 grade with founding of grey cast iron in bimetallic system and determination of the influence of cooling rate of bimetallic system in classical sand mould with bentonite on microstructure and hardness of the working layer. The castings were manufactured using mould cavity preparation method, where steel plate was poured by grey cast iron using different pouring temperature and thickness of base part. Then, the quality of joint between cast iron and steel plate was estimated by using ultrasonic non-destructive testing. The efficiency of heat treatment process was analysed by measurement of hardness and in metallographic examination. Conducted studies showed, that self-hardening's ability of steel X46Cr13 let obtain technologically usable layered casting characterized by hardness of working surface up to 35 HRC.

Keywords: Bimetallic casting, Stainless steel, Grey cast iron, Hardness, Microstructure

1. Introduction

Layered and reinforced castings find wider and wider application in many fields of the industry as elements of machines working in difficult conditions, in which previously used uniform castings destroyed too quickly. Complex layered constructions, deriving benefits of combined properties of different materials, are the response on growing demands towards machines and devices components. Apart from the opportunity of acquirement the components with enhanced combinations of properties, it is also possible to reduce cost of their production. It is very common, that high final properties, as hardness, high corrosion or wear resistance, are demanded only on the working surface of the castings, so manufacturing whole casting from material which meet these requirements seems not to be reasonable, because such components are usually made from expensive and hard to reach materials [1-5].

Therefore, the concept of the researches uses existing layered casting technology, based on the mould cavity preparation method with a monolithic insert [6-13], to obtain a bimetallic casting in system: working layer made of corrosion-resistant steel, from the high-chromium group X46Cr13 grade with a grey cast iron EN-GJL-HB 255 base part. In initial state i.e. in time of placement in the mould and before pouring with liquid cast iron, the hardness of X46Cr 13 steel equals 200HV. At the same time, taking into account the possibility of martensite transformation of aforementioned steel grade [14-16], during the cooling even with not too high rates, it is possible to integrate its heat treatment with the casting process of gray cast iron, and therefore with the process of manufacturing cast bimetal characterized by a permanent connection of a steel working layer with a cast iron base part.

Table 1.
Chemical composition of high-chromium X46Cr13 steel

Mass contents in wt %											
C	Cr	Mo	Co	Si	Ni	Al	Cu	W	V	S	P
0,443	13,5	0,007	0,007	0,280	0,520	0,002	0,046	0,018	0,089	0,001	0,033

Table 2.
Chemical composition of grey cast iron EN-GJL-HB 255

Mass contents in wt %											
C	Mn	Si	Cu	Cr	Mo	Ni	Ti	Al	S	P	Sn
3,14	0,72	2,29	0,12	0,087	0,011	0,057	0,007	0,031	0,006	0,039	0,034

2. Range of studies

The object of the researches were castings consisting of two parts: working part as high-chromium steel plate, and base part as grey cast iron. Range of studies contained a manufacture of 9 layered castings differing in thickness of base part and in pouring temperature. Studied elements were prepared in classical sand mould with bentonite. Chemical compositions of the studied materials, estimated using optical emission spectrometer LECO GDS500A, is presented in Table 1 and 2.

The working part in all studied bimetallic castings was made of steel plate with dimensions 50x50x5 mm (Fig.1). Whereas the dimensions of the base part was 50x50xt mm, where t is thickness which was variable for each casting. In studied layered castings the thickness ratio between working part and base part was: 1:4, 1:8 and 1:12, so the base part thickness was: 20, 40 and 60 mm, respectively (Fig. 1).

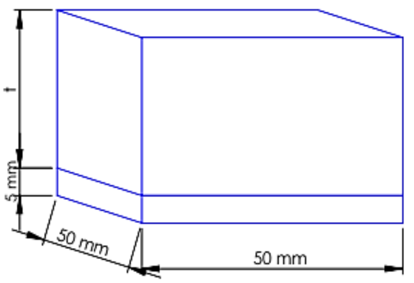


Fig. 1. Geometry of studied layered casting

The bimetallic castings were made using mould cavity preparation method by monolithic insert (Fig. 2) which is described in detail in paper [14]. The steel inserts, previously placed in sand moulds cavities, were poured by liquid grey cast iron in 3 variants of pouring temperature: 1400, 1450 and 1500°C. In each cases the surface of the steel insert, staying in contact with grey cast iron, was covered by boron and sodium compounds, what favours the formation of permanent joint between both components of bimetal, as show in papers [10 and 13].

