D.Sc. Roman BOGUCKI*
D.Sc. Adam PIETRAS**
Prof. Ph.D. D.Sc. Adam WIŚNIEWSKI***
***** Research and Development Centre for Mechanical Appliances Ltd Co
****** Institute of Welding
*** Military Institute of Armament Technology

FRICTION STIR WELDING OF NON-WELDED ALUMINIUM ALLOYS

Abstract: The principle of Friction Stir Welding (FSW) and the way the plasticized materials move during the welding process are presented in this paper. The optimal welding conditions were determined. Findings of friction stir welding of screw made of aluminium alloy EN AW-2017A to the flat bottom of the cassette made of cast aluminium alloy EN AC-42100 are presented. From the microscopy examination, conducted for the specimens which were taken from the different areas of weld, arises that on the entire length of the welding area metallic connection occurs. Results of the hardness test conducted in the weld zone in accordance with PN EN 1043-2 and results of the drop test from the height of 12 meters are presented. The range of tests of the joints of cassettes with the screws, welded with FSW, indispensable to make before the implementation into a production are determined.

ZGRZEWANIE TARCIOWE NIESPAWALNYCH STOPÓW ALUMI-NIOWYCH METODĄ FSW

Streszczenie: W pracy przedstawiono zasadę zgrzewania tarciowego z mieszaniem materiału zgrzeiny metodą FSW (Friction Stir Welding) oraz sposób przemieszczania się uplastycznionych mas materiału podczas procesu zgrzewania. Określono optymalne warunki zgrzewania oraz przedstawiono wyniki badań zgrzewania FSW prętów wyciskanych ze stopu EN AW-2017A z płaski dnem kasety ERAWA, wykonanych z odlewniczego stopu aluminium EN AC-42100. Wyniki badań mikroskopowych próbek pobranych z różnych obszarów zgrzewania wskazują na występowanie ciągłego powiązania metalicznego na całej długości złącza. Przedstawiono wyniki badań twardości prowadzonych w zgrzeinie FSW zgodnie z normą PN EN 1043-2 oraz wyniki badań po próbie zrzutu kaset z wysokości 12 m. Określono zakres niezbędnych badań eksploatacyjnych i badań ostrzałem lekkich kaset ze stopu aluminium ze śrubami ze stopu aluminium zgrzewanych za pomocą metody FSW przed wdrożeniem ich do produkcji.

1. Introduction

Friction Stir Welding (FSW) technology was invented and patented by TWI Ltd in 1991 [1]. The principle of the FSW process and the scheme of displacement of welded materials is shown in Figure 1.

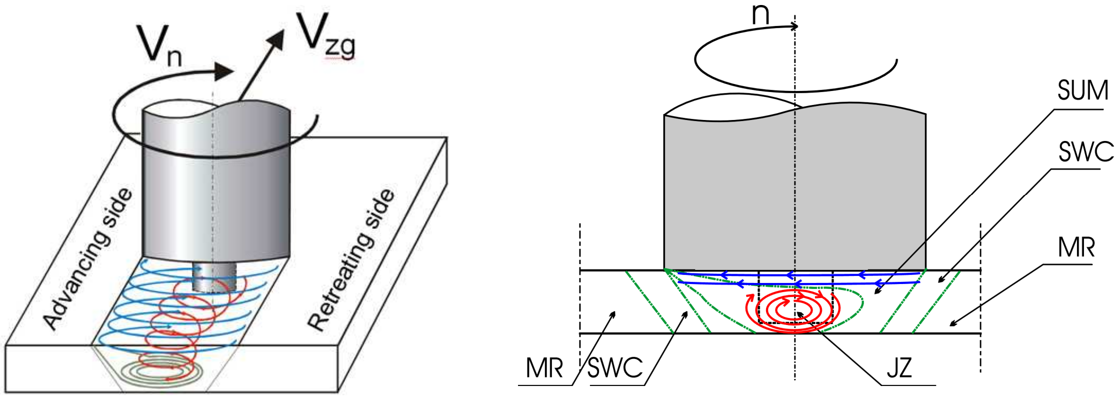


Fig. 1. The principle of the FSW process [2]: V_n - rotational speed of the tool, V_{zg} - welding speed, JZ – the nugget, MR - base material, SWC - heat affected zone, SUM - thermo- mechanical affected zone

In this method the tool with rotational pin is placed in the contact line of the sheets, heats and plasticizes the material in this area. After put of the tool into the rotational speed, its penetration in the contact line of welded sheets, heat and plasticize of the material in near area of the tool, mixing of the welded materials takes place. Heated and plasticized material is moved backwards behind the tool, is mixed and before solidification is being thickened by the shoulder. The seam weld is created behind the tool. The properties of the weld depend on the welding parameters [2, 3].

Investigations of the test welds confirm that it is possible to achieve a good quality of friction stir welded joints [2, 4].

2. Investigation of the friction stir welding conditions

Analyses and investigations of the welding conditions of the joint of two screwed screws with the plate were conducted [5, 6]. Taking into consideration that there are no standards concerning the tests of the FSW joints, the quality assessment of test joints were conducted in accordance with the Polish standard like for the resistance welds [7].

Laboratory tests of the welding conditions were conducted on the flat samples made of the casting aluminium alloy EN AC-42100 and extruded screws made of the aluminium alloy EN AW-2017A [6]. The mechanical properties of the materials are presented in Table 1.

