International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 09, September-2015

Investigation of Effects of Friction Stir Welding Parameters on Bending Behavior of AA7075-T6

Duong Dinh Hao
Department of Engineering Mechanics
Nha Trang University
Nha Trang, Vietnam

Tran Hung Tra
Department of Engineering Mechanics
Nha Trang University
Nha Trang, Vietnam

***Abstract*- The influence of tool rotation speed and welding speed on the bending strength of the friction stir welding (FSW) of AA7075-T6 were investigated in this study. The experimental results shown that, the joint is fabricated successfully with a properly good bending strength when the ratio of rotational speed to weld speed is in range from 4.0÷10.0 rev/mm. The grain size rise when the ratio of rotational speed to weld speed or the rotation speed is increased. Most of the bending specimens are fractured when bending angle reaches 90º except the regime of 4.0 rev/min. Furthermore, the temperature and hardness distribution in and around the welded zone were considered and discussed.**

Keywords—Friction stir welding; bending strength; aluminum alloy AA7075-T6; microstructure; temperature and hardness distribution

I. INTRODUCTION

In recent years, the materials that are lightweight and durable such as aluminum alloys, composite materials... has increased steadily in the industries of aerospace, automotive, shipbuilding... Fig. 1 shows that the materials used in the manufacture of the Boeing 777, which accounts for the highest percentage of 70% aluminum that is mainly aluminum alloys are AA7xxx and AA2xxx group [1]. This shows a significant factor in the use of lightweight materials and high strength in aircraft manufacturing.

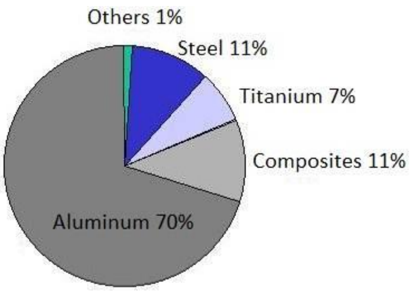

Fig. 1. Materials used in the Boeing 777.

Today, besides the use of lightweight materials, many modern technologies are used in many industries of aerospace as friction stir welding (FSW). This is a solid-state joining technique and was initially applied to aluminum alloys. It was invented at The Welding Institute (TWI) of the United Kingdom in 1991 [2-3]. The basic concept of FSW is remarkably simple. A non consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and subsequently traversed along the joint line (Fig. 2) [4].

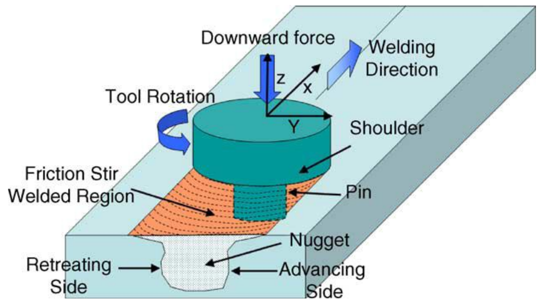

Fig. 2. Schematic drawing of friction stir welding.

This welding technology is very important role in the joints of aluminum alloy part that is difficult to weld by fusion welding method. The aim of this paper is to present and report the results of bending behaviors of dissimilar friction stir welding of aluminum alloys AA7075-T6 that were produced at different welding parameters.

II. EXPERIMENTAL INVESTIGATION

A. Materials

The mechanical and thermal and, the chemical composition, properties of the base metal (AA7075-T6) are presented in Table 1 and Table 2, respectively [5].

Table 1. Mechanical and thermal properties of the base metal.

Material	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Hardness (Rockwell B)
Base metal	572	503	11	87
Material	Modulus of elasticity (GPa)	Poisson's ratio	Solidus (ºC)	Liquidus (ºC)
Base metal	71.7	0.33	477	635

Table 2. Chemical composition (wt.%) of the base metal.

Element	Al	Zn	Mg	Cu	Si
Base metal	87.1÷91.4	5.1÷6.1	2.11÷2.9	1.2÷2	Max 0.4
Element	Fe	Mn	Ti	Cr	
Base metal	Max 0.5	Max 0.3	Max 0.2	0.18÷0.28	

B. Experimental Procedures

The Friction stir welding AA7075-T6 aluminum alloys were produced at Nha Trang University. The dimensions of the aluminum alloy plates are 300 mm length, 150 mm width, and 5.0 mm thickness (Fig. 3). In this work, the tool geometry was a scrolled shoulder tool and a truncated cone pin with a pin height of 4.8 mm, the pin diameter of 5.0 mm at the middle pin length, and a screw pitch of 1.0 mm (Fig. 4). The welding process was accomplished at three rotational speeds, 600, 800 and 1200 rpm, three welding speeds, 80, 150 and 200 mm/min by combining them each other. The pin was aligned at a tilt angle of 2.0 deg. in the plane describing the pin axis and the center weld line (the tilt angle is defined as the angle between the pin axis and the direction perpendicular to the workpieces).

