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FEATURES OF INITIATION AND PROPAGATION OF FATIGUE CRACKS UNDER CYCLIC MECHANICAL LOADS ON SURFACED PLATES

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ABSTRACT

The features of initiation and propagation of fatigue cracks were investigated at cyclic mechanical loads on specimens, deposited in one wear-resistant layer or with an additional plastic sublayer. Fundamentally different nature of propagation of fatigue cracks was revealed in the specimens, deposited with a ductile sublayer of low-carbon steel compared to the specimens without a sublayer. In the specimens deposited with a ductile sublayer unlike the specimens deposited without a sublayer when the main fatigue crack passed through the deposited layer and the sublayer, at the boundary of the wear-resistant layer and the plastic sublayer, as well as the sublayer and the base metal, branching and a kind of inhibition of the main fatigue crack are observed.

KEYWORDS: arc surfacing, cyclic loading, fatigue life, fatigue cracks, single-layer surfacing, multilayer surfacing, wear-resistant layer, ductile sublayer

INTRODUCTION

Term of service of machines and mechanisms operating in different industries, depends primarily on their operating conditions and properties of materials, from which these parts are made. Many of these parts are operating under the conditions of different kinds of wear and cyclic mechanical loads of different intensity. A combination of such operating conditions most often leads to premature, and sometimes emergency failure of these parts, as a result of fatigue fracture. It may also lead to failure of technological equipment, including such parts.

This problem is particularly relevant for mining and metallurgy, mechanical engineering and other industries, where high-efficient technological equipment is used. Stopping such equipment to replace the worn parts leads to losses from unreleased products, which can be several times higher than the direct costs of purchasing new parts and replacement of the worn ones. Such parts include cold and hot rolling rolls for various purposes; rolls of continuous casting machines; knives for cold and hot metal cutting etc. [1–4].

It is known that many of these parts are clad during manufacture. Practically all of them are many times reconditioned by the surfacing methods after a certain term of service and partial wear, and are used again [1]. During further long-term service under the conditions of simultaneous action of wear and cyclic mechanical loads fatigue cracks can initiate and propagate in the deposited and base metal, which may lead to emergency destruction of the part. Harmful tensile residual stresses induced by such manufacturing processes as welding, deposition/cladding could also significantly decrease the fatigue life of parts both at the stages of initiation and propagation of fatigue cracks. From other side the application of stress relieving techniques could significantly increase the fatigue performance [5, 6]. Therefore, relevant and important is the problem of investigations of the influence of materials and technologies, used in manufacturing and restoration surfacing of the above-mentioned parts, on their fatigue life, in particular on the peculiarities of initiation and propagation of fatigue cracks in themHighly wear-resistant carbon or high-carbon materials having poor weldability are applied for surfacing the working surfaces of the above-mentioned parts. In order to improve it, preheating or deposition of ductile sublayers and sometimes both are used [1]. Deposition of a ductile sublayer can influence the fatigue life of the surfaced part, and, primarily, the nature of initiation and propagation of fatigue cracks in it.

THE OBJECTIVE OF THE WORK

is to study the features of fatigue crack initiation and propagation under cyclic mechanical loading of the specimens, deposited in one wear-resistant layer or with additional deposition of a ductile sublayer.

INVESTIGATION MATERIALS AND PROCEDURES

In order to study the features of fatigue crack initiation and propagation, prismatic blanks of specimens from 40Kh steel of 25×45×300 mm size were prepared with 12.5×150 mm area treated for surfacing in the specimen blank center.

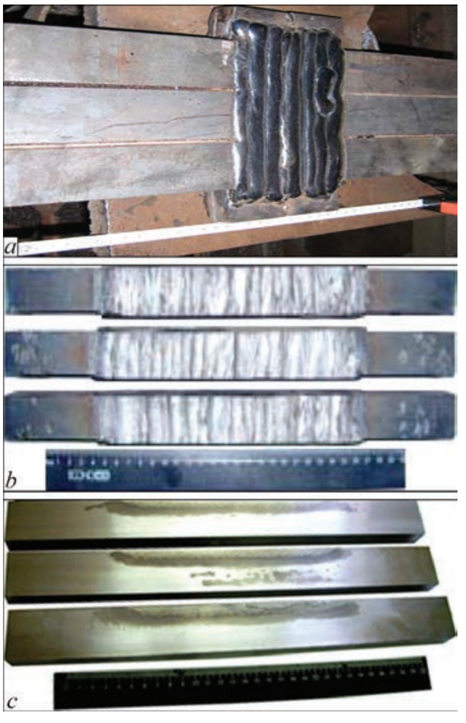

Figure 1. The blank package after surfacing (*a*), specimen blanks after cutting (*b*), specimens after final grinding (*c*)

