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Rotating extrusion technique and its effect on quality of aluminum alloy thin-plate weldments

LI Jun(李 军), YANG Jian-guo(杨建国), YAN De-jun(闫德俊),
ZHANG Yong(张 勇), FANG Hong-yuan(方洪渊)

State Key Laboratory of Advanced Welding Production Technology, Harbin Institute of Technology,
Harbin 150001, China

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Abstract: A new technique named rotating extrusion was proposed that uses rotating extrusion action to rectify residual distortion of aluminum alloy thin-plate weldments to improve mechanical properties of welded joints. The basic principle and device of rotating extrusion were introduced. The residual distortion and stresses in rotating extrusion weldments were compared with those in conventional weldments. The differences in microstructure and mechanical properties between conventional welded joints and rotating extrusion welded joints were investigated and analyzed in order to make clear the effect of rotating extrusion on the performance of aluminum alloy weldments. Experimental results show that rotating extrusion can enhance the hardness and tensile strength of aluminum alloy welded joints evidently. This method has also potential effect on extending the life of welded structures.

Key words: rotating extrusion; aluminum alloy; thin plate; welding distortion; mechanical property

1 Introduction

In recent years, there has been a tendency towards lightweight transport vehicles, enthusiastically encouraged by the requirements for global environmental protection and energy conservation[1−2]. The use of lightweight materials, such as aluminum and its alloys, is most effective in reducing the weight of automobiles. Aluminum-based light alloys are found their place not only in transport vehicles, but also in aircraft constructions and other branches of industry due to their advantageous combination of physical, mechanical, anticorrosive and processing properties[3−7]. But, the welding deformation of aluminum alloys is one of the crucial detriments that go against fabrication accuracy. Especially, in the fabrication of aluminum alloy thin-plate weldments, the buckling distortion affects the performances of welded structures in many ways[8−11]. Besides, there are usually numbers of air holes in welded joints of aluminum alloys, which weakens mechanical properties of welded structures seriously. The tensile property of aluminum alloy welded joints is only 50%−70% that of base metals[12].

In order to rectify residual distortion of aluminum alloy weldments, some mechanical methods, such as rolling[13], peening and thermal tensioning[14] are among the often adopted processes. All these methods have definite controlling effect on reducing welding deformation, but problems including high production cost, loud working noise, complex process procedure and so on arise. And some of them are incapable of improving mechanical properties of welded joints. Rotating extrusion(RE) is a new technology developed for solving welding problems of aluminum alloy thin plates. This method features simple device and friendly working environment, and has evident effect on reducing welding distortion and enhancing mechanical properties of welded joints. In this work, the basic principle and device of RE are introduced first, then by taking 2A12T4 aluminum alloy as research material, the controlling effects of RE on welding residual stresses and distortion are revealed. Finally, the microstructure and mechanical properties of RE welded joints are observed and tested in comparison with those of conventional welded joints.

2 Basic principle and device of RE

Bucking distortion in a welded thin-plate structure is the result of non-uniform expansion and contraction of

Corresponding author: LI Jun; Tel/Fax: +86-20-37238052; E-mail : lijun20066002@sina.com.cn
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weld metal and surrounding base material during welding, caused directly by residual tensile stress resulting from residual compressive plastic strain in and around the weld. So, the way to mitigate or eliminate bucking distortion of thin-plate weldments is to decrease or eliminate the residual tensile stress existing in the weld and its neighboring zone. Based on this viewpoint, rotating extrusion method was developed and its basic principle is shown in Fig.1, where an extrusion head is pressed and rotated against the surface of metals in and around the weld when the weldment moves towards a given direction with an invariable speed.

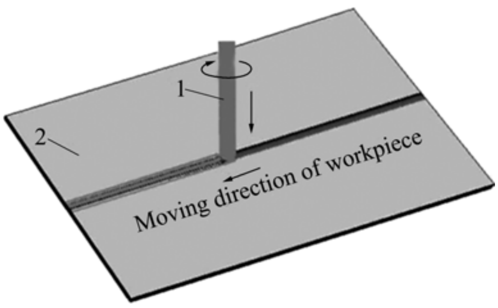

Fig.1 Basic principle of rotating extrusion (1 Extrusion head; 2 Welded piece)

In the process of RE treatment, the RE tool stretches the metals in and around the weld in longitudinal and traverse directions to produce tensile plastic strain that can reduce or even counteract residual compressive plastic strain. As a result, the residual tensile stress existing in and around the weld is decreased or even changed to compressive stress. Therefore, the buckling distortion of thin-plate weldments is mitigated or even basically eliminated due to the decrease of welding-induced residual tensile stress.