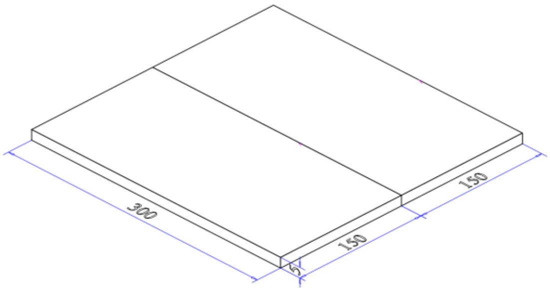

Fig. 3. Dimension of the aluminum alloy AA7075-T6.

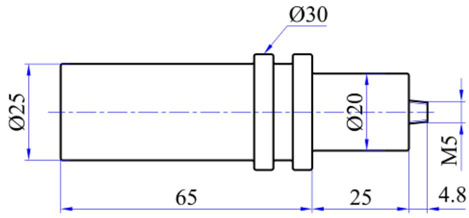

Fig. 4. Dimension of tool used in this study.

Temperature measurements were made on the welded joint during the process by means of thermocouples placed at the end weld center and at the shoulder limit areas in retreating side (1.0 mm far from the shoulder limit line). Thermocouples were attached to a data acquisition system and data collection was accomplished with the system attached to a personal computer (Fig. 5).

After welding, the samples were sectioned normal to the welding direction and then prepared by grinding disks, polished, and finally etched with a reagent: 150 mL H_2O, 3 mL HNO_3, 6 mL HCl, and 6 mL HF [6]. The microstructure was observed by Scanning Electron Microscope. The hardness in and around the welded zone was measured by a Rockwell machine with a ball indenter, 100 kg loading [7] (Fig. 6). The bending specimens were prepared according to ASTM E290 [8] (Fig. 7). The bending tests were performed by an Instron machine 3366, 10 kN at a constant strain rate of 2.0 mm/min.

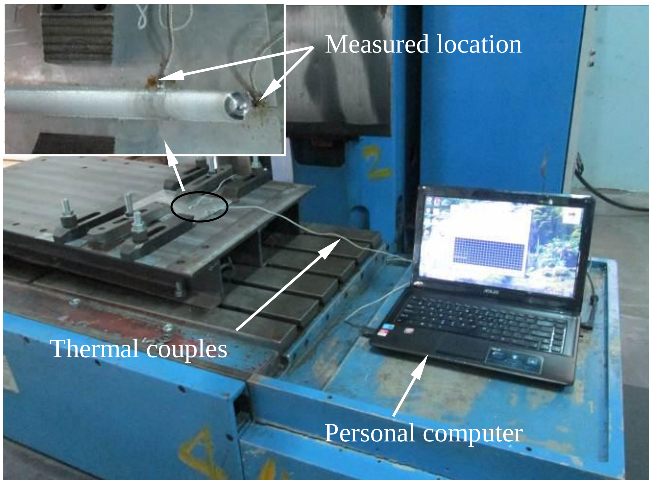

Fig. 5. Process measuring temperature.

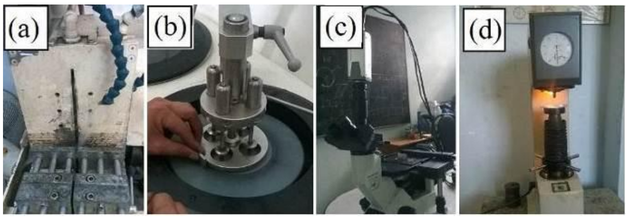

Fig. 6: Process of observing the microstructure and measuring hardness.

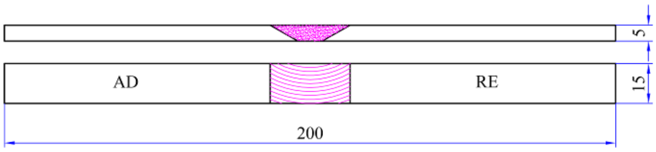

Fig. 7. Dimensions of the sub-size specimens.

