Effect of water-cooling treatment times on properties of friction stir welded joints of 7N01-T4 aluminum alloy

T H Zhang¹, Y Wang², X F Fang³, P Liang⁴, Y Zhao⁵, Y H Li⁶, and X M Liu*¹

¹ CRRC QINGDAO SIFANG CO., LTD., Qingdao, China
² CRRC QINGDAO SIFANG CO., LTD., Qingdao, China
³ CRRC QINGDAO SIFANG CO., LTD., Qingdao, China
⁴ School of materials science and engineering, Shandong University, Jinan, China
⁵ School of materials science and engineering, Shandong University, Jinan, China
⁶ School of materials science and engineering, Shandong University, Jinan, China
⁷ School of materials science and engineering, Shandong University, Jinan, China

*E-mail: xuemei_buaa@sdu.edu.cn 981424318@qq.com

Abstract. Due to the deformation caused by residual stress in the welding process, welded components need treatment to reduce welding distortion. In this paper, several different times of flame-heating and water-cooling treatment were subjected to the friction stir welding joints of 15mm thick 7N01P-T4 aluminum alloy sheets to study the microstructure variation of friction stir welding joints of 7N01P-T4 aluminum alloy, and to analyze the effect on micro-hardness, tensile and fracture mechanical properties. This investigation will be helpful to optimize treatment methods and provide instruction on industrial production.

1. Introduction
Nowadays, friction stir welding technology has been widely used in welding of high-speed EMU, intercity EMU, urban rail, and aluminum alloy car-body parts. Friction stir welding joints have the advantages of good mechanical properties and small welding distortion. As for welding products, the distortion can be well controlled. However, the aluminum alloy car-body structure is not completely welded by friction stir welding, some welds are arc welded. In this case, distortion still remains in the structure after welding process and the weld area needs to be adjusted to meet the requirements of geometric tolerance. Flame-heating followed by water-cooling treatment on weld joints is the common adjustment method. However, references on the influence of flame straightening on the performance of friction stir welding joint are still rare both at home and abroad. Therefore, it is necessary to start a research on the influence of water-cooling treatment on the performance of friction stir welded joints.

This paper is concerned with the influence of different water-cooling treatment times on the properties, macro and micro structure of FSW joints of 7N01-T4 aluminum alloy. The influence and regularity of mechanical properties of FSW joints were also studied.

2. Materials, methods and equipment
1100mm × 310mm 7N01P-T4 aluminum alloy sheets with 15mm thickness were used in this research. The sheets were welded by MTI static LONGMEN numerical control friction stir welding machine in butt joints.
The weld joints were heated to 350 °C by oxy propane flame after welding, and then the water-cooling treatment was applied in different times. Specimens with once, twice and thrice water-cooling treatment and specimens with no water-cooling treatment were made for corresponding testing. The microstructures of the joint area were observed by VHX-500FE ultra-high resolution digital microscopy system, and the micro-hardness of the joint area was measured by DHV-1000 digital micro-hardness tester, following the standard of GB/T 2654-2008 (ISO 9015-1:2000, IDT) and GB/T 27552-2011 (ISO 9015-2:2003, MOD). The hardness curve was drawn according to the hardness tests on BM, HAZ, TMAZ and WN, including near surface, middle part and near bottom 3 layers. According to GB/T 2651-2008(ISO 4136:2001, IDT), tensile test specimens were made to measure the tensile strength, yield strength, extensibility of the joints and record the fracture position. Bending tests were conducted in accordance with GB/T 2653-2008(ISO 5173: 2000, IDT). The bending angle was 180°. Cracks existing on the workpiece longer than 3mm would be regarded as non-conformity. Charpy impact test was conducted in room temperature in accordance with ISO9016:2001 to study the effect of FSW on the impact performance of welding joints. The notch was taken from the weld and the notch surface was parallel to the surface of the specimen.

3. Results and discussion

3.1. Effect of water-cooling treatment times on microstructure
Figure 3. Comparison of microstructure of welding nuclear area with different times of water-cooling treatment. (a) One time. (b) Two times. (c) Three times. (d) None.

The microstructure photos from same section of welding nuclear area are shown in the Figure 3. Different water-cooling treatment time have some influences on the grain size. The grain size of joints with no water-cooling treatment is about 20-50 μm, and it increased with once water-cooling treatment. But with the increasing treatment times, the grain size starts to reduce, which is close to the one with no water-cooling treatment.

