Radiographic Detection of Defects in Friction Stir Welding on Aluminum Alloy AMg5M

Sergei Yu. Tarasov[1, 2, a)], Valery E. Rubtsov[2, b)], and Evgeny A. Kolubaev[1, 2, c)]

[1] *National Research Tomsk Polytechnic University, Tomsk, 634050, Russia*
[2] *Institute of Strength Physics and Materials Science SB RAS, Tomsk, 634055, Russia*

[a)] Corresponding author: tsy@ispms.ru
[b)] rvy@ispms.ru
[c)] eak@ispms.ru

Abstract. In order to reveal weld defects specific to friction stir welding we undertook radiographic inspection of AMg5M aluminum alloy welded joints. Weld defects in the form of voids have been revealed in the weld obtained under the non-optimal rotation and feed rate. Both shape and size of these defects have been confirmed by examining metallographically successive sections prepared in the weld plane as well as in the plane transversal to the tool feed direction. Linear defects have been also found in the sections that are not seen in the radiographic images. Both the preferable localization and origination of the defects have been analyzed.

Keywords: friction stir welding, radiography, weld defects

INTRODUCTION

Friction stir welding (FSW) finds worldwide application for aluminum-based alloys [1]. As compared to conventional fusion welding methods, friction stir welding has peculiar mechanisms of joint formation and consequently produces defects specific with this welding technique. Nevertheless, judging from the available data in the literature, all testing methods used for conventional welding can be applied to friction stir welding but with account for these specific types of defect [2]. Those specific features of friction stir welding defects are small size and specific shape of defects as well as their localization, which makes them difficult to detect by using only one method. In friction stir welding the following basic types of weld defects are distinguished [2]: 1) kissing bonds; 2) root flaws; 3) voids on the advancing side; 4) second phase particles and oxide alignments (Lazy S). In addition to the above ones there are such linear defects as wormholes and tunnels. According to the available literature, radiography is most frequently used to detect such defects as tunnels and there is little information on the observation of other types of defects. The present paper makes an attempt to determine the applicability of the X-ray television system in detecting defects of friction stir welds. The present paper aims at relating the radiographic and real shape and size of defects formed in friction stir welding. For this purpose specimens of welded joints have been prepared from aluminum alloy at different process parameters such as the plunge force, rotation and feed rate.

MATERIAL AND INVESTIGATION PROCEDURE

Friction stir welding is performed on 5 mm plates from wrought alloy AMg5M in the annealed condition. Two plates are welded lengthwise using a friction stir welding machine developed by CJSC Cheboksary Enterprise Sespel. The length of joints welded under different conditions is about 500 mm. In a general case the weld width L_w depends on the tool size. The friction stir welding tool has been made of 1.2344 X40CrMoV5-1 steel tool and had a 19 mm diameter shoulder and consequently produced a weld ≈20 mm in width. Standard friction stir welding process parameters were as follows: rotation rate 1350 rpm, plunge force 2600 kg, feed rate 500 mm/min.

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The metallographic analysis has been carried out using a Neophot-32 (Carl Zeiss) optical microscope. Specimens have been ground and polished to obtain successive layer-by-layer sections in the weld plane to directly inspect the shape and size of the radiographically detected defects.

The radiographic analysis of the weld defects has been performed using FILIN 1010 X-ray flat panel detection system (Testron, St.-Petersburg) with the detector window 100×100 mm in size and a resolution of 2048×2048 pixels. The pixel size was 48 μm. Compact ICM CP120 X-ray source has been used.

RESULTS AND DISCUSSION

The joints welded under standard conditions have no void-like defects. However, the kissing-bond defects are metallographically detected because no mechanical processing has been applied to edges of welded sheets to remove an oxide layer.

The welding conditions with the reduced rotation rate of the tool result in almost no pore-like defects. However, the onset part of the weld (Fig. 1(a)) reveals some large and many small dark tungsten inclusions from a GTAW tack weld used to secure the plates before the friction stir welding. The metallographical examination of cross sections in the middle part of the weld also reveals no discontinuities. Similarly to the standard welding condition, these specimens demonstrate only such weld defects as kissing bonds and oxide alignments. Thus, the reduced rotation speed of the tool causes no discontinuities in the weld, i.e. the metal plasticity in the welding zone proves to be high enough despite the reduced rotation rate. The temperature of the weld surface has been measured using an A655 thermal imaging camera at a distance of 20 mm from the tool and comprised 250°C–280°C and 220°C for the welds in Fig. 1(a) and Fig. 1(b), respectively.

