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Effect of Pin Profile on Defects of Friction Stir Welded 7075 Aluminum Alloy

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Abstract

In this work, effect of the pin profile on defects of FSWed 7075 alloy was investigated. Three pins with cylindrical, square and triangle geometry were used for welding. Microstructure of the welding zone showed that the tunnel hole produced by triangle pin has smaller dimensions compared to cylindrical pin. On the other hand, results of optical microscope indicated that the size of grains resulted from square pin is smaller than the other kinds of tools. Also, the results showed that when the pin is cylindrical, tunnel, kissing bond, and zigzag line defects are formed. On the other hand, when the pin is triangle, original joint line with severe plastic deformation and crack defects are created.

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Keywords: 7075 Al alloy; Friction stir welding; Pin profiles; Defects

1. Introduction

Over the years FSW has increased significance for joining such as aluminum alloys as the heat produced during the process is not severe enough to produce the defects which are generally observed in these materials during fusion welding, Thomas et al. (1999). Rotational speed of the tool, tool traverse speed, and vertical pressure on the plates during welding are the main process parameters of FSW, Rajakumar et al. (2010). However the tool geometry which includes the geometry of the FSW tool shoulder and tool pin probe profile is also a significant characteristic which affects the weld strength. Therefore, study of the FSW process also includes the investigation and study of tool

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characteristics, Su et al. (2003). The effectiveness of an FSW joint is strongly affected by several tool parameters; in particular, geometrical parameters such as the height and the shape of the pin (cylindrical, trapezoidal, screwed, etc.) has a related influence on the metal flow and on the heat generation due to friction forces, Leal et al. (2008), Querin et al. (2009), Rai et al. (2011), Zhang et al. (2012). The FSW tool is a critical part of this welding process. Dawes and Thomas (1999) defined in detail the tool development approach taken at The Welding Institute and outlined the tool design aspects of the scroll shoulder concept. While there have been several studies focused on the variation of rotation and welding speeds to optimize the welding parameters and study their microstructures for aluminum alloys, limited research has been carried out on the effects of tool structure, Leal et al. (2008), Barcellona and Buffa (2004), Boz and Kurt (2004). A large majority of research conducted on the FSW process has focused specifically on visualizing the material flow around the FSW tool, Guerra et al. (2002). It is well understood that plastically deforming material is forced to flow in the direction of tool rotation from front to the rear of the FSW tool. Even though some work has been done in contemporary literature on the study of the tool shoulder and probe profile, a comparative detailed study of different basic tool features for a given material is rarely found. There is, therefore, a need to systematically investigate the effect of tool pin profile geometries on the FSW weld. In this study, the effects of various tool geometries on mechanical properties, microstructural characteristics and defects of the welded joint made from 7075 aluminum alloy were studied.

2. Experimental

5 mm thickness 7075-T6 Al alloy plate with chemical composition of Al-5.7 Zn-2.4 Mg-1.55 Cu-0.19 Cr-0.18 Fe (in wt.%) was used as base material. The tools are shown in Fig. 1. The welding and rotation speeds were 63 mm min-1 and 1600 rpm, respectively. The microstructure of the specimens was studied by using optical (OM) and electron microscopes (SEM). An Olympus BX60M optical microscope and a VEGE/TESCAN-XMU field emission scanning electron microscope (FESEM) were used to examine the microstructure of the joints. Fracture surfaces of the FSWed specimens after tensile test were examined with FESEM.