RE tool is a columned extrusion head, as shown in Fig.2. The working end face of extrusion head is a circular plane with round edge. The design of round edge is to avoid generating excessive stress concentration at the boundary between extruded surface and untouched surface. RE tool is made of material with superior high-temperature properties. In this work, heat-treated W9Mo3Cr4V was used.

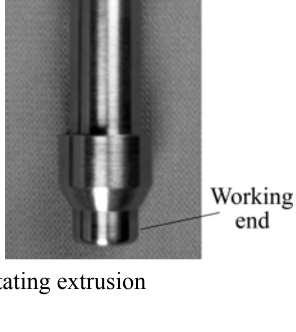

Fig.2 Tool of rotating extrusion

RE device used in this study is shown in Fig.3. It was rebuilt from a vertical milling machine. A common vertical milling machine can be easily refitted into rotating extrusion device if only replacing milling cutter with an extrusion head and fixing a restraint fixture on its working table. In Fig.3, the AC electromotor with power of 2.2 kW provides rotary power for extrusion head and the pressure exerted on the surface of workpiece comes from the mechanical driving force of screw pair and the weight of mill head.

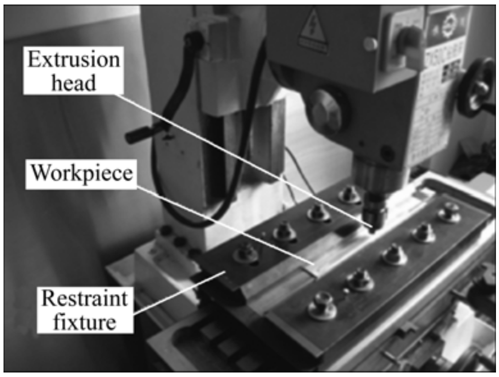

Fig.3 Device of rotating extrusion

3 Effect of RE on welding residual stresses and distortion

Fig.4 and Fig.5 give comparison between conventional weldment and RE weldment in terms of residual distortion and stresses, respectively. All specimens were made of 2A12T4 aluminum alloy sheet of 2 mm in thickness, 150 mm in width and 350 mm in length. Alternating argon tungsten-arc welding heat source was adopted to heat whole sheet along the midline of plate in width without filler metal to produce stresses and distortion.

Fig.4 shows that the distortion of RE weldment is hardly visible with a maximum longitudinal deflection of merely 0.26 mm, 2.32% that of conventional weldment.

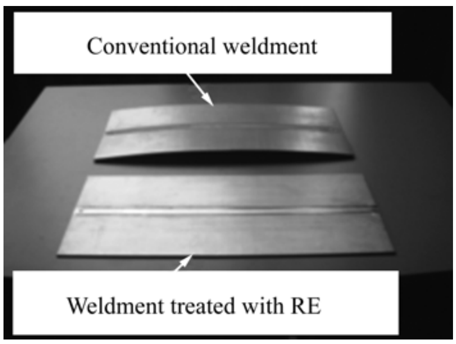

Fig.4 Comparison of residual distortion between conventional weldment and RE weldment

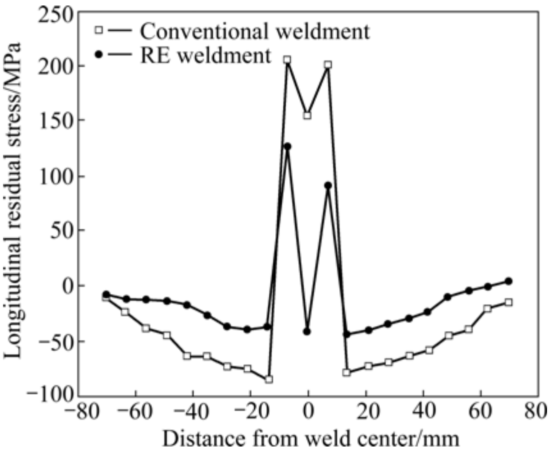

Fig.5 Comparison of longitudinal residual stresses of mid-section between conventional weldment and RE weldment

In Fig.5, the longitudinal residual stresses of both conventional weldment and RE weldment were measured in the middle sections of weldments by reliable stress-free method. It can be seen that the longitudinal residual stress of RE weldment is much lower than that of conventional weldment. The longitudinal residual stress in the weld center of conventional weldment is tensile stress with value of 153.7 MPa, while for RE weldment, the one in the weld center is compressive stress with value of 41.8 MPa. Experimental results credibly verify the effectiveness of RE method in reducing welding residual stresses. As for RE weldment, there is a gap of about 35 MPa between the peak tensile stresses in both sides of the weld. This may be attributed to the difference of plastic flow direction of metal on the surface of weldment under the drive of extrusion head.

