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EVALUATION OF SUSCEPTIBILITY OF WELDED JOINTS OF HEAT-RESISTANT CHROMIUM MARTENSITIC STEEL TO CRACKING AT HEAT TREATMENT

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The mechanisms of cracking of welded joints in tempering used to relieve stresses are considered. It has been found that welded joints on steel 10Kh9MFB with a homogeneous martensitic structure are insensitive to temper cracking. Formation of δ-ferrite in the martensitic structure may lead to cracking of the weld metal. Cracks form in tempering in the range of about 450--550 °C as a result of concentrated deformation within the zone of soft ferrite interlayers in development of secondary hardening of the martensitic matrix. A probable cause of hardening is precipitation of chromium carbide M_7C_3.

Keywords: *arc welding, martensitic steel, welded joints, heat treatment, dispersion hardening, soft interlayers, temper cracking*

Manufacture of welded structures from hardening heat-resistant and high-temperature steels is related to the need to perform heat treatment of welded joints for tempering of quenching structures and lowering of the residual stress level. In some cases temper cracks can form in the welded joints during heating or soaking in certain temperature intervals. The risk of cracking increases at treatment of rigid joints, as well as in the presence of design stress raisers, lacks-of penetration, undercuts and extended inner defects in them.

Temper cracks (or reheating cracks) are defects forming as a result of a non-uniform plastic deformation under the conditions of high-temperature relaxation of inner stresses [1]. The non-uniform nature of relaxation creep of metal at tempering can be related to chemical microinhomogeneity (which is characteristic of weld metal) and development of dispersion hardening of grain bodies at certain temperatures as a result of precipitation of finely dispersed phases, namely carbides, intermetallics. Grain strengthening due to secondary hardening is a factor of «relative softening» of grain boundary regions. As a result, the deformation at relieving of inner stresses is concentrated in the grain boundary zone. A fast increase of density of crystalline structure defects at local deformation, as well as formation of interatomic discontinuities under the impact of embrittling impurities, leads to initiation of microdamage in the form of initial pores [2--4] and to crack propagation. A feature of temper cracks is their intergranular nature.

A susceptibility to hardening and, therefore, to formation of cracks at tempering is found in steels containing strong carbide-forming elements (titanium, vanadium, niobium) and elements strengthening the solid solution (molybdenum, chromium, which also belong to carbide-forming elements) [1, 5--9]. Depending on the alloying system, strengthening can be induced in structural and heat-resistant steels by Cr_7C_3, Mo_2C, V_3C_4 carbides, in austenitic steels ---- by NbC, TiC carbides, in nickel-based alloys ---- by intermetallics of $Ni_3(Al, Ti)$ type [1, 3, 7, 10, 11]. Lowering of high-temperature ductility in the boundary zone and crack formation are caused by impurities of phosphorus, arsenic, antimony, tin and sulphur [1, 5, 12--16]. According to the data of [17], the embrittling action of such impurities as phosphorus and sulphur is due to weakening of the bonds between the metal atoms as a result of formation of electronic bonds on the levels of *s*-orbitals of metal atoms and *p*-orbitals of impurity atoms. Such elements as silicon, manganese, carbon, aluminium and copper [3, 5, 18] also increase the temper cracking susceptibility. They, however, have an indirect influence on embrittlement, for instance, by enhancing the grain-boundary segregation of phosphorus (silicon, carbon, manganese) [5], or ousting carbon from the zone of their clustering with formation of soft microstructural components (silicon, aluminium).

In welded joints the metal in the near-weld sections is more susceptible to cracking, these sections developing a coarse-grained structure as a result of heating to subsolidus temperatures and a high degree of hardening as a consequence of a more complete dissolution of the carbide precipitates and saturation of γ-solid solution by carbon and carbide-forming elements. In the welds cracks can form predominantly in the microsections, in which the solidification boundaries enriched in liquating impurities, coincide with the secondary boundaries ---- the austenite grain boundaries.

There is a sufficient number of publications devoted to studying the problem of temper brittleness of low-alloyed pearlitic and bainitic heat-resistant steels with up to 2--5 % Cr [2, 4--6]. Introduction of new complex-alloyed martensitic steels with increased chromium content leads to the need to study the properties of their welded joints, including temper crack sensitivity. Possible predisposition of such steels to development of processes usually accompanied by cracking, is associated with the presence of carbide-