THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF FRICTION STIR WELDED TI6AL4V TITANIUM ALLOY UNDER β TRANSUS TEMPERATURE

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Abstract:

Ti6Al4V titanium alloy is friction stir welded using a W-Re rotational tool. The effects of welding speed on the microstructure, tensile strength and fracture properties of weld are investigated. At the rotational velocity of 250 r/min, the peak temperature is lower than β transus temperature, and the weld nugget is made up of fine α phase and transformed β phase. The grain size of shoulder affected zone is bigger than that of weld nugget because of low thermal conductivity of Ti6Al4V titanium alloy. By increasing the welding speed, the grain size of weld nugget, the tensile strength and the ductility of weld all are decreased.

1 Introduction

Pure titanium and titanium alloys have high specific strength and good erosion resistance, and thus have been widely applied to aerospace, chemical and nuclear industries. From the view of reducing the weight of titanium alloy structures, it is very important for the structures to be joined by the welding technology rather than the mechanical joining technology. Friction stir welding (FSW) is a solid-state joining technique which was introduced by The Welding Institute (TWI) [1, 2]. Similar to other friction welding methods [3], FSW owns many advantages, for example, low stress, low heat input, non-pollution, etc.

So far, FSW of titanium and titanium alloy has been attracting the researchers' attention [4-15]. Sato et al. [4] with a PCBN tool attained the weld of pure titanium and showed that the weld was made up of fine equiaxed α grains. Liu et al. [6, 7] pointed out that the stir zone was the weakest part of the weld and the tensile strength was increased with an increase in the welding speed. Butta et al. [9] by FEM method investigated the phase transformation process. By lots of reported results [6, 7, 10-14], the $\alpha+\beta$ titanium alloy can be welded by FSW and the peak temperature during FSW process is higher or smaller than β transus temperature according to different welding procedure parameters. If the β transus phenomenon does not happen, the microstructure of friction stir weld of $\alpha+\beta$ titanium alloy may be similar to that of the base metal (BM), which may attain a sound weld. In this study, the experiment of friction stir welded Ti6Al4V is performed. And then the microstructure and

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mechanical properties of FSW joint are investigated at different welding speeds.

2 Experimental

In this manuscript, Ti6Al4V titanium alloy with the thickness of 2 mm was welded by FSW. The welding speeds were 50 mm/ min, 75 mm/min and 100 mm/min, respectively. The rotational velocity of tool was 250 r/min. During the welding process, argon shielding was employed to prevent the welding plate from being oxidized. Moreover, FSW was performed with a W-Re tool. The diameter of tool shoulder is 12 mm, the diameter of pin bottom is 6mm, the diameter of pin tip is 4mm and the length of pin is 1.8 mm.

The specimens of weld were observed by optical microscopy (OM) after metallographic etch with Keller's reagent. The Keller's reagent is made up of 1 ml HF, 1.5 ml HCl, 2.5 ml HNO_3 and 95 ml H_2O. The tensile tests were carried out at room temperature using a universal tensile machine with the experimental speed of 5mm/min. The fracture morphology of FSW joint was observed by scanning electron microscopy (SEM).

3 Results and discussion

According to differences in the microstructure, the weld of Ti6Al4V titanium alloy is divided into five regions: shoulder affected zone (SAZ), weld nugget (WN), thermo-mechanically affected zone (TMAZ), heat-affected zone (HAZ) and BM. The sketch map of weld is shown in Fig. 1. This manuscript is primarily concerned with the microstructures of SAZ, WN and BM.

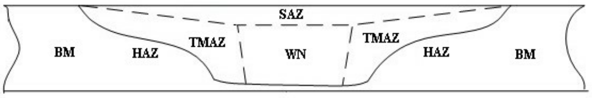


Figure 1. Sketch map of Ti6Al4V friction stir weld.

3.1 Microstructure of weld

The Ti6Al4V titanium alloy plate used in this study is made up of primary α and transformed β, whose microstructure is shown in Fig. 2. Therein, the black region and white regions respectively represent primary α and transformed β of BM.

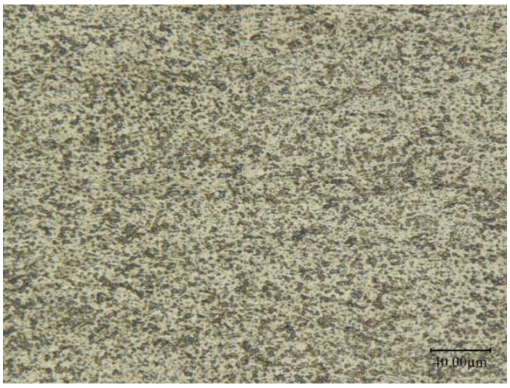


Figure 2. Microstructure of BM.

