FRACTURE BEHAVIOUR OF TITANIUM ALLOY DIFFUSION WELDED JOINTS SUBJECTED TO CYCLIC LOADING

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ABSTRACT

Fracture mechanics approaches enables selection of materials with high fracture toughness characteristics to be made and optimisation of welding parameters with regard to allowable defect size. There are at present about 600 types of materials joined by diffusion welding technique. The diffusion welding method makes possible to design joints with predetermined structure and properties. In this paper data on fatique strength and cyclic fracture toughness of joints formed by diffusion welding with forced deformation and having various initial surface roughnesses are presented. It is shown that fracture toughness characteristics and fatique strength of diffusion welded joints are similar to those of base metal.

KEYWORDS

Fracture toughness, diffusion welding, titanium alloy, fatique, crack rate.

INTRODUCTION

All the methods of welding without melting may be divided into three groups (Karakozov, 1976). The first group includes the methods of welding with high-intensive force action (explosion welding, magnetic discharge welding). The second group consists of welding methods with medium intensive force action (cold welding, friction welding, roll welding etc.). The methods of welding with low-intensive force action (diffusion welding) belong to the third group. Plastic deformation of material in weld zone is the necessary condition of joint formation in each method of welding without melting, the strain rate controlling the formation of welded joint. The methods of welding with low-intensive force action are based as a rule on creep-type deformation. Creep rate is a function of welding parameters and resistance to plastic deformation of base metals, structure-sensetive characteristic of material. The joint formation occurs in 3 stages (Krasulin, 1971):

1. Formation of physical contact, i.e. the approaching of atomic planes of joining materials to the distance at which the physical interaction between atoms becomes possible. This is achieved by plastic deformation.
2. Activation of contact surfaces occuring along with the first stage when joining similar materials and resulting in active nuclei formation.
3. Three-dimensional interaction beginning with the moment of formation of active nuclei of interaction.

In general case the process of sound joint formation at the three-dimensional interaction stage may be limited by adhesion of contact surfaces or new fases formation. The general condition of achieving a sound joint is

$$\tau_B \geq \tau_c \geq \tau_p$$

where τ_B is duration of interaction controlling by the time of force action causing the plastic deformation and being the function of welding parameters, τ_c is duration of adhesion of total area of contact surfaces and τ_p is duration of stress relaxation in contact zone to stress level at which formed interatomic bonds do not rupture. If $\tau_B > \tau_p$ unwelded regions - defects such as voids and cracks remain on the interface after predetermined period of time. Further if $\tau_c < \tau_p$, defects may be formed as a result of incomplete residual stress relaxation. Defects in the welded joint usually are classified into two types: I type is elongated narrow discontinuties, large voids and crack-like defects and II type is fine voids. The defects of the first type form in the region with a lack of physical contact. The level of defects in welded joints substantially depends on amount of strain and surface roughness of material.

MATERIAL AND TECHNIQUE

The investigation was carried out using titanium BT1-0 and titanium alloy BT6. The chemical composition and mechanical properties of these alloys are presented in Table 1 and 2 respectively.

TABLE 1 Chemical composition of studied materials

Alloy	The type of alloy	Ti	Chemical composition (wt %)							
			Al	V	Si	Fe	C	O_2	N_2	H_2
BT1-0	α	base	-	-	0,10	0,18	0,07	0,12	0,04	0,01
BT6	$\alpha+\beta$	base	6,63	4,1	0,07	0,40	0,10	0,14	0,05	0,01

TABLE 2 Mechanical properties of studied materials

N	Material	σ_u MPa	σ_y MPa	δ %	ψ %
1.	BT1-0	656	506	-	-
2.	BT6	940	860	13,5	35,5

Diffusion welding with forced deformation was performed on a modified Instron testing machine using a specially developed attachment. The cylindrical specimens to be welded were 10 mm in diameter and 17 mm long. The turning was used to obtain predetermined level of defects on contact surfaces by creating microroughnesses of different height. Just after the machining the specimens were placed in acetone to prevent surface oxidation. Just before the welding the specimens were washed in alcohol. The diffusion welding was carried out in vacuum, the amount of accumulated strain was 1,5 and 10%, the welding temperature for BT1-0 and BT6 was 850 and 940°C respectively. The duration of welding depended on the time required to accumulate selected amount of strain and varied between 10 and 25 min depending on amount of strain. The welding temperature was controlled with chromelalumel thermocouple attached to the welded specimens. The temperature was maintained within ± 1°C. Standart mechanical properties were determined from the results of testing cylindrical specimens on the testing machine Instron 1195 and fatique properties - from the testing on magnetic resonance-type machine Instron 1603 under assymetric cycle of loading. The fracture toughness of base metal and welded joints was determined on cyclic loaded WOL-specimens.

