

INFLUENCE OF EXTERNAL DEFECTS ON MECHANICAL PROPERTIES OF BIMETALLIC CASTINGS AND CAST-WELDED BIMETALLIC CONSTRUCTIONS

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Abstract. Improving the wear resistance of materials, extending the service life of machines and equipment parts operating under significant dynamic loads, reducing metal loss and the consumption of expensive high-alloy alloys are the most important tasks of resource saving modern industries. Application of bimetallic castings, which possess a unique set of properties differentiated by the volume and surface area, is a promising solution. However, manufacturing complex parts and structures is not always feasible due to the limitations of the manufacturing technology. The most practical option was selected to manufacture cast-welded bimetallic structures. The study of the external defect influence, such as cracks, on the strength and ductility properties of the transition layer in bimetallic castings and the weld was in the focus. The research was conducted on 25GSL steel – 300Kh12G3M bimetallic castings and cast-welded constructions after heat treatment. Stress concentrators in the form of double-sided notches were introduced to the transition layer and the weld to reveal their effect on the mechanical properties. It was found that for almost the same notch area (74.9 and 74.3% of the total contact area) the mechanical properties of cast-welded bimetallic constructions exceed the properties of bimetallic castings: the tensile strength is 8% higher (180 MPa) than that of the bimetallic casting (167 MPa); the reduction of area is 0.4% higher (4.00 and 3.98%, respectively) and the relative elongation is 18.8% higher (0.40 and 0.34%, respectively). A technology was developed for the manufacture and testing cast-welded bimetallic structures “Hammer” in crushing gypsum rock, the operating efficiency of which is 2.5 times higher than the generally accepted use of monometallic hammers made of 110G13L steel.

Keywords: steel, cast iron, transition layer, work layer, base, bimetallic casting, welding seam, tensile strength, elongation, reduction of area, abrasive wear.

Introduction

Many modern types of machines and constructions operate under conditions of intense abrasive and impact-abrasive wear. It is especially true for impact, centrifugal, and hammer crushing and grinding equipment designed to process granite, basalt, clinker, quartzite, glass, limestone and other mineral raw materials [1; 2]. The limited durability of such machine components and the significant costs of their repair reduce economic efficiency and increase irreversible metal loss. However, the demand for processed natural mineral products in industrial and civil construction, including highways and high-speed rail, is constantly growing. Therefore, increasing the wear resistance of materials, extending the service life of machinery and equipment components operating under significant dynamic loads are most actual worldwide [3; 4].

Application of the bimetallic castings, which possess a unique set of properties differentiated by the volume and surface area of the product, may be a promising solution [5]. Due to their optimal combination of physical, mechanical, technological, and operational characteristics, such castings have wide application in mining and metallurgy, agricultural machinery, and other industries [6].

However, the use of bimetallic castings for the manufacture of complex components and large-scale structures is not always feasible due to the significant complexity of the manufacturing technology. Such components include reversible impact hammers of rotary crushers, large-sized working parts of hammer crushers and others.

These parts are commonly manufactured as welded bimetallic structures by joining bimetallic castings to a monometallic structural base or bimetallic castings to each other. The use of cast welded bimetallic structures significantly simplifies their manufacturing process and increases the service life of crushing and grinding equipment working parts, reduces the consumption of high-alloy alloys [7].

However, during operation under abrasive wear, external defects such as cracks significantly affect the transition layer in bimetallic castings and the weld seam in cast welded bimetallic structures, worsening the mechanical properties, the reliability and performance of equipment components. Therefore, to develop a new manufacturing technology for cast welded bimetallic constructions, it is

necessary to study the influence of external defects, such as cracks, on the strength and ductility properties of the transition layer in bimetallic castings and the weld seam in cast welded bimetallic constructions.

Materials and methods

The research was carried out on 25GSL steel – 300Kh12G3M cast iron bimetallic castings and a cast-welding construction the chemical composition of which is given in Table 1.

Table 1

Chemical composition of bimetallic castings and cast-welding construction

Parts of casting	C	Si	Mn	Cr	Mo	S	P
	wt. %						
Bimetallic castings							
Base (25GSL steel)	0.26	0.7	1.2	0.29	-	0.03	0.03
Work layer (300Kh12G3M cast iron)	2.8	0.7	4.85	13.5	0.6	0.06	0.08
Cast-welding construction							
Base (25GSL steel)	0.25	0.65	1.1	0.25	-	0.025	0.02
Work layer (300Kh12G3M cast iron)	2.9	0.6	3.8	14	0.7	0.05	0.09

The alloys were smelted in IST-0.16/0.25-II induction melting furnaces. The chemical composition of the steels and cast iron were determined with a SPAS-05 optical emission spectrometer. The experimental bimetallic castings with overall dimensions of 220x61x18 mm and 180x61x18 mm (Fig. 1) were obtained by sequential pouring of layers into a liquid glass casting mold (CO₂ process) through autonomous gating systems.