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Temperature distribution

The temperature distribution within and around the stirred zone was important in explaining the microstructure of friction stir welded joints. It influences directly on grain size, grain boundary character, coarsening and dissolution of precipitates [9-12]. The results of temperature distribution measured at the retreating side and end weld center are shown in Fig. 8. The dependence of the peak welding temperatures on the rotation speed and the weld speed are shown in Fig. 9. It is shown that weld temperature increases with an increase in rotation speed or a decrease in weld speed. This increase can be generated by a combination of friction and plastic dissipation during the deformation of the metal. Therefore, when the rotation speed increases or weld speed decreases the friction that is created by the tool shoulder increased. Furthermore, the maximum weld temperature was found in the stirred zone in all cases and this temperature was lower than the melting temperature of the base metal as is shown by the dash-lines.

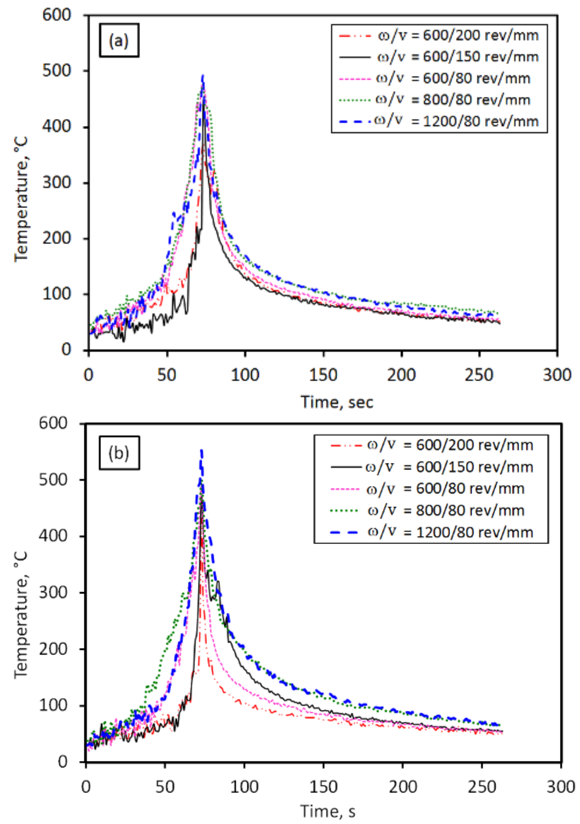

Fig. 8. Effect of weld parameters on the thermal cycle at the retreating side (a) and the end weld center (b).

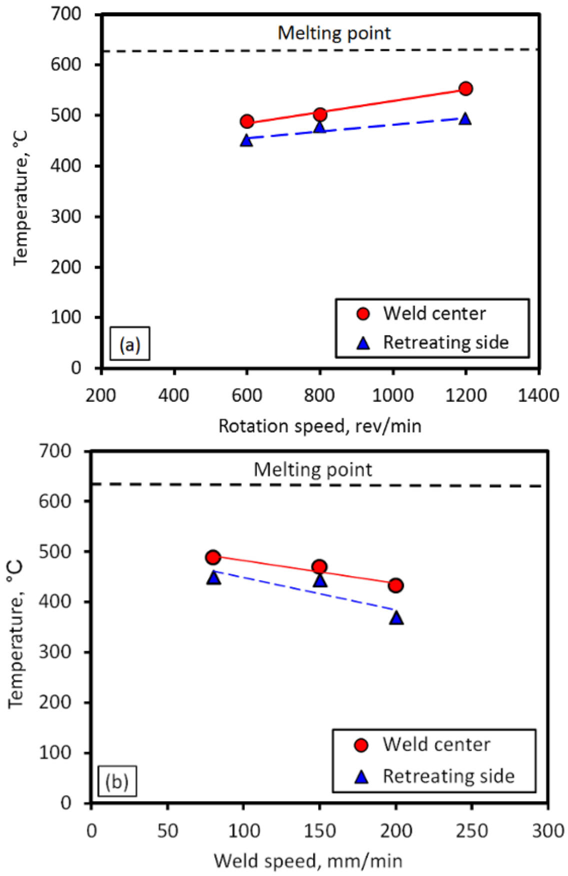

Fig. 9. Effect of rotation speed at v = 80 mm/min (a) and weld speed on peak temperature at ω = 600 rev/min (b).