RESULTS AND DISCUSSION

The fatique curves for alloy BT6 and commercially pure titanium BT1-0 are shown on Fig.1. The tests were performed at frequency 60Hz with load ratio 0,2 and stress range of (0,4-0,7) σ_y. The fatique limit was achieved at 10^5 cycles for BT1-0 and 5.10^4 cycles for BT6 and was equal to 170 and 340 MPa respectively. It is known that fatique behaviour of materials in high-cycle region is more sensitive to the presence of defects (in the given structural state) than in low-cycle region. Therefore the study of welded joints fatique behaviour in the low stress range enables to reveal more clearly the influence of defects remaining on interface after completing of diffusion welding on the joint serviceability.

On the Fig.2 and 3 the fatique curves for BT1-O welded joints are presented in comparison with the fatique curve for the base metal. It may be seen that in the case of contact surface microroughness height R_z=20 + 160 μm the joints formed

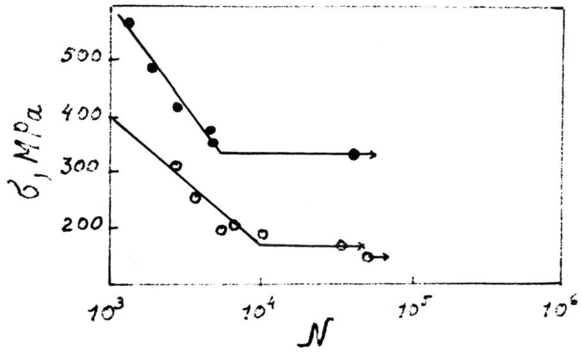

Fig.1. S-N curves for BT6 - alloy (●) and titanium BT1-O (○).

by plastic deformation amounted to 10% had the high serviceability. The fatique strength of joint equal to that of base metal was achieved at stress level about 300 MPa. In the case of stress amplitude less than 300 MPa, that is about 0,35 σ_y, the fatique life of welded joints was longer than that of base metal.

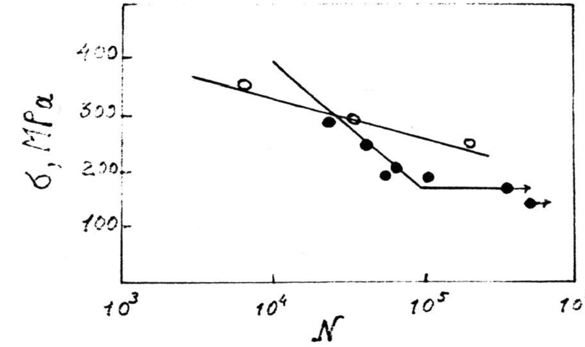

Fig.2. S-N curves for the titanium BT1-O welded joints (○), (R_z = 20 + 80 μm) and BT1-O (●).

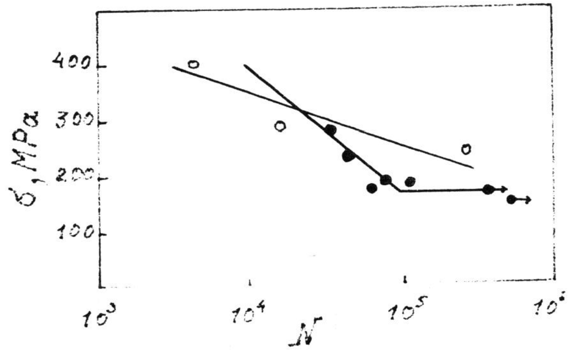

Fig.3. S-N curves for titanium BT1-O welded joints (○), R_z = 80 - 160 μm and BT1-O (●)

On the Fig. 4,5 and 6 the fatique curves for alloy BT6 welded joints with amount of accumulated strain 1,5 and 10% and microroughness height in the range from 0,32 to 160 μm are shown.

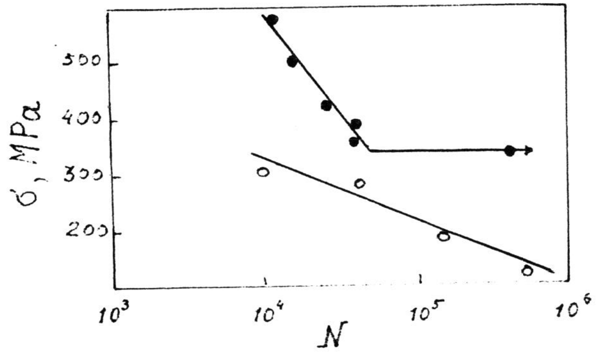

Fig. 4. S-N curves for alloy BT6 welded joints (○), ε =1% and BT6 (●).

