EFFECT OF PROBE LENGTH ON TENSILE STRENGTH OF DISSIMILAR FRICTION STIR WELDED LAP-JOINT BETWEEN AA6061 AND 316 STAINLESS STEEL USING MARINE STRUCTURE

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ABSTRACT

Recently, optimizing marine structure have been facing with a lot of challenges to reducing weight, increasing strength, and improving resistance corrosion. Using dissimilar joint may be one of the suitable solutions for manufacturer. In this study, dissimilar lap-joints between aluminum alloys 6061 and 316 stainless steel was produced by friction stir welding technology. The attention was put on the effect of different probe lengths on joint strength. The probe length was arranged from 2.7 mm to 2.9 mm. The experimental results show that the tensile strength of lap-joints increased with long probe length. The highest tensile strength is obtained approximately 6976 at the probe length of 2.9 mm that fracture location was found at aluminum side. The impact of interface properties on the joint strength was investigated and analyzed in this work.

Key works: *Dissimilar joint, FSW, probe length, tensile strength.*

I. INTRODUCTION

The automotive, aerospace, offshore and shipbuilding industries are looking for lightweight and low cost materials to manufacture. Aluminum alloys is a low cost, light metal and are often used in the aircraft and aerospace industry widely [1]. Stainless steel used in the dairy, seafood and food industries has high corrosion resistance and durability [2]. However, the price of stainless steel is expensive. The combination of aluminum alloys and stainless steel is considered as a suitable solution for these issues. The application of dissimilar joint between aluminum alloy to steel was used in fishing boat (Fig. 1). In spite of this, the difference in material properties of aluminums and stainless steel is big challenge in welding technology. In fact, the joint produced by traditional fusion welding [3]. Currently, friction stir welding (FSW) is considered as advanced technology in joining dissimilar metal [4-11]. The structures of ferry and cruise ships have been fabricated by FSW method. Besides, lap-joints between aluminum AA5083 and DH36 steel by FSW are produced in the ship-building industry [12]. Reduced weight helps the ship move at higher speeds, thus reducing fuel consumption. Therefore, it contributes to reducing environmental pollutants.

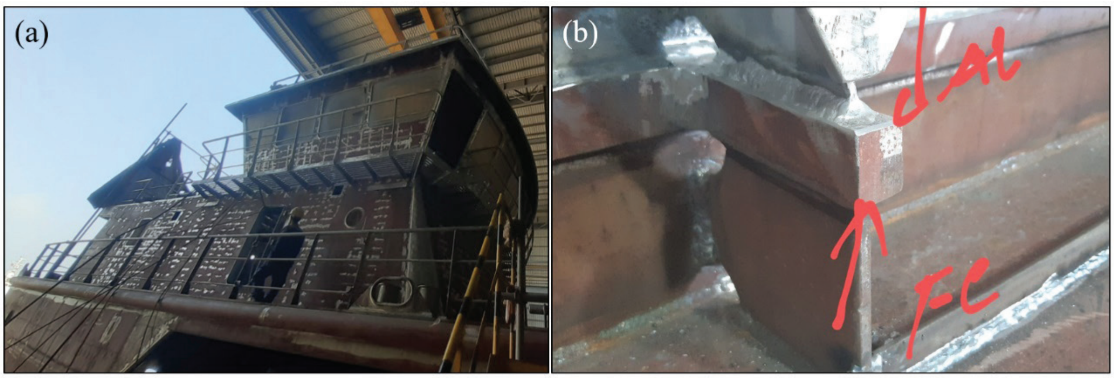

Fig. 1. Application of dissimilar joint between aluminum alloy to steel in fishing boat.

The role of probe length in interface formation of FSWed T-lap joint was investigated in former research [13]. The results show that changing probe length would lead to significant difference in interface morphology. Yanxin Zhang et al. studied lap-joints of AA2024-T4 with different thickness [14]. Tensile strength decreased via the increasing pin length from 2.7 mm to 3.1 mm. The effect of pin length on FSWed lap-joints between aluminum alloys AA6063 and galvanized low carbon steel was investigated by Joaquin M. Piccini and Hernan G. Svoboda [15]. The highest tensile strength of the joint increased when pin penetration increased and pin length decreased. Increasing the pin length will increase the heat input of joint and affect the formation of diffusion layer of 430/304 stainless steels lap-joints [16].

From over views, the probe length might keep an important role in FSWed joint strength. However, its effect on FSWed lap-joints of AA6061/316 SS is limited in literature. In this paper, the effect of pin length on the tensile strength of FSWed AA6061/316 SS lap-joints is investigated and analyzed in detail.

