EFFECT OF LOW-FREQUENCY RESONANCE OSCILLATIONS ON STRUCTURE AND CRACK RESISTANCE OF DEPOSITED HIGH-CHROMIUM CAST IRON

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An experiment was carried out on cladding with high-chromium cast iron. The probability of impact on formation of structure of the deposited metal by low-frequency oscillations, the frequency of which coincided with that of natural oscillations of a workpiece (under resonance conditions), was established, the deposited metal having higher hardness and being characterised by a uniform distribution of chromium between dendrites and eutectic, and by smaller sizes of dendrites near the fusion line. A higher crack resistance of the deposited metal was noted.

Keywords: *arc cladding, low-frequency oscillations, resonance condition, structure of deposited metal, cold cracks*

Strains and stresses formed in cladding of workpieces may lead to cold cracking of metal. The most common methods for preventing cold cracking is preliminary and concurrent heating, as well as delayed cooling. These methods are energy-consuming, and they do not improve the quality of cladding. For example, cladding with high-chromium cast irons is accompanied by formation of transverse cracks in the deposited bead immediately behind the zone of movement of the welding arc, and heating of a workpiece does not guarantee their absence.

Study [1] proposed methods for improving cold crack resistance of alloys by using a rational system of alloying of the materials welded or composition of the weld metal, selecting an initial structure of steel before welding, etc. However, these recommendations are hard to use for cladding.

One of the ways of improving crack resistance of alloys is to externally affect the metal that solidifies. Electromagnetic, ultrasonic, low-frequency and other types of oscillations are used as sources of external effects [2–5]. They provide metal with a microcrystalline structure and improved mechanical properties, which reduces the probability of cracking [6].

Available are welding, cladding and stress relief methods, where workpieces are affected by elastic sound-range oscillations. Statements on the efficiency of welding methods, which meet the conditions of resonance of frequencies of an exciting force and frequencies of natural oscillations of a workpiece, can be found in other publications as well [7–9]. However, in practical application of this technology, the frequency of affecting a piece being welded is chosen arbitrarily, as a rule. The efficiency of welding is assessed from structure of the deposited metal. Study [10] gives the following characterisation of this approach: «it is likely that the problem of an optimal frequency and amplitude of oscillations of the melt in terms of achieving maximal refining of the primary structure has to be solved empirically so far, by allowing for practical results of the previous studies».

The purpose of the present study is to assess the efficiency of low-frequency resonance oscillations (LRO) and their impact on cracking of the deposited high-chromium cast iron. This assessment was performed visually from the quantity of cracks in the deposited metal, as well as by comparative analysis of its structure.

The flow diagram of cladding of samples by involving the external effect by LRO is shown in Figure 1. Samples of steel St3 measuring 50 × 60 × × 180 mm and 6 kg in weight were prepared for cladding. The cladding process was performed with device AD-231 by using 2.6 mm diameter flux-cored wire PP-AN197, which provided chromium cast iron as a deposited metal. Length of the deposited bead was 140–150 mm. The cladding process parameters were as follows: current I = 500 A, arc voltage U_a = 28 V,

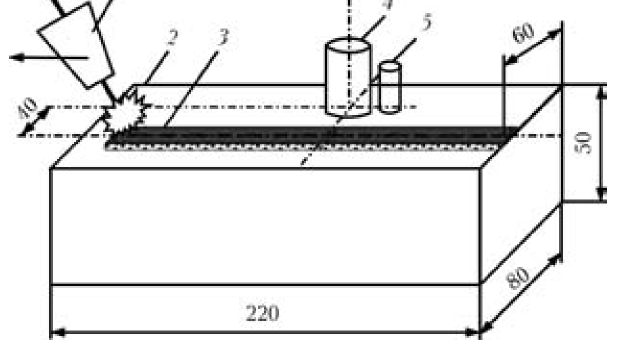

Figure 1. Flow diagram of cladding of samples by involving the external effect by LRO: *1* — welding head; *2* — sample; *3* — deposited cast iron bead; *4* — oscillations exciter; *5* — sensor

