Hardness of low-alloy steel obtained by cold metal transfer in the magnetic field

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Abstract. In recent years, the technology of creating metal materials by the Cold Metal Transfer method has been actively developed, which helps to obtain products of various shapes and sizes. The hardness of 9CrMoV-N low-alloy steel obtained by the Cold Metal Transfer method in the field of a permanent magnet was investigated. The magnetic field induction did not change in the entire series of tests and was equal to 200 mT. As a result of the studies, it was found that the hardness of the obtained sample is more than 2 times higher than the hardness of the starting material and is 590.97±14.87 HV in comparison with the hardness of the wire before surfacing 265 HV. It was found that the distribution of hardness over the volume of the material is heterogeneous and depends on the place of testing. It was suggested that changes in hardness are associated with the structural features of the deposited material.

1. Introduction
The development of industry requires constant modernization of existing technologies in connection with the need to reduce costs, increase the operational properties of finished products, reduce technological operations to bring products to the final stage. This is especially true of high-tech industries, the products of which are subject to increased requirements. The development of metal materials by the Cold Metal Transfer (CMT) method has been actively developed. The technological process for creating products using the CMT method is as follows: the wire automatically moves in the direction of the deposited substrate, between the electrode (deposited wire) and the substrate a difference of potentials is applied. At a certain distance from the substrate, a short circuit occurs, which is detected by the automatic process control system and the wire is removed from the zone of deposition, thereby reducing the time of heat supply to the weld (the process of wire approach and its removal is cyclic up to 70 times per second). As a result, the average process temperature is much lower in comparison with the conventional welding, since there is no constant arc burning process. For this reason this method is called Cold Metal Transfer. Summarizing, we can say that controlled processes of short circuit, metal separation from the electrode and its transfer to the pool of the weld (solder bead) literally drop by drop take place during CMT. The result is a metal transfer process, characterized by the absolute absence of splashes.

Surfacing using the CMT process is extremely effective, since the required quality of the metal layer is provided in just one or two passes instead of two or three with traditional methods. The main focus during surfacing is given to the following areas: minimum penetration of the base metal,
minimum mixing of the deposited layer with the base metal, minimum value of residual stresses and deformations of the metal in the surfacing zone [1]. However, the production of metallic materials by this method is accompanied by some problems, among which are: obtaining of an inhomogeneous microstructure of the material, gradient of thermal stresses over the cross-section of the resulting part, the high cost of units for the production of parts, etc.

The analysis of the current state of the problems of product formation by additive technology methods showed that the use of cryogenic temperatures [2] and magnetic fields, both transverse and longitudinal, in the process of deposition and the formation of welded joints is a very relevant research area [3-10].

The influence of the magnetic field during arc welding and deposition with wire can increase the coefficient of fusion of the electrode metal, strength characteristics of the weld (deposited metal), control the penetration depth of the base metal, grind the structure of the weld metal [11-15]. Mostly, researchers use small magnetic fields with induction up to 200-500 mT [16]. Based on the foregoing, the purpose of these studies was to study the effect of an external magnetic field on the mechanical properties of 9CrMoV-N steel obtained by the Cold Metal Transfer method. The material for research was not chosen by chance, a steel wire of this chemical composition is used for welding equivalent steels of type 9 "P91 9CrMo", modified with small additives of niobium, vanadium and nitrogen, to improve the long-term creep properties. Modified 9CrMo steels are currently widely used for components such as manifolds, main steam lines and turbine housings in fossil fuel power plants.

2. Methods of experiment

The wire was surfaced using a numerically controlled robot and a multifunctional wire feed device for argon-arc welding FANUC Robot M-10iA. Surfacing parameters were set using software and RSU 5000i controller, which made it possible to select the optimal wire feed speed to the melt pool, as well as current and voltage parameters. Additive production of samples of specified sizes was carried out under the action of a constant transverse magnetic field. A highly homogeneous magnetic field was created using WD-175 electromagnet and RA-3KW programmable direct current source, and the field induction was measured using CH-1500 gauge. Figure 1 schematically shows the process of surfacing 9CrMoV-N steel in the permanent magnet field.