II. EXPERIMENTAL PROCEDURES

Aluminum alloys 6061 and 316 stainless steel was welded lap-joints by friction stir welding. Thickness of aluminum alloys and stainless steel are 3.0 mm and 1.0 mm, respectively. The location of them is shown in Fig. 2. The welding tool is a cylindrical with non-thread pin and was made of SKD11 steel. The pin length was arranged from 2.7 mm to 2.9 mm.

The microstructure specimen was extracted perpendicularly to welding line. After polishing by abrasive paper and alumina, the microstructure was observed by mean of microscope, scanning electron microscope (SEM), and Energy-dispersive X-ray spectroscopy (EDS). Tensile test specimen with dimensions is shown in Fig. 3. Testing process was performed universal Instron 3366 machines at 1.0 mm/min.

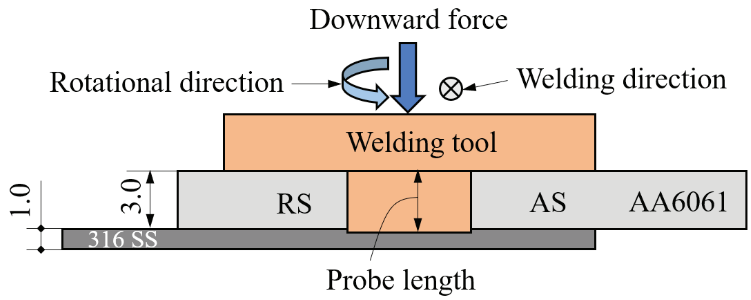

Fig. 2. Overview of FSWed lap-joints [17].

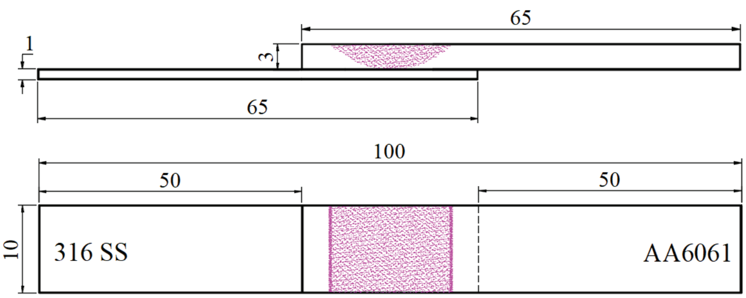

Fig. 3. Geometry of tensile specimen (unit in mm).

III. RESULTS AND DISCUSSION

1. Lap-joint geometry

The welding surface of joints by different pin lengths is shown Fig. 4. There is not any crack observed on welding surface. However, some flash defects were found in Fig. 4(c). It seems that increasing pin length would lead to increasing heat input that is reason for this result.

Fig. 4. Welding surface of the joint by different pin lengths: (a) 2.7 mm, (b) 2.8 mm, (c) 2.9 mm.

2. Microstructure and interfacial bonding

The grain microstructure at stir zone produced by different pin length is shown in Fig. 5. The coarse grain size was produced by the pin length of 2.9 mm (Fig. 5(c)). This result can be contributed by increasing welding temperature corresponding to extending pin length.

SEM images of the lap-joints interface produced by various pin lengths are shown Fig. 6. The oxide layer appeared on the welding interface produced by the pin length of 2.7 mm (Fig. 6(a)). With increasing the pin length, this phenomenon was reduced significantly, as seen in Fig. 6(c). This result might relate to increase in effective stirring action that depend on the pin length [13]. Increasing the length of pin would lead to breaking the oxide layer along the welding interface. In addition, the intermetallic compunds (ICMs) was also formed at the longer pin length of 2.9 mm (Fig. 6(c)).

