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FRICTION STIR WELDING OF DISSIMILAR IN THICKNESS Al-5Mg ALLOY BUTT JOINTS

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Abstract

The use of dissimilar in thickness welds, especially for the thin aluminium sheets, has been increasing in automobile and civil ship building industries due to its potential for energy saving. The purpose of the present research is to develop the technology of friction stir welding for dissimilar in thickness Al–5Mg alloy butt joints. The thicknesses of the sheets for FSW were 1 mm and 2 mm. The FSW was provided on the 5-axis FSW-machine in horizontal plane with the constant tilt angle equals to 2°, tool rotation speed equals to 700 RPM and welding speed equals to 5 mm/s. The probe high equals to 1; 1.15 and 1.3 mm and dissimilar thick angle in the range from 4° to 6° were taken for the investigation. The macrostructure of the welds was analyzed in order to select defect free welds. The mechanical tests of the selected welds were done.

Introduction

The application of tailored blanks technology in automotive industry offers a significant potential for weight reduction, since it consists of joining sheets of different thicknesses into one piece, which is then submitted to a stamping process. Using this process, it is possible to produce a reduction in cost and in manufacturing operations [1]. The different in thickness sheets are joined by seam welding, spot welding, riveting and stamp welding techniques [2]. These processes create weaker weld/joint region due to straining parallel to the weld line [3]. These difficulties can be overcome by using the solid state welding processes like FSW process. Friction stir welding (FSW) is a solid state joining method, which was developed especially for aluminum alloys [4, 5] to avoid hot cracking, porosity or distortion. This process is widely used for joining of Al alloys and also for the welding of tailored blanks, especially for automotive industry [2, 3, 6-13]. Moreover, the welding of the sheets with the thickness lower than 2 mm by means of conventional methods leads to the high level of the distortion, which is not appropriate for the final structure.

In the present research the friction stir welding of the tailored blank consisted of 1 and 2 mm sheets for the trimaran buoy was realized. According to the fact, that Al-Mg alloys provide low density, high strength, formability and corrosion resistance [14], Al-5Mg alloy was chosen as a material for the buoy body. The dissimilar in thickness butt joints were provided by means of friction stir welding, all other joints were made on 2 mm sheets with the use of the robotic gas metal arc welding to minimize the distortion of the buoy body.

Material and methods

The investigated material, work hardening Al-5Mg alloy with temper designation O, was produced by hot and cold rolling in the form of sheets with the thickness of 1 and 2 mm. The chemical composition and the mechanical properties of the Al-5Mg alloy used in the present research is given in Table I and II respectively. The initial microstructure of the Al-5Mg alloy sheets is presented in Figure 1, the average grain size is 15 for the sheet with the thickness of 2 mm and 30 μm for the sheet with the thickness of 1 mm.

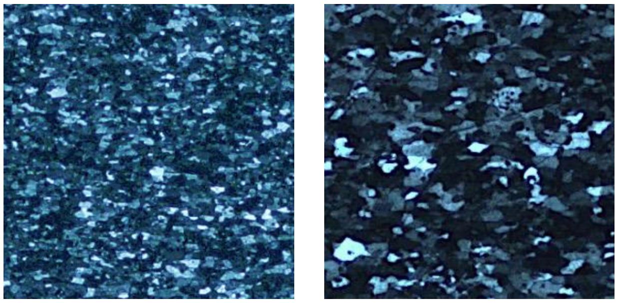

Figure 1. The initial microstructure of the Al-5Mg alloy sheets: *a* – thickness 2 mm, *b* – thickness 1 mm.

Table I. Chemical composition of Al-5Mg alloy

Element	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
Concentration, (wt.%)	4.80	0.44	0.25	0.06	0.44	0.03	0.09	0.04	bal.