In experiment the pouring temperature was measured directly in ladle with use of thermoelement Pt-PtRh10, that was fixed in thermal center on external surface of the insert. This type of the thermoelement also was used to temperature measurements of external surface of steel insert in time of layered casting cooling in the mould.

The efficiency of joint between grey cast iron and stainless steel was measured using ultrasonic non-destructive testing (examinations made on DIO 1000 flaw detector by STARMANS ELEKTRONICS). The hardness of obtained layered castings was measured using Rockwell (hardness tester KABiD-PRESS, type PRL-010A) and Vickers (microhardness tester of FUTURE-TECH, type FM 700) methods. Metallographic examination were carried out on light microscope NIKON and scanning electron microscope PHENOM ProX with spot and surface EDS analysis.

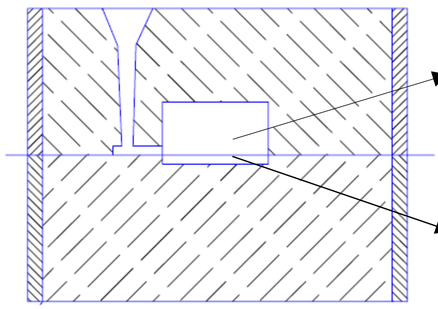
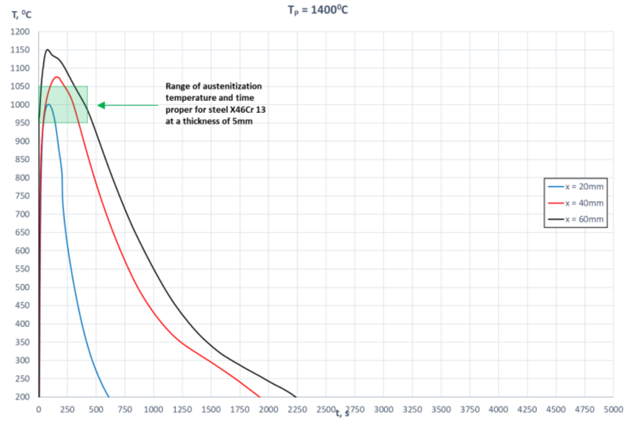


Fig. 2. Scheme of cross-section of the sand mould with monolithic insert prepared to be poured

3. Results of studies

As it is seen in Figure 3, lower limit of austenitization temperature for X46Cr13 steel equalling 950°C was achieved on external surface of working part in all studied layered castings. Whereas upper limit of austenitization temperature for analysed stainless steel equalling 1050°C was not achieved for the thinnest castings (thickness of base part equal 20 mm) at pouring temperature 1400 and 1450°C. Moreover was affirmed that the cooling rate of insert place in mould cavity essentially depends on pouring temperature and thickness of base part i.e. increases with decrease of pouring temperature and thickness of base part of the layered casting. However the reverse dependence occurs in case of efficiency of permanent joint between steel and cast iron. Based on non-destructive ultrasonic examination, it was stated that this efficiency of permanent joint in bimetallic castings increases with increase of base part thickness, as with well as pouring temperature (Fig. 4).

a)



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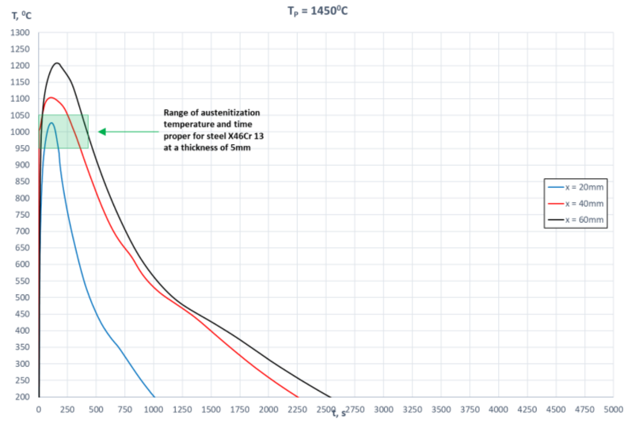