Fig. 3 shows the microstructure of SAZ and WN in the weld at the welding speed of 50 mm/min and the rotational velocity of 250 r/min.

a) SAZ

b)WN

Figure 3. Optical photograph of SAZ and WN at the welding speed of 50 mm/min.

From Fig. 2 and Fig. 3, it is known that the microstructure of WN is made up of equiaxed α phase and transformed β phase, which is similar to BM and verifies that the temperature in WN is lower than β transus temperature. During the welding process, the material in SAZ and WN undergoes large strain, large strain rate and high temperature, so dynamic recrystallization (DRX) happens [9, 10], which results in the grain sizes in WN or SAZ being both smaller than that of BM.

During the welding process, the welding heat is mainly generated by tool shoulder and pin tool. The heat generated by tool shoulder is much larger than that by tool pin [2]. The thermal conductivity of Ti6Al4V titanium alloy is 7 W/m·k, which is greatly lower than that of aluminium alloy. Therefore, the temperature of SAZ is higher than that of WN, which makes the temperature of SAZ exceed β transus temperature and result in the decrease of primary α and increase of the grain size (Fig. 2, Fig. 3a). In the cooling process, the phenomenon of $\beta \rightarrow \alpha + \beta$ occurs and then the lamellar $\alpha + \beta$ microstructure appears, which plays an important role in determining the properties of the weld [6, 7]. In order to make the temperature lower than β transus temperature in the whole weld, the larger welding speed should be used.

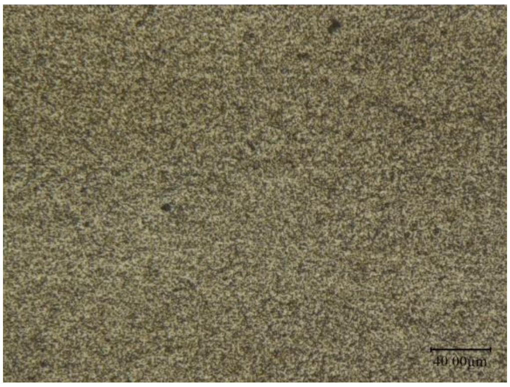
Fig. 4 is the microstructure of WN at different welding speeds.

In the welding process, by increasing the welding speed, the heat input in one unit length can be decreased and made the welding temperature decrease, which results in the restraint of grain growth. From Fig. 3 b) and Fig. 4, it is seen that by changing the welding speed at the rotational velocity of 250 r/min the microstructure of WN remains unchanged and the grain size is decreased with an increase in the welding speed of low heat input welding process.

3.2 Mechanical properties of weld

The tensile strength and the elongation of welds are shown in Fig. 5. Fig. 6 shows the stress-strain diagram of Ti6Al4V titanium alloy. It is well-known that both recrystallization and recovery occur in WN during FSW process [6-9] and make the deformed material soften, which influences the hardness and tensile strength of the weld. This is why the tensile strength of weld is lower than that of BM (Fig. 5). At the rotational velocity of 250 r/min, by increasing the welding speed, the tensile strength of weld is decreased. The tensile strength and the elongation of BM are 1013 MPa and 8.5%. The maximum tensile strength and the maximum elongation of FSW joint achieve 80.2% and 37.6% of BM, respectively.

(a) 75mm/min



(b)100mm/min

Figure 4. Optical photograph of WN at different welding speeds.

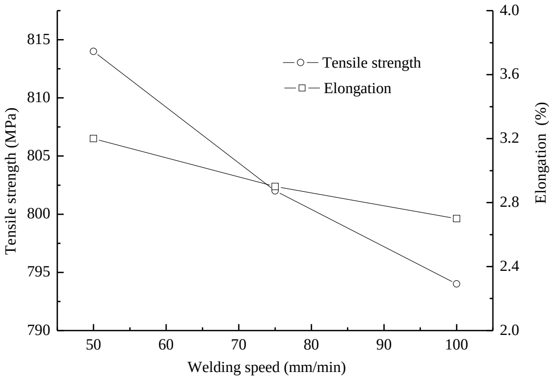


Figure 5. Tensile strength and elongation of welds at different welding speeds.

