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Residual Stress Distribution and Mechanical Properties of TA15/BTi-6431S Titanium Alloy Welding Joints by Ultrasonic Impact Treatment

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Abstract. TA15 (Ti-6.5Al-2Zr-1Mo-1V) and BTi-6431S (Ti-6.5Al-3Sn-3Zr-3Mo-3Nb-1W-0.2Si) titanium alloy plates were welded through gas tungsten arc welding (TIG) and different ultrasonic impact treatment (UIT) were conducted on the weldment. The effects of ultrasonic impact treatment (UIT) on the microstructure and residual stress distribution and mechanical properties for the welding joint were investigated through optical microscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM) and tensile tests. After TIG welding, the structure of welding joint is composed of fusion zone (FZ), heat-affected zone (HAZ) and base metal. The FZ is widmannstatten structure with coarse β grains and a large number of acicular α due to the fast cooling rate. The microstructure in the HAZ shows a gradual change because of the presence of temperature gradients during welding. The residual stress after TIG is mainly tensile stress and the maximum longitudinal stress appears in the centerline of welding joint. The UIT process shows dramatic influence on residual stress distribution. After employing UIT twice, the residual stress near the welding joint shows a uniform distribution and the maximum tensile stress changes to compressive stress. However, the tensile properties at room temperature almost remain unchanged after UIT.

1. Introduction

High-temperature titanium alloys are widely used in the aerospace industry owing to its excellent combination of mechanical and physical properties, such as low density, excellent high-temperature mechanical properties, good corrosion to resistance and excellent weldability [1-2]. In order to reduce the structure weight and improve the overall performance, welded structure becomes a preferred choice in the design and manufacture of aerospace. Titanium alloys can be joined by a variety of welding methods, such as gas tungsten arc welding (TIG), laser beam welding (LBW) and electron beam welding (EBW). TIG is a usually used method and has drawn more attention [3-4].

Sometimes, there are different performance requirements for the different parts of the same component; the weldments of similar material cannot satisfy the demand. Therefore, dissimilar metal alloys are welded to make full advantage of properties of each component material. However, the residual stress is generated due to the heterogeneous distribution of temperature formed during the welding process, which may have adverse impacts on mechanical properties of welding joints [5]. Many methods have been used to reduce the residual stress of welding parts, which are classified into heat treatment and mechanical methods. Compared with the traditional methods, ultrasonic impact treatment (UIT) can not only introduce compressive stress, but has advantages of easy operation, high working efficiency and low energy consumption [5-7].

TA15 titanium alloy (Ti-6.5Al-2Zr-1Mo-1V) is a kind of near-α titanium alloy with excellent thermal stability and welding performance and widely used in the welding parts of aerospace, engines and military industries [8]. BTi-6431S alloy (Ti-6.5Al-3Sn-3Zr-3Mo-3Nb-1W-0.2Si) is a novel α+β high-temperature titanium alloy, which can be applied at 700 ℃ for short term [9-10]. In this study, TA15 and BTi-6431S titanium alloy plates were welded via TIG method and UIT was employed to reduce the residual stress of the welding joints. The effects of UIT processes on the distribution of residual stress were investigated through optical microscopy (OM) and X-ray diffraction (XRD) method, so as to provide experimental basis for UIT in dissimilar welded components.

2. Experimental procedures

BTi-6431Sand TA15 titanium alloy plates with dimensions of 250 mm×200 mm×3 mm where the rolling direction is parallel to the length direction were used for this study. Figure 1 shows the original microstructures of BTi-6431S and TA15 titanium alloys observed by optical microscope. The microstructure of BTi-6431S alloy is composed of lamellar primary α phase (α_p) and transformed β (βt) structure, and that of TA15 alloy is composed of equiaxed α_p phase and a small amount of β phase. The welding direction was parallel to the rolling direction. The TIG parameters were shown in Table 1. Different UIT methods were conducted with a HTUIT-20 ultrasonic impactdevice in the welding joints on welding toe and the parameters of UIT process were shown in Table 2.