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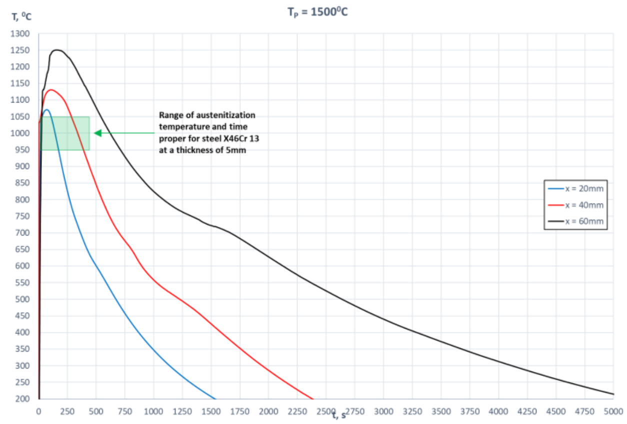


Fig. 3. Characteristic curves T = f(t) for the X46Cr13 steel inserts in dependence on thickness of grey cast iron base part (t) and pouring temperature (T_p): a) 1400°C, b) 1450°C and c) 1500°C

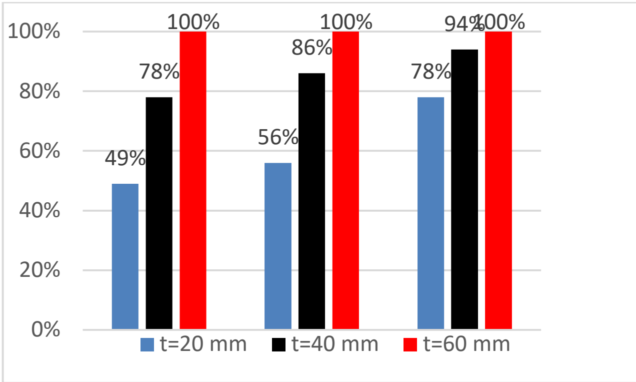


Fig. 4. The influence of thickness of grey cast iron base part (t) and pouring temperature (T_p) on percentage size of the area on which is present the permanent joint between working and base parts of layered casting

In Figure 5 the microstructure of permanent joint area obtained in analysed bimetallic castings is presented. According to detailed descriptions of microstructure of this type of bimetallic castings presented in paper [13], also in analysed cases the five zones are present in the microstructure i.e. in direction from the base to working part occurred: flake graphite in pearlite matrix (1), pearlite (2), fine Cr(Fe) carbides mainly M_7C_3 in pearlite matrix (3), Cr(Fe) carbides in pearlite matrix (4) and Cr(Fe) carbides in martensitic-pearlitic matrix (5).

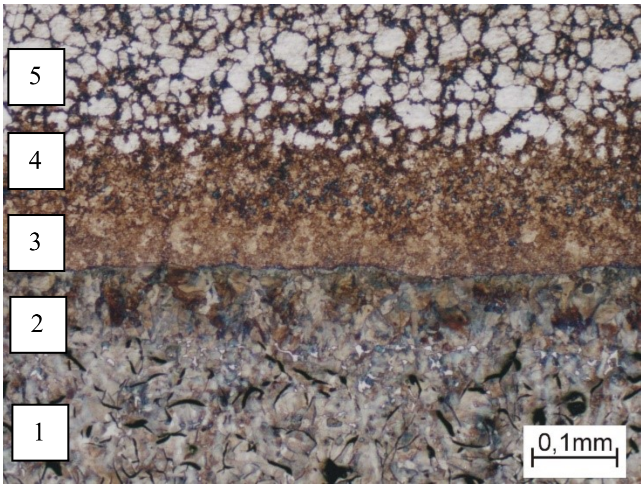


Fig. 5. Microstructure of bimetallic casting X46Cr13 steel (upper)– grey cast iron (bottom), mag.50x

Taking into consideration the aim of researches, the most important aspect was analysis of microstructure of steel working surface layer (Fig.6). It was estimated that process of heating connected with next even slow rate cooling of the insert in mould causes self-hardening of X46Cr13 steel which increasing hardness of working layer of bimetallic casting. It result the microstructure of steel working part contains approximately constant amount of fine Cr(Fe) carbides, $M_{23}C_6$ type, in martensitic-pearlitic matrix (Fig.7, 8 and Tab. 3) but content of both matrix components depends of variable parameters of cast process (Fig.6).

