attempt to achieve formation of an increased content of low-temperature bainitic ferrite forms in their structure through alloying by elements increasing the austenite stability.

CONCLUSIONS

1. Application of the method of strengthening evaluation, which allows for the strengthening mechanisms, enables an adequate prediction of strength properties of HSLA steel weld metal.

2. At simulation of the composition of HSLA steel weld metal, in order to achieve high values of strength, ductility and toughness of welded joints, it is necessary to achieve an increase of the contribution of $\Delta\sigma_{d.str}$ and $\Delta\sigma_{gr}$ at limitation of $\Delta\sigma_{s.s}$. The structure of weld metal in this case will develop morphological forms of bainitic ferrite, while the presence of a dispersed carbide phase will promote formation of a fine-grained secondary structure.

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ROLE OF NON-METALLIC INCLUSIONS IN CRACKING DURING ARC CLADDING

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The effect of non-metallic inclusions in the base metal on initiation and propagation of cracks in the deposited metal is considered. It is shown that, in addition to the non-metallic inclusions, the propagation of cracks in the deposited metal is also promoted by the hardening phases present in its structure, as well as by the polygonisation boundaries. However, the latter are not the initiating factors of cracking.

Keywords: *base and deposited metals, non-metallic inclusions, cracks, hardening phases, polygonisation boundaries*

The optimal composition of a wear-resistant deposited metal is chosen experimentally or by mathematical modelling. The second variant is a better choice, as it is more cost-effective. However, as shown by practice, in many cases, especially in cladding of high-carbon steels, at a stage of verification of workability of a chosen cladding consumable the calculated «optimal» composition should be corrected to avoid cracks in the deposited metal. The use of this twofaced method of assessment of the investigation data results in formation of the final composition of the deposited metal. In this case, the technological part of the investigations is usually limited to studies of the processes taking place only in the deposited metal. Moreover, in view of some economical difficulties with purchasing of metal, the use is made of the «available» steels, although the provisions are made for conducting a high-quality chemical analysis of this metal.

This study is dedicated to investigation of the effect of quality of the base metal on the results of cladding, and in particular on the initiation of cracks in the deposited metal.*

Cladding was performed on specimens cut by the gas cutting method from the «available» rolled steel

*The study was carried out with participation of Dr. I.I. Ryabtsev.

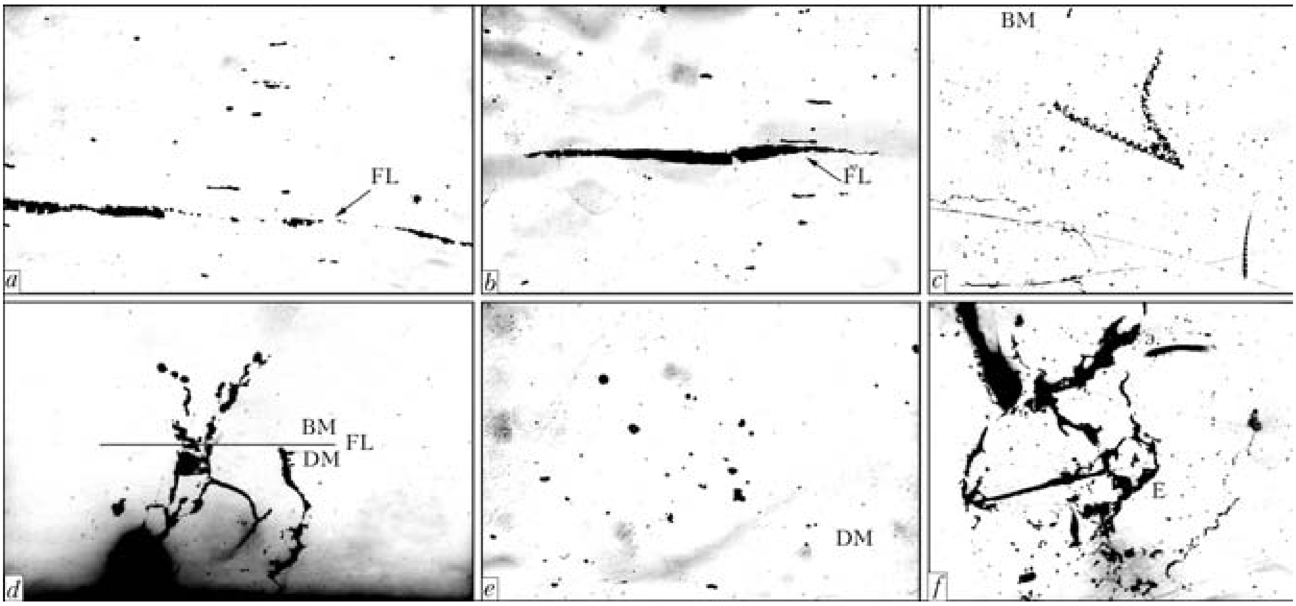

Figure 1. Non-metallic inclusions, dislocations and cracks in base (BM) and deposited (DM) metals: *a* — stringers of alumina, inclusions of aluminosilicates and oxysulphides of the base metal (×400); *b* — stringers of iron-manganese sulphides, inclusions of aluminosilicates and oxysulphides of the base metal (×400); *c* — dislocation stringers located near cracks in the base metal (×200); *d* — cracks propagating from globular inclusions of the base metal (×250); *e* — globular inclusions in the deposited metal (×400); *f* — cracks propagating through eutectic (E) (×25)