4 Effect of RE on mechanical properties of welded joints

4.1 Experimental set-up

All test pieces used in this work were butt weldments of 2A12T4 aluminum alloy sheets by alternating argon tungsten-arc with Al-5%Si welding wire of 1.6 mm in diameter. Extrusion head used here has a diameter of 14 mm and a round edge of 1.5 mm as shown in Fig.6. During the operation of rotating extrusion, metals in and around the weld bear a pressure of about 3.5 kN exerted by extrusion head with rotary speed of 140 r/min. The travel speed of test pieces is 100 mm/min.

4.2 Microstructural variations

Fig.7 gives morphology comparison of cross sections between conventional welded joint and RE welded joint. It can be seen from Fig.7 that rotating extrusion can transfer stress concentration from weld toe

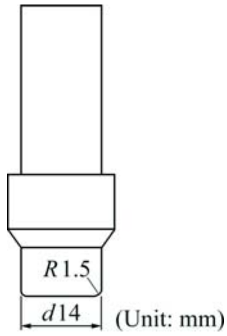

Fig.6 Dimension of extrusion head

to the surface of base metal, indicating that this technology has potential as an effective method for extending the life of welded structures because weld toe is the weakest position of welded joints. There is a layer of deformed texture, which is composed of squeezed and stretched grains, in area close to the upper surface of weld. The layer of deformed texture helps to increase the tensile strength of welded joints due to the aberrance of crystal lattices, multiply of dislocations and appearance of substructures [15]. However, RE treatment has little effect on the grains in deep inside of weld.

4.3 Hardness

Hardness is the token of elasticity, plasticity, strength and toughness of metal material, so the increase of hardness means enhancement of mechanical properties of welded joints. Fig.8 shows the positions of hardness measuring points and Fig.9 shows the hardness distribution of conventional welded joint and RE welded joint. It can be seen that the Vickers hardness of metal in the weld center of conventional welded joint is about HV105, much less than that of RE welded joint, HV138, which is slightly higher than the hardness value of base metal. The average hardness of HAZ gets also enhanced by RE treatment.

4.4 Tensile property

To verify further the effect of RE treatment on mechanical property of welded joints, tensile property tests were carried out on INSTRON−5569 electron universal tester. Eight specimens with dimension shown in Fig.10 were tested for every kind of welded joints. The test results reveal that the average tensile strength of conventional welded joints is 286.8 MPa, 62.1% that of base metal; while the average tensile strength of RE welded joints is 332.8 MPa, 46 MPa more than that of conventional welded joints. Typical stress—stain curves obtained on tensile specimens are shown in Fig.11. It can be concluded from the comparison of areas, which are enclosed by every stress—strain curve and the abscissa axis, that the ductility of RE welded joints is better than