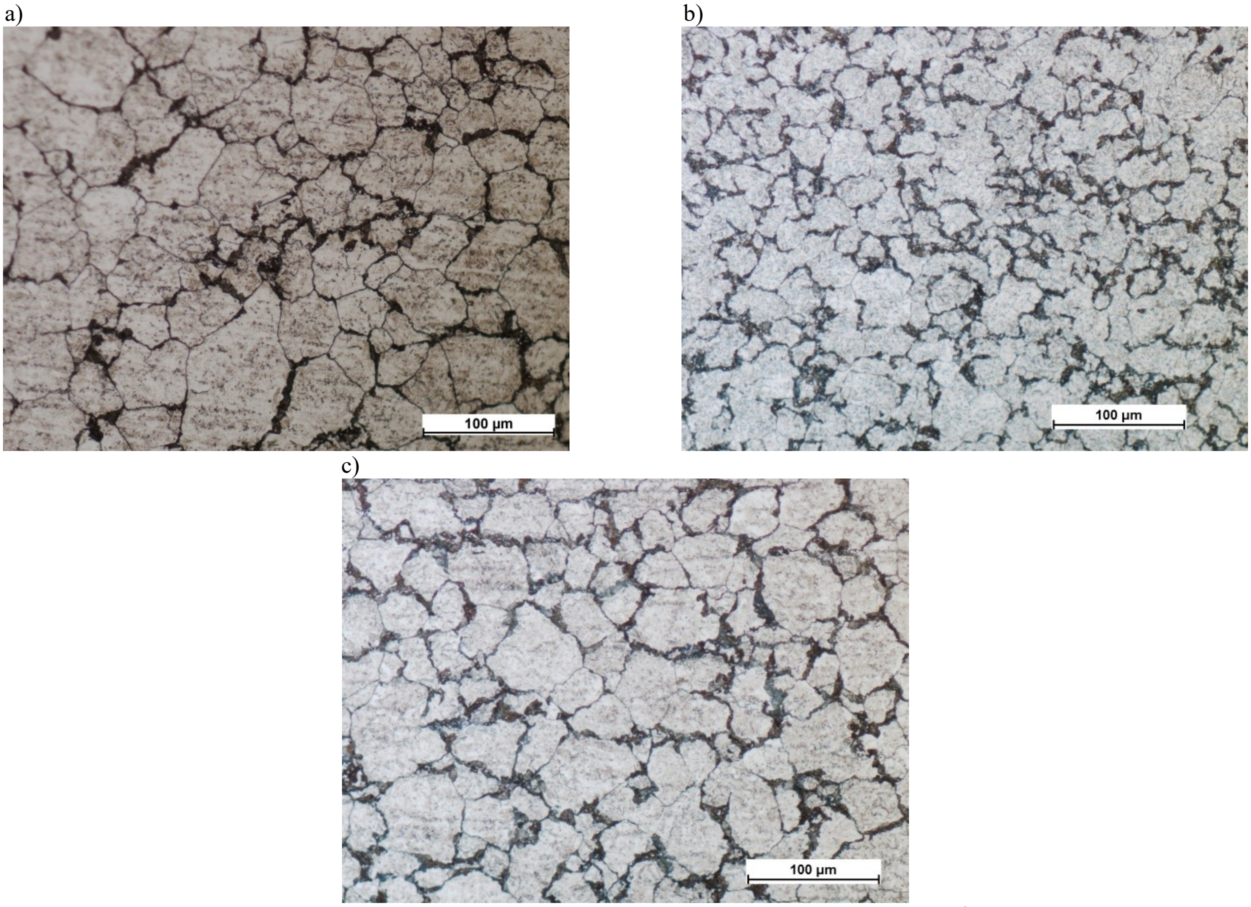


Fig. 6. Microstructure of X46Cr13 steel working part of bimetallic casting at pouring temperature 1450°C and thickness of grey cast iron base part: a) 20 mm, b) 40 mm and c) 60 mm, mag. 200x