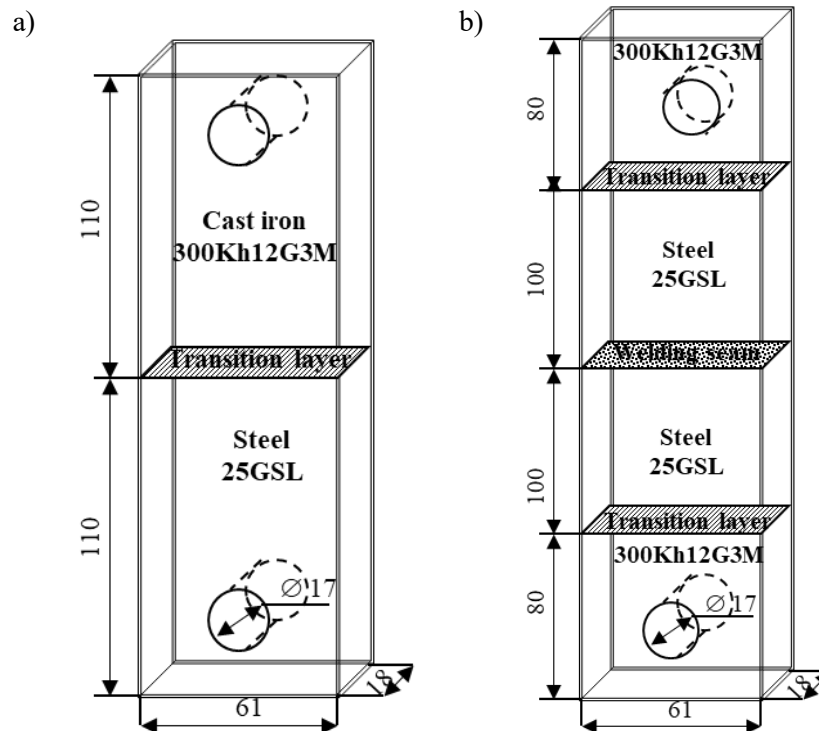


Fig. 1. Dimensions and shape of the studied bimetallic castings (a) and cast-welded bimetallic construction (b)

Heat treatment of bimetallic castings was performed using the following procedure:

- heating to 950 °C for 5 hours (holding for 4 hours), cooling under a fan to room temperature;
- tempering at 200 °C for 4 hours, cooling under air.

The cast-welded constructions were produced by welding bimetallic components using the electric arc with ANO-21 electrodes with a rutile (TiO₂) coating. The electrode diameter was 3 mm; length

350 mm. The chemical composition of the electrode rod (wt.%) was as follows: C = 0.9; Mn = 0.47; Si = 0.02; P = 0.03; S = 0.025; Cr = 0.1; Ni = 0.2.

To study the influence of the external defects on the mechanical properties, stress concentrators in the form of double-sided notches with a radius of 1 mm were applied to the transition layer of the bimetallic castings and the weld of the cast-welded bimetallic constructions on a plane of 61 mm wide. The notch size was estimated based on its area (F_n) relative to the total area of the transition layer and weld ($61 \times 18 = 1098 \text{ mm}^2$). The mechanical properties were studied with TsDMU-30T tensile testing machine. Multiple correlation analysis was carried out according to the methodology in [8].

Results and discussion

The influence of the notch area on such tensile fracture process parameters as the tensile strength (σ_{cw} , σ_{bm}), reduction of area (ψ_{cw} , ψ_{bm}) and elongation (δ_{cw} , δ_{bm}), where indexes bm and cw correspond to bimetallic castings and cast-welded bimetallic constructions, accordingly, was investigated. The results are shown in Fig. 2.

From these plots it is obvious that the mechanical properties of cast-welded bimetallic constructions with practically the same notch area exceed the properties of bimetallic castings.

For a notch area 74.9% and 74.3% the tensile strength of a cast-welded bimetallic construction is 8% higher (180 MPa) than that for the bimetallic casting (167 MPa). The reduction of area is 4.00% and 3.98%, respectively, which is 0.4% higher, and the relative elongation is 0.40% and 0.34%, which is 18.8% higher than those of the bimetallic casting.