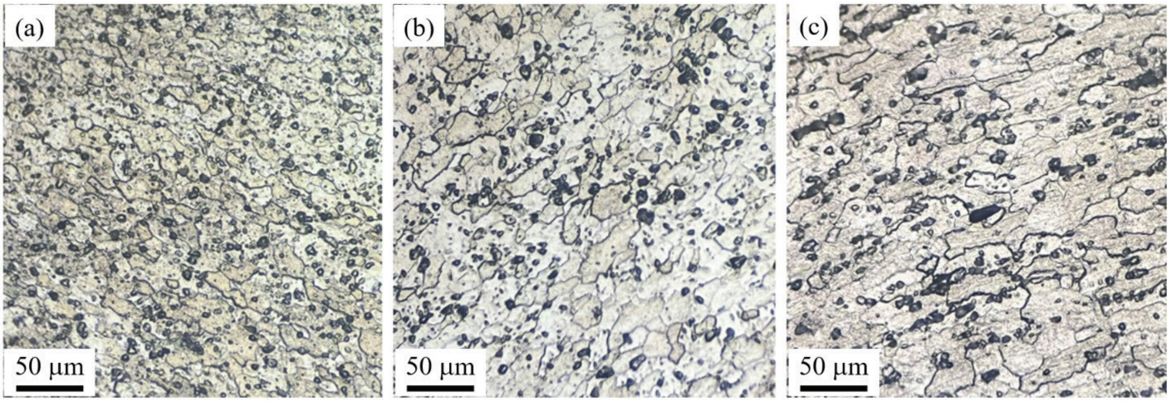

Fig. 5. Microstructure of aluminum alloy under different pin lengths.

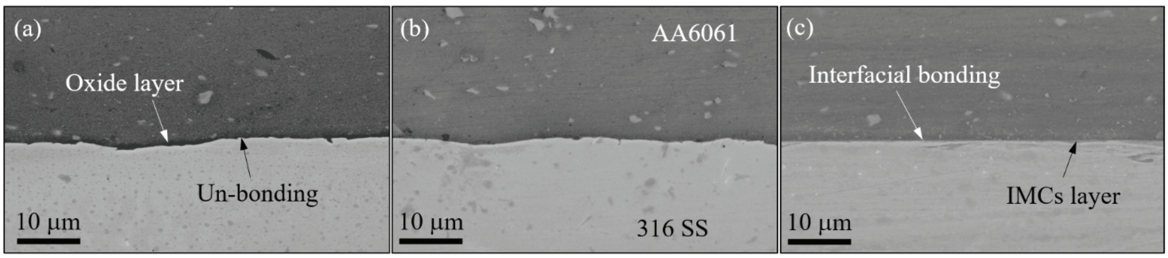

Fig. 6. SEM images of the interface produced by different pin lengths: (a) 2.7 mm, (b) 2.8 mm, and (c) 2.9 mm.

The diffusion layer of the joint interface created by different pin lengths is shown in Fig. 7. The highest thickness value of diffusion layer was 4.4 µm at the pin length of 2.9 mm, as seen in Fig. 7(b). As the pin length increased, the diffusion layer thickness increased from 2.2 mm to 4.4 mm. The change in diffusion layer thickness can affect to the tensile strength of the lap-joints, as reported in previous work [17].

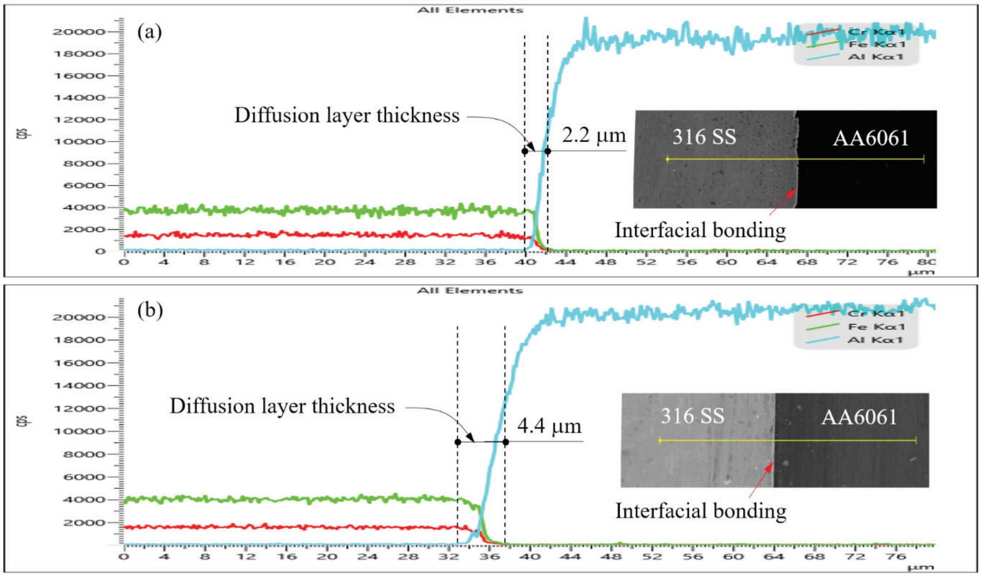

Fig. 7. EDS line analysis of diffusion layer thickness by different pin lengths: (a) 2.7 mm and (b) 2.9 mm.

