

Fatigue Behavior of Weld Titanium Alloy Hydraulic Tube

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Abstract: Titanium alloy hydraulic tubes were weld with gas tungsten arc welding method in this work. The microstructure of weld zone and heat affected zone are clarified with metallographic microscope, And followed by tensile test and fatigue test, with stress rate R is 0.1 and frequent is 10 Hz. It is found that, the microstructure in weld zone is coarse and uniform β grains about 1.5 mm and paralleled acicular martensite α phase. Mechanical test shows that cracks initiate at inner circle of pipeline and spread along circle line promptly throughout the whole inner circle. Cracks initiation side appearance a clusters of slip bands, those may along the coarse and laminated acicular martensite α phase in weld zone and heat affected zone.

Introduction

Titanium alloys, especially for Ti6Al4V, were widely used in the aeronautics industry[1][2], due to their excellent specific strength weight ratio and good fracture toughness. With the increasing application of Titanium alloys tube in hydraulic systems of aeronautics industry, the connecting of tube was a big problem for the reason of poor ability of vibrating wear and erosion resistance. Many new technologies were proposed to increase the maintainability and reliability of connectors. And welding methods were also convenient and efficient methods, frequently used in aeronautics industry.

Main welding methods such as gas tungsten arc welding, electron beam welding, friction stir welding and laser spot welding, and laser beam welding are used in titanium industries. Titanium alloys are highly susceptible to embrittlement by oxygen, nitrogen, carbon and hydrogen at temperatures exceeding 500 °C. Thus, two conditions must be satisfied when welding of titanium and its alloys: total protection of the weld setting from normal atmosphere by creating an inert gas surroundings. Due to the welding high temperature, the microstructure gradient change from welding zone (WZ) and heat affected zone (HAZ) to matrix zone. The deformation mechanism of welding Ti alloy is always the focus of research.

A proper fatigue assessment and deformation mechanism is of course a crucial requirement for all structural components in flight service, since fatigue loading conditions always occur in these assemblies position for reason of the stress concentration. Many approaches are focus on the sample of welding plane plate specimens and thus use of phenomenological equations such as Paris Law. Which shown that the size of laminate alpha grain and original β grain size significant affect the crack initiation [3][4]. As an alternative, the practically components of hydraulic systems are almost tube. So with variation from uniform stress state to localization stress state, the deformation mechanism and fatigue life may different from the plane plate.

The object of the work is to investigate the fatigue mechanism of welding Titanium alloy hydraulic tube and provide a fatigue assessment for it. So a TA18 Alloy is selected for the well cold deformation and welding ability. And two hydraulic tubes are head-to-head welded, and then the ledges are abrasion to get a uniform cross section. So tension and fatigue deformation are imposed on the welding tubes, the fracture surfaces are observed to clarify the mechanism.

Materials and sample preparation

The material investigated here was a α type Ti alloy TA18 provided by LYSY Titanium Co., LTD, the chemical composition given by Table 1. Where tubes with the diameter of 10 and 1.0 mm wall thickness were hot drawing and cut to 100 mm length. Microstructures using a stereoscopic

microscope, of received tube are show in fig 1, thus no distinctive differences are present. The microstructures consist of primary alpha grain and a little content of remaining β -phase.

Table 1 Chemical composition of TA18 (%)

Composition	Al	V	Fe	C	N	H	Ti
	2.0~3.5	1.5~3.0	0.25	0.08	0.05	0.015	balanced

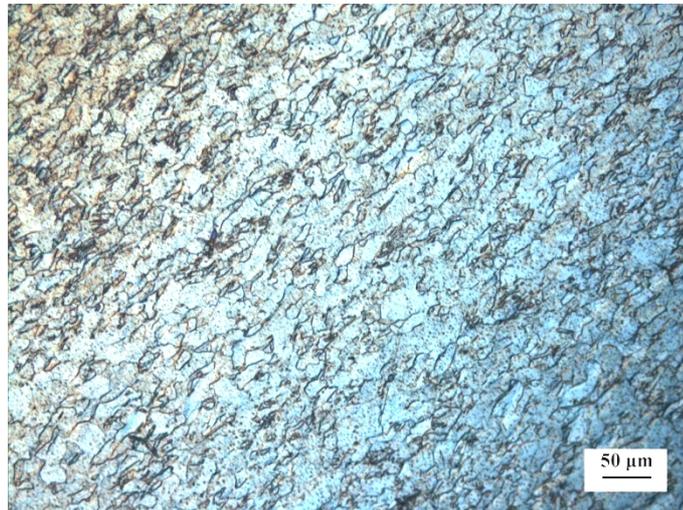


Fig 1 Microstructure of received Ti alloy tubes

Experiment

Every two tubes in 100 mm length were welding in head-to-head type, using gas tungsten arc welding method. Then a low temperature annealing was adopted to release the residual stress. Tensile and tension-tension fatigue mechanical test are performed with a MTS 810 universal testing machine, as ASME IX standard.