For arc surfacing of a wear-resistant layer on specimen blanks, 2.4 mm flux-cored wire PP-Np-25Kh5FMS was used, which provides deposited metal of the type of heat-resistant tool 25Kh5FMS steel. Surfacing was performed with fusible AN-26P flux. Solid Sv-08A wire 2 mm in diameter and fusible AN-348A flux were used for arc surfacing of a ductile sublayer.

To minimize distortion of the deposited specimens and to reduce the scope of machining work, the blanks for surfacing were stacked into a packet of 3–5 pieces, special gaskets between them were used, and they were fastened with tack-welds. Run-off tabs were welded to the sides of the packet.

Before surfacing blank packets were preheated to 250–300 °C. This was followed by automatic submerged-arc surfacing of the blank packets. Some blank packets were surfaced by PP-Np-25Kh5FMS flux-cored wire using AN-26P flux without a ductile sublayer, others — with a ductile sublayer deposited with Sv-08A wire using AN-348A flux. After surfacing, the blank packets were placed under a layer of flux for slow cooling.

After cooling each blank packet was cut along the gaskets with abrasive wheels into individual specimens. Magnitudes of deformation in the surfaced specimens were measured. The value of out-of-plane bending of the blanks in the vertical plane after surfacing did not exceed 1.5 mm on a 300 mm length, which did not require any additional straightening before specimen grinding from the four sides to the size of 20×40×300 mm with 10×150 mm deposited layer in the specimen center (Figure 1, *a*–*c*).

Before the start of fatigue testing, a sharp notch 1 mm deep with 0.25 mm radius in its tip was made in the deposited layer center of all the produced prismatic specimens. The initial crack was grown from the sharp notch during three-point bending with additional load from the base metal side with cycle asymmetry of 0.01 and 5 Hz frequency at the levels of maximal applied stresses, not exceeding the service stresses.

Despite the presence of a sharp notch in the specimen center, after initiation all the fatigue cracks developed on the specimen side surfaces from one or two of its side edges. Nature of fatigue cracks initiation and propagation on the specimen side surfaces was photographed and they measured using calipers.