corresponding in chemical composition to steel St3. Self-shielding flux-cored wires providing the high-carbon (C = 1 %) deposited metal served as a deposited metal. Cladding was performed in four layers.

Cracks were revealed in the deposited metal after cladding. Because of small (through thickness) sizes of the cracks, they could not be visually detected after deposition of each layer. Therefore, it was difficult to locate the site of initiation of a crack. It could be done only on metallographic sections.

The clad specimens were prepared by the conventional procedure in the form of transverse sections for metallographic examinations, which were conducted both on polished surfaces and on surfaces after electrolytic etching in 20 % aqueous solution of chromic acid.

Examinations of polished surfaces of sections. A large number of non-metallic inclusions were fixed in the base metal. They were arranged in the form of stringers of different thicknesses and lengths, or in the form of isolated inclusions of various shapes and sizes. Supposedly, dark-gray stringers elongated in the rolling direction were inclusions of alumina Al_2O_3 (Figure 1, *a*). Although, being relatively brittle components, they most often fractured in rolling into isolated particles. Iron-manganese sulphides FeS·MnS of the light-gray colour had an identical direction of the arrangement (Figure 1, *b*).

Isolated inclusions were presented by aluminosilicates $3Al_2O_3{\cdot}SiO_2$ and $Al_2O_3{\cdot}SiO_2{\cdot}FeO$, and by oxysulphides (Figure 1, *a*, *b*). This quantity of various non-metallic inclusions formed the zones of weakness in the base metal, which might act as centres of probable initiation of cracks in them. Heterogeneity of metal and imperfection of its structure led to the fact that dislocation stringers were detected near some of the cracks (Figure 1, *c*).

Despite that the acute-angled non-metallic inclusions of the type of alumina, silica etc. are most dangerous in terms of initiation of cracks [1], in fact a crack may initiate in a zone with the most stressed state (Figure 1, *d*).

Moreover, in the case of small non-metallic inclusions (in the form of isolated inclusions or stringers in the base metal) the welding arc affecting them may cause their crushing and spheroidisation. Further on these rounded particles will transfer step-by-step from the base metal to the deposited layers (Figure 1, *e*). Floating of non-metallic inclusions and their forwarding to each of the next deposited layers were detected. Further propagation of cracks takes place along various hardening phases of structure, in particular along locations of eutectic (Figure 1, *f*). As a result, the crack may have a developed zigzag (Figure 2, *a*) or straight-line shape (Figure 2, *b*).

Examination of surfaces of sections after etching. Examination of microstructure after etching allows a more detailed evaluation and checking of the sequence of stages of propagation of a crack: from the moment of its initiation to the final stage. The zone of fusion of the base metal and first layer of the deposited metal with globular non-metallic inclusions located in the base metal is shown in Figure 3, *a*. The site of initiation of the crack near one of the non-metallic inclusions in the base metal is clearly proved in Figure 3, *b*. Transfer of non-metallic inclusions from the first layer to a boundary of the second and third deposited layers is shown in Figure 3, *c*.

The earlier conclusion on propagation of cracks in the deposited metal along the zones of location of the

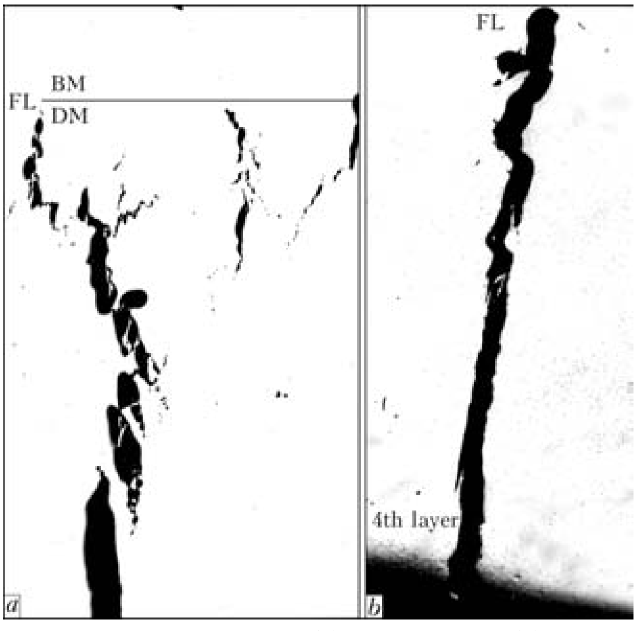

Figure 2. Propagation of zigzag (*a*) and straight-line (*b*) cracks in four layers of the deposited metal (×25)

