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METHODS FOR INCREASING THE FATIGUE LIFE OF DEPOSITED PARTS (REVIEW)

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ABSTRACT

A review of literature data on the problem of increasing the fatigue life of deposited parts operated under the simultaneous action of various types of wear and cyclic mechanical loads is presented. It is shown that an increase in the fatigue life of deposited parts can be achieved by rational selection and optimization of the chemical composition of surfacing materials, development of the optimal design of deposited layers and the use of the technology of sequential surfacing of hard wear-resistant layers and intermediate layers with high ductile characteristics.

KEYWORDS: arc surfacing, multilayer surfacing, repair surfacing, ductile sublayer, fatigue life, fatigue cracks, stress intensity factor

INTRODUCTION

The service life of machine and mechanism parts in various industries depends primarily on their operating conditions and properties of the materials from which they are made. Many of these parts are operated simultaneously under different types of wear and cyclic mechanical loads of unequal varying intensity. The combination of such operating conditions often leads to premature and, sometimes, emergency failure of expensive process equipment. The time spent on replacing worn parts and subsequent reconfiguration of equipment reduces labour efficiency and significantly increases material costs.

This problem is particularly relevant for the mining and metals and machine-building industries, where high-performance equipment is used. Stopping the equipment to replace worn parts leads to losses caused from unproduced products that can be many times higher than the direct costs on purchasing new parts and replacing worn ones. These parts include cold and hot forming rolls and dies; rollers for continuous casting machines; parts of the support and rotary devices of lifting machines and excavators; teeth of large-module gears, etc. [1–4].

At the same time, many of these parts are deposited during manufacturing or repeatedly restored by surfacing methods after partial wear and reused [1]. In the course of further long-term operation under the simultaneous action of wear and cyclic mechanical loads, fatigue cracks can arise and propagate in the deposited and base metal, causing accidental failure of a part (Figure 1) [5].

The residual tensile stresses occurring as a result of the effect of thermal surfacing cycle contribute to the reduction in the cyclic fatigue life of deposited parts. The intensity of fatigue damage accumulation during cyclic loading of multilayer deposited metal can also be negatively affected by its structural and chemical heterogeneity.

In addition, during surfacing of hard-to-weld high-alloy steels and alloys, on structural carbon and high-carbon steels, which are also welded poorly,

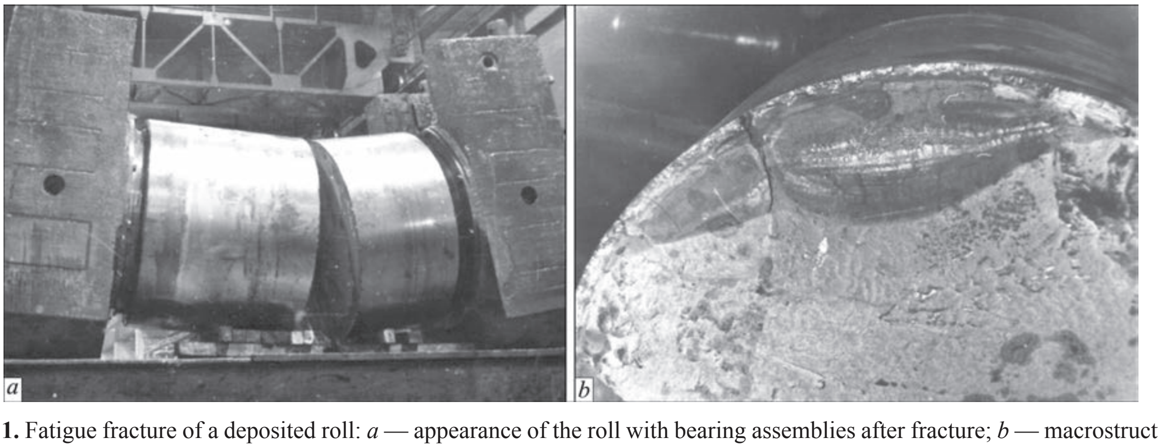

Figure 1. Fatigue fracture of a deposited roll: *a* — appearance of the roll with bearing assemblies after fracture; *b* — macrostructure of the crack initiation and propagation zone [5]

