INFLUENCE OF THE WELDING TECHNOLOGY ON CRACKING RESISTANCE OF THE TITANIUM PSEUDO-ALPHA-ALLOYS

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ABSTRACT

The influence of technological process of argon-arc welding (AAW) on the stress corrosion cracking resistance and cyclic cracking resistance on air and 3%NaCl solution with pH=1 (298 K) of the high-strength pseudo-alpha-alloy of Ti-6Al-1.5V-6Zr titanium and its welding joints has been investigated. It has been shown, that the high resistance to stress corrosion cracking of the welded specimens with a cut along the weld and heat affected zone performed automatically, that operate in chloride solution is caused by high structure dispersivity, eveness distribution of the alloying elements along the welds zones. The elevated ductility of the weld metal is due to additional alloying of it during automatic welding by zirconium from the matrix metal, what provides the higher cyclic cracking resistance of the weld metal in the high-amplitude area of the fatigue fracture curves in air and corrosive environment than the analogous index of the basic metal.

KEY-WORDS

Titanium alloys, welding zone, stress corrosion cracking, corrosion environment, crack resistance, fatigue fracture curve.

INTRODUCTION

The titanium pseudo-alpha-alloys are widely used in welding structures of different application in chemical industry, ship- and aircraft bulding industries, due to the following advantages as: good weldability, thermal stability, high specific strength, corrosion resistance. As fas as the considered alloys are not hardened by thermal treatment, the structural and mechanical properties of titanium semifinished items are determined, in general, by the technological process and welding regimes, under which structural variation, redistribution of the alloying and additive elements as well as their local concentration; formation and nonuniform distribution of the residual stresses and sometimes microdefects appearence take place. This forms thermodynamic conditions for localization of corrosion processes and corrosion cracks initiation first of all in the stressed welding joints regions under static and cyclic loading. Therefore the evaluation of corrosion-mechanical properties of the titanium pseudo-alpha-alloys weldments are very important and are topical in investigations of the new titanium alloys testing system, thus providing workingability of the welded parts, made from them and widening of their application.

EXPERIMENTAL PROCEDURES

A tendency of the high strength experimental Ti-6Al-1.5V-6Zr pseudo-alpha-alloy and its weldments to corrosive cracking and cyclic crack resistance in air and 3%NaCl solution with pH1 (298 K) depending on the technological process of argon-arc welding (AAW) (hand or automatic) has been investigated. A hand AAW of the plates, from which tested specimens have been cut was perfomed by a non-melting tungstem electrode with an addition Ti-3Al-1.5V alloy wire for 15 runs at a current I=415 A, while automatic welding was perfomed for 1 run by a melting electrode at I=750 A.

Stress corrosion cracking testing has been performed under cantilever bending of the fatigue precracked beam (250×50×35 mm) specimens and cyclic cracking resistance testing under pure pulsating bending of the specimens (140×15×6 mm).

The fracture toughness characteristics under static loading in air (K_Q) showed, that the very high values of K_Q are typical of the automatically welded specimens, having a notch along the weld (217 MPa√m), which exceeds the value of K_Q of the basic metal as well as the hand- and automatically welded specimens with a notch along the heat affected zone (HAZ) by 25 and 38% (respectively K_Q=133,135 and 162 MPa√m (see Table)).

Table. Crack resistance properties of the Ti-Al-V-Zr pseudo-alpha-alloys.

Specimens characteristics	K_Q, air (MPa√m)	K_{SCC}, 3%NaCl, pH=1 (MPa√m)
Basic metal	133	67
HAZ, hand welding	135	84
HAZ, automatic welding	162	87
Weld, hand welding	203	180
Weld, automatic welding	217	184

The investigations of stress corrosion cracking in 3%NaCl solution with pH=1 showed that a crack resistance K_{SCC} criterion in corrosion environment during 5000 hours of testing is reduced for basic metal by 2 times as compared to the testing in air (see Table). At the same time the weldment metal has a very high crack resistance value in corrosion environment (K_{SCC}= 184 MPa√m) though it is lower than fracture toughness obtained in air testing (K_Q= 217 MPa√m). It is caused by the fact, the welding joints of the tested titanium specimens have been

performed using the addition Ti-3Al-1.5V wire which is characterized by high plasticity and ductility.