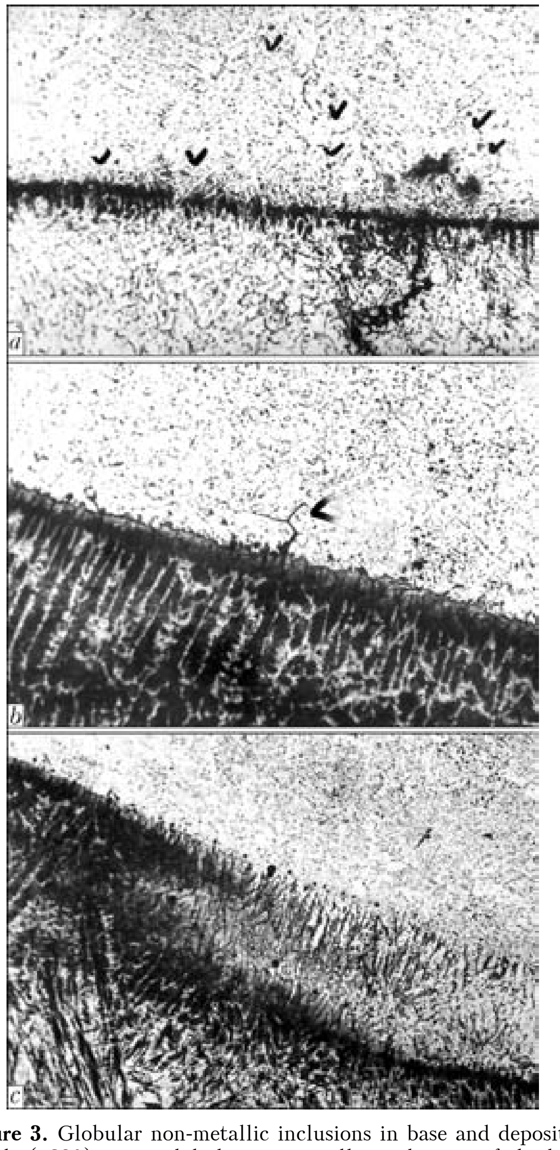

Figure 3. Globular non-metallic inclusions in base and deposited metals (×320): *a* — globular non-metallic inclusions of the base metal located near the fusion line; *b* — initiation of cracks near the base metal; *c* — non-metallic inclusions that transferred («floated») from the 1st deposited layer to the 2nd one

hardening phases, i.e. martensite and eutectic, is proved in Figure 4.

However, the new information was generated. It was found that the ways of propagation of cracks in the deposited metal are not only the hardening phases but also the polygonisation boundaries, which are manifestations of physical microheterogeneity of the deposited metal [2]. Propagation of cracks in a zone of location of martensite and polygonisation boundaries (going along the polygonisation boundary) is shown in Figure 5. To check correctness of this mechanism of initiation and propagation of cracks, small ingots were melted in a copper mould 20 mm in diameter and 50 mm long. This allowed elimination of the probability of the effect of non-metallic inclusions, which is characteristic of the base metal.

No cracks were detected in the deposited metal. The lower part of an ingot consisted of martensite in the austenitic matrix and a developed network of the polygonisation boundaries. Hardness of martensite was HV0.5-5090 MPa, and microhardness of austenite was HV0.5-2710–3030 MPa. Eutectic was located along the polygonisation boundaries (Figure 6). The