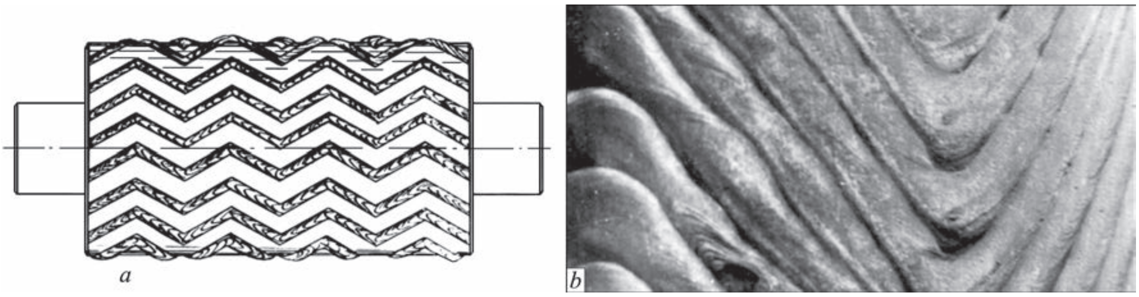

Figure 2. Surfacing of zigzag (*a*) and sinusoidal (*b*) beads with gaps between them to inhibit fatigue crack propagation [16]

there is a probability of formation of various defects. These defects can also serve as a source for initiation of fatigue cracks. Moreover, an increase in the number of deposited layers causes not only an increase in the probability of defect formation, but also in the level of residual tensile stresses, which can significantly reduce the cyclic fatigue life of deposited parts [1, 2].

It should also be remembered that surfacing materials with a higher degree of alloying are often used to increase the fatigue life and other operational properties of parts, as the properties of the cast deposited metal are usually inferior to those of a deformed metal of the same chemical composition [1–4]. However, this approach causes a growing cost of surfacing technology and the probability of forming defects in the deposited metal and at its fusion interface with the base metal.

THE AIM OF THE PAPER

is to summarize the data on methods for increasing the fatigue life of deposited parts obtained by the authors of the article and other researchers; to develop recommendations for their practical use in industry.

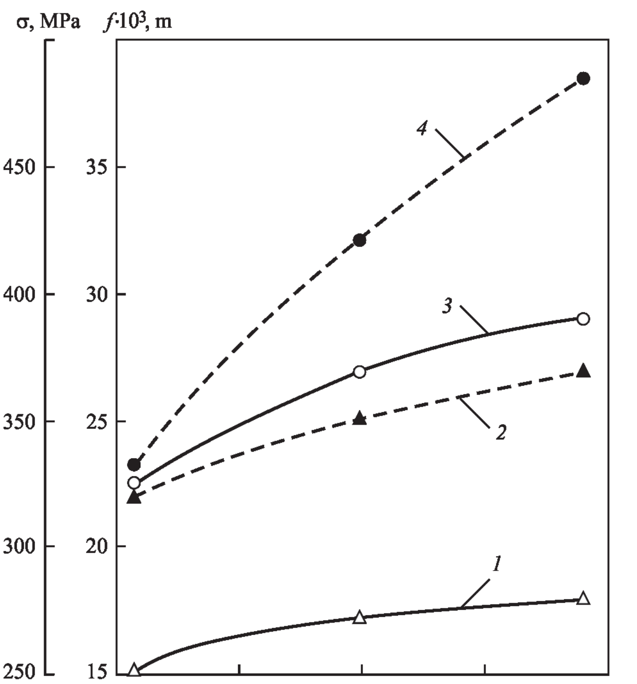

Figure 3. Dependence of welding stresses σ (*3*, *4*) and deflection strains *f* (*1*, *2*) in plates with dimensions of $(8\times120\times900)\cdot10^{-3}$ m (dashed curves) and $(30\times120\times900)\cdot10^{-3}$ m (solid curves) on welding heat input [9]

THE MAIN METHODS FOR INCREASING THE FATIGUE LIFE OF DEPOSITED PARTS

An analysis of the literature data shows that one of the most widespread methods for increasing the fatigue life of deposited parts is surface hardening [6], heat treatment [7, 8], reduction in the heat input of surfacing [9–11], etc. The mentioned operations reduce residual tensile stresses or create compressive stresses that contribute to an increase in fatigue crack resistance [12–15].

However, the depth of effect of most mechanical and chemical types of surface hardening ranges from 0.03 to 2.0 mm, and heat treatment capable of forming a specified structure to a greater depth (from 3 to 100 mm or more) is associated with significant energy losses and the need in using complex and large-sized equipment.