Table II. Mechanical properties of Al-5Mg alloy

Yield stress, MPa	Tensile stress, MPa	Elongation, %	Hardness, Vickers
130	275	10-12	87.5

The Al-5Mg alloy was chosen as a material for the buoy body according to high strength, formability and good corrosion resistance. In order to reduce the residual distortion of the final structure it was decided to use the sheets with the thickness of 2 mm. On the other hand, to reduce the weight of the final structure the central part of the buoy body was made from the sheet with the thickness of 1 mm (see Figure 2). The transverse welds of dissimilar in thickness sheets were made by FSW. After that, the bending operation was provided to get the buoy body ready for the final step of arc welding. Arc welding was done on 2 mm thick parts with the use of robotic gas metal arc welding and ColdArc® technology for residual distortion minimizing.

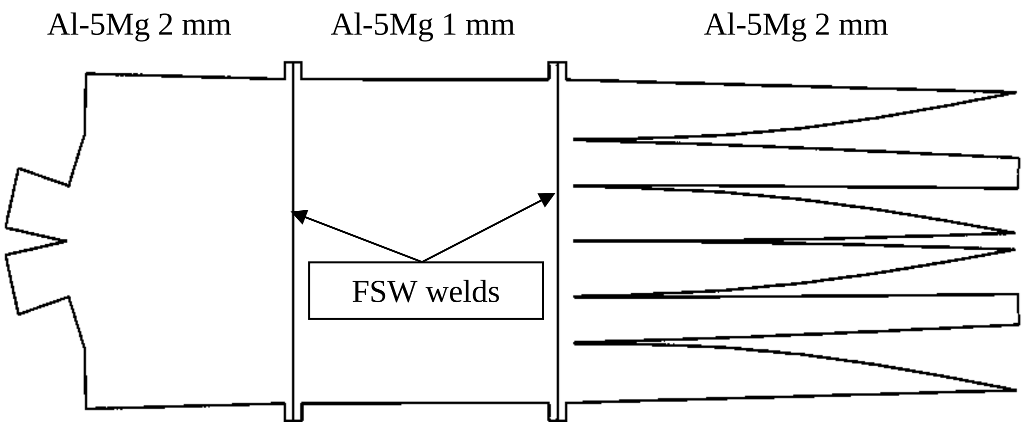

Figure 2. The scheme of buoy body welding before the bending.

The welding of the dissimilar in thickness Al-5Mg alloy sheets was made with the help of the conventional tool consisting of a smooth cylindrical probe with a 5 mm diameter and a flat shoulder with a 15 mm diameter. The probe length was varied as follow: 1, 1.15 and 1.3 mm. The FSW was realized with a constant tilt angle TA (β) equals to 2° (see Figure 3), constant tool rotation speed equals to 700 RPM, upset force 11 kN and welding speed equals to 5 mm/s. These parameters of FSW were set before to receive the sound weld of the similar in thickness Al–5Mg 2mm sheets. In addition to the probe length variation the dissimilar thick angle (DTA) (α) was also varied from 4° to 6° with the step of 0.5° (see Figure 3). To realize simultaneously the both angles β and α FSW was provided on the 5-axis metal processing machine Matec 40-P (see Figure 4).