Fatigue experiments were carried out in symmetrical push-pull with a servohydraulic MTS 810 test system under load control at a frequency of 10 Hz, with a sinusoidal command signal. All experiments were stopped by specimen failure or at 2×10^6 cycles. The samples which survived this number of cycles are referred to as run-out specimens. Two cylindrical bar with 60 mm length and diameter of 8 mm were intake both side of the welding tubes to increase the hold stability of test system. All the fracture surfaces were investigation with scanning electron microscope (SEM). A ZEISS Discovery V20 microscope equipped with automated focus system was employed for all analytical research work.

Results and discussion

Microstructure: Microstructure of welding tube in longitudinal section and crose section direction are show in fig 2 and fig 3. Coarse and uniform β grains with grain size almost 1.5 mm, filled with laminate acicular martensite α phase are found in weld zone. The acicular martensite alpha grains amost parallel arrangement in individual grain, with Distances between laminates are about 20 μm . With distance increasing to the weld zone, microstructures gradually change to equiaxed α phase and laminate acicular martensite along grain boundary of original β grains, the average grain size is about 200 μm .

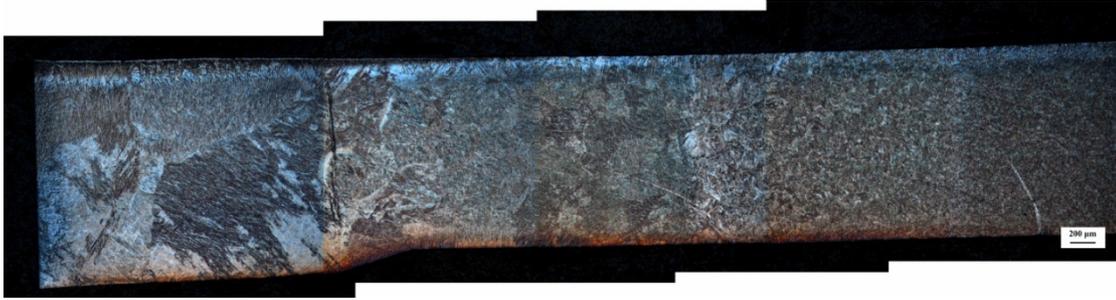


Fig 2 Microstructure in longitudinal section of welding Titanium alloy tube

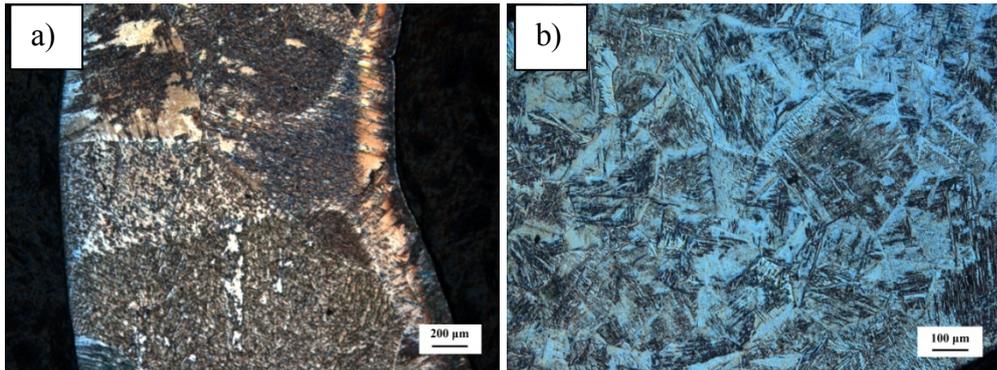


Fig 3 Microstructure in Cross section of weld zone and heat affected zone

a) weld zone, b) heat affected zone

Tensile failure Fracture morphology of tensile failure is shown in fig 4. The tubes broke in weld zone and heat affected zone, as shown in fig 4a. Some V type cracks initiate from internal side and propagate to external side. It may be because that the internal microstress along 45 degree direction in interior is bigger than outside, under tensile loading. The initiation of cracks is along the original β grain boundary or laminate α grain boundary.