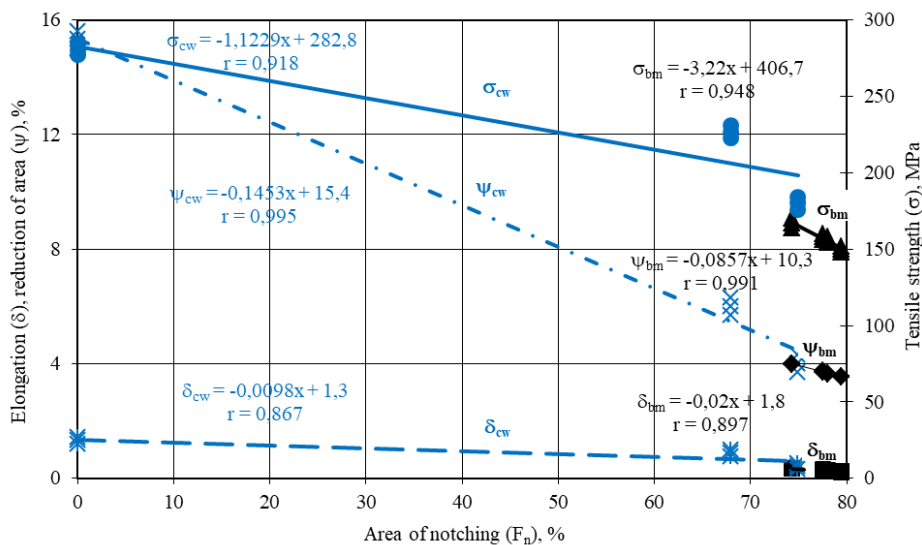


Fig. 2. Influence of the notch area on the tensile strength (σ_{cw} , σ_{bm}), reduction of area (ψ_{cw} , ψ_{bm}) and elongation (δ_{cw} , δ_{bm}) of bimetallic castings (σ_{bm} , ψ_{bm} , δ_{bm}) and welded bimetallic constructions (σ_{cw} , ψ_{cw} , δ_{cw})

The results of the study examining the influence of external defects on the mechanical properties of bimetallic castings and cast-welded bimetallic constructions show that the manufacture of machine and equipment parts from welded bimetallic materials should improve the reliability of the equipment while maintaining the efficiency of the bimetallic castings. The analysis of the parts and components of machines and equipment operating under conditions of intensive abrasive, impact-abrasive and hydro abrasive wear in mining and metallurgical production has shown that cast-welded bimetallic constructions are most appropriate for large-sized working elements of complex configuration such as reversible impact beaters of rotary crushers, hammers etc.

The analysis of the nature and intensity of wear on hammer crusher hammers allowed to develop the bimetallic cast-welded construction. Upper and under seam steel base of it was poured using a lateral supply of liquid metal (Fig. 3a, b and e, f, accordingly), and the working layer was poured after rotating the mold over 90° (Fig. 3c, d). The developed design of the cast-welded construction is shown in Fig. 4.

The optimal process parameters for manufacturing bimetallic castings, as the components of “Hammer” cast-welded bimetallic constructions, were selected as follows:

- pouring temperature of the steel base: 1580-1600 °C, the working layer: 1350-1370 °C;
- pouring time of the steel base: 7-9 sec, the working layer: 10-12 sec.

The steel base and working layer chemical compositions are given in Table 1.