3. Results

In fusion welding of aluminum alloys, the defects like porosity, hot crack etc. depreciates the weld quality and joint properties. Usually, friction stir welded joints are free from these defects since there is no melting takes place during welding and the metals are joined in the solid state itself due to the heat created by the friction and flow of metal by the stirring action. However, FSW joints are disposed to other defects like tunnel defect, cracks, pinhole, piping defect, kissing bond, etc. due to unsuitable flow of metal and inadequate consolidation of metal in the FSW region, Elangovan and Balasubramanian (2007). As revealed in Fig. 2, five types of defects can be observed from the overall cross-sectioned samples. First, tunnel defects can be found in all of the samples that created with cylindrical and triangle tools. Second, kissing bond and zigzag defects can be found in joints that created with cylindrical tool. Third, crack and OJLwSPD defects can be found in the advancing side of joints that created with triangle tool. But, for joints that created with square tool all of the as welded specimens were sound. Also, fracture surfaces of the tensile samples were investigated by scanning electron microscope (SEM). It should be noted that different failure patterns could be caused by different defects distributions. Therefore, representative tensile fracture surfaces of the samples are shown in Fig. 3. From the fractured surface analysis, it can be inferred that the defect free welds are showing uniform deformation across the weld before failure.

Fig. 1. FSW tool pin profiles.

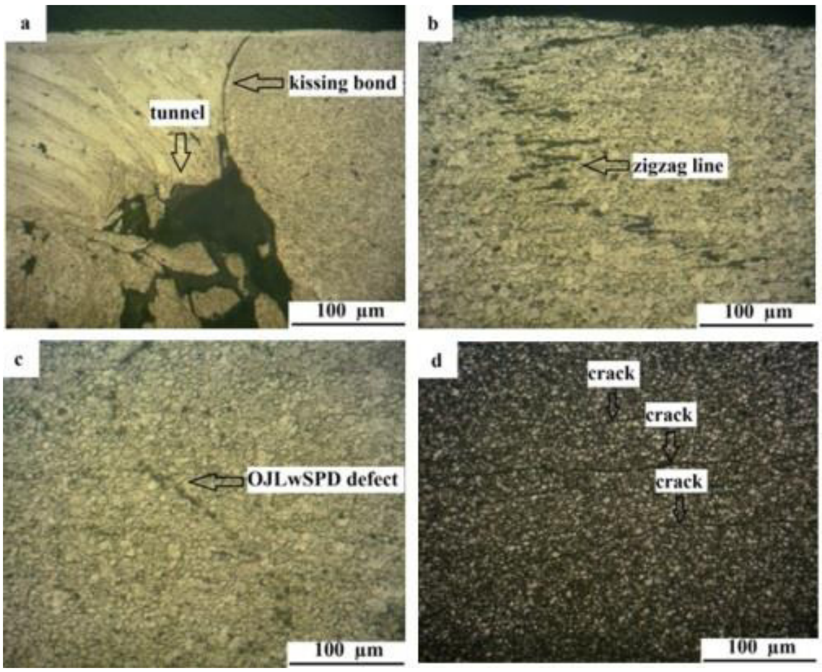

Fig. 2. Optical microscopic observations of defects in the weld zone; (a),(b) cylindrical; (c),(d) triangle.

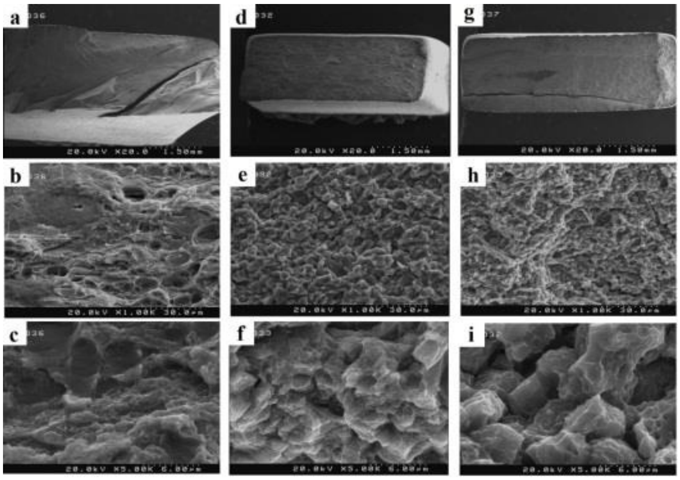

Fig. 3. (a) Fracture surface of tensile specimen that created with cylindrical pin; (b),(c) Higher magnification; (d) SEM image of the fracture surface that generated by square pin;(e),(f) Higher magnification; (g) SEM fractographs of tensile tested specimen that formed with triangle pin; (h),(i) Higher magnification.