Fig. 7 shows the fracture surface morphologies of welds. For Ti6Al4V titanium alloy friction stir weld, the fracture position lies in the weld.

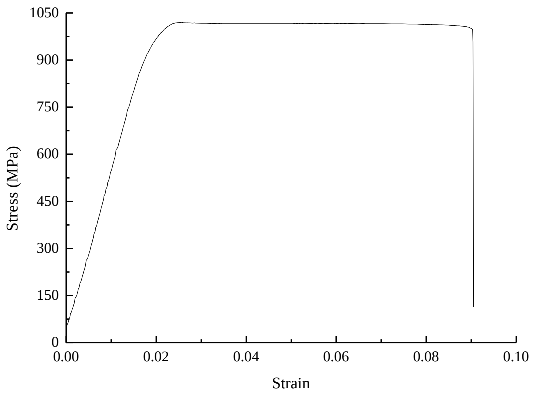
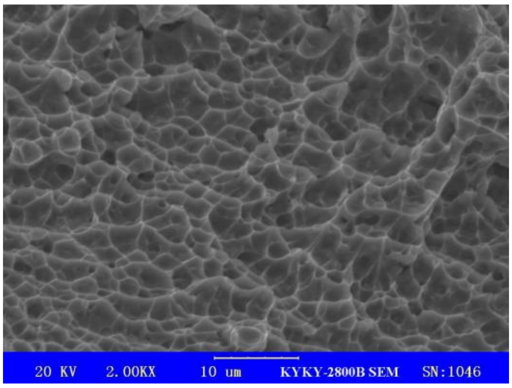


Figure 6. Stress-strain diagram of Ti6Al4V titanium alloy.

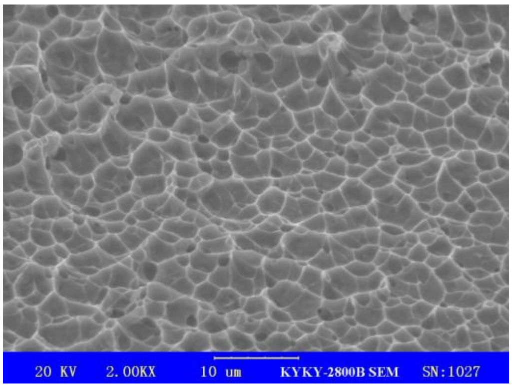
The fracture surface presents the typical ductile fracture and is made up of large amounts of dimples. The ductility of weld depends on the deformation capacities of grain in SAZ and WN, such as grain size and grain orientation. Generally speaking, the boundaries of large grains are more randomly oriented than those of small grains, so large grains turn out to be beneficial to the ductility of material. The better the ductility of FSW joint is, the deeper the dimples are. According to the depth of dimples, it is concluded that the ductility of joint at the welding speed of 50 mm/min is the best and the ductility of joint at the welding speed of 100mm/min is the worst, which is in agreement with the elongation of FSW joint, as shown in Fig. 5.

4 Conclusions

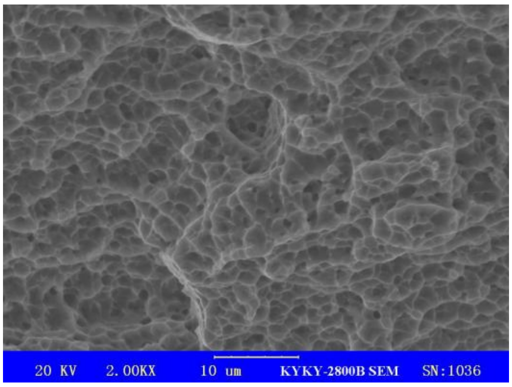
1) Ti6Al4V titanium alloy is welded by friction stir welding. The experimental results show that the grain size of shoulder affected zone is bigger than that of weld nugget. At the rotational velocity of 250 r/min, the grain size of weld nugget is decreased by increasing the welding speed.
2) At the rotational velocity of 250 mm/min and the welding speeds from 50 mm/min to 100 mm/min, the peak temperature in the weld nugget during the welding process is lower than β transus temperature. By decreasing the welding speed, the tensile strength and the ductility of weld are increased.



(a) 50 mm/min



(b) 75 mm/min



(c) 100 mm/min

Figure 7. Fracture surface morphology of welds at different welding speeds.

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