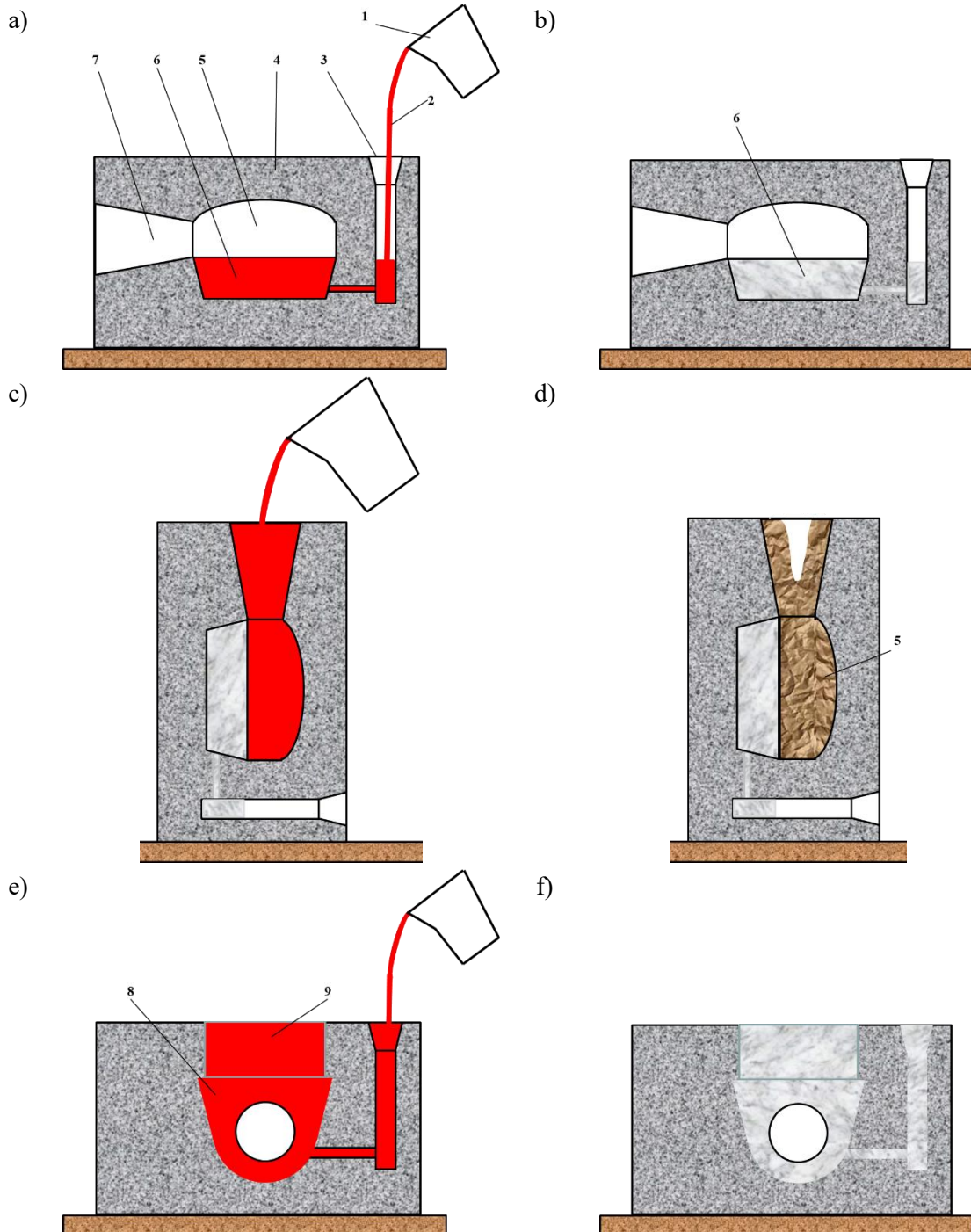


Fig. 3. Manufacturing technology of the bimetallic cast-welded construction components:
 1 – ladle; 2 – melt; 3 – gating system; 4 – casting mold; 5 – cavity for the working layer (a) and solidified working layer (b); 6 – melt (a) and solidified upper component of the steel base; 7 – cavity for the riser of the working layer; 8 – melt of the lower component of the steel base; 9 – riser for the lower component of the steel base

Before welding, the bimetallic castings were positioned on a horizontal tilting plate, joined together, and secured with the clamps to prevent warping of the welded structure and deviations from its basic dimensions. The weld-affected zone was preheated to $220 \pm 20 \text{ }^\circ\text{C}$, after which the bimetallic components were manually joined using intermittent welds of $30 \pm 5 \text{ mm}$ long with a pitch of $160 \pm 10 \text{ mm}$. Welding of the bimetallic casting with the base was performed using a PDG-251 semiautomatic arc welding machine by direct current in a carbon dioxide protection environment, grade “welding” [9], and Sv-08G2S steel electrode wire [10].