4. Discussion

Pin profile plays a critical role in material flow and in turn regulates the welding speed of the FSW process. Pin profiles with flat faces (square and triangle) are associated with eccentricity, Elangovan and Balasubramanian (2007), Thomas Nicholas (1997). In addition, the triangle and square pin profiles produce a pulsating stirring action in the flowing material due to flat faces. There is no such pulsating action in the case of cylindrical pin profiles. It was reported that two representative defects namely tunnel and kissing bond were easy to form in FSW, Cui et al. (2012). In the present study, as mentioned above, these two kinds of defects could also be found in weld zone in cylindrical tool pin profile (Fig. 2a). According to the previous study, materials near the rotational tool probe can be divided into three regions, i.e. rotation layer, transition layer, and deflection zone, Schmidt et al. (2006). During FSW process, materials in these three regions present severe plastic deformation and flow with the rotation of the tool probe. Materials in advancing sides tend to flow forward of the tool probe, but, on the contrary, materials in retreating side tend to flow backward. On the other hand, material flow is asymmetric in advancing side and retreating side of the weld, Schmidt et al. (2006). Therefore, it can be considered that, during the welding process of FSW, cavities form preliminary in AS, and immediately, flowing materials in other regions fill these cavities to form a sound weld. If the full filament is insufficient or lagging, these cavities will remain inner the weld. As a result, when the welding process has finished, a tunnel defect forms inner the weld and distributes through longitudinal direction of the weld. Based on the experimental result, the formation of kissing bond is close correlated to the flow patterning of the materials inner the weld and the die radii cavity. Zigzag line and crack are characterized by a continuous curve on the etched cross-section of an FSW weld under the observation of optical microscope (OM). But under the transmission electron microscope (TEM) observation, numerous Al_2O_3 particles could be found around the zigzag line. Therefore, the zigzag line was generally regarded as the remnants of the oxide layer in the FSW welds by the previous investigators, Cui et al. (2012). In the present study, zigzag line was found in weld zone made up with cylindrical and triangle pin profile (Figs. 2b,2d). A distinct continuous dark line can be observed in Fig. 2c which shows the weld zone created with triangle tool pin profile. It could be considered as a bonding line that could also be found inner the welds lap joints, T-joints, and even in butt joints, Cao and Jahazi (2011), Oosterkamp et al. (2004), Ren et al. (2008). A relative new and proper expression of this kind of defects called original joint line with severe plastic deformation (OJLwSPD) defects, Cao and Jahazi (2011) is adopted by the author in this article. Main formation mechanisms and features of the OJLwSPD defect can be summarized as follows: first, the initial joining oxide surface between the two AA7075-T6 blanks is not completely destroyed during the welding process, Schmidt et al. (2006). Second, heat input and axial force result in the downward flow of the softened metals in the skin. Third, the material flow in retreating side and advancing sides around the tool probe is asymmetric. Material flow during FSW is a complex question and hard to be understood in nature, Schmidt et al. (2006), Reynolds (2008). In butt joints, OJLwSPD defects could be easily vanished by increasing the tool rotational speed and, meanwhile, decreasing the traverse speed, because of the increased heat input, Cui et al. (2012). During tensile test, most of the specimens failed in the weld zone. Fig. 3 shows the fracture surfaces of the samples in different conditions. From the macroscopic view of the fracture surface (Fig. 3b), a uniform rough surface can be observed. Magnified SEM morphology is shown in Fig. 3c. Ductile fracture with void nucleation and coalescence is distinct in this micrograph. From the overall observation of the fracture surface on stringer of sample created with square pin, as shown in Figs. 3d, e, f it can be considered that ductile failure occur under the action of axial tensile stress. Under a higher magnification of observation (Figs. 3e and 3f), it can be recognized that the main failure mechanism is transgranular fracture. For the sample created with triangle pin (Figs. 3g, h, i), which is similar to (Figs. 3d, e, f) it can be recognized that the main failure mechanism is transgranular fracture.