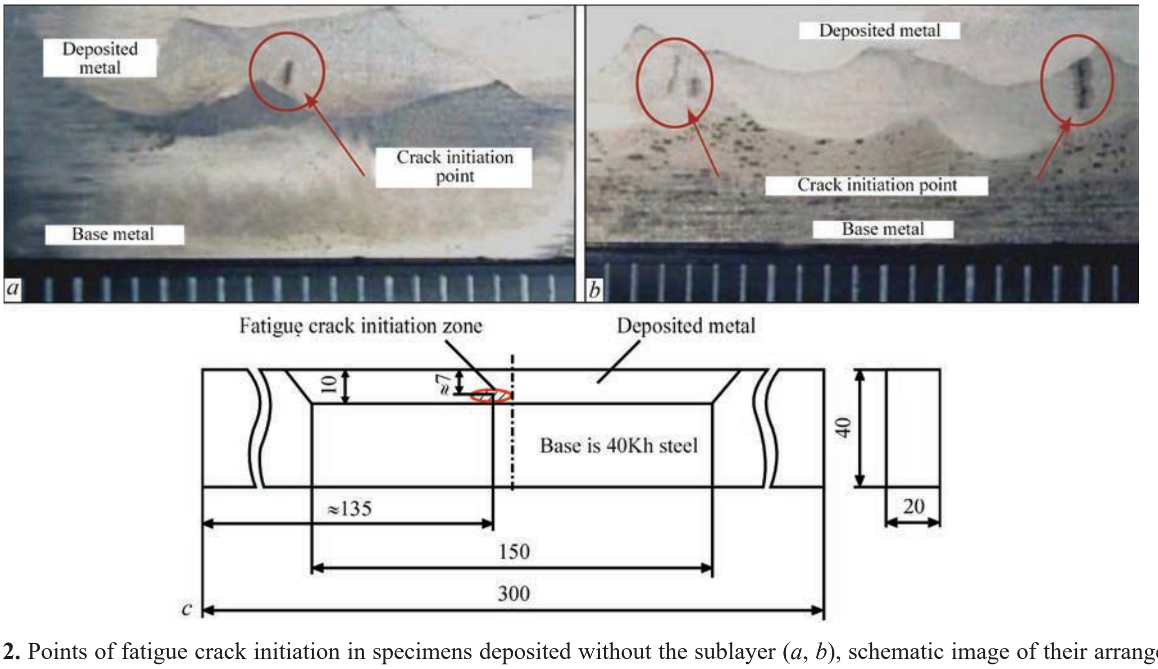

Figure 2. Points of fatigue crack initiation in specimens deposited without the sublayer (*a*, *b*), schematic image of their arrangement in the surfaced specimen (*c*)

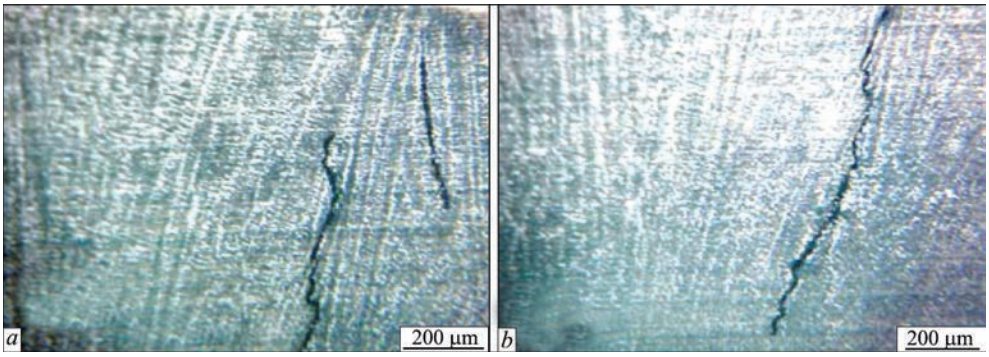

Figure 3. Nature of fatigue crack propagation in deposited metal 25Kh5FMS

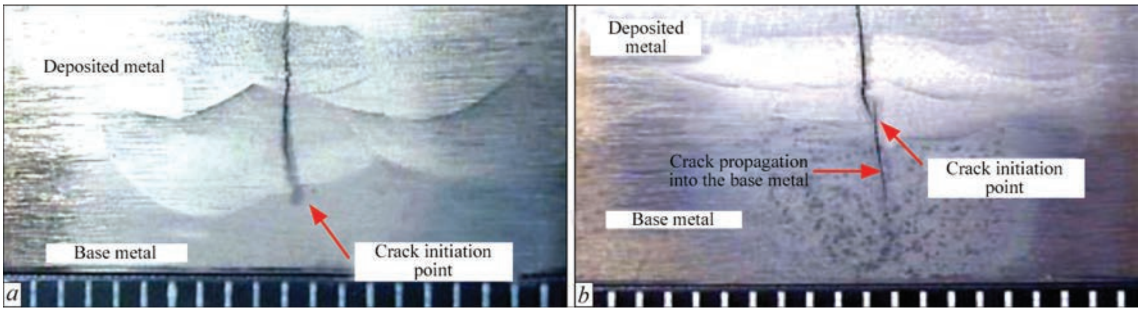

Figure 4. Nature of initiation and propagation of fatigue cracks in specimens deposited without a sublayer

INVESTIGATION RESULTS AND THEIR DISCUSSION

INITIATION AND PROPAGATION OF FATIGUE CRACKS IN SPECIMENS OF 40Kh STEEL DEPOSITED WITH PP-Np-25Kh5FMS FLUX-CORED WIRE WITHOUT A SUBLAYER

During cyclic mechanical loading in specimens deposited without a sublayer the fatigue cracks formed predominantly in the deposited layer at 1–3 mm distance from the fusion line between the base metal and the deposited wear-resistant layer (Figure 2, *a*–*c*).

The line of fusion of the deposited and base metal has the role of a stress concentrator, so that the fatigue cracks predominantly initiate near it (215–760 μm), and at the first stage of cyclic mechanical loading they are located in the deposited metal, which is attributable to its lower ductility and higher hardness, compared to base metal. Microstructural studies of etched sections of the specimens deposited without the sublayer after fatigue testing showed that the fatigue cracks predominantly propagate in the direction of the axes of dendrite formation in 5Kh5FMS deposited metal (Figure 3, *a*, *b*).