The K_{SCC} values of specimens welded by hand or automatic AAW, containing a notch along the HAZ are reduced as compared to that obtained in air (K_Q values) by 38 and 46% respectively (see Table). When the values of fracture toughness K_Q of the specimens with crack along the HAZ obtained due to definite welding technological process differ by 16%, the values of K_{SCC} differ insignificantly - by about 3% (84 and 87 MPa√m correspondingly during hand or automatic welding). These indexes when compared to the K_{SCC} values in the specimens with a crack along the weld axis (K_{SCC}=180 and 184 MPa√m) are 2 times lower.

The decrease of the K_{SCC} values of the HAZ metal is due to local increase of the content of implantation impurities as well as to the higher level of residual welding stresses and additional tensile stresses, caused by the α-β phase transformations, accompanied by change of the metal crystal lattice volume. Evidently, in such cases the presens of defects in the crystal lattice of HAZ metal increases, thus providing diffusion ability of implantation impurities and their segregations development (Zadery et al, 1987). All this causes the micro- hardness index variation of the HAZ metal, and was proved experimentally (Fig. 1).

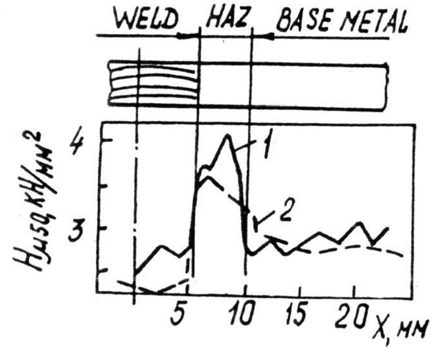

Fig.1. Microhardness distribution along the zones of Ti-Al-V-Zr alloys weldments, performed by hand (1) and automatic (2) welding.

The X-ray microanalysis of the distribution of alloying elements along the different weldments zones carried out on the MS-46 "CAMECA" device with a probe location of 1 μm proved the probability of existance only solid homogeneous solutions on the basis of α-Ti, β-Ti and Ti_3Al inter-metallic phase. At medium aluminium concentration of 5.27% in the alloy, its content variation in HAZ of weldment performed by automatic welding constitutes ±1.3% and by hand welding - ±2.5%. Consequently, the evolution of the Ti_3Al particles is reduced by 2 times during automatic welding using the investigated technological process as compared to hand welding. In weldments performed by two type of welding, the variation in aluminium concentration is ±0.5%, and medium aluminium content in a weld in automatic welding is - 2.65%, while in hand welding it is - 1.84%.

In the process of automatic welding, performed at elevated energies, the more intensive mixing of the basic and weld metal takes place. As a result, the obtained welds are thicker than those obtained due to hand AAW, and besides circonium appears in them (up to 1.34%). The positive zirconium effect on titanium plasticity and ductility is caused by the fact, that it suppresses the brittle ω-phase formation and reduces negative oxygen impurity effect, thus bringing the oxygen atoms into such position in crystal lattice, at which the efficiency of blocking by them of dislocations sharply decreases (Shorshorov et al, 1978). According to Khorev (1969, 1978) a complex alloying (by aluminium, vanadium, zirconium) causes the more homogeneous distribution of alloying elements atoms, providing simultaneous strengthening of α- and β-solid titanium solution. A strehgth difference in the phase compounds lowers, thus causing the decrease of the stress gradient on the grain boundary and providing uniform participation of α- and β-phases in loading process.

The regular concentration fluctuations have been observed for vanadium (from 0.5 to 2.5%), zirconium (from 5.52 to 7.78%) in a basic metal, possess a corser lamellar structure alternating with matrix metal. After two types of welding, the structure of HAZ and weld metal of the tested alloy differs by higher dispersivity, thus causing its higher (as compared to the basic metal) electrochemical homogeneity. Possibly, this is the reason of the difficult initiation of corrosion cracks in above described experiments, what is witnessed by the given above data on the specimens tendency to stress corrosion cracking (see Table). A weld metal moderately alloyed by vanadium (1.63%), zirconium (1.34%), aluminium (2.64%) differs by maximal stress corrosion cracking resistance. To a great extent it is caused also by the diffrence between weld metal structure and basic metal and HAZ structure, in which aluminium concentration exceeds a critical value, i.e. this value at which dislocation structure varies from cellular (at concentration of Al<4%) to planar (Al>4...5% depending on alloying) (Zwicker, 1979; Melekhov, 1979).