B. Microstructure of the friction stir welded joints

The microstructure of the friction stir welded joints was observed by naked eye and microscope, and some defects were found. These defects occurred in the regimes of ω/v = 3.0 rev/mm and of 15.0 rev/mm and the defect size is about 500 µm (Fig. 10). The typical microstructure of a FSW AA7075-T6 when fabricated at ω/v = 10.0 rev/mm is characterized by the dynamic recrystallization was seen in Fig. 11. In general, the grains in the stirred zone (III) are finer than those in TMAZ (II) and HAZ (I). The average grain diameter in the region (I) where the material has undergone a heat cycle without plastic deformation is the same size as in the base metal (BM) about 25.2 µm (Fig. 11a). Region (II) where the material underwent plastic deformation due to the heating friction created by the shoulder tool, the average grain size appears to be finer than that in the zone (I). The average grain size here is about 10.8 µm (Fig. 11b). In the stirred zone (III), material was the most severely deformed during soldering at the highest heat. Therefore, average grain diameter is smallest about 6.4 µm compared with other regions (Fig. 11c).

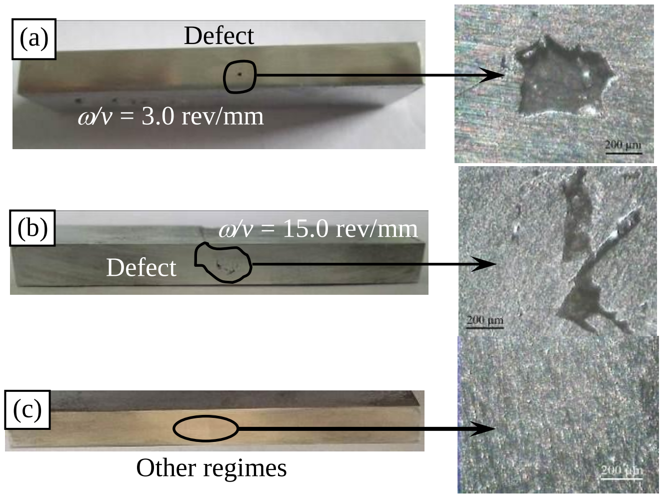

Fig. 10. The cross-sectional shape of the weld defect.

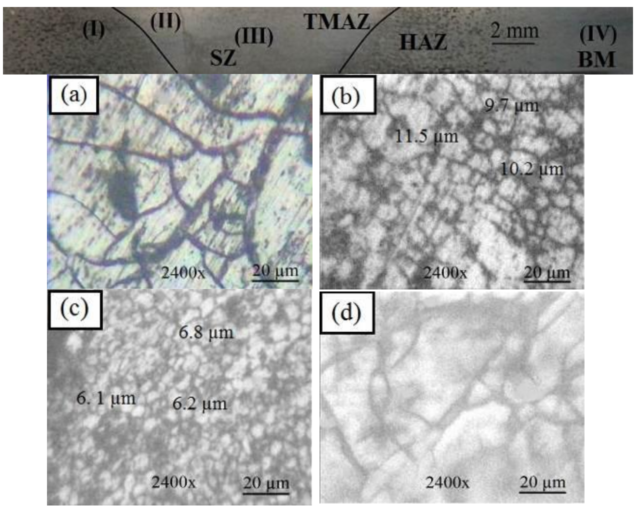

Fig. 11. Microstructure in the cross section of FSW at ω/v = 10.0 rev/mm.
(a) region (HAZ), (b) region (TMAZ),
(c) region (SZ), and (d) base metal (BM)

In addition, the optical micrographs taken at stirred zones of all the joints are shown in Fig. 12. From experimental results, it is understood that there is an appreciable variation in average grain diameter of the stir zone microstructure. The particle size depends on the ratio ω/v and the peak weld temperature presented in Fig. 13. The results shown that the grain size of the stirred zone increased when the ratio of ω/v rose. This elevation can be related to the welding temperature effects on microstructural properties of friction stir welding. This may be one of the reasons for mechanical properties of these joints such as tensile strength, hardness, bending strength, impact energy, etc.