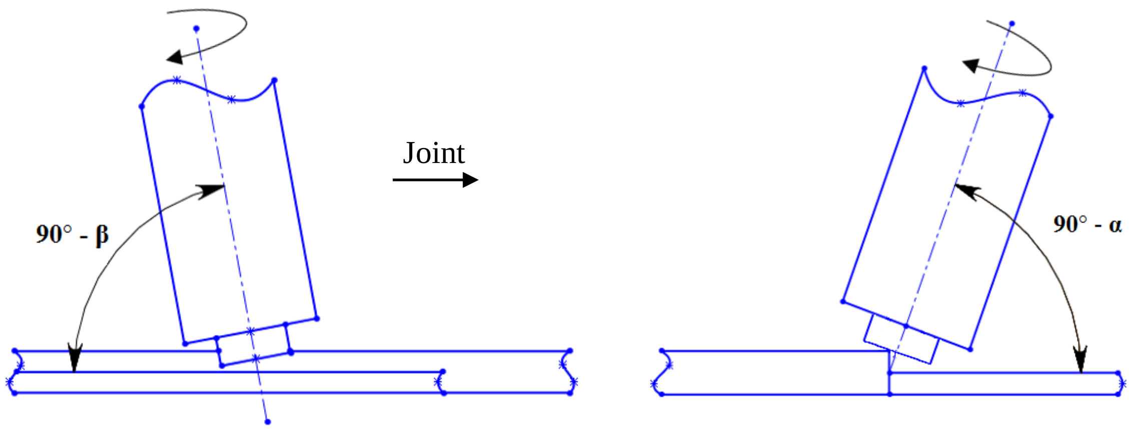

Figure 3. Plan for carrying out the welds. β - tilt angle (TA) equal to 2°, α - dissimilar thick angle (DTA) from 4° to 6°.

Figure 4. The 5-axis FSW-machine Matec 40-P.

The metallographic analysis of the FSWed material was done using electrolytic etching with a Baker reagent and a polarized light microscope. The tensile test was done on the Zwick//Roell Z050 machine in accordance with the Russian standard #1497-84 standard, at the ambient temperature.

Results and discussion

Metallographic Analysis

As a result of the macrostructure analysis of the joints it was established that during FSW with the probe length of 1 and 1.15 mm the defects such as "kissing bonds" were observed. The FSW with the probe length of 1.3 mm lead to the contact of the probe and the machine table. Therefore, to avoid the defects appearance after FSW of dissimilar in thickness Al-5Mg alloy sheets it was decided to use probe with the length of 1.3 mm.

Figure 4 shows the macrostructures of the FSWed joints with the probe length of 1.3 mm and DTA as follow: a – 4°, b – 4.5°, c – 5°, d – 5.5°, e – 6°. The advancing side is on the side of 1 mm sheet, the retreating side – 2 mm sheet. It is clearly seen that in the cases when DTA is less than 5° the flashes appear on the surfaces of the sheets (see Figure 4 a,b). It could be explained by the lack of the shoulder and sheet contact on the advancing side and increase of the tool force on the sheet on the retreating side. The metal on the advancing side goes into the space between the shoulder and the sheet and is forced aside made a flash. On the retreating side the shoulder goes too deep into the metal and forces it out from the weld zone made a flash. During the FSW with the DTA more than 5° the shoulder on the advancing side goes into the metal too deep which leads to the banding of the 1 mm sheets on the boarder of the base material and the welding zone (see Figure 4 d,e).