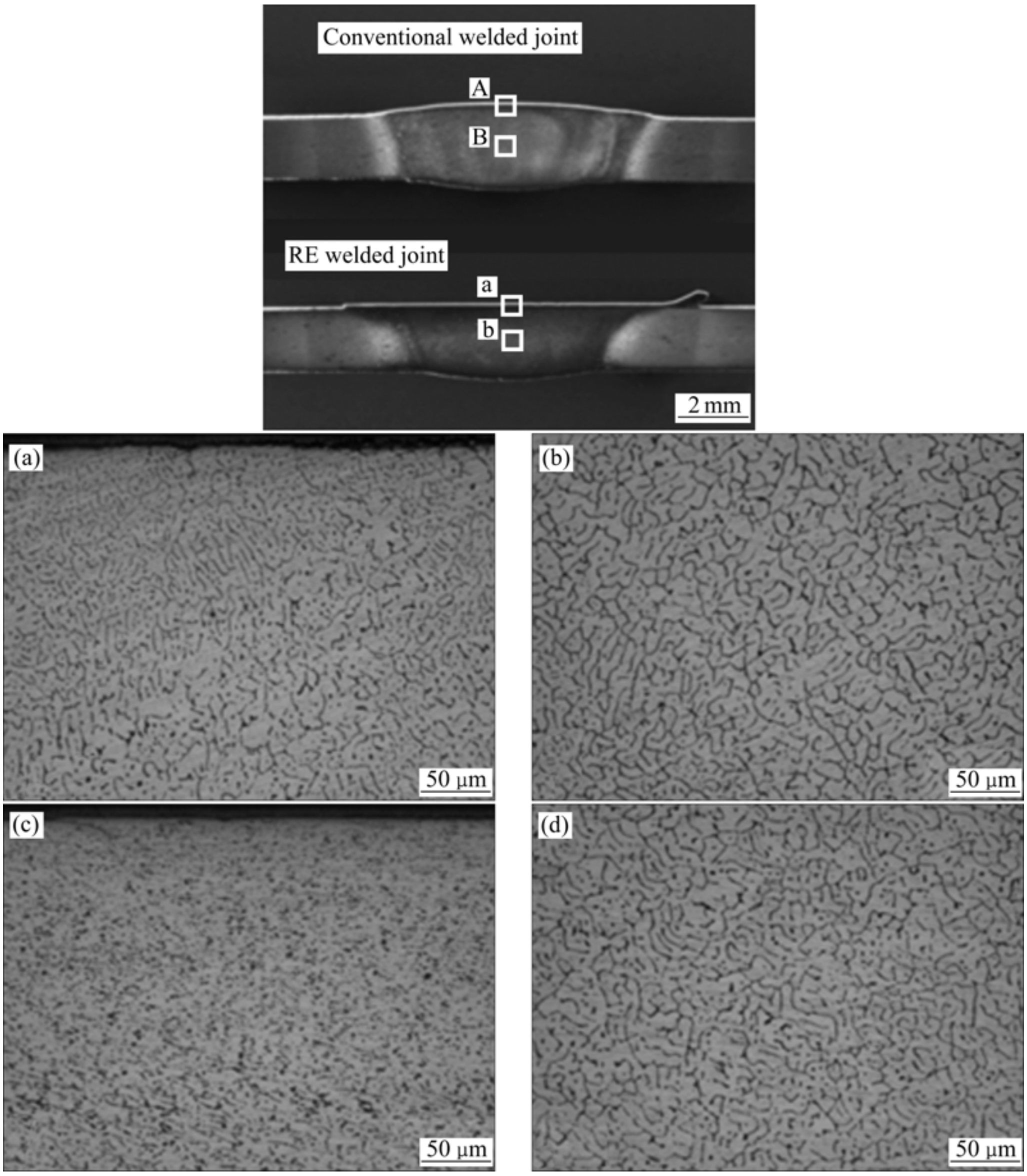

Fig.7 Morphology comparison of cross sections between conventional welded joint and RE welded joint: (a) Zone A; (b) Zone B; (c) Zone a; (d) Zone b

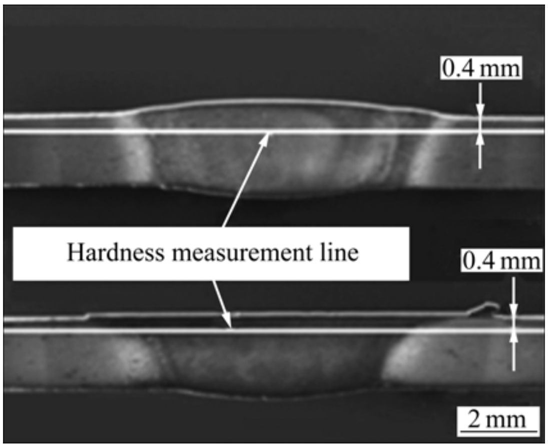

Fig.8 Positions of micro-hardness measuring points

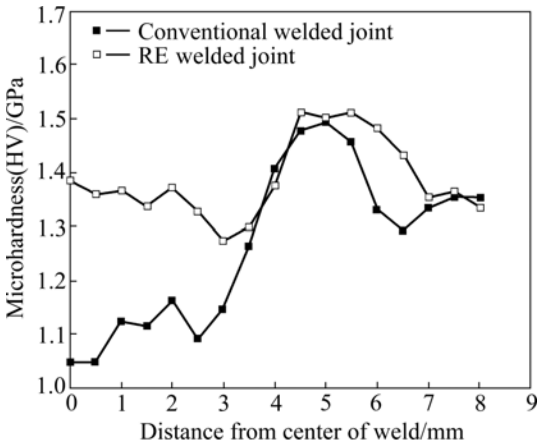

Fig.9 Micro-hardness distribution of conventional welded joint and RE welded joint