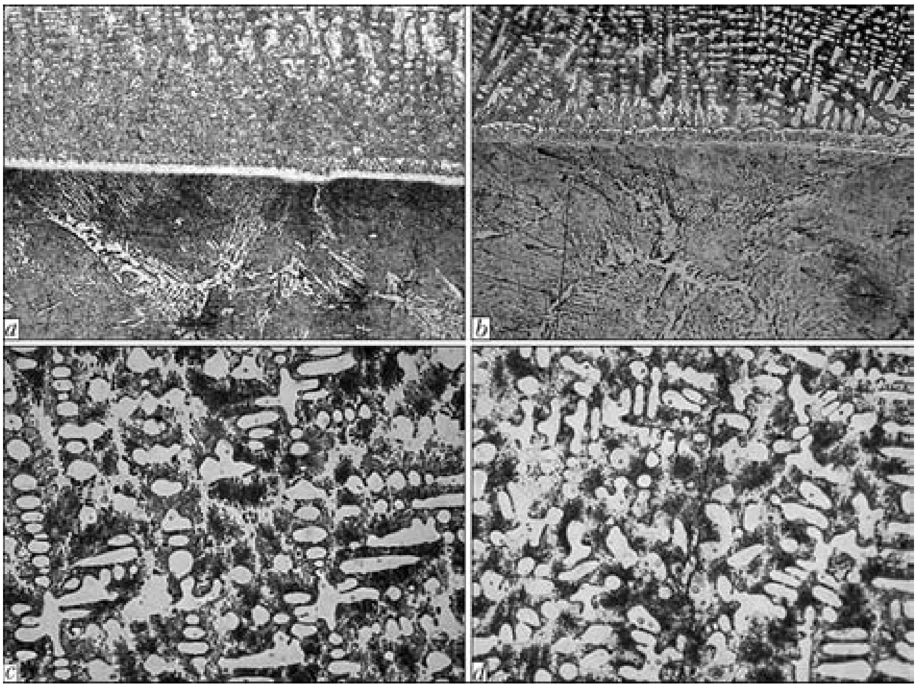

Figure 2. Microstructures of fusion zone between steel St3 (*a*, *b* — ×400) and deposited high-chromium cast iron (*c*, *d* — ×1000) obtained without (*a*, *c*) and with LRO (*b*, *d*)

cladding speed v_c = 20 m/h. The samples were not subjected to preheating, and after cladding they were cooled in air. While performing cladding, the exciting force frequency was varied according to readings of a sensor to meet the condition at which the sensor showed the maximal amplitude of oscillations of a sample, which corresponded to the coincidence of frequencies of external and natural oscillations of the sample (resonance). The external oscillations frequency was 136 Hz, and power was 20 W.

It was found out that cladding by involving LRO provided improvement of crack resistance of the deposited metal. For example, during the experiments a transverse crack initiated only in one out of five samples. Cladding with LRO at frequencies other than the resonance ones (higher or lower than 136 Hz) did not give the expected result: up to 7–8 transverse cracks were detected on the bead surfaces, like in the case of cladding without LRO.

Results of metallographic examinations with an optical microscope showed that in both cases a transition layer 8–20 μm thick formed in the base to deposited (high-chromium cast iron) metal fusion zone, this layer having an austenitic-martensitic structure with clearly defined needles, and hardness of about *HV* 7400–7900 MPa (Figure 2, *a*, *b*).

Structure of the deposited metal consisted of dendrites (alloyed austenite–carbides) and eutectic of the rosette type, composed of austenite and carbides (Cr_7C_3 or $FeCr_7C_3$), as well as austenite decomposition products (troostite) (Figure 2, *c*, *d*).