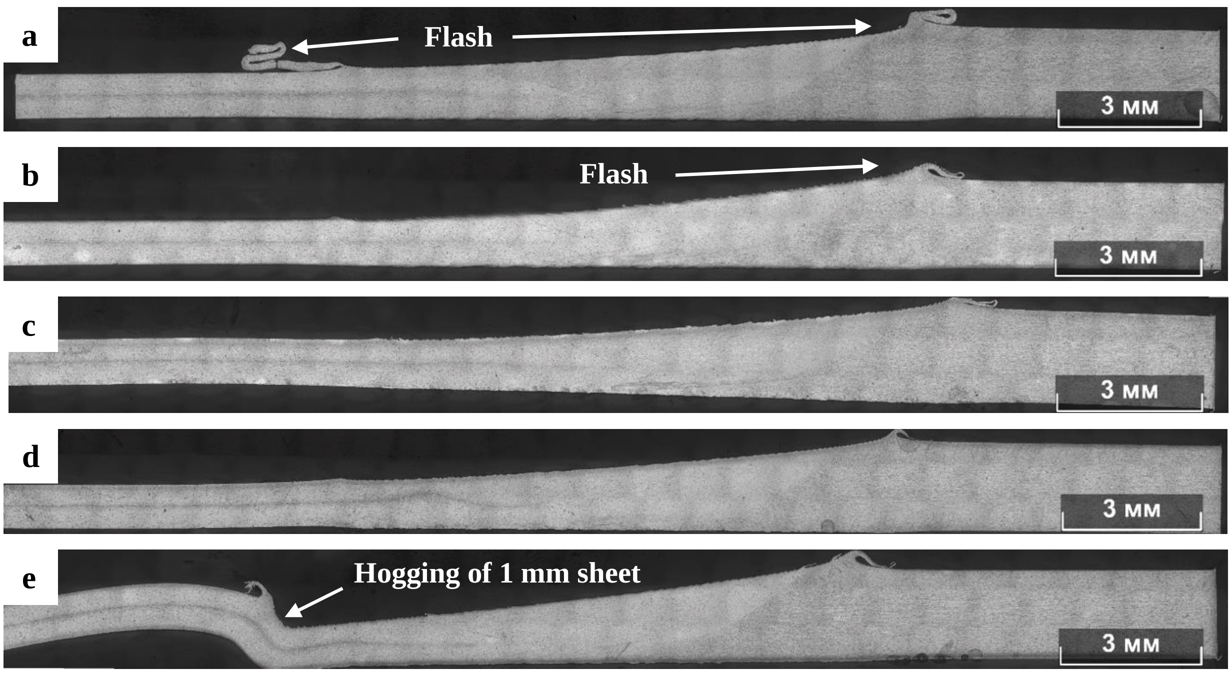

Figure 4. Macrostructure of dissimilar in thickness welds with DTA:
a – 4°, b – 4.5°, c – 5°, d – 5.5°, e – 6°

Therefore, the sound weld with suitable geometry of dissimilar in thickness Al-5Mg alloy sheets with the thickness of 1 and 2 mm could be received by means of FSW with DTA equals to 5°.

Figure 5 shows the microstructure of the weld, received after FSW with the probe length of 1.3 mm and dissimilar thick angle 5°. The refining of the grains in the Termo-Mechanical Affected zone (TMAZ) and in the Nugget zone (NZ) is determined according to the Figure 5 d, e, f, g. The average grain size of the 1 mm sheet base material is about 30 μm, and the 2 mm sheet base material – 15 μm. After FSW the average grain size was reduced in the TMAZ and NZ in 3-6 times and equals to 5 μm.