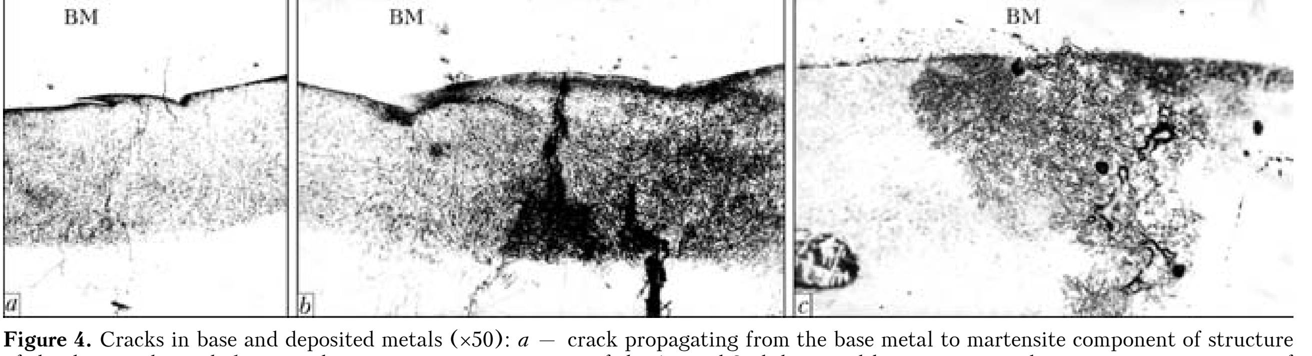

Figure 4. Cracks in base and deposited metals (×50): *a* — crack propagating from the base metal to martensite component of structure of the deposited metal; *b* — cracks in martensite component of the 1st and 2nd deposited layers; *c* — cracks in eutectic component of structure of the 1st and 2nd deposited layers

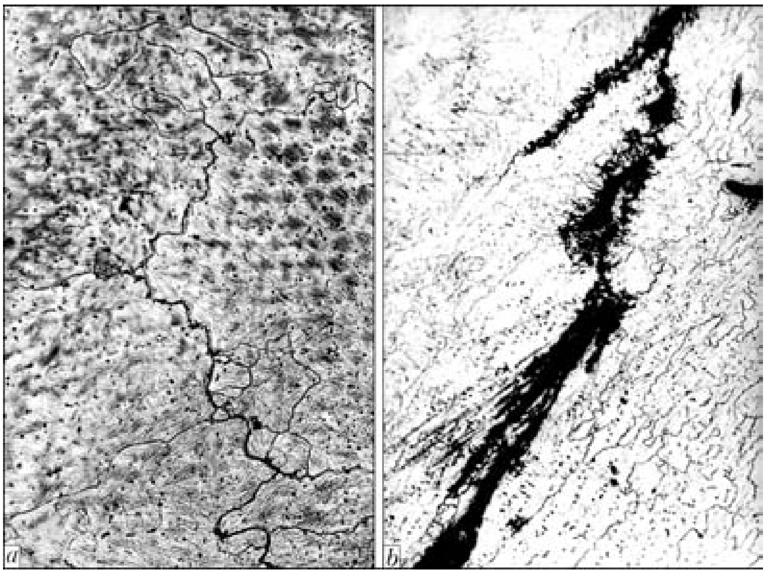

Figure 5. Propagation of crack in martensite component of structure along polygonisation boundaries in the 1st layer of the deposited metal (a — ×200; b — ×400)

presence of the hardening phases in the form of martensite and eutectic is not a cause of initiation of cracks in the deposited metal.

CONCLUSIONS

1. In cladding of steels, especially those that are susceptible to cracking, special consideration should be given to the quality of the base metal in terms of its purity from non-metallic inclusions.

2. Non-metallic inclusions in the base metal may not only initiate cracks but also affect their further propagation in the deposited metal due to the effect of «floating» from layer to layer of the deposited metal.

3. The cracks initiated in the base metal propagate in the deposited metal not only along the non-metallic inclusions and hardening phases of structure, but also along the polygonisation boundaries.

4. The hardening phases in structure of the deposited metal and polygonisation boundaries are not always the sources of initiation of cracks in it.

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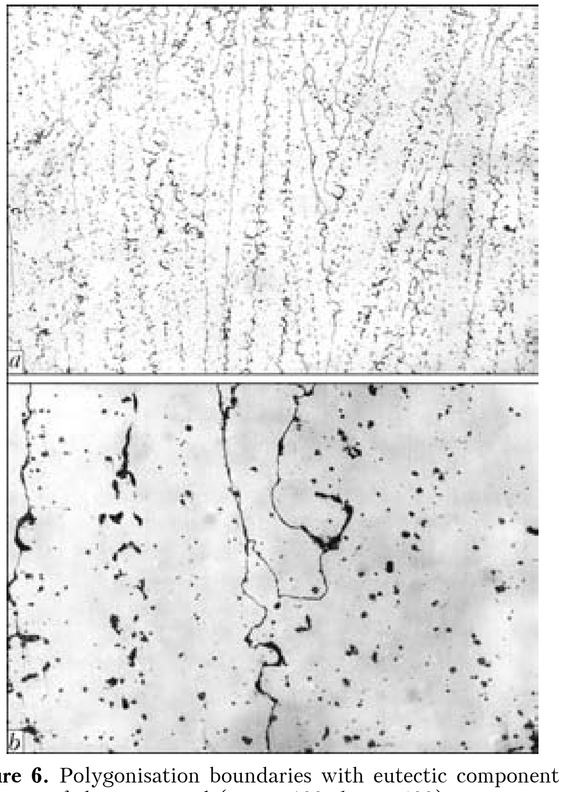

Figure 6. Polygonisation boundaries with eutectic component of structure of the cast metal (a — ×100; b — ×400)