3.2. Tensile mechanical properties

As is shown in Table 1 and Figure 4, four specimens in each group were subjected to tensile test, and the average data was considered to reflect the mechanical properties of the joints.

|                | Tensile strength (MPa) | Yield strength (MPa) | Elongation (%) |
|----------------|------------------------|----------------------|----------------|
| Base metal     | 436.6                  | 308                  | 20.336         |
| No treatment   | 350.2                  | 220.4                | 10.828         |
| One time of treatment | 345.8                | 217.4                | 11.14          |
| Two times of treatment | 351.4                | 191.2                | 14.754         |
| Three times of treatment | 354.6                | 215.6                | 16.558         |

Figure 4. Influence of different water-cooling treatment times on tensile mechanical properties.

The study shows that after once 350 °C flame conditioning, the tensile strength of the joint decreases with a small amplitude. However, with the increasing times of treatment, the tensile strength has minor increase to about 350MPa. The tensile strength of joints is about 80% of the measured strength of the base metal, and about 111% of the base metal standard strength (315MPa). The yield
strength is about 200MPa. The elongation of joints increases compared with joints without treatment after 350 °C flame conditioning. With the increase in the number of water-cooling treatment, the elongation shows an upward trend. After three times of flame conditioning, the elongation can reach 81.4% of the measured value of the base metal, and 150% of the base metal standard value. After once flame conditioning, the tensile strength declines due to the growth of grains and the decreasing density of precipitated phase. But after two and three times of flame conditioning, with the increase of precipitated phase which has strengthening effect, the tensile strength of the joint rises again.

3.3. Micro-hardness
The average micro-hardness value of 7WN1,7WN2,7WN3 and 7WN4 in upper parts of the joints is 113.2Hv, 111.2Hv, 109.9Hv and 108.2Hv. As is shown in Figure 5, for the upper part, joints with once treatment have the highest micro-hardness in weld nuclear area, then joints with twice treatment, thrice treatment and no treatment. After once treatment, the hardness value of the back side becomes significantly higher than the forward side.

The average micro-hardness value of 7WN1,7WN2,7WN3 and 7WN4 in weld central layer of the joints is 109.9Hv, 107.7Hv, 106.2Hv and 109.4Hv. As is shown in Figure 6, for the central layer, joints with once water-cooling treatment have the highest hardness value and the weld nuclear area has the lowest hardness value. The study also shows that joints with water-cooling treatment have higher hardness value than those with no treatment in weld nuclear area.

The average micro-hardness value of 7WN1,7WN2,7WN3 and 7WN4 in lower part of the joints is 114Hv, 113.3Hv, 110.2Hv and 107.4Hv. According to Figure 7, the joints hardness value is significantly improved after treatment. Joints with once water-cooling treatment have the highest hardness except the weld nuclear area, and twice treatment can lower the hardness of weld nuclear area. The weld nuclear area has the lowest hardness value.
Figure 6. Hardness distribution of joints under different times of water-cooling treatment in middle part

Figure 7. Hardness distribution of joints under different times of water-cooling treatment in lower part

4. Results and discussion
According to the experiment about flame-heating and water-cooling treatment on 7N01-T4 aluminium alloy FSW joints, conclusions can be drawn that the grain size in weld nuclear area of FSW joints starts to be smaller with the increasing times of water-cooling treatment. Water-cooling treatment barely has influence on micro-hardness and tensile strength of the joints. But the elongation increases with the increasing times of water-cooling treatment.

References
[1] Lv C J and Li L L 2015 J. Informatization Construction 09 59-60+62
[2] Ma K X 2013 J. Electric Locomotives & Mass Transit Vehicles 36 1-6
[3] He G Z, Wang F, Li J and Hu Z C 2015 J. Hot Working Technology 05 206-8+211
[4] Han X H, Zhou C Q, Zhang T H and Wang X 2016 J. Modern Welding Technology 06 16-20
[5] Zhang T H, Han D C and Liu S L 2013 J. Welding & Joining 10 25-6
[6] Song X C, Zhu Z Q and Chen Y F 2013 J. Hot Working Technology 13 5-7+12
[7] Zhao Q Y, Wu Z S, Liu C R, Zheng H H and Wu C X 2016 J. Welding Technology 01 1-5