Several parallel cracks most often formed at the distance of 1–15 mm from each other and, as a rule, near the fusion zones of two adjacent beads (Figure 4, *a*). During fatigue testing, the cracks first propagated in the deposited metal only towards the surface. Having passed the entire deposited metal, the cracks started propagating in the other direction — towards the base metal (Figure 4, *b*). After the crack reaching and propagating through the base metal, specimen destruction took place.

INITIATION AND PROPAGATION OF FATIGUE CRACKS IN SPECIMENS OF 40Kh STEEL, DEPOSITED WITH PP-Np-25Kh5FMS WIRE WITH A LOW-CARBON STEEL SUBLAYER

As in the case of specimens deposited without a sublayer, in specimens deposited with a sublayer, a sharp notch 1 mm deep with 0.25 mm radius at the tip was made in the deposited layer center, from which the initial crack up to 1 mm deep was grown.

When studying the kinetics of fatigue crack growth during cyclic mechanical loading it was determined that the main fatigue crack propagates predominantly along the fusion boundary of individual beads. No fatigue cracks parallel to the main one, were found in specimens with a low-carbon sublayer (unlike specimens without the sublayer). However, during fatigue fracture, side branches from the main crack were observed in the zones of transition of one metal layer into another one, which propagated along the fusion line of the wear-resistant layer with the sublayer (Figure 5) and along the line of fusion of the sublayer with the base metal (Figure 6). After the crack has passed the wear-resistant layer and

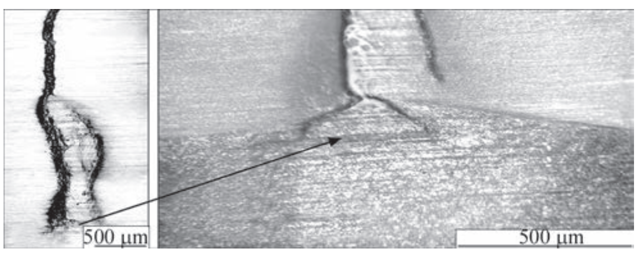

Figure 5. Fatigue crack branching near the fusion boundary of the wear-resistant layer and the sublayer

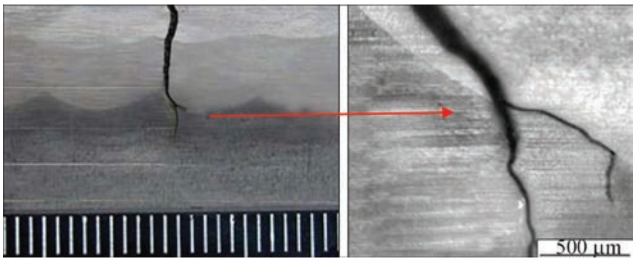

Figure 6. Fatigue crack branching near the fusion boundary of the sublayer and the base metal

the sublayer from low-carbon steel, specimen destruction occurred in the base metal.

Such kinetics of specimen fatigue fracture is explained by manifestation of several factors. First, a zone of chemical and structural heterogeneity is located in the zone of overlapping of adjacent deposited beads, which has a negative influence on material properties [7]. Secondly, during multibead multilayer surfacing relatively sharp angles can form on the fusion boundary of adjacent beads and layers, which will be stress concentrators, and which will initiate formation of side cracks along the fusion line, accordingly [8, 9].

Thus, similar to specimens deposited without a sublayer, it is found that the fusion boundaries of individual beads and layers have an important role in the process of fatigue fracture of the surfaced parts, as the cracks mainly propagate either along the fusion boundary of individual beads, or directly near this boundary (Figure 6).

The only important difference between these two surfacing technologies as regards fatigue crack propagation consists in formation of side branches from the main fatigue crack during deposition with a sublayer, leading to a kind of deceleration of these cracks.

CONCLUSIONS

Proceeding from the conducted experimental studies, a fundamentally different mode of fatigue crack development was found in the specimens deposited with a ductile sublayer from low-carbon steel, compared to specimens deposited without the sublayer. In specimens, deposited with a ductile sublayer, during the main fatigue crack passing through the deposited layer, branching and a kind of deceleration of the main fatigue crack occur on the boundary of the wear-resistant layer and the ductile interlayer, as well as the sublayer and the base metal.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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