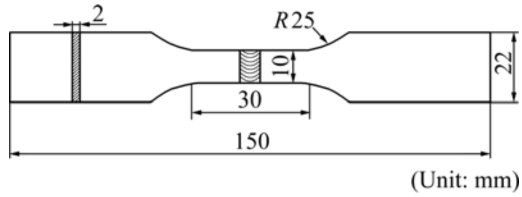

Fig.10 Tensile specimen configuration

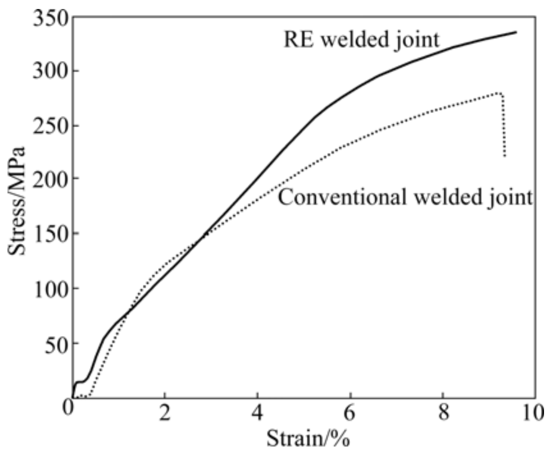

Fig.11 Typical stress — stain curves obtained on tensile specimens

that of conventional welded joints.

The reason that RE can enhance tensile strength of welded joints may be explained mainly from two aspects. First, the cold working leads to the increase of deformation resistance of extruded metal; secondly, the extrusion operation can decrease the amount of air holes in welded joints. Fig.12 shows the comparison of tensile fractographs between conventional welded joint and RE welded joint. It can be seen that there are lots of holes in the fractures of both welded joints. These holes are hydrogen air holes that often appear in the welding of aluminum alloys. By observation, there are many large sized air holes in the upper area of fracture of conventional welded joint, while there is hardly hole in the same position of RE welded joint. Fracture observation reveals that RE can reduce the number of air holes in upper area of welded joints, as a result, weakening the influence of notch effect. Therefore, RE treatment helps to improve the tensile property of welded joints.

5 Conclusions

1) Rotating extrusion is a new technology used to rectify residual distortion of thin-plate weldments as well as improve mechanical properties of welded joints.

2) Rotating extrusion has significant effect on controlling residual distortion of thin-plate weldments. As for weldments made of 2A12T4 aluminum alloy thin plates with dimensions of 350 mm×150 mm×2 mm, this technology can decrease its maximum longitudinal deflection to below 3% of original value.

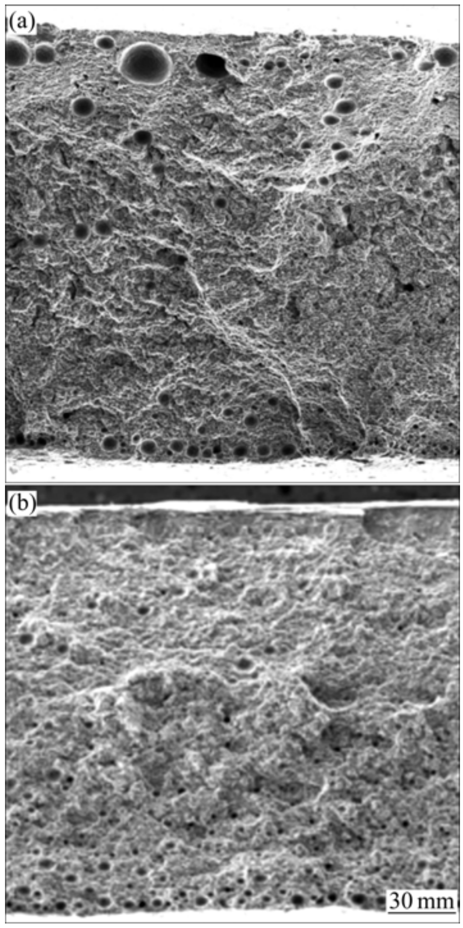

Fig.12 Comparison of tensile fractographs between conventional welded joint (a) and RE welded joint (b)

3) Rotating extrusion can enhance mechanical properties of aluminum alloy welded joints evidently. With proper technological parameters, this method can increase tensile strength of 2A12T4 aluminum alloy welded joints by 46 MPa.

4) Rotating extrusion has potential effect on extending the life of welded structures.

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