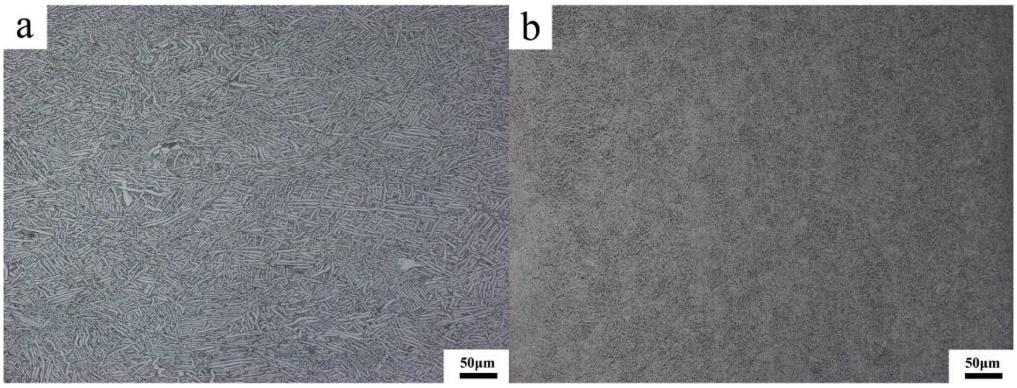

Figure 1. OM microstructure of BTi-6431S(a) and TA15(b) titanium alloys

Table 1. The parameters of TIG process

Groove angle, °	Current, mA	Voltage, kV	Welding speed, mm/s
60	130	15	2

Table 2. The parameters of ultrasonic impact treatment process

Frequency, kHz	Actual Frequency, kHz	Amplitude, μm	Speed, mm/min	Times	Current, A
20	19	20	200	1~3	1.2~1.5

The specimens for microstructural observation were cut through electro-discharge machine and conventional titanium metallographic procedures were subsequently applied. The specimens were etched in the solution of HF: HNO3: H2O=1: 3: 7. The microstructures of base metals and welding joint were observed using the Axiovert200 MAT Zeiss optical microscope. The residual stresses of the welding joints were tested before and after UIT by X-ray diffraction (XRD) method on an X-350 instrument (Cu target, 25kV, 8mA). The diffraction crystal face is (213) and stress constant is -277MPa per degree. Taking the center of the welding joint as the symmetry axis, the measuring point is set at each 4mm from base metal to the welding line. The tensile tests were performed on Instron 5582 machine at room temperature and three specimens were tested to get an average. The fracture morphologies were observed through JSM-7001F scanning electron microscope (SEM).

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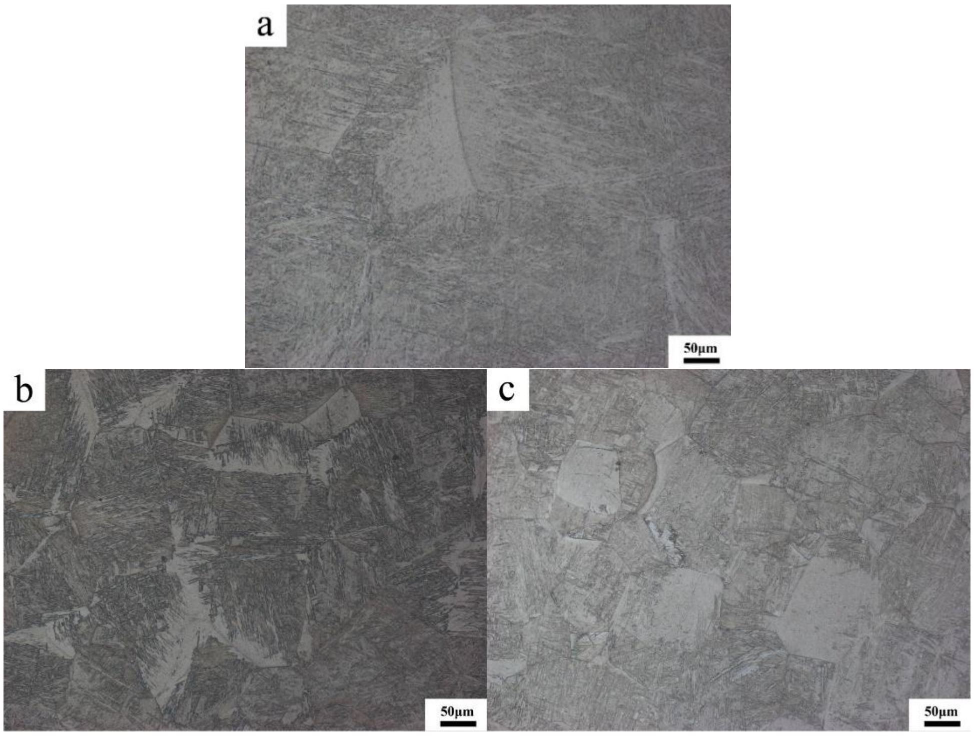
3. Results and discussion