![Figure 1. Schematic representation of material deposition in the permanent magnet field: 1 – RSU 5000i controller; 2 – robot for argon-arc welding FANUC Robot M-10iA; 3 – direct current source RA-3KW; 4 – electromagnet WD-175; 5 – deposited sample.](image-url)

The surfacing parameters (with application of software) were initially set using RSU 5000i controller (1), as well as the magnetic field parameters, the field induction was changed by adjusting
the current flowing through the coils. In this work, the magnetic field induction did not change in the entire series of tests and amounted to 200 mT. Then low-alloy steel (5) was surfaced by means of FANUC Robot M-10iA (2) in the field of a permanent magnet (4). Deposition of 9CrMoV-N was carried out in argon. The wire feed speed into the molten bath was 5 m/min at a welding current 160 A and arc voltage 14.1 V, the surfacing speed was 8 mm/s.

The evaluated mechanical characteristic showing the strength of the resulting material was hardness. The measurement was carried out according to the Vickers method, in accordance with the requirements of the standard ISO 6507-1:2005 “Metallic materials. Vickers hardness test. Part 1 Test Method”[17]. Microhardness tester HXD – 1000TM/LCD was used in the work, the indenter load was 9.8 N, the application time and load retention time was 15 s, and the removal of test load – 10 s. To assess the hardness of the material, samples of 10×6×30 mm in size were cut by EDM cutting, and measurements were made on transverse sections.

3. Results and discussion

As a result of electric arc deposition in the field of a permanent magnet, 9CrMoV-N steel samples were obtained. The sample was a parallelepiped, consisting of 30 layers of weld metal with dimensions of 60×6×100 mm. According to AWS A5.28 technical documentation, the 9CrMoV-N steel wire has the chemical composition shown in table 1 and a hardness approximately 265 HV.

Table 1. The chemical composition of the wire 9CrMoV-N in wt. %.

| C | Mn | Si | S  | P  | Cr | Ni | Mo | Nb | V  | N  | Cu | Al |
|---|----|----|----|----|----|----|----|----|----|----|----|----|
| 0.08- | 0.40- | 0.15- | ≤ | 8.5- | 0.40- | 0.85- | 0.03 | 0.15- | 0.03- | ≤ | ≤ |
| 0.13 | 0.80 | 0.50 | 0.010 | 0.010 | 9.5 | 0.80 | 1.10 | 0.25 | 0.07 | 0.10 | 0.40 |

For greater reliability of the obtained experimental results, the hardness was measured at various distances from the substrate with a step of 5 mm, in different parts of the sample. The quantitative value of hardness was determined by averaging more than 70 measured values. The measurement results showed that the hardness of the obtained sample exceeds the hardness of the original wire by more than 2 times, and is 590.97 ± 14.87 HV. It is also worth noting that the values of hardness, which reflect the mechanical properties of the whole sample, are heterogeneous, and the distribution of hardness by volume of the material is shown in figure 2.

Figure 2. Hardness distribution of the 9CrMoV-N steel obtained by cold metal transfer.

The analysis of experimental data shows that the hardness is not uniformly distributed over the volume of the material and depends on the place of measurement. The minimum hardness values are observed at distances of 10 and 45 mm from the substrate, the maximum hardness takes at 25 and 70 mm. Such behavior is possibly associated with different states of the microstructure of the material in different regions of the samples. According to crystallization kinetics and solidification theory [18],
the formation of a fine-grained or larger structure depends on the cooling rate, the heat accumulation of the deposited layer will be less in the upper layers, which will lead to faster cooling and, as a result, grain refinement.

Thus, it can be assumed that in the upper part of the sample the microstructure is finer-grained, and therefore, the hardness value is higher than that of the starting material and the material located closer to the substrate. However, this assumption requires verification by metallographic analysis or scanning electron microscopy, which will be the goal of our subsequent work.

4. Conclusion

The paper analyzes the hardness of low-alloy steel 9CrMoV-N obtained by the cold metal transfer method. As a result of studies, it was found that during CMT, the material is formed, the hardness of which is more than 2 times than the hardness of the original wire. It was suggested that a significant increase in hardness is associated with the structural features of the material obtained as a result of surfacing. All this makes it possible to conclude that the CMT technology can be used as a reliable method for obtaining modern structural materials, however, further study and improvement of technological parameters is required.

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