A significant increase in the feed rate generated 0.2–0.6 mm voids periodically distributed along the weld (Fig. 1(b)). The actual shape and size of discontinuities are estimated by successive layer-by-layer grinding of the metal in the weld plane starting from the surface. The size of these defects revealed by metallographic sections shows good agreement with those shown in the radiographic images (Fig. 2). With depth the defects change their shape. At a depth of 1 mm (Fig. 2) there arises such a type of defects that are the zones where the oxide film is mixed in the weld by the tool shoulders. These oxide alignments are clearly visible in Fig. 3 too. At a depth of 2.2 mm there appear linear discontinuities that become fully revealed at a depth of 2.4–2.6 mm (Fig. 2) in the form of wormholes. The location of these defects is in good agreement with the radiographic data.

Figure 3 shows a stacked image of the cross section of the weld obtained at 560 rpm, 2600 kg, 1200 mm/min, which is illustrative of all the defects found including the radiographically undetected ones.

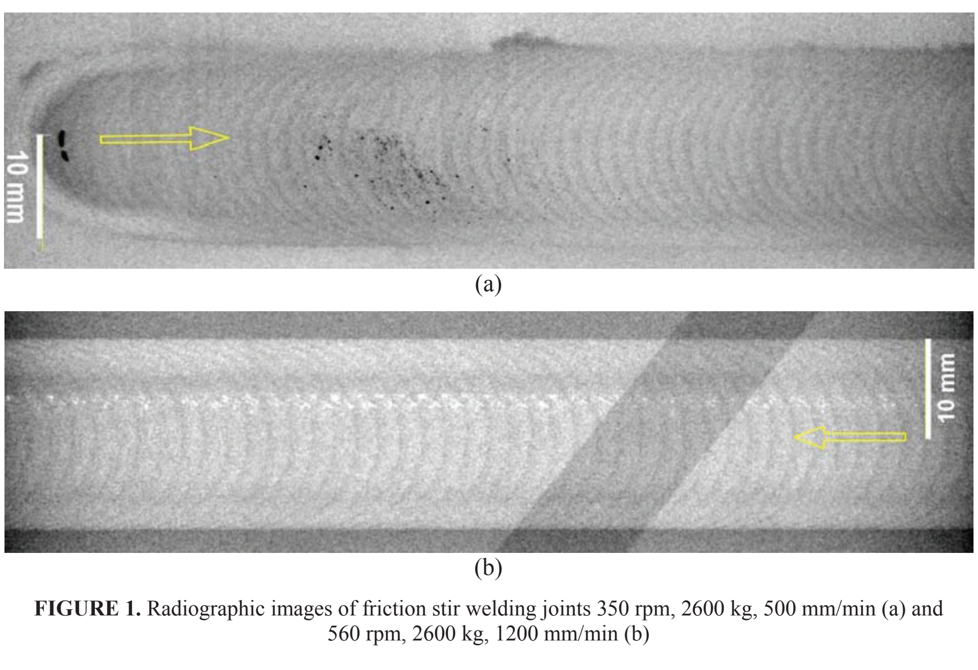

FIGURE 1. Radiographic images of friction stir welding joints 350 rpm, 2600 kg, 500 mm/min (a) and 560 rpm, 2600 kg, 1200 mm/min (b)

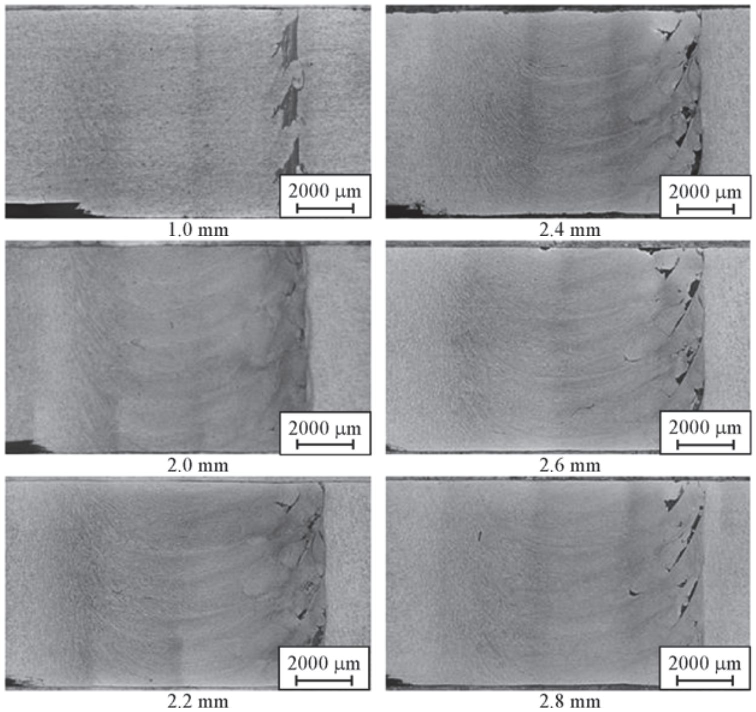

FIGURE 2. The metallographic images of sections parallel to the weld plane at different depths below the weld surface

DISCUSSION

Material flow processes in the friction welding zone and defect generation mechanisms have been thoroughly studied in the literature [2]. The greatest attention should be paid to those types of weld defects that are formed at the non-optimal ratio of the plunge force, rotation and feed rate of the tool. Such defects in the weld can result from the interaction of two flows of the plasticized material, one being generated by the working surface of the tool (tool pin) and the other by the tool shoulders [3]. At complete fusion of these flows a defect-free weld is produced while at incomplete fusion tunnel- or wormhole-like defects appear in the weld. In intermediate cases a system of certainly distributed voids is formed.