The use of LRO provided decrease in sizes of dendrites in the deposited layer. Their sizes decreased two times with distance to the fusion zone. For instance, the mean size of dendrites with the application of LRO was 5–7 μm, and that without LRO was 13–15 μm (Figure 3). Owing to the LRO effect the sizes of dendrites, D_d, decreased approximately to 1–2 μm

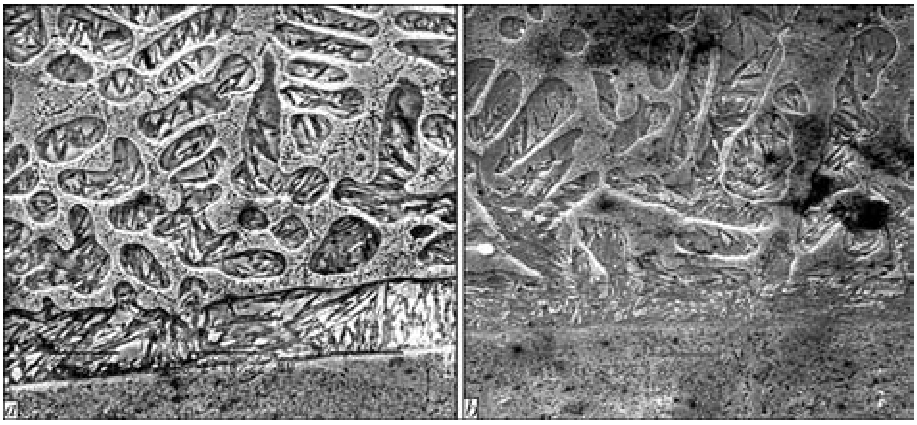

Figure 3. Microstructures (×2300) of high-chromium cast iron fusion zone obtained without (*a*) and with LRO (*b*) under scanning electron microscope

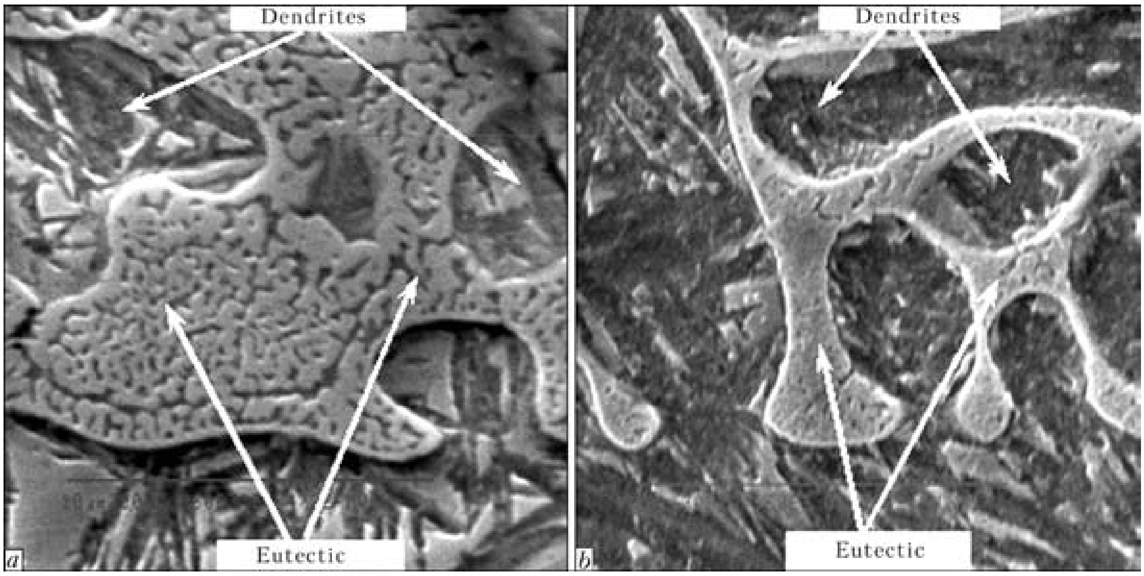

Figure 4. Microstructures (×9600) of fusion zone between steel St3 and high-chromium cast iron illustrating dendritic-eutectic structure produced without (*a*) and with LRO (*b*)

(minimum) and 5 μm (maximum) directly at the fusion line with thickness $\delta \approx 100-200$ μm. The similar trend to change in sizes of dendrites took place in the eutectic components of structure with size $D_{eut} \approx \approx 15$ μm (without LRO) and $D_{eut} \leq 8$ μm (with LRO) (Figure 4).