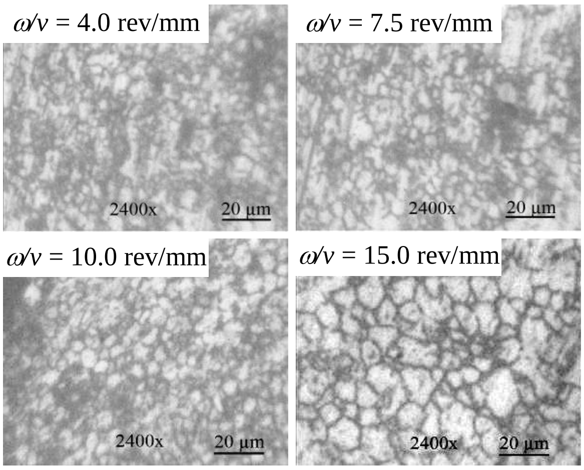

Fig. 12. Grain size of the stirred zone in the regimes.

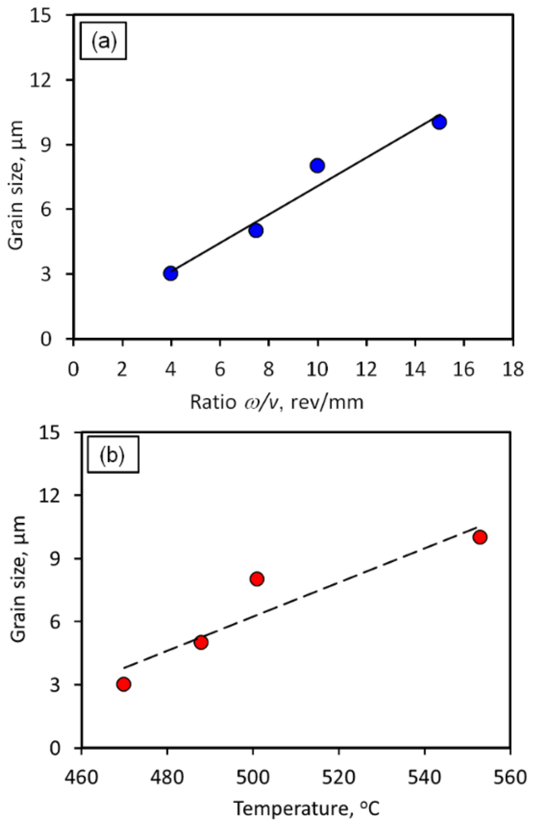

Fig. 13. Effect of ratio ω/v (a) and temperature (b) on grain size.

C. Hardness distributions

Hardness distributions were measured at mid thickness region across the weld (location 1) and away from that 2 mm. This value is presented in Fig. 14. The base metal recorded a hardness of 87 HRB, which is highest. The results showed that the hardness of the stirred zone is considerably higher than that of the HAZ and TMAZ irrespective of the welding speed used but lower than that of the base metal. It is one of the reasons that effect on hardness distribution of stirred zone is grain size. It can be seen that the grain size of stirred zone is much finer than that of others zone. So, according to the Hall–Petch equation, hardness increases as the grain diameter decreases [7]. Hardness at the location 1 is higher than at the location 2 but being the difference is not significant.

The hardness distributions measured at the middle-line in the cross sections are shown in Fig. 15. In general, a softened area around the welded zone is observed in all FSWs. The width of the soft zone increases with an increase of ω/v. The softening appearing in and around the welded zone could be related to the dissolution and/or coarsening of precipitates in this alloy [12]. It was also found that, in all cases, the lowest hardness in the cross section of the FSW is located in the heat affected zone (HAZ) in the advancing side and/or retreating side, outside the stirred zone. The fact that the hardness in the stirred zone is higher than that in HAZ might be associated with high density of grain boundaries in the stirred zone or Hall Petch effect [7].