5. Conclusion

The joints made-up using different tool pin profiles like cylindrical, square and triangle tool with a rotational speed of 16000 rpm, weld speed of 63 mm/min. The following important conclusions were made for the present study. Tunnel, kissing bond and zigzag line defects were observed in weld zone created with cylindrical, also, tunnel, OJLwSPD and crack defects were observed in weld zone created with triangle, but not any defects in samples created with square pin.

References

Barcellona, A., Buffa, G., 2004. Pin shape effect on friction stir welding of AA6082-T6 sheets. Proceedings of ICME 4, 499-502.

Boz, M., Kurt, A., 2004. The influence of stirrer geometry on bonding and mechanical properties in friction stir welding process. Materials & Design 25, 343-347.

Cao, X., Jahazi, M., 2011. Effect of tool rotational speed and probe length on lap joint quality of a friction stir welded magnesium alloy. Materials & Design 32, 1-11.

Cui, L., Yang, X., Zhou, G., Xu, X., Shen, Z., 2012. Characteristics of defects and tensile behaviors on friction stir welded AA6061-T4 T-joints. Materials Science and Engineering: A 543, 58-68.

Dawes, C., Thomas, W., 1999. Development of improved tool designs for friction stir welding of aluminium. Proceedings of the First International Conference on Friction Stir Welding, 2-6.

Elangovan, K., Balasubramanian, V., 2007. Influences of pin profile and rotational speed of the tool on the formation of friction stir processing zone in AA2219 aluminium alloy. Materials Science and Engineering: A 459, 7-18.

Guerra, M., Schmidt, C., McClure, J., Murr, L., Nunes, A., 2002. Flow patterns during friction stir welding. Materials Characterization 49, 95-101.

Leal, R., Leitao, C., Loureiro, A., Rodrigues, D., Vilaça, P., 2008. Material flow in heterogeneous friction stir welding of thin aluminium sheets: effect of shoulder geometry. Materials Science and Engineering: A 498, 384-391.

Oosterkamp, A., Oosterkamp, L. D., Nordeide, A., 2004. Kissing bond phenomena in solid-state welds of aluminum alloys. Welding Journal 83, 225.

Querin, J., Rubisoff, H., Schneider, J., 2009. Effect of weld tool geometry on friction stir welded Ti-6Al-4V. Trends in Welding Research (ASM International, Materials Park). 108-112.

Rai, R., De, A., Bhadeshia, H., DebRoy, T., 2011. Friction stir welding tools. Science and Technology of Welding and Joining 16, 325-342.

Rajakumar, S., Muralidharan, C., Balasubramanian, V., 2010. Optimization of the friction-stir-welding process and tool parameters to attain a maximum tensile strength of AA7075–T6 aluminium alloy. Journal of Engineering Manufacture 224, 1175-1191.

Ren, S., Ma, Z., Chen, L., 2008. Effect of initial butt surface on tensile properties and fracture behavior of friction stir welded Al–Zn–Mg–Cu alloy. Materials Science and Engineering: A 479, 293-299.

Reynolds, A., 2008. Flow visualization and simulation in FSW. Scripta Materialia 58, 338-342.

Schmidt, H. N. B., Dickerson, T., Hattel, J. H., 2006. Material flow in butt friction stir welds in AA2024-T3. Acta Materialia 54, 1199-1209.

Su, J. Q., Nelson, T., Mishra, R., Mahoney, M., 2003. Microstructural investigation of friction stir welded 7050-T651 aluminium. Acta Materialia 51, 713-729.

Thomas, W., Nicholas, E., 1997. Friction stir welding for the transportation industries. Materials & Design 18, 269-273.

Thomas, W., Threadgill, P., Nicholas, E., 1999. Feasibility of friction stir welding steel. Science Technology Welding 4, 365-372.

Zhang, Y., Cao, X., Larose, S., Wanjara, P., 2012. Review of tools for friction stir welding and processing. Canadian Metallurgical Quarterly 51, 250-261.