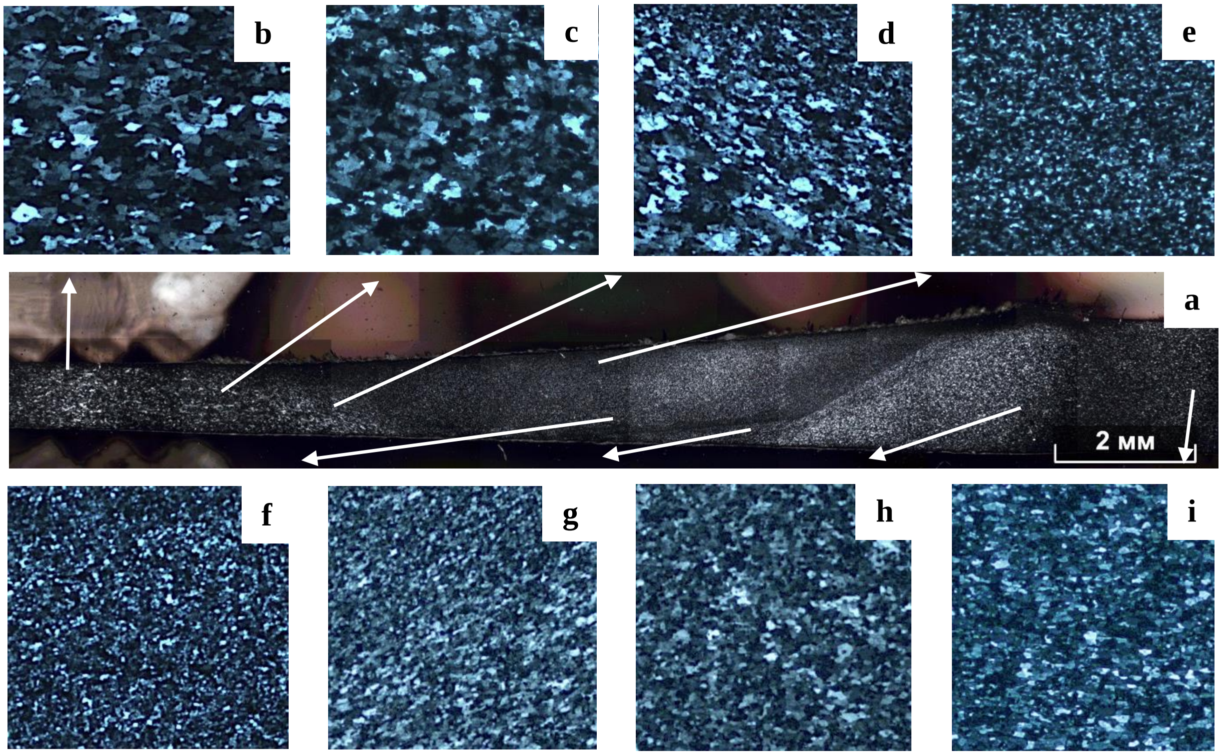

Figure 5. Microstructure of FSW of dissimilar in thickness welds: a – FSW joint, b – base metal of 1mm Al-5Mg alloy, c – Heat Affected Zone (HAZ) of 1mm Al-5Mg alloy, d – TMAZ of 1mm Al-5Mg alloy, e, f – NZ of FSW-weld, g – TMAZ of 2mm Al-5Mg alloy, h – HAZ of 2mm Al-5Mg alloy, i – base metal of 2mm Al-5Mg alloy.

Tensile Tests

The tensile tests were made for the 5 welded samples after FSW with probe length of 1.3 mm and dissimilar thick angle 5°. The results of the tensile test is presented in Table III.

The results of the tensile tests show that the mechanical properties of the FSWed joints are close to the mechanical properties of the base material. The crack initiation in all samples occur in the base material with the thickness of 1 mm. Therefore, the mechanical properties of the welded dissimilar in thickness samples are determined by the mechanical properties of the thinner sheet.

Table III. Values obtained from the tensile test

Sample number	E, GPa	Yield Srength, MPa	Tensile stress, MPa	Elongation, %
1	61.70	115.49	258.93	9.42
2	61.85	117.03	254.92	9.10
3	66.23	124.47	265.09	7.92
4	61.98	119.14	257.05	7.18
5	59.42	120.52	259.12	7.61

Buoy Body Structure

After the FSW process, the bending operation was provided to get the buoy body ready for the final step of arc welding. Arc welding was done on 2 mm thick parts with the use of robotic gas metal arc welding and ColdArc® technology for residual distortion minimizing. The final welded structure of the buoy body is presented on Figure 6.

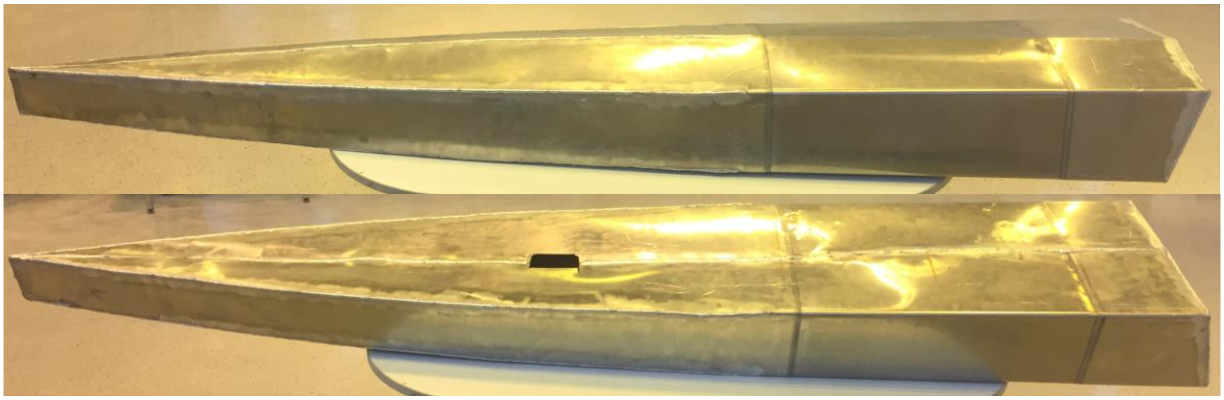

Figure 6. The final welded structure of the buoy body.

