Structure-phase states and wear resistance of deposition surface formed on steel by electric arc method

S V Raikov, E V Kapralov, E S Vashchuk, E A Budovskikh, V E Gromov, Yu F Ivanov, and K V Sosnin
1 Siberian State Industrial University, Novokuznetsk, 654007, Russia
2 Institute of High Current Electronics SB RAS, Tomsk, 634055, Russia
3 National Research Tomsk Polytechnic University, Tomsk, 634050, Russia
E-mail: gromov@physics.sibsiu.ru, yufi55@mail.ru

Abstract. Investigations of elementary and phase structure, state of defect structure and tribological characteristics of deposition, formed on a low carbon low-alloy steel by a welding method were carried out. It was revealed that deposition, formed on a steel surface is accompanied by the multilayer formation, and increase of wear resistance of the layer deposition as determined.

1. Introduction
Electric arc deposition takes strong positions in the improvement of structure of machine parts and mechanisms in different branches of industry. As a result of deposition and in manufacture of machine parts it is possible to obtain a working surface possessing a necessary complex of properties: wear resistance, heat stability, heat resistance, corrosion resistance, etc. Using a deposition, it is possible to reduce the consumption of the expensive nonferrous metals and alloys and high carbon steels. Besides, repeated restoration of the worn parts decreases to a large extent the consumption of metal for the manufacture of spare parts of the equipment. The increase of service life of equipment parts is especially important, if the performance of high efficient equipment depends on their reliability and durability. A high economical and technical efficiency of deposition in metallurgical machine building is specified by it.

The efficiency of structure improvement by deposition is determined by the right choice of deposited metal composition based on the conditions of work of a part and main type of wear. The choice of the deposited material is done with regard to exploitation conditions of the part being restored, type of protection, design features of a part and the equipment available. At present a large number of electrode materials has been developed on the base of iron for arc deposition.

2. Materials and research method
Steel Hardox 400 was used as the test material; its element composition is shown in Table 1. Thick deposited layers (3 - 5 mm in thickness) were formed on steel surface by welding method. Element composition of welding wire used for formation of a layer is shown in Table 1.

Investigation of element and phase composition, state of defect substructure of deposited layer was done by methods of optic (metallographic microvisor mVizo-MET-221), scanning (scanning electron microscope Philips SEM-515 with microanalyzer EDAX ECON IV) and transmission (transmission electron microscope EM-125) electron microscopy, X-ray structural analysis (X-ray diffractometer DRON-7). Tribological characteristics of coating were revealed by wear resistance
and friction coefficient determination (tribotester Tribotechnic). Tribological tests were done under the following conditions: a ball with diameter of 3 mm from a hard alloy VK-8 was used as a counterbody. A counterbody was shifted on the sample surface along the circle of 4 mm diameter at linear velocity 2 cm/sec under normal load 5 N. The total number of revolutions of counterbody was 5000.

**Table 1.** Chemical composition of test materials (the remainder Fe, weight%).

| Chemical element | C  | Si   | Mn  | P  | N   | B   | S   | Mo  | Cr  | Nb |
|------------------|----|------|-----|----|-----|-----|-----|-----|-----|----|
| Steel Hardox 400 | 0.18 | 0.70 | 1.60 | 0.01 | 0.004 | 0.025 | 0.01 | 0.25 | ----- |    |
| Welding wire SKA 70-G | 2.6 | 0.6  | 1.7  | ----- | ----- | 2.2  | ----- | 14.8 | 4.7 |

3. Results of investigations and their discussion

Tribological test has shown that the formation of deposition on the surface of steel Hardox 400 results in the increase of wear resistance of material surface layer by a factor of ~ 2.25 and friction coefficient – by a factor of ~ 1.05.

To establish the physical mechanisms of wear resistance increase of steel with deposited material the studies of structure, phase and element composition of deposition/steel system were carried out. Structure and element composition analyses were done in two sections: in section parallel to the surface of deposition and in section perpendicular to the deposited layer.

Structure of deposition is shown in Figure 1. A large number of inclusions are of edged shape. Inclusion sizes vary within 1 mcm to 5 mcm. The second morphological element of the deposited layer is a structure of dendritic (Figures 1, b, c) and cellular (Figures 1, c,d) crystallization. The cell sizes vary within 0.3 mcm to 0.8 mcm. The cells are separated by interlayers of 50 to 100 nm thickness.

![Figure 1](image)

**Figure 1.** Structure of deposition being formed on the surface of steel. Section is parallel to the surface of deposition. Frames show the sites of X-ray spectrum analysis of the material.
X-ray microspectrum analysis of deposition sites, designated by frame in Figure 1, has shown that particles of the edged shape are enriched by atoms of niobium (Figure 1, b, zone 1); zones of dendritic crystallization (Figure 1, c, zone 2) are enriched by atoms of iron, chromium and carbon. A characteristic feature of the cellular crystallization structure being formed largely by atoms of iron is the presence of carbon and chromium atoms of large concentration (Figure 1, c, zone 3). The given results are shown in Table 2 in a quantitative ratio.

Table 2. Results of X-ray microspectrum analysis of deposition structure formed on the surface of steel.

| Spectrum  | C  | Si  | Ti  | Cr  | Mn  | Fe   | Nb   | Result |
|-----------|----|-----|-----|-----|-----|------|------|--------|
| Field 1   | 0,0| 0,0 | 1,02| 6,50| 0,0 | 7,07 | 85,42| 100.00 |
| Field 2   | 3,74| 1,40| 0,0 | 7,89| 1,44| 85,53| 0,0  | 100.00 |
| Field 3   | 4,11| 0,71| 0,0 | 13,07| 1,71| 80,40| 0,0  | 100.00 |

Figure 2. Part of X-ray photograph obtained from the surface layer of deposition.

4. Conclusions
The carried out studies of structure, element and phase composition of deposition formed on the low carbon low-alloyed steel Hardox 400 make it possible to make the following conclusions:

1. Formation of deposition on the surface of steel is accompanied by the formation of multi-layer structure, the layer of which differs in the morphology of element substructure.

2. Deposition is a multi-phase material and is presented by solid solution grains on the basis of α-iron, by particles of iron carbide of composition Fe₃C (cementite), the volume fraction of which is 10%, of niobium and chromium carbides NbC and Cr₃C₂ (sum volume fraction of carbides is 20%) and of boride of iron Fe₃B, the volume fraction of which is 10%.

3. The revealed multiple (more than twice) increase of wear resistance of deposited layer (para to volume of steel) is specified by formation of submicro- and nanosize structure of α-phase crystallization and precipitation of large volume (~40%) of particles of high strength of carbide and boride phases.

Electric arc deposition with powder wire is used for strengthening the excavator’s buckets and bodies of large-size automobiles.
References

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