It is suggested to use methods for inhibiting crack growth, which consist in creating a system of other cracks that are more favourably located and can significantly reduce the value of tensile stresses. This is achieved, in particular, during formation of each deposited layer by depositing beads along a sinusoidal or zigzag trajectory (Figure 2) [16]. In this case, the effect of crack inhibition due to intersection with other cracks is used. However, the prospects of this approach in terms of the fatigue life of a part as a whole are rather doubtful, since it is almost impossible to control and regulate the location and propagation of cracks in the deposited metal. It is also impossible to guarantee that these cracks, in turn, will not become the beginning of fatigue failure.

Methods aimed at reducing the surfacing heat input [15, 16] may be promising. This is explained by the fact that a decrease in the effective heating power of a product by the welding arc leads to a decrease in the level of residual tensile stresses and strains (Figure 3), as well as refinement of the deposited metal structure as a result of an increase in the crystallization rate, which has a positive effect on crack resistance.

In our opinion, the most promising way to increase the fatigue life of deposited parts made of carbon

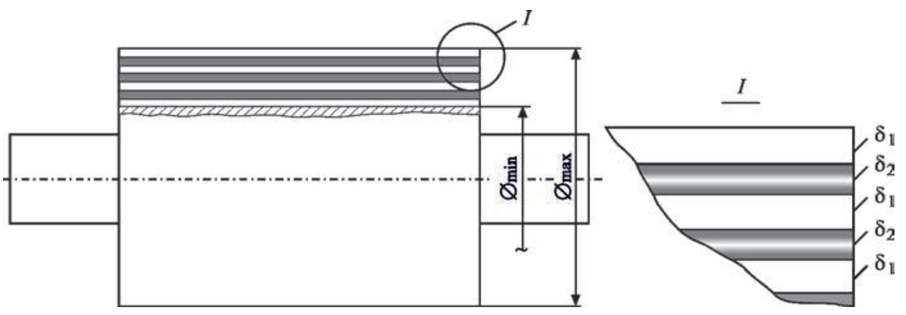

Figure 4. Design of a multilayer deposited metal of a roll made alternately using materials with lower (δ_1) and higher (δ_2) elastic moduli [5]

structural steels is to use multilayer surfacing with the sequential deposition of hard wear-resistant and ductile steels and alloys.

In [17], to increase the fatigue life of parts, it is proposed to use materials with different mechanical properties for their surfacing, creating a kind of barriers that help to inhibit the propagation of cracks or arrest them completely due to the need in additional energy consumption to overcome the boundary between the layers. Thus, when studying the effect of surfacing on the fatigue resistance of bronze-steel bimetal, it was found that the fusion boundary of two dissimilar materials acts as a barrier to crack growth that initiated on the surface [2].

Some researchers [5, 14, 17 and 18] propose alternating high-strength and ductile layers (Figure 4), which, in their opinion, can arrest cracks oriented perpendicular to the layer boundary. Thus, according to [14], a composition consisting of 3 layers (20Kh6GMFS + 12GS + 20Kh6GMFS) sequentially deposited one on top of the other has a higher crack resistance than a homogeneous three-layer metal of the 20Kh6GMFS type.

Studies in this direction, conducted at the PWI [2, 19–29], confirmed that an increase in the fatigue life of deposited parts can be achieved by rational selection and optimization of the chemical composition of materials for surfacing, development of the optimal design of deposited layers and the use of surfacing technology of intermediate layers with high ductile characteristics.

In particular, fatigue tests of deposited specimens without and with a sublayer with high ductility characteristics showed that the fatigue life of specimens with a sublayer was 40 % higher than that of specimens without a sublayer [19, 20 and 23].

It was found that the cyclic fatigue life of 40Kh steel specimens deposited using PP-Np-25X5FMS flux-cored wire with a sublayer deposited using Sv-08A solid wire with maximum compressive stresses from the zero cycle of 600 MPa exceeds $2\cdot10^6$ cycles of stress changes. The fatigue fracture kinetics of these specimens showed that the main crack mainly propagates along the fusion boundary of individual beads. No fatigue cracks parallel to the main one were found, unlike the specimens deposited without a sublayer. After the crack passed through the wear-resistant deposited layer and the sublayer, the specimens were fractured along the base metal [19, 20 and 23].