3.1. Microstructure

The welding seam by TIG method is in bright sliver colour and shows little deformation. Microstructures of the welding joint are shown in Figure 2 and Figure 3. The surface of the joint was slightly convex with the width of front bead about 16mm. The microstructure of the welding joint is obviously divided into fusion zone (FZ), heat-affected zone (HAZ) and base metal zone. After TIG, a significant change occurs in the (FZ and HAZ. The microstructure is related to the cooling rate. The microstructure of FZ is characterized as widmannstatten structure which consists of coarse β grains and a large number of acicular α (shown in Figure 3(a)) due to the fast cooling rate. The microstructure in the HAZ shows a gradual change due to the presence of temperature gradients during welding. HAZ near fusion zone (shown in Figure 3(b, c)) consists of widmannstatten structure because the temperature in this area is also higher than β transus temperature, while the size of β grains is much smaller than that in FZ. The microstructure of the HAZ near base metal (shown in Figure 3(d, e)) is similar to the parent alloy, that is, the microstructure near TA15 alloy is composed of coarse equiaxed α phases and that of BTi-6431S alloy is coarse lamellar α phases.

Figure 2. The profile of butt jointby TIGwelding



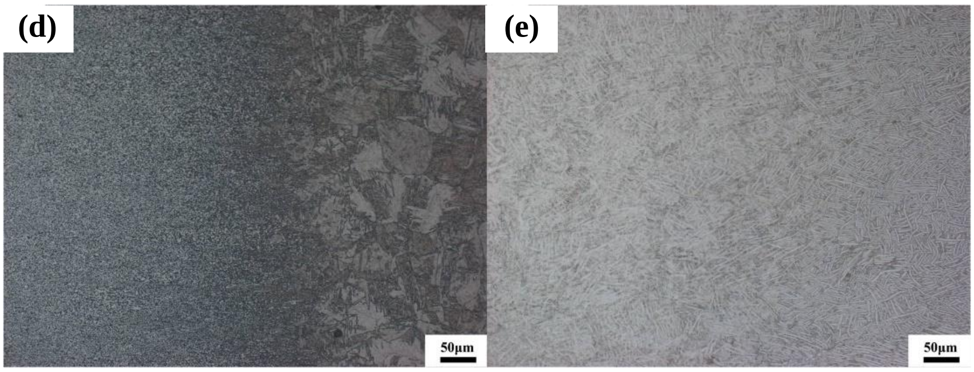


Figure 3. Microstructure of the TIG welding joint: (a) welding centerline, (b) HAZ near FZ in TA15 alloy side, (c) HAZ near FZ in BTi-6431S alloy side, (d) HAZ near base metal in TA15 alloy side, (e) HAZ near base metal in BTi-6431S alloy side

3.2. Residual stress distribution

Figure 4 shows the residual stress distribution of the welding joint along transverse direction (σ_x) and longitudinal direction (σ_y), respectively. It can be found that before UIT the residual stresses along both directions are distributed symmetrically along the center line of the welding joint.The value of residual stress along transverse direction is much smaller than that along longitudinal direction. It is noted that the residual stresses in the FZ and HAZ are tensile stress and the values of σ_y range from 544 MPa to 616 MPa. The maximum residual stress exists in the centerline and is almost 60% of the yield stress of the base metal. This isresulted from the heat-expansion and cold-contraction of weldment.