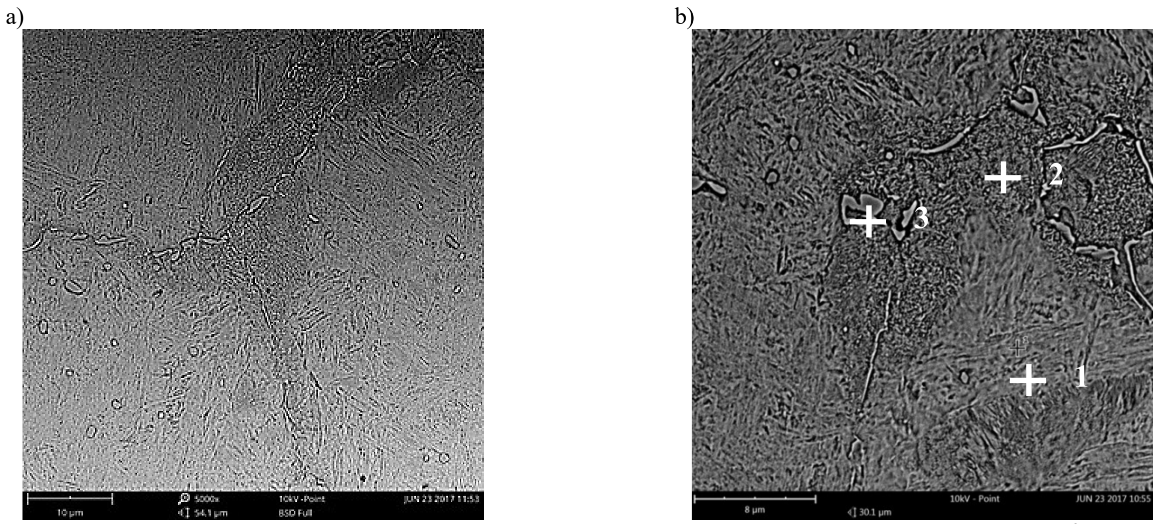


Fig. 7. Microstructure of X46Cr13 steel working part of bimetallic casting at pouring temperature 1450°C and thickness of grey cast iron base part 40mm: a) mag. 5000x and b) 9000x

Table 3.
The result of spot EDS analysis (number of measuring points as in Fig. 7b)

No	Fe%		Cr %		C%	
	atomic	weight	atomic	weight	atomic	weight
1	78,91	83,76	15,03	14,86	6,06	1,38
2	74,03	82,91	13,51	14,09	12,46	3,00
3	43,17	48,21	39,43	47,30	17,40	4,49

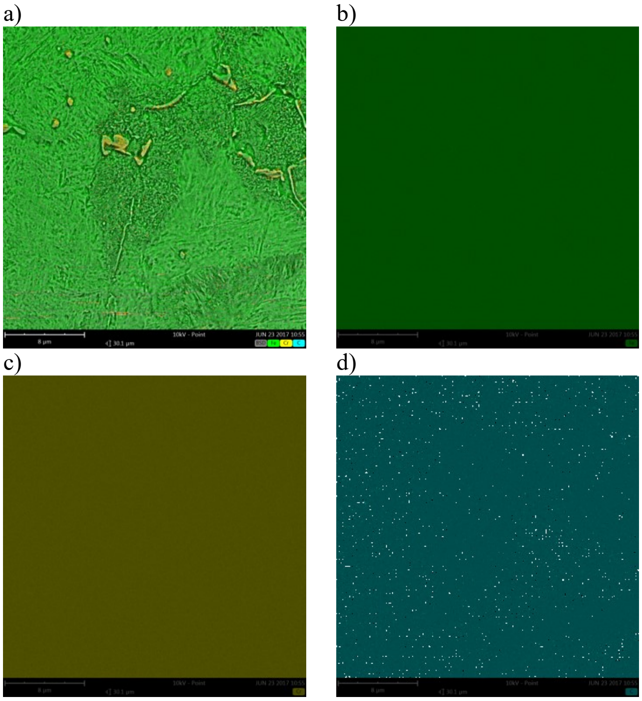


Fig. 8. The result of surface EDS analysis for area on Fig. 7b: a) distribution of all elements, b) distribution of Fe, c) distribution of Cr and d) distribution of C

The mutual content of matrix components depends on pouring temperature and thickness of base part. Content of martensite relative to pearlite increases with decrease of pouring temperature and thickness of base part. In result with increase in martensite content in microstructure increases hardness of steel working layer. Therefore the biggest values of hardness of surface layer was achieved for layered castings with the thinnest base part and which were manufactured at lower pouring temperature (Fig.9).

Whereas on Figure 10 the distribution of hardness on cross-section of steel working layer of studied bimetallic castings are presented. On the basis of obtained results was affirmed that in spite of not fulfilling in any case the criterion of required austenitizing time for thickness of steel plate equal 5mm (Fig.3), in all analysed layered castings process of self-hardening occurs in depth to approx. 4,5mm. Increasing of hardness in depth of steel working part above 4,5mm results from presence of large amount of Cr(Fe) carbides which precipitated in carburized area of joint between both components of bimetallic casting.