In addition to differences in size, dendrites also exhibited differences in morphology of the phase components. Thus, dendrites had a characteristic non-equiaxed shape (e.g. sizes 15 × 10, 15 × 13 μm, etc.) in structure of the deposited metal produced without LRO (Figure 4, *a*). In case of the application of LRO the shape of dendrites became more globular (e.g. 5–7 μm) (Figure 4, *b*). In cladding without LRO, dendrites had a clearly defined orientation, i.e. mostly normal to the fusion line (columnar crystals) (see Figure 2, *c*).

The use of LRO promoted disorientation of crystal boundaries relative to the fusion line, the disorientation angle changing from 20° or more (see Figure 2, *d*). In case of LRO, the dendrites, especially of a small size, were characterised by higher hardness (approximately by 13–40 %). Hardness of the eutectic also increased approximately by 22–48 %.

The averaged values (5–10 measurements) of weight content of the main alloying element, i.e. chromium, in dendrites and eutectic indicate to the fact that its content in the eutectic was higher than in the dendrites (Table). Chemical heterogeneity of chromium in the deposited metal produced with LRO was 1–5 %, whereas without LRO it amounted to 5–8 %. This is indicative of homogenisation of the content of chromium in the deposited metal when using LRO. Furthermore, increase in the chromium content (Figure 5) led to strengthening of the fusion zone and decrease in the probability of cracking.

Analysis of the results obtained allows a conclusion that the use of LRO in cladding with high-chromium cast iron leads to formation of more dispersed dendrites and eutectics in structure of the deposited metal, the degree of their dispersion increasing with distance to the fusion zone (Figure 6). The application of LRO promotes morphological changes in structural components of metal. They acquire the globular shape with disoriented crystal boundaries, this causing decrease in size of the dendrite spacings in crack initiation regions, i.e. in the base to deposited metal transition zone (Figure 6, *b*). The metal deposited with LRO has high hardness.

Distribution of the content of chromium (approximately, wt.%) in depth of deposited layer

Investigated region of deposited layer	Cladding parameters			
	Without LRO		With LRO	
	Dendrites	Eutectic	Dendrites	Eutectic
Surface	12.3	17.5	11.5	16.5
Low-etchable zone	10.0	18.8	15.0	16.9
Near fusion line	10.0	18.0	10.3	14.0–15.6
Fusion line	9.0–1.0	9.0–1.0	8.0–4.0	8.0–4.0

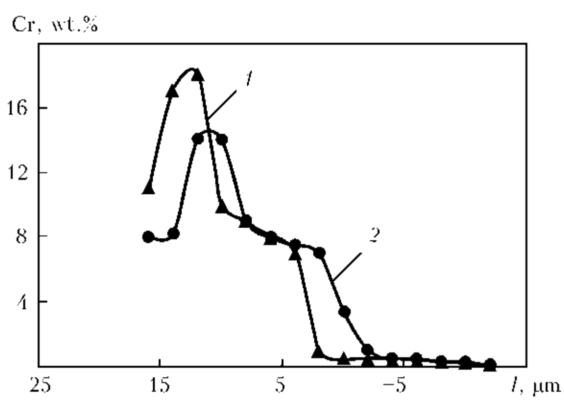

Figure 5. Dependence of content of chromium in fusion zone upon cladding parameters: *1* — without LRO; *2* — with LRO; *l* — distance from fusion line

