Study of the structure and properties of welded joints of micro-alloyed reinforcing steels made in the atmosphere of carbon monoxide

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Abstract. The structure and properties of welded joints of reinforced steel micro-alloyed with vanadium were investigated. The reasons for the formation of cold cracks are given. It has been established that welding at negative ambient temperature in the near-weld zone of rebar class A500C forms quenching structures with a hardness of up to 470 HV. Preheating of the rods by gas welding leads to a decrease in the temporary tensile strength. The technology of mechanized welding in carbon monoxide is proposed. It has been established that in multilayer welding in a reducing atmosphere, the carbon equivalent value of the weld metal increases. The hardness of the heat-affected zone decreases to 200 ... 260 HV. Mechanical properties of welded joints made in carbon monoxide environment comply with the requirements of regulatory documents.

1. Introduction
Welded reinforcing steel A500C providing significant metal savings as compared with reinforcement one of classes AII and AIII is used in industrial and civil construction. The required strength characteristics are provided due to the presence of vanadium in austenite solid solution, which is manifested during the thermo-mechanical processing of rolled products, as well as the effect of the formation of vanadium carbonitrides due to the mechanism of dispersion hardening of ferrite in the heat-affected zone during welding. The basic requirements for the above-mentioned reinforcing steel are given in GOST 52544-2006 and STO ASChM 7-93. In accordance with these requirements, the reinforcing steel is produced thermo-mechanically hardened in the flow of rolled, hot-rolled with micro-alloying or cold-deformed. The production method and the lower boundaries of the chemical composition are chosen by the manufacturer on the basis of guarantees of weldability without softening, plasticity, bending angle around the mandrel, and other indicators. At the same time use of this fittings to-50 ° C is allowed. In accordance with TU 14-1-5543-2006, it is allowed to use micro-alloyed steels for the reinforcement of reinforced concrete structures in the conditions of the Far North.

However, in some cases, the occurrence of cracks in welded joints of reinforced concrete structures, mounted at negative ambient temperatures, is noted, and therefore the need has arisen to optimize the existing welding technology.
2. Urgency and scientific significance
Steel micro-alloyed by vanadium begins to find application in the manufacture of rebar [1]. At the same time, reinforced concrete structures can be operated at design temperatures below -55 ° C [2], ensuring the required strength and sufficient ductility. However, there are a number of works [3,4] in which the negative effect of vanadium on the weldability and brittle fracture resistance as a result of the thermal effects of welding is noted. In [5] a significant drop in the cold resistance of welded joints from steels micro-alloyed by vanadium was found. In [6] it is recommended to exclude vanadium from the chemical composition of steels in order to ensure the required viscosity of welded joints. It should be noted that in the above works, high mechanical properties (including cold resistance) of the base metal, and significant embrittlement of welded joints at negative ambient temperatures are noted. Therefore, the study of the structure and properties of welded joints, performed and operated at low temperatures is a very urgent task.

3. Results of the experimental researches
Welded reinforcement joints, made by manual arc welding in which cold cracks were detected during the installation of reinforced concrete structures, were investigated. The chemical composition of these steels was determined using an ARGON-5SF spectrometer. The results of chemical analysis are shown in table 1. The microstructure of the welded joint is shown in figure 1.

Table 1. Metal chemical speciation.

| Element                        | Mass fraction of elements, % |
|--------------------------------|-------------------------------|
|                                | C  | Si  | Mn  | V  | Cu  | S   | P   |
| According to GOST R 52544, not more than | 0.24 | 0.95 | 1.70 | --- | 0.50 | 0.050 | 0.055 |
| According to the results of chemical analysis of reinforcement | 0.20 | 0.579 | 1.162 | 0.08 | 0.054 | 0.011 | 0.009 |
| The chemical composition of the weld metal during manual arc welding | 0.143 | 0.544 | 1.176 | --- | 0.033 | 0.0064 | 0.0053 |
| The chemical composition of the weld metal in welding | 0.143 | 0.716 | 1.345 | --- | 0.086 | 0.0088 | 0.0108 |

Figure 1. The microstructure of the welded joint of the A500C reinforcement made by manual arc welding: a - the base metal, b - the heat-affected zone, c is - weld.

It has been established that in the near-weld zone of the welded joint of reinforcement bars A500C, made at negative air temperatures, quenching structures are formed. The hardness of the metal was 400 ... 470 HV. In [7], it was shown that, at a hardness level of 400 HV, steel refers to a limited weldable and the use of electric arc welding of reinforcement is excluded.

When using preheating with a gas flame, the hardness of the weld metal and the heat-affected zone decreased. However, along with this there was a decrease in temporary resistance to a gap of about 20 ... 25%. It was suggested that the reinforcement under investigation is either thermomechanically
strengthened or cold-formed. Preheating before welding was actually a release, reducing internal stresses and reducing the strength of the base metal. In order to confirm this hypothesis, heating of the rods with a gas flame was performed, with their subsequent tensile tests. The test results are shown in figure 2.

There is a technology of arc welding in a reducing environment of carbon monoxide [8] in which the additional heating of the weld pool by the oxidizing carbon monoxide is carried out. According to this technology, the butt weld seam of the reinforcement was made using a mechanized method. The chemical composition of the weld metal is shown in table 1.

It was found that as a result of applying the recommended welding method, the carbon equivalent value increased from 0.34 to 0.37. The obtained values of carbon equivalent steel meet the requirements of GOST R 52544-2006. It should be noted that the values of carbon equivalent of a welded joint made by manual arc welding are less than those recommended by GOST R 52544-2006.

The microstructure of a welded joint made in carbon monoxide is shown in figure 3. It has been established that, as a result of multi-pass welding, the weld metal undergoes repeated recrystallization. As a result, a fine-grained ferritic-pearlitic structure is formed in the weld seam and the heat-affected zone. The hardness of the metal is 230 ... 270 HV, depending on the control area and the ambient temperature when welding the joint. The hardness of the heat-affected zone was 200 ... 260 HV.
Tensile tests of reinforcement were conducted. It was established that the temporary resistance to rupture of the welded joint was 606 ... 608 MPa, which corresponds to the requirements of GOST 52544-2006. The destruction of all samples occurred on the base metal.

Figure 4. The values of toughness of the weld metal made in the environment of carbon monoxide.

Tests for impact bending in accordance with GOST 9454 were conducted. It was established that the weld metal, made in an environment of carbon monoxide, has high values of impact strength at positive and negative temperatures.

4. Conclusion
It has been established that the applied manual arc welding of reinforcement bars of class A500C at negative temperatures leads to the formation of quenching structures and may cause the formation of cold cracks. The use of multipass mechanized welding in carbon monoxide ensures the formation of high-quality weld. The properties of the welded joint comply with the requirements of the current regulatory documents.

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