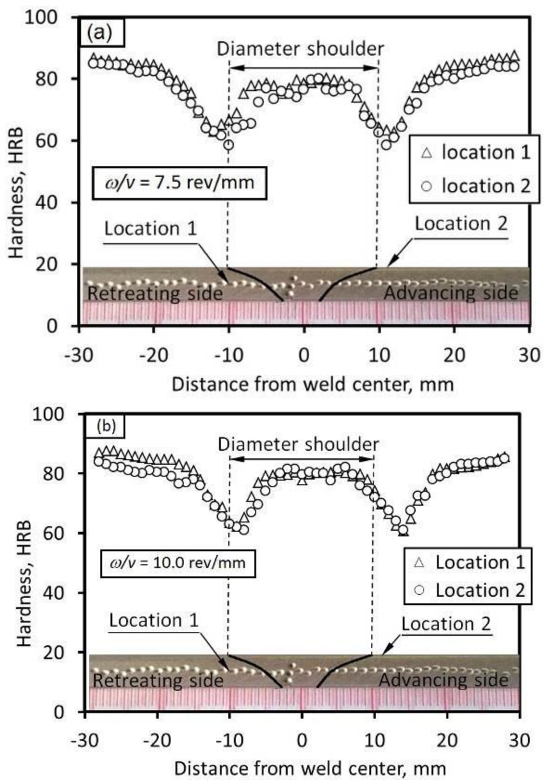

Fig. 14. Hardness distribution in the cross section of the weld at ω/v = 7.5 rev/mm (a) and ω/v = 10.0 rev/mm (b).

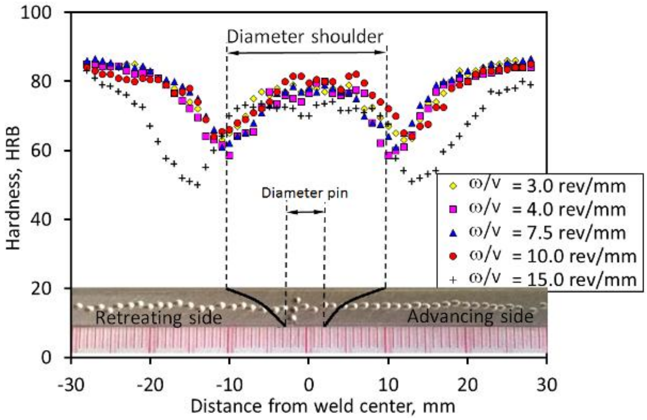

Fig. 15. Hardness distributions measured at the middle-line.

D. Bending strength

In order to retrieve the data that is basic to test the quality of welds base metal were investigated and the values are tabulated in Table 3. The results showed that AA7075-T6 aluminum alloy was brittle and cracked when the angle of bending was approximate 70º (Fig. 16). The experimental bending results for the different regimes are listed in Table 4.

Table 3. Bending strength for base aluminum alloys.

Material	Angle of bending	Bending strength	Remarks
AA7075-T6	70º	701.22 MPa	Cracks

Fig. 16. Bend tested base alloys AA7075-T6.

Table 4. Bending strength for experimental combinations.

Ratio ω/v (rev/mm)	Average of bending strength (MPa)	Average of flexure strain at maximum flexure load (%)	Remarks	Angle of bending (º)
3.0	638.54	2.38	Cracks	30
4.0	796.00	4.14	No cracks	90
7.5	841.67	4.27	Cracks	65
10.0	731.30	2.30	Cracks	24
15.0	43.68	0.41	Cracks	5

Fig. 17 shows bending behavior of friction stir welding AA7075-T6 that is cracked after testing. It can be seen that the most of testing specimens are broken with a small angle of bending. One of the reasons that effect on bending strength is temperature. With the regime of ω/v = 3.0 rev/mm the temperature increase was not enough to soften the base material, the materials were not sufficiently plasticized to be stirred and forged easily. Since the joints are defect and bending strength decrease. However, the high temperature also will impact on joint not well, such as the regime of ω/v = 15.0 rev/mm. This joint is very brittle since bending strength and angle of bend are low.

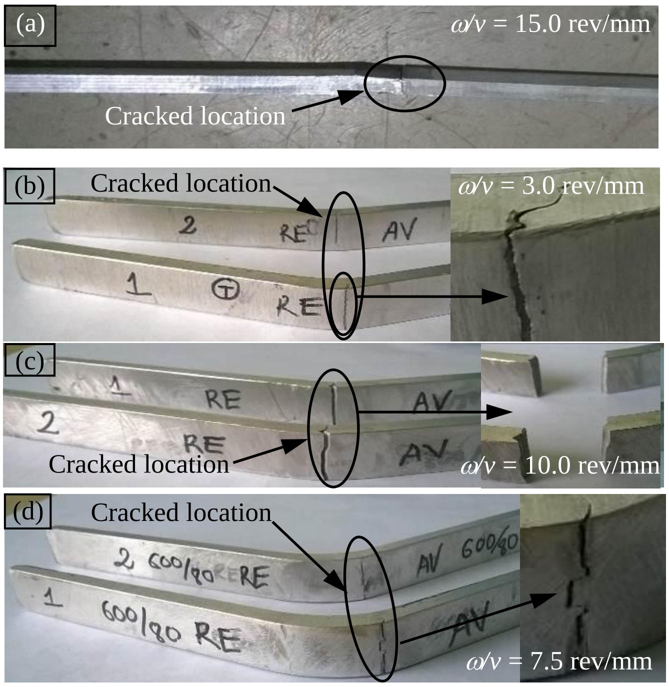

Fig. 17. Bending fracture locations in the FSWs.