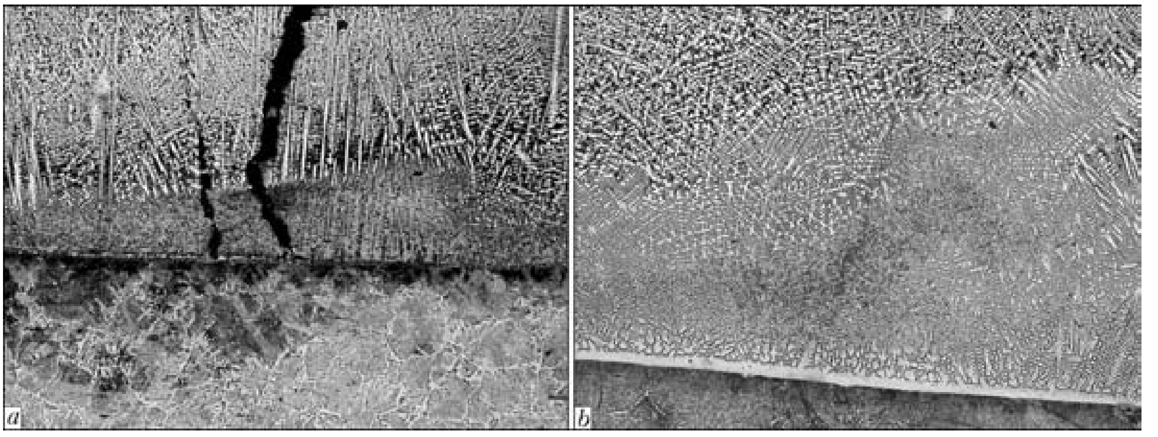

Figure 6. Microstructures (×300) of typical sites of initiation of cracks in deposited high-chromium cast iron produced without (*a*) and with LRO (*b*)

Structure of the deposited metal produced without LRO is characterised by the presence of columnar dendrites near the fusion zone (Figure 6, *a*). As a rule, cold cracks forming in the deposited metal have a clearly oriented character, i.e. they are arranged along the dendrites. The width of COD ranges approximately from 10–20 μm (near the origin of a crack) to 35–85 μm (as it propagates deep into the deposited metal). Formation of cracks occurs primarily along the interfaces between the dendrites and eutectic. The cracks initiate mostly within the fusion zone. It should be noted that the deposited metal near the fusion line about 10–20 μm wide has a pronounced acicular structure, consisting mostly of the martensitic component, this being confirmed by very high values of hardness (about *HV* 7400 MPa). At the same time, the deposited metal adjoining the fusion line is characterised by a coarse-grained structure and low hardness of the dendrites (about *HV* 2970–3300 MPa). The eutectic has low hardness (approximately *HV* 1400–1430 MPa).

Therefore, hardness in the fusion zone varies from *HV* 1400 to 7400 MPa. It seems that it is this fact that creates favourable conditions for initiation of cracks.

In a number of cases the cracks may also initiate in the cast iron deposited by using LRO. But in this case the cracks differ in size, character of propagation and COD, compared to the cracks that initiated without LRO (Figure 6, *b*).

Firstly, with LRO the cracks initiate not near the fusion line, but at a substantial distance from it (approximately 125–150 μm), i.e. in depth (in bulk) of the deposited metal. Secondly, the width of COD is about 2–8 μm, which is 10–15 times smaller than in cladding without LRO. Thirdly, the crack propagation path is of a wavy character. It is indicative of the presence of considerable barriers the crack collides with, the barriers being dispersed disoriented structural increased-hardness components of cast iron.

CONCLUSIONS

1. Low-frequency resonance oscillations applied to a workpiece, the frequency of which coincides with the frequency of natural oscillations of the workpiece (resonance conditions), affect the structure and mechanism of formation of cracks in cladding with high-chromium cast iron.

2. High-chromium cast iron deposited by involving LRO is characterised by an increased hardness, more uniform distribution of the main alloying element, i.e. chromium, between dendrites and eutectic, as well as by smaller sizes of the forming dendrites.

3. The metal deposited with LRO is much less sensitive to formation of cold cracks, which are characteristic of high-chromium cast iron.

4. To achieve the maximal efficiency of impact by LRO on the solidifying metal, it is necessary to build an upgraded automated equipment capable of controlling the frequency of external oscillations depending on the variable cladding conditions, weight of the deposited metal and temperature of a piece being clad.

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