Paper [19] presents the results of determining the stress intensity factor (SIF) for the base metal (40Kh steel), the sublayer metal deposited using solid Sv-08A wire, and the wear-resistant layer metal deposited using flux-cored PP-Np-25Kh5FMS wire. SIF is an indicator of the stress intensity at the crack tip, and it characterizes the operability of a particular metal in the presence of cracks. It was found [19] that in the wear-resistant deposited 25Kh5FMS metal, the fatigue crack propagated unstably and its rate was constantly changing in the range of values 10^{-8}–10^{-7} m/cycle (SIF 45–60 MPa$\sqrt{m}$). In the metal of the sublayer, the fatigue crack growth rate increases by an order of magnitude: up to $2\cdot10^{-7}$–$2\cdot10^{-6}$ m/cycle in the SIF range of 60–100 MPa$\sqrt{m}$. In the base metal of 40Kh steel, the crack propagated steadily at a constantly increasing rate of $6\cdot10^{-7}$–$7\cdot10^{-6}$ m/cycle until the specimen fractured at SIF 140–180 MPa$\sqrt{m}$.

The analysis of the microstructure of the specimens also revealed that the fine grain size of the structure and a more uniform distribution of alloying elements in the specimen deposited with a sublayer of low-carbon rimmed steel 08kp, compared to other specimens, as well as its high ductile properties, have a positive effect on the resistance to fatigue cracking. This explains the 2.4–3.0-fold increase in the fatigue life of specimens with a low-carbon steel sublayer compared to other specimens [19, 20, 23].

The comparative fractographic analysis of fractures of multilayer specimens showed that specimens deposited with a sublayer of low-carbon rimmed steel 08kp and a wear-resistant working layer of 25Kh5MFS steel, which have a fairly uniform fibrous fracture type in the areas of the deposited and base metal, provide the best indices of fatigue life. Fractures of multilayer specimens deposited with a sublayer of low-alloy 12K1MF steel and a wear-resistant working layer of 25Kh5MFS steel have a predominantly crystalline nature and a high heterogeneity of the fracture sur-

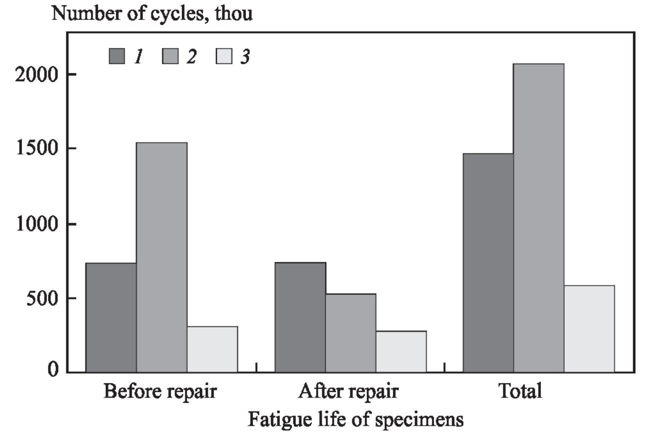

Figure 5. Fatigue life of deposited specimens before and after repair: *1* — surfacing using PP-Np-25Kh5FMS wire without a sublayer; *2* — the same, with rimmed steel 08kp sublayer; *3* — the same with 12Kh1MF sublayer [2]

face in the area of deposited metal, where there is a large number of columnar precipitations of crystalline type associated with the redistribution of carbon and chromium. This nature of fractures leads to a decrease in the fatigue life of multilayer deposited specimens [19, 20, 23 and 29].

The authors investigated the possibilities of repair (restorative) surfacing of specimens with fatigue cracks [2]. It was found that the cyclic fatigue life of 40Kh steel specimens with a deposited wear-resistant layer without or with a sublayer of rimmed steel 08kp after restorative repair is 31–56 % of the fatigue life of defect-free specimens after fabrication surfacing (Figure 5).

It was proved that repair of multilayer deposited parts after long-term operation, i.e. after the number of cycles close to the fatigue life at fabrication surfacing, is not effective, since it does not provide a significant increase in the fatigue life after repair due to the high level of accumulated fatigue damage in the wear-resistant deposited metal at a distance from the repair site.

CONCLUSIONS

1. The analysis of literature data shows that one of the most widespread methods of increasing the fatigue life of deposited parts is surface hardening, heat treatment and reduction in surfacing heat input, which result in the reduction of residual tensile stresses or creation of compressive stresses that contribute to the fatigue crack resistance of the deposited metal.

2. Increasing the fatigue life of deposited parts can be achieved by the rational selection and optimization of the chemical composition of surfacing materials, development of the optimal design of deposited layers, and the use of surfacing technology of intermediate layers with high ductile characteristics.

3. It is shown that repair of multilayer deposited parts after long-term operation, i.e., after the number of cycles close to the fatigue life at fabrication surfacing is not effective, since it does not lead to a significant increase in the fatigue life after repair as a result of the high level of accumulated fatigue damage in the wear-resistant deposited metal at a distance from the repair site.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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