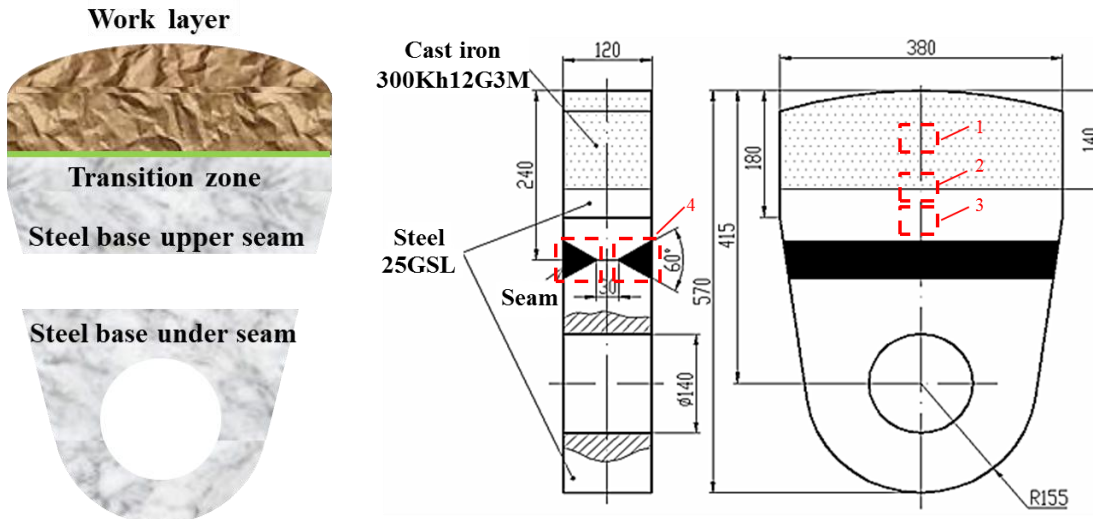


Fig. 4. Cast-welded bimetallic construction “Hammer” of hammer crushers

The microstructure in 1-4 zones is shown in Fig. 5.

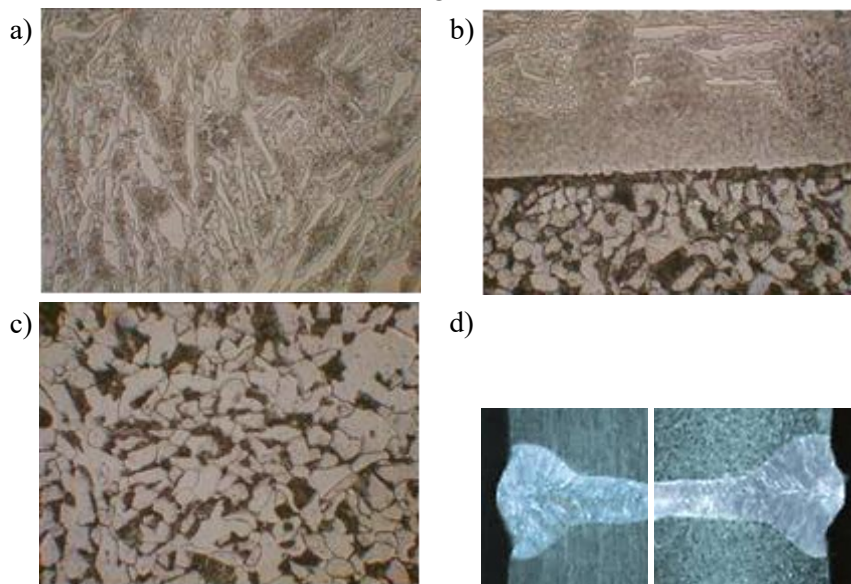


Fig. 5. Microstructure of the working layer (a), transition zone (b), base (c), and weld (d) of cast-welded bimetallic construction “Hammer”: a, b, c, d – points 1, 2, 3, 4 in Fig. 4, respectively, magnification x1500

An analysis of the structures shown in Fig. 5 shows that the working layer of the cast-welded bimetallic construction “Hammer” consists of carbides with an average size of $40 \text{ }\mu\text{m}$ in an amount of 32 wt.%, martensite with a volume fraction of 56% and an average packet size of $40 \text{ }\mu\text{m}$, austenite with a volume fraction of 12% and an average grain size of $50 \text{ }\mu\text{m}$ (Fig. 5a). The transition zone consists of ferrite on the side of the working layer and pearlite on the side of the steel base. The width of the ferrite zone is $1 \text{ }\mu\text{m}$, and that of pearlite is $11 \text{ }\mu\text{m}$ (Fig. 5b). The structure of the steel base consists of 50% by

volume ferrite and 50% by volume pearlite. The average grain size of ferrite is 22.7 μm , and that of pearlite is 20.3 μm (Fig. 5c). The structure of the weld is shown in Fig. 5d.