3. Tensile strength

The tensile strength of the joints produced by the different pin lengths is depicted in Fig. 8. The lowest joint strength was reached at the pin length of 2.7 mm, which the fracture location took place at the welding interface (Fig. 9(a)). As shown in Fig. 8, increasing the probe length improved the joint strength. The highest tensile strength of the lap-joints was obtained approximately 6976 N at the pin length of 2.9 mm. In this case, the joint specimen was broken in the heat affected zone (HAZ) on the aluminum side, as shown Fig. 9(b). The good interface might be reason for this result, as seen in Fig. 6(c).

The fracture surface of the joint is shown in

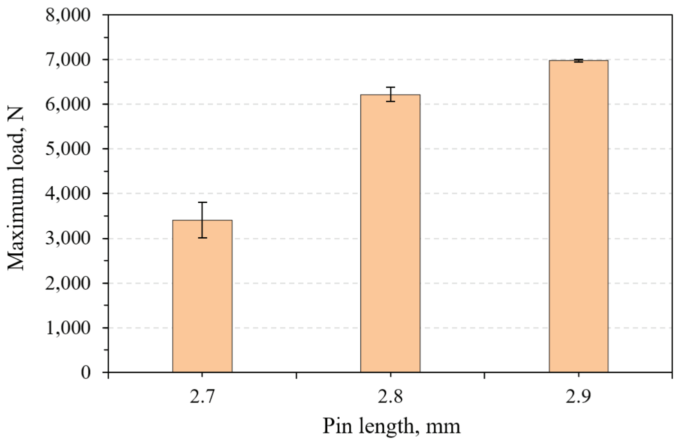

Fig. 8. The effect of pin lengths on tensile strength of the lap-joints.

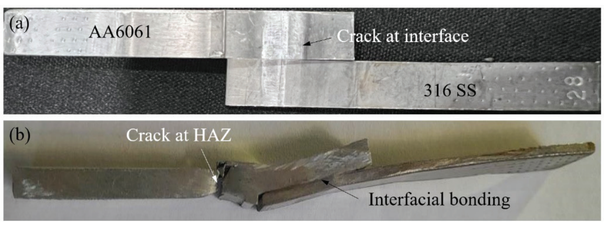

Fig. 9. The fracture location at pin length of (a) 2.7 mm and (b) 2.9 mm.

Fig. 10(a). Bonding area produced by the pin length of 2.7 mm is low, as seen in Fig. 10(b), resulting in low tensile strength. Bonding area increased via increasing pin length. This result might affect significantly the lap-joints strength, as presented in Fig. 8. The similar result was also found in [17].

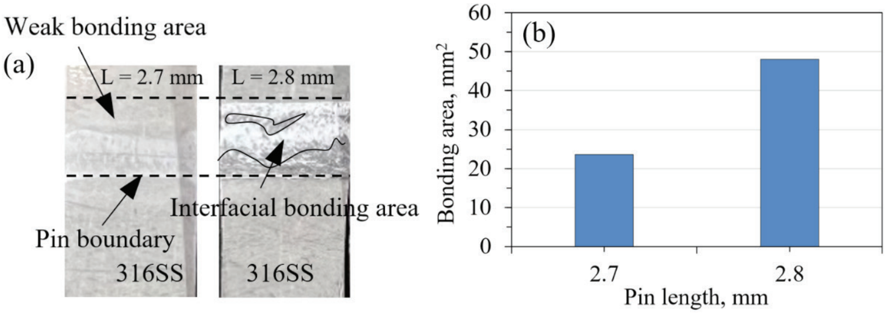

Fig 10. Effect of pin length on bonding area.

IV. CONCLUSIONS

Aluminum alloys 6061 and 316 stainless steel are friction stir welded via lap-joint configuration by the various pin lengths. Some results were obtained as followings:

- The interfacial bonding with IMCs layer was detected at the longer pin length. The diffusion layer thickness increased corresponding to extending pin length.
- Increasing probe length is useful for improving the joint strength of lap-joints of AA6061/316 SS. The highest tensile strength is 6976 N at the pin length of 2.9 mm which was broken in the HAZ of aluminum side.
- Based on fracture surface, the bonding area significantly affected the lap-joint strengths, which was obtained by the pin length of 2.9 mm.
- The obtained results might bring about a potential application in marine structure.

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