At the cyclic loading the alloy BT6 welded joints formed at amount of accumulated strain 5 and 10% had the better fatique life than the base metal under the same load range regardless of level of initial surface microhardness (the height of microroughnesses in the range from 0.4 to 160 µm).

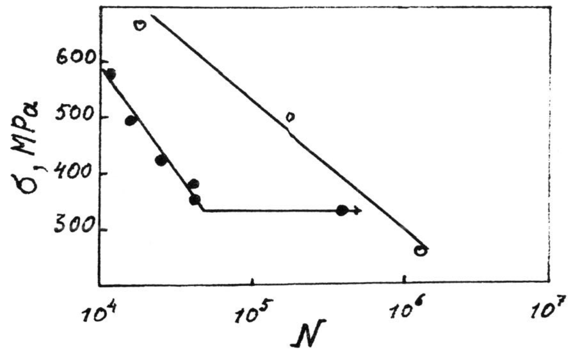

Fig.5 S-N curves for alloy BT6 welded joints (O), ε =5% and BT6 (●).

In the case of rough surface (80-160 µm) and amount of accumulated strain 1% the fatique life of welded joints was 10 times of less than that of base metal under the same range of stress.

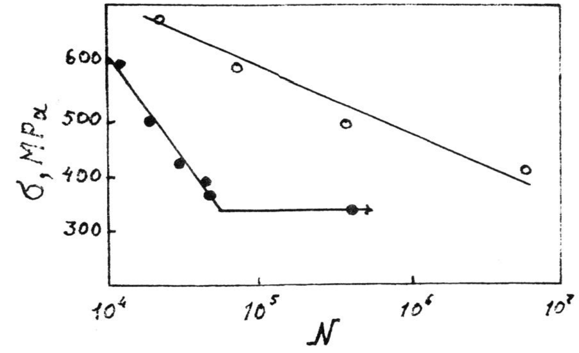

Fig.6. S-N curves for alloy BT6 welded joints (O), ε =10% and BT6 (●).

The high fatique strength of BT6 joints may be resulted from:

1. formation of contact of total joined surfaces due to superplasticity effect;
2. strengthening effect of martensitic α - phase formed due to $\beta \rightarrow \alpha$ transformation in the plastic zone ahead of propagating crack during the cyclic loading;
3. healing the voids under cyclic loading.

Yoder et al. (1976) has found that β - annealing of alloy Ti-6Al-4V substantially increased the resistance to crack growth in the stage II of the fatique fracture kinetic diagram. $\Delta K < 23$ MPa.m$^{1/2}$ was due to crack branching in the α - plate location planes and restricted fracture within the separate packets.

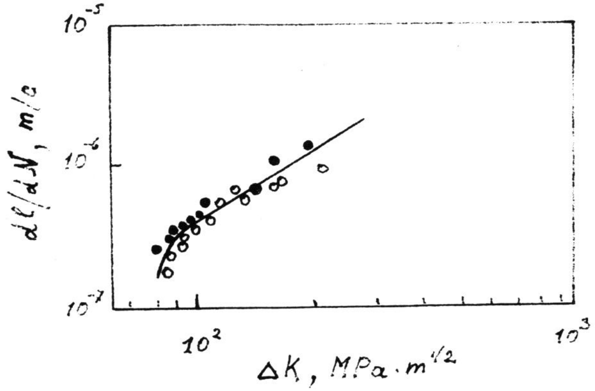

Fig. 7. The relationship between crack growth rate and ΔK for base alloy (●) and welded joint (O).

However all this factors may be effective only in stress range less than yield strength. It may be explained by following consideration. Under the stress level more than yield strength the β - phase of alloy BT6 is mechanically stable as shown elsewhere. Besides at the high stress range the cyclic loading initiates the processes of twinning that lead to embrittlement of material for the twin boundaries are potential sites of crack initiation (Yoder et.al.(1976).

We have measured cyclic fracture toughness of diffusion welded joints. On the Fig.7 the crack growth rate (al/aN as the function of stress intensity coefficient (ΔK) for the alloy BT6 is presented. It may be seen that cyclic fracture toughness of welded joint is equal to that of base metal.

CONCLUSION

In this paper the possibility of formation diffusion welded joints with the same fatique strength and fracture toughness as those of monolitic material is shown.

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