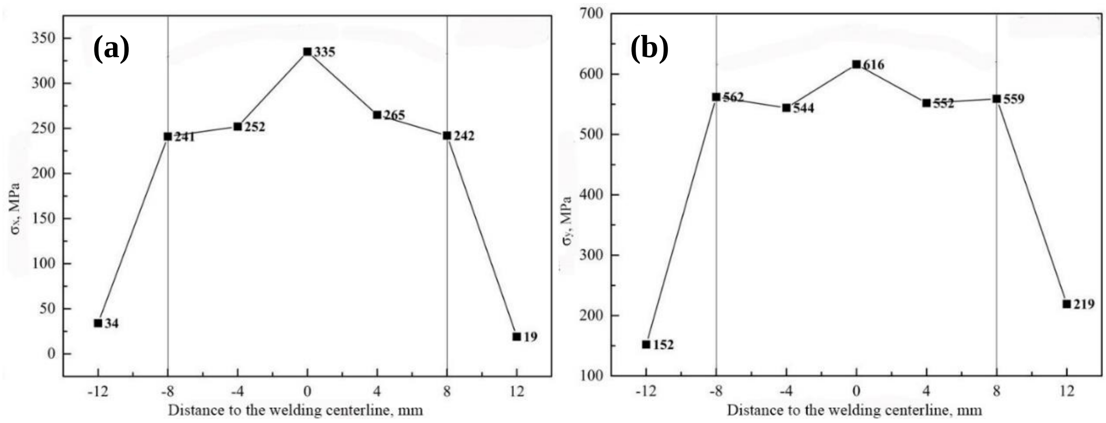


Figure 4. Distribution of residual stress of the TA15/BTi-6431S TIG welding joint: (a) transverse direction (σ_x), (b) longitudinal direction (σ_y)

Figure 5 shows the longitudinal residual stress (σ_y) distribution of the welding joint after different UIT processes. The number of impact has significantly influence on the distribution of residual stress. After UIT for one time, the residual stress of the welding joint is relieved slightly and the maximum value decreases from 616 MPa to 531 MPa, but still remains tensile stress. As the number of ultrasonic impact increases to two, the residual stress changes from tensile to compressive, and the maximum compressive residual stress reach to -100 MPa. Comparing with stress-relief annealing, UIT not only decreases the residual stress, but introduces compressive residual stress which is benefit for the fatigue properties of welding joint [11].