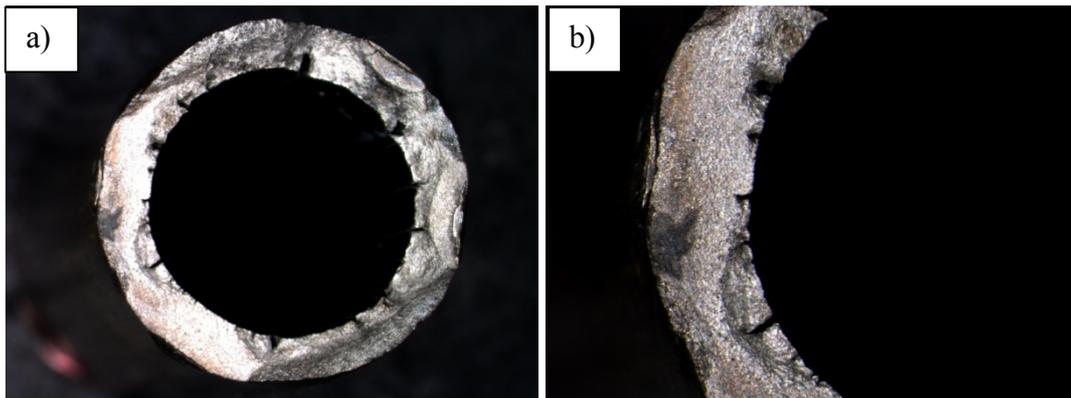


Fig 4 Fracture morphology of welding Titanium alloy tube by tension

Fatigue failure The fatigue life and stress amplitude curve is shown in fig 5, the black square marked the experimental data. Basquin equation [5] is used to fitting the data:

$$s = s_f' (2N_f)^b \quad (1)$$

Where σ_f' is the fatigue strength coefficient and b is the fatigue strength exponent, which are get with the least-squares algorithm linear fitting from the logarithmic curve of stress amplitude and fatigue life. The result is that:

$$s = 839(2N_f)^{-0.206} \quad (2)$$

The fatigue strength exponent for Ti alloy of plane plate sample is about -0.1, but which for weld tube sample is lower. Which mean that is more stress sensitivity, and fatigue strength decrease more quickly than plate samples.

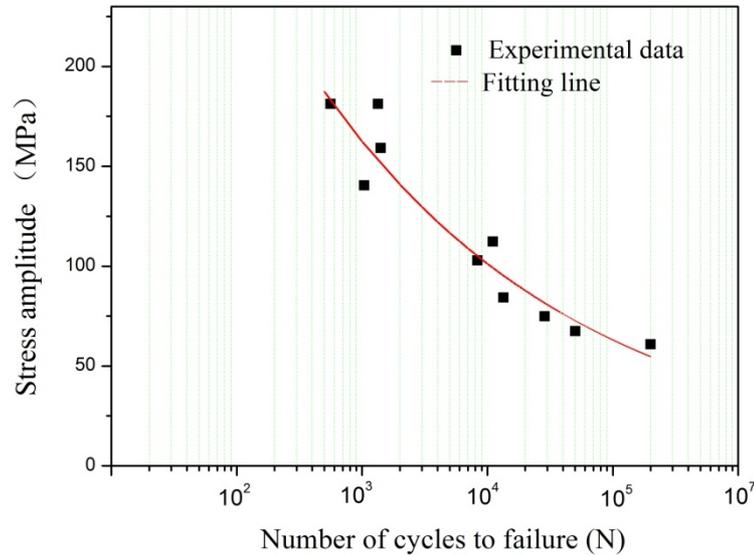


Fig 5 Stress amplitude vs number of cycles to failure

The fracture microstructures of fatigue failed sampe are investigated with SEM, the sample failed at 1.03×10^4 cycles is shown in fig 6. Several V type crack are also found in this sample, but not so much as tensile failed sample as fig 5. The fatigue source is linear sources, microstructure is intergranular cleavage characteristic. Cracks propagate side appreance a clusters of slip bands, those may along the coarse and laminated acicular martensite α phase as proposed by Helge 0. And micrstructure in final rupture zone is dimple fracture. Linear fatigue sources are initiated from internal circle line and propagate to external circle, and the crack spreading zone is about 300 μm , as shown in fig 6a. Almost all dimple fracture zone localize on the outer side, and no cracks propagate through the pipeline wall thickness.

Fig 7 illustrate the fracture surface of sample failed at 80 MPa and 5.02×10^5 cycles. The fatigue sources are also line sources local at inner circle of pipleline, but crack initiate side is more plate than sample failed at lower cycles, without many clusters of slip bands. More magnificent photos show that a lot of slip bands are also found in the crack initiation zone. With the stress amplitude decrease the area ratio between crack propagation zone and final rupture zone increase gradually, and in some region the crack propagates throughout all the pipeline wall direction to the outer wall.