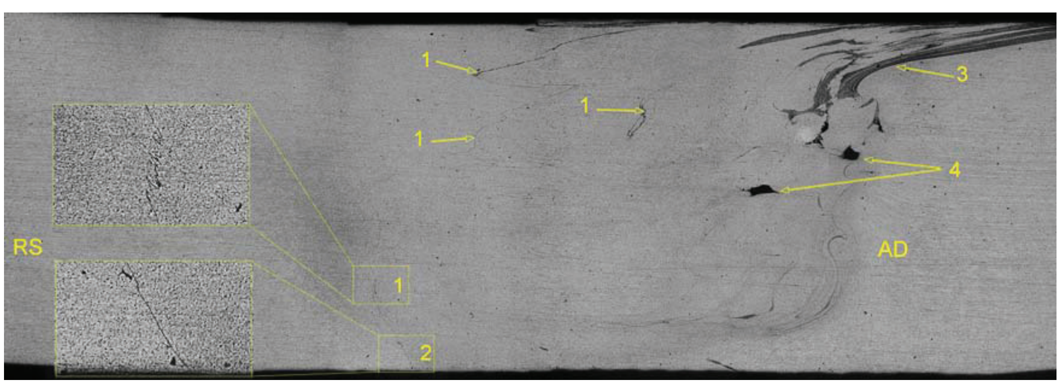

FIGURE 3. The stacked image of the friction stir welding joint cross section made at 560 rpm, 2600 kg, 1200 mm/min

Our experimental data show that the found defects are in the form of almost isolated voids in the interaction zone of the material flows. This is due to the insufficient plasticity of the material resulted from the non-optimal ratio of feed and rotation rates of the tool at a given plunge force level [4]. It is reported [5] that these parameters are responsible for the formation of defects. In addition, from the viewpoint of paper [6] the material flow in the friction zone is accompanied by the development of turbulence and formation of voids.

Note that defects metallographically detected 1 mm below the surface may be related to a different type, which is formed by the tool shoulders carrying oxide layers from the untreated workpiece edge surfaces. They can be avoided if the workpiece edges have been properly prepared by milling before the welding. In our case the workpieces have been deliberately unprepared for the illustration purposes as well as such welding parameters as plunge force, rotation and feed rates have been varied to reveal their effect on the defect generation. The obtained radiographic images give no direct evidence of those defects detection because of their specific geometry and insufficient magnification (Fig. 3).

There is another type of defects formed in friction welding, which is most difficult to detect by a radiographic method. These defects are the so-called kissing bonds (shown by arrows and in the enlarged fragment in Fig. 3), which have a very small thickness and consequently low contrast in the radiographic image.

CONCLUSIONS

The X-ray television complex used to detect defects in friction stir welds allows us to reliably determine the 0.2–0.6 mm size voids (wormholes) formed as a result of too high feed rate as well as their locations relative to the weld axis. Direct metallographic observations of obtained defects confirm the results obtained by radiography. The effect of feed rate on the quality of the FSW weld bead defects in the form of oxide alignments (Lazy S) and linear defects such as kissing bonds can not be detected using radiography methods except may be for those using high-geometrical magnification and microfocus X-ray tubes.

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REFERENCES

1. R. S. Mishra and M. Mahoney, *Friction Stir Welding and Processing* (ASM International, Materials Park, OH, 2007).
2. D. Lohwasser and Zh. Chen (Eds.), *Friction Stir Welding: From Basics to Applications* (Woodhead Publishing Limited and CRC Press LLC, Cambridge, UK, 2010).
3. K. Kumar and S. V. Kailas, Mater. Sci. Eng. A. **485**(1–2), 367 (2008).
4. Y. G. Kim, H. Fujii, T. Tsumura, T. Komazaki, and K. Nakata, Mater. Sci. Eng. A. **415**(1–2), 250 (2006).
5. B. Li, Y. Shen, and W. Hu, Mater. Design **32**, 2073 (2011).
6. V. E. Rubtsov, S. Yu. Tarasov, and A. V. Kolubaev, Phys. Mesomech. **15**(5–6), 337 (2012).