The primary requirements for cast-welded bimetallic constructions of machine parts to ensure high performance under significant dynamic loads and abrasive wear are increased wear resistance of the working surfaces and the strength of the welded joints. The wear resistance of welded constructions is determined by the wear resistance of the alloys of the working layer of the bimetallic components of such constructions, which is achieved through optimal alloying and heat treatment. For high-chromium hypoeutectic cast iron 300Kh12G3M, used as the working layer in the production of the “Hammer” cast-welded bimetallic construction, the required structure and hardness (60-62 HRC) are achieved through air quenching and low-temperature tempering.

An important feature of producing cast-welded bimetallic constructions is the need of high-temperature tempering to eliminate residual welding stresses and deformations that could lead to construction failure during operation. However, this process also involves high-temperature tempering of the working layer alloy, resulting in a significant reduction in its hardness to 46-48 HRC and wear resistance, due to the formation of a sorbite structure in the cast iron metallic base instead of martensite. Therefore, to ensure high wear resistance of the working surfaces and the required strength of the welded joint during the manufacture of the cast-welded bimetallic constructions, heat treatment was performed after welding according to the following regimes:

1. Quenching after heating to 930-950 $^{\circ}\text{C}$ at a rate less than 150 $^{\circ}\text{C}\cdot\text{hour}^{-1}$. Holding at 930-950 $^{\circ}\text{C}$ from 4.5 to 5.0 hours. Cooling under the air fan (capacity not less than 24000 $\text{m}^3\cdot\text{hour}^{-1}$).
2. Tempering. Heating to 180-200 $^{\circ}\text{C}$ at a rate of less than 100 $^{\circ}\text{C}\cdot\text{hour}^{-1}$. Holding at 180-200 $^{\circ}\text{C}$ from 4.0 to 4.5 hours and air cooling.

Heating and holding at high temperatures during quenching reduce the stresses that arise during welding and eliminate the need for high-temperature tempering of the weld. When heat treatment of cast-welded bimetallic constructions is difficult, local tempering of the welded joint is the most practical option.

Pilot tests of four cast-welded bimetallic “Hammers” (Fig. 3) were conducted under real-life production conditions at a quarry during gypsum rock crushing. The hammers were mounted on a rotor rotating at 735 rpm. Before installation in the crusher, the mass of the cast-welded bimetallic constructions was determined to be 136 kg. During the tests, the service life of the cast-welded bimetallic constructions and their wear during gypsum rock crushing were determined.

The results showed that the service life of the cast-welded bimetallic “Hammer” was 2900 hours, with a wear rate of 3.17 grams per ton of the finished product. Similar indicators for conventional monometallic hammers made of 110G13L steel [11] were 1169 hours of service life and 7.9 grams of weight loss per ton of the finished product. Thus, the use of cast-welded bimetallic constructions is 2.5 times more efficient than the conventional monometallic hammers made of 110G13L steel.

Conclusions

It was established that the most practical option to simplify the technology for effectively increasing the abrasive wear resistance of large-sized working parts of complex machine and equipment components was to manufacture them as cast-welded bimetallic constructions.

The influence of notches on the transition layer and weld seam, and the mechanical properties of bimetallic castings and cast-welded bimetallic constructions is demonstrated. It was found that, with practically identical notch areas (74.9 and 74.3% of the total contact area), the tensile strength of the cast-welded bimetallic construction is 180 MPa, which is 8% higher than that of the bimetallic casting (167 MPa). The reduction of area is 4.00 and 3.98%, respectively, which is 0.4% higher, and the relative elongation is 0.40 and 0.34%, which is 18.8% more than of the bimetallic casting.

It was found that the mechanical properties of cast-welded bimetallic constructions exceed the properties of bimetallic castings for almost the same notch area (74.9 and 74.3% of the total contact area): tensile strength is 8% higher (180 MPa) than that of the bimetallic casting (167 MPa); the reduction of area is 0.4% higher (4.00 and 3.98%, respectively) and the relative elongation is 18.8% higher (0.40 and 0.34%, respectively).

The technology was developed for the manufacture and testing of cast-welded bimetallic structures “Hammer” in crushing gypsum rock, the operating efficiency of which is 2.5 times higher than the generally accepted use of monometallic hammers made of 110G13L steel.

Author contributions

Conceptualization, Y.A.; methodology, Y.A., S.G. and I.K.; experimentation, S.G., I.K., K.K. and V.N.; results analysing, Y.A., S.G. and I.K.; formal analysis, Y.A. and S.G.; writing – original draft preparation, Y.A. and S.G.; writing – review and editing, S.G., K.K. and V.N. All authors have read and agreed to the published version of the manuscript.

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