Affect by the geometrical shape of tubes, the localization stress state is more complex than plane plate and bar samples. When crack initiation, it spread along circle line promptly and spread speed along pipeline wall direction is slower.

Among these welding methods, the weld heat input of gas tungsten arc welding os very huge, temperature is very high and dwell time is long. So the grain size and laminate microstructure is coarse, which decrease the objects of dislocation movements, and increase the length of dislocation pile-up. Those factors decrease the strength of weld zone. So the weld zone especially for the original β grain boundary always are susceptible.

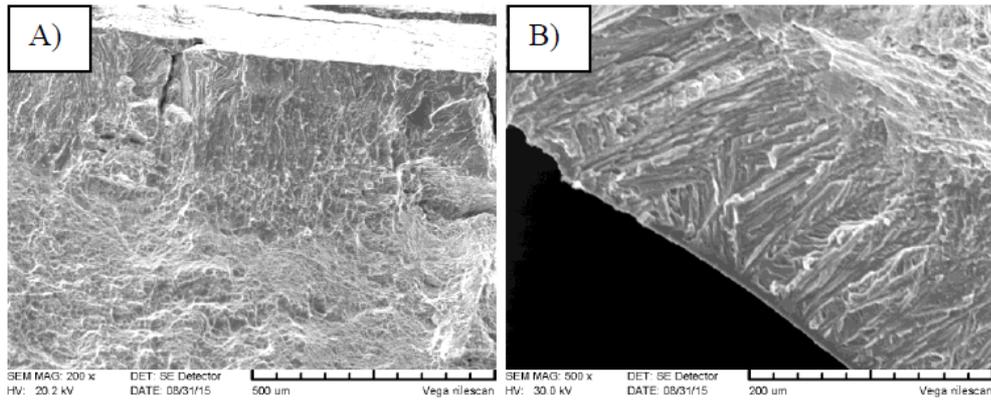


Fig 6 fracture microstructure of sample failed at 140 MPa, 1.03×10^4

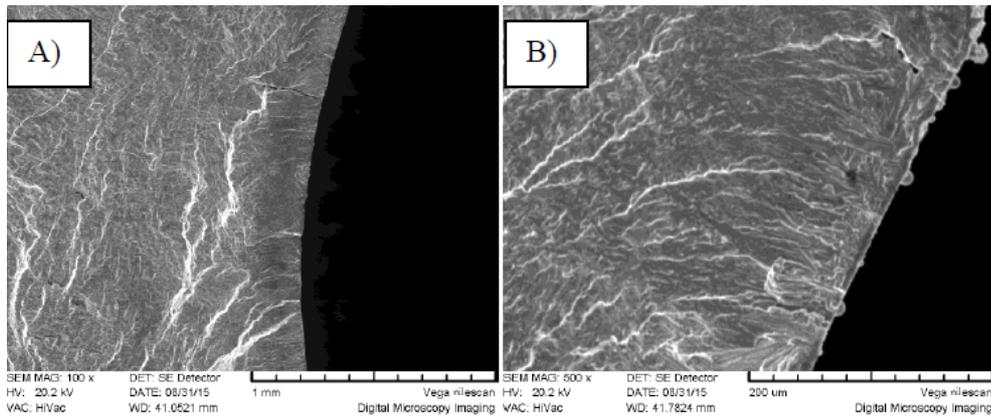


Fig 7 fracture microstructure of sample failed at 80 MPa, 5.02×10^5

Summary

Ti alloy TA18 hydraulic tubes were welded by gas tungsten arc welding method, the microstructure of welding zone and mechanical behavior are investigated, and some important conclusions can be drawn from the results presented in this paper.

- 1 The microstructure in weld zone is coarse and uniform β grains and paralleled acicular martensite α phase, with grain size about 1.5 mm. Gradually, the microstructure changes to equiaxed α phase and laminated acicular martensite along grain boundary of original β grains.
- 1 For tensile failure mode, tubes broke in weld zone and heat affected zone. Some V type cracks initiate from internal side and propagate to external side.
- 1 For tensile fatigue failure mode, cracks initiate at inner circle of pipeline and spread along circle line promptly throughout the whole inner circle and spread speed along pipeline wall direction is slower.
- 1 Cracks initiation side show a clusters of slip bands, those may along the coarse and laminated acicular martensite α phase in weld zone and heat affected zone.

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