Conclusions

The probe length and DTA were determined to receive sound weld after FSW of dissimilar in thickness Al-5Mg alloy sheets. To weld 1 and 2 mm in thickness sheets the probe length should be 1.3 mm and DTA should be 5°.

After FSW the average grain size was reduced in the TMAZ and NZ in 3-6 times and has average size of 5 μm.

The crack initiation during tensile tests occur in the base material with the thickness of 1 mm. Therefore, the mechanical properties of the welded dissimilar in thickness samples are determined by the mechanical properties of the thinner sheet.

The final welded structure of the buoy body was received with the low level of the residual distortion and reduction in weight.

References

1. R.W. Davies et al, “Characterising Al tailor welded blanks for automotive Applications,” Journal of the Minerals, Metals and Materials Society, 51 (11) (1999), 46–50.
2. L. Fratini, G. Buffa, and R. Shivpuri, “Improving friction stir welding of blanks of different thicknesses,” Mater. Sci. Eng. A, 459 (2007), 209–215.
3. G. Buffa, L. Fratini, J. Hua, and R. Shivpuri, “Friction stir welding of tailored blanks: investigation on process feasibility,” Annals of the CIRP, 55 (2006), 1-4.
4. C. Dawes, and W. Thomas, TWI Bull., (1995), 124.
5. M.A. Sutton, B.Y. Yang, A.P. Reynolds, and R. Taylor, Mater. Sci. Eng. A, 323 (2002), 160.
6. E. C. Bonome, C. B. Carletti, N. G. De Alcantara, and J.F. dos Santos, “Friction stir welding – FSW applied to tailored blanks,” Welding International, 21 (4) (2007), 279–283.
7. S. Sheikhi, and J. F. dos Santos, “Effect of process parameter on mechanical of friction stir welded tailored blanks from aluminium alloy 6181-T4,” Science and Technology of Welding and Joining, 12 (4) (2007), 370-375.

8. C. Leitão, B. Emílio, B.M. Chaparro, and D.M. Rodrigues, "Formability of similar and dissimilar friction stir welded AA 5182-H111 and AA 6016-T4 tailored blanks," Materials and Design, 30 (2009), 3235–3242.
9. A. Tronci, R. McKenzie, R. M. Leal, and D. M. Rodrigues, "Microstructural and mechanical characterisation of 5XXX-H111 friction stir welded tailored blanks," Science and Technology of Welding and Joining, 16 (5) (2011), 433-439.
10. M. Ghaffarpour, B. M. Dariani, A. H. Kokabi, and N. A. Razani "Friction stir welding parameters optimization of heterogeneous tailored welded blank sheets of aluminium alloys 6061 and 5083 using response surface methodology," Proc IMechE Part B: J Engineering Manufacture, 226 (12) (2012), 2013–2022.
11. J. P. Bergmann, R. Schuerer, and K. Ritter, "Friction Stir Welding of Tailored Blanks of Aluminum and Magnesium Alloys," Key Engineering Materials, 549 (2013), 492-499.
12. Y. Hovanski, P. Upadhyay, B. Carlson, R. Szymanski, T. Luzanski, and D. Marshall, "FSW of Aluminum Tailor Welded Blanks Across Machine Platforms," Friction Stir Welding and Processing VIII, (2016), pp 99-105.
13. P. K. Sahu, and S. Pal, "Mechanical properties of dissimilar thickness aluminium alloy weld by single/double pass FSW," Journal of Materials Processing Technology, 243 (2017), 442–455.
14. S.J. Maddox, Int. J. Fatigue, 25 (2003), 1359.