Results of cyclic crack resistance testing in air and 3% NaCl solution with pH1 of different weldments zones of the alloy allows to conclude the following. The specimens tested in air and having a notch along the welded axis welded by automatic AAW, possess high cracking resistance. With stress intensity factor (SIF) increase (ΔK > 27 MPa√m) it becomes greater than that of the basic metal (Fig. 2). The increased plasticity of the weld due to automatic welding causes the more easy slope of the kinetic curves in the middle amplitude region and at crack growth rate of $v=10^{-7}$ m/cycle, (ΔK= 27 MPa√m), the curves of the basic metal and a welds intersect in a point, above which the crack resistance of the welds is higher than that of the basic metal and below this point it is - lower. The influence of the corrosive medium on crack resistance of the weldment metal is more expressed during hand welding as compared to automatic one. The C parameter of the Paris equation ($v=C*K_{max}{}^{m}$), which describes the middle- amplitude area of the fatigue fracture diagram, is increase in the first case by 2 orders and in the second case less than by an order; m parameter was reduced correspondingly from 6 to 4.7 and from 4.4 to 3.9 (Fig. 2).

The minimal cracking resistance under two types of AAW is observed in the HAZ metal, moreover the negative corrosion environment effect on fatigue crack growth resistance of the HAZ metal as compared to that of weldment quantitatively remains unchanged. With reduction of ΔK level, the

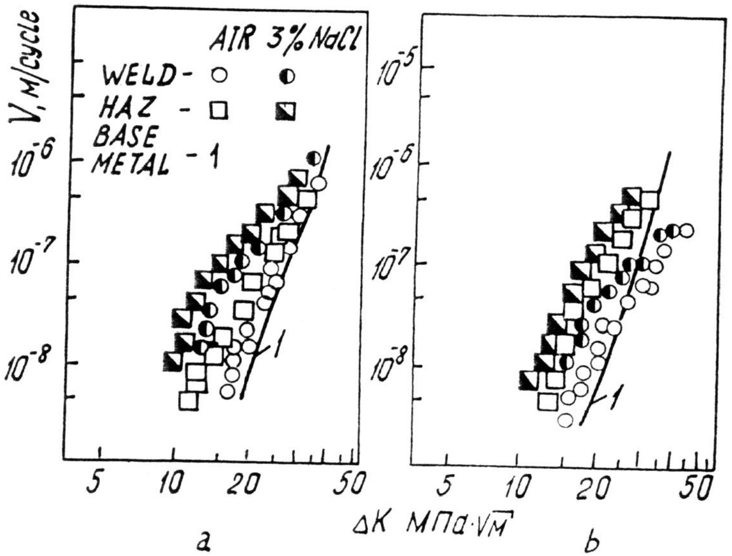

Fig.2. Fatigue fracture curves obtained in air and 3% NaCl solution with pH 1 of the different weldment zones of the titanium alloy, welded by hand(a) and automatic(b) welding.

chloride solution effect on cracking resistance of HAZ metal is more negative in specimens welded by a hand AAW than by automatic welding. In the last case the middle-amplitude areas of the diagrams (curves) have almost similar slopes (m= 5.9 ... 5.3) at the investiged ΔK values under testing both in air and 3% NaCl solution (pH1) (Fig. 2).

SUMMARY

The hand and automatic argon-arc welding of the high-strength Ti-6Al-1.5V-6Zr titanium alloy of the test melting do not reduce the resistance of its welding zones against stress corrosion cracking in 3% NaCl solution (with pH1) when comparing it with basic metal. While comparing the automatic AAW performed according to the tested technological process with a hand one, we observe that the first one reduce the concentration heterogeneity of the alloying elements

distribution along the welds zones, increases toughness and dispersivity of a structure and provides a high cyclic cracking resistance of weld metal, which in the high-amplitude region of fatigue fracture curves exceeds the similar index of the basic metal.

The lowest cyclic cracking resistance in acidic chloride solution is observed in HAZ metal of the specimens, welded by two types of welding, which is caused by the elevated electrochemical heterogeneity of the metal in this zone and high residual postwelding stresses.

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