Finally, the regime of ω/v = 4.0 rev/mm is the best bending behavior. With this mode, the joint does not crack despite considerable angle of bend 90°. Specially, the bending strength and toughness are better than that of base metal (Fig. 17).

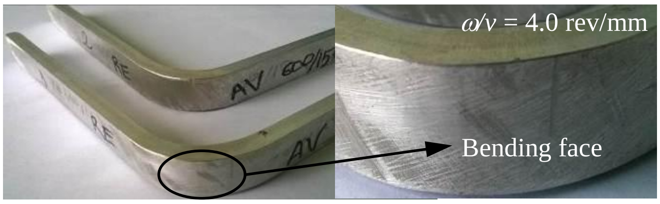

Fig. 18. Bending face of the regime ω/v = 4.0 rev/mm.

The ductility of the welds in the regimes is shown in Fig. 19. In the two modes of welding with ω/v = 10.0 and 15.0 rev/mm was very brittle welds. They are cracked and broken easily with a small angle of bend. This can be relative to the temperature that is created by welding parameter. However, the welds in two regimes of ω/v = 4.0 and 7.5 rev/mm are more supple than that of ω/v = 10.0 and 15.0 rev/mm with the angle of bending 90º and 65º, respectively. The effects of welding parameter on angle of bending and toughness are shown in Fig. 20. In general, the bending toughness decreases when the ratio ω/v increases. It can be seen that the change in microstructure had a significant influence on the mechanical properties of the joint.

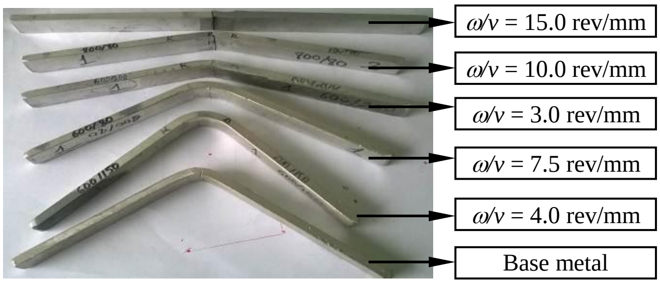

Fig. 19. The toughness of the regimes.

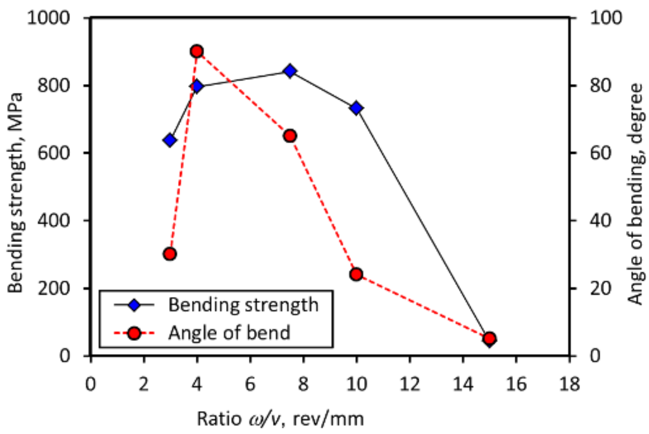

Fig. 20. Effect of welding parameter on bending strength and the angle of bending.

IV. CONCLUSIONS

Friction stir welds of aluminum alloy AA7075-T6 were successfully fabricated and have reasonably identified welding regimes on criteria not defect structure and the best flexural strength. The effects of welding parameters on temperature, microstructure, hardness, and bending behavior were investigated.

1. The heat input was found to be proportional to the ratio of tool rotation speed to welding speed *ω/v*.
2. The microstructure of the friction stir welded joints isn't defect when the ratio of rotational speed to welding speed *ω/v* is in the range from 4.0 rev/mm to 10.0 rev/mm.
3. When the ratio *ω/v* increases the grain size of the stirred zone rise but the bending toughness decreases.
4. The ratio *ω/v* = 4.0 rev/mm is the toughest in the regimes even base metal.

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