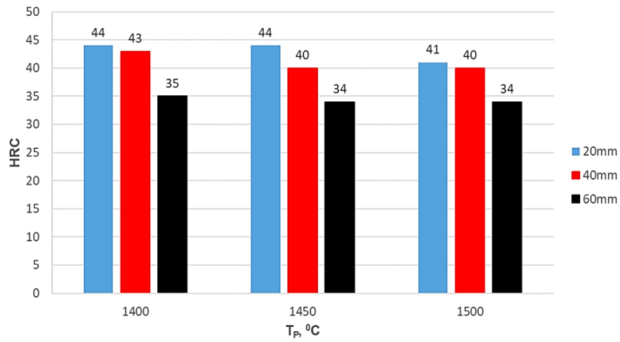


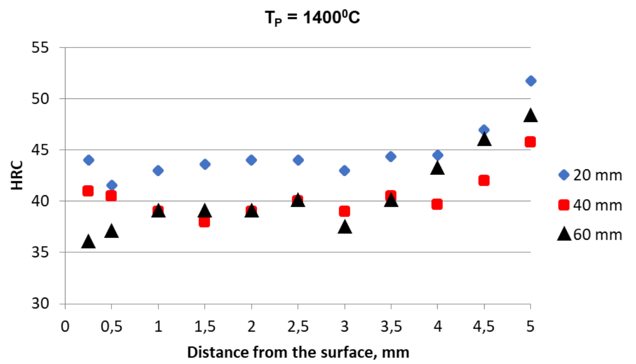
Fig. 9. The influence of thickness of grey cast iron base part (t) and pouring temperature (T_p) on hardness of surface of working part of layered casting

4. Conclusions

Based on conducted studies, following conclusions have been formulated:

1. It is possible to integrate heat treatment of high-chromium steel X46Cr13 grade with founding process of grey cast iron in bimetallic system.
2. Increase of intensity of cooling of monolithic insert made of high-chromium steel X46Cr13 grade by using lower pouring temperature and smaller thickness of grey cast iron base part, favours growth of hardness on the surface of bimetal, but simultaneously impair on quality of joint between components of layered casting.
3. Self-hardening's ability of high-chromium steel X46Cr13 lets obtain in classical sand mould with bentonite, the technologically usable layered casting characterized by hardness of working surface up to 35 HRC.

a)



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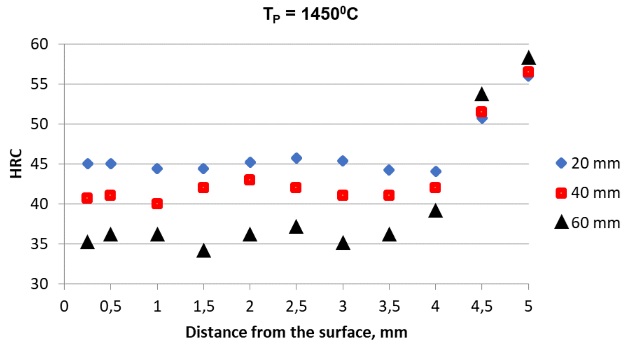

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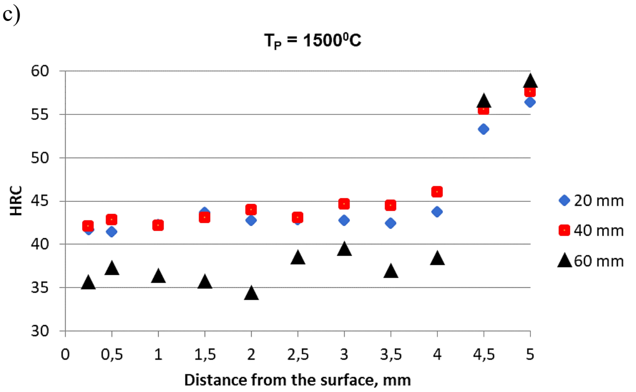

Fig. 10. Distribution of hardness on cross-section of X46Cr13 steel working part of bimetallic casting: a) T_p = 1400°C, b) T_p = 1450°C and c) T_p = 1500°C

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