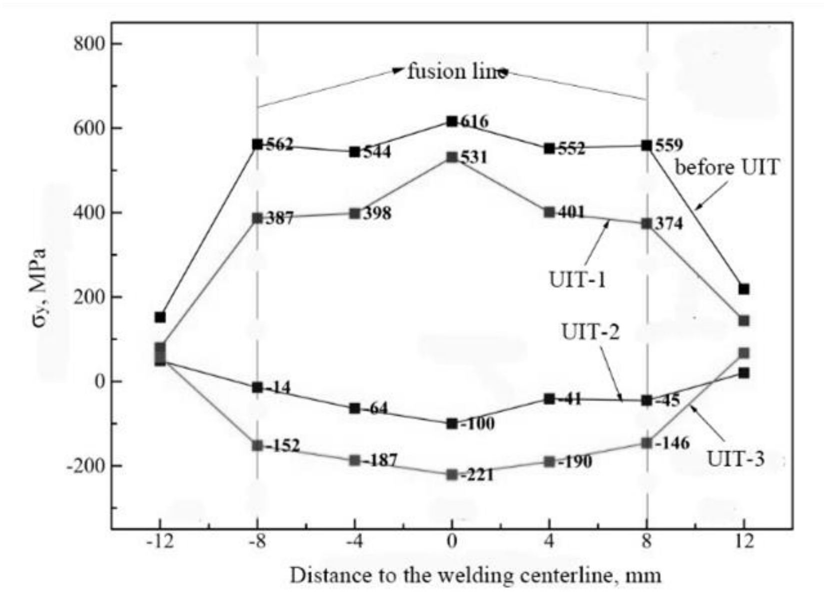


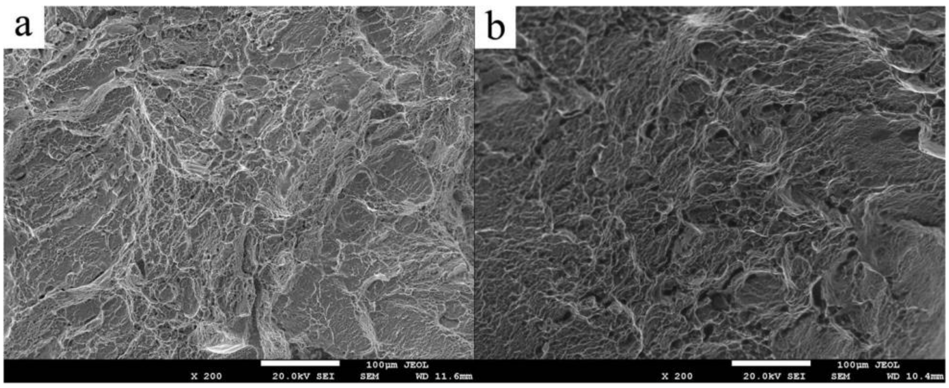
Figure 5. Longitudinal residual stress (σ_y) of welding joint after UIT with different impact numbers

3.3. Mechanical properties

The tensile properties of the TIG weldment through different UIT process are studied at room temperature, and the results are listed in Table 3, including yield strength, ultimate tensile strength and elongation. After UIT, the tensile properties remain unchanged. Figure 6 shows the SEM images of fracture morphologies for TA15/BTi-6431S alloys TIG weldment after tensile tests. It can be found that shallow dimple fracture is predominant, and some secondary cracks are visible. By ultrasonic impact treatment, the fracture mode is also not changed.

Table 3. Room-temperature tensile properties of TA15/BTi-6431S alloy weldment after different UIT

UIT process	Ultimate tensile strength, MPa	Yield strength, MPa	Elongation, %
Before UIT	1011	912	6
UIT-1	1026	887	4.5
UIT-2	1059	914	5
UIT-3	1055	904	5.5



(a) before UIT, (b) after UIT

Figure 6. Fracture morphologies of TA15/BTi-6431S alloys TIG weldment after tensile tests.

The variation of mechanical properties is obviously different from residual stress after different UIT process. Ultrasonic impact is a mechanical strengthening method on the surface. As the strength of the titanium alloy is high, plastic deformation is not easy to produce. The depth of the influence layer after ultrasonic impact is only micrometer, which is very shallow compared to the thickness of the plate. It is not enough to change the tensile mechanical properties of the welded joint. In order to further improve the mechanical properties of joints, it is necessary to amplify the depth of ultrasonic impact layer, such as increase the impact number or working current.

4. Conclusions

(1)The microstructure of TIG welding joint of TA15/BTi-6431S dissimilar alloys is compose of FZ, HAZ and base metal due to the presence of temperature gradients during welding. The microstructure in FZ with fast cooling rate is widmannstatten structure, consisting of coarse β grains and a large number of acicular α. The microsture of HAZ near FZ is also widmannstatten structure with smaller β grains than that in FZ

(2) The number of impact treatment has great influence on residual stress distribution. After employing UIT twice, the residual stress near the welding joint shows a uniform distribution and transforms from tensile stress to compressive stress.

(3) The tensile properties at room temperature and fracture characteristics almost remain unchanged through ultrasonic impact treatment. This is because that the depth of the influence layer after ultrasonic impact is too shallow compared to the thickness of the welding joint.

5. Acknowledgement

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6. References

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