Table 1. Mechanical properties of tested aluminium alloys [8, 9]

Serial number	Material type	Material form	State	Dimension, mm	R_M, MPa min.	R_{02}, MPa min.	A,% min.
1.	EN AC-42100 (ALSi7Mg0,3)	Cast (samples casted separately)	T6	-	230	190	2
2.	EN AW-2017A (Cu4MgSi(A))	Extruded screws	T4	ϕ 25	380	260	12

Investigations included selection of the shape and dimensions of the tool and determination of the preliminary welding conditions of aluminium alloys, considered to be unweldable with other welding methods.

As a result of investigations and examinations the following FSW welding parameters of screws with the bottom of ERAWA reactive cassette were determined:

1. friction rotation speed - 560 min^{-1};

2. welding speed - 224 mm/min;
3. inclination angle of tool - 0°;

The view of the joints from the face and the root side of the weld is shown in Figure 2.

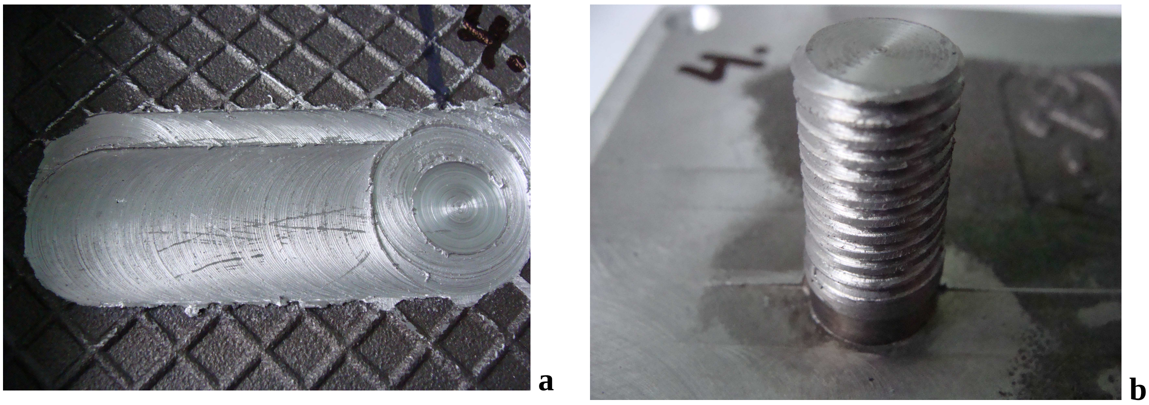


Fig. 2. The view of the joints after FSW process: a – form the face side of the weld, b – from the root side of the weld, sample no. 4 [10]

Fragments of the ERAWA cassette after the peel test (the view from the side of the tool and from the side of the screwed screw) are shown in Figure 3. Examinations of FSW joints showed the proper quality of joints. Peel of the screws through their pulling out from the bottom of the cassette, around the heat affected zone took place, similarly to the typical joints made with conventional welding methods.

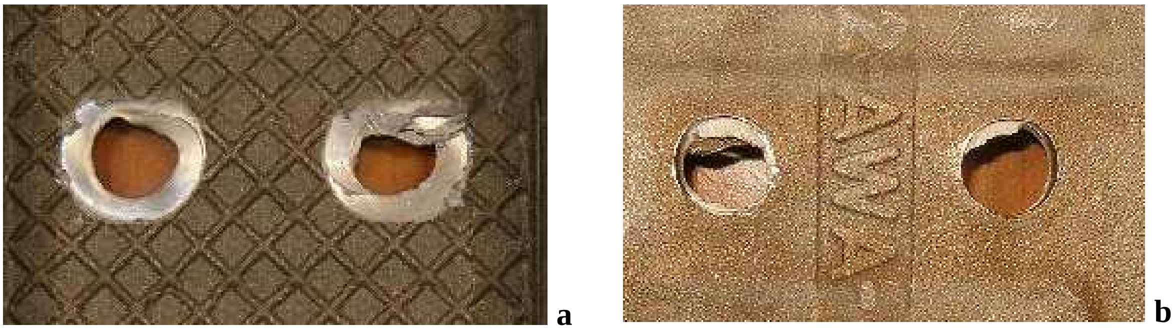


Fig. 3. The view of the cassette after the peel test of the screws: a – from the side of the tool, b – from the side of the screw [6]

It was found that the bigger tool was used in the FSW process the larger was the weld and the higher was the tensile strength of the joint. The specimens for microscopic examinations were cut across the weld line. Typical macrostructures of welds obtained during the FSW process in the initial (a) and in the final (b) welding area are presented in Figure 4.

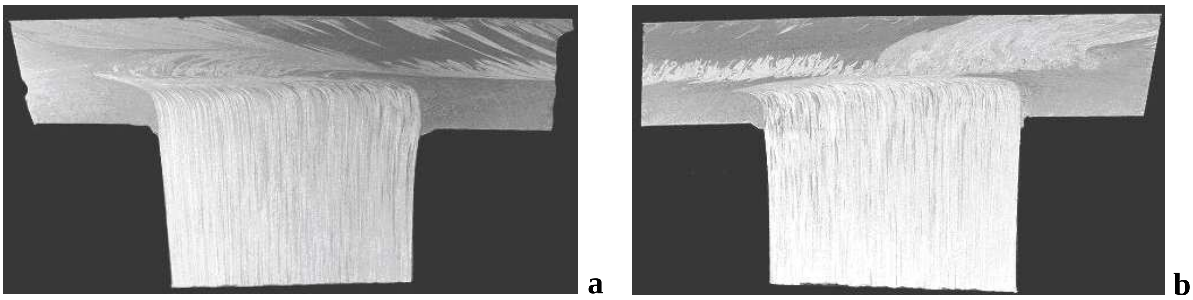


Fig. 4. Macrostructure of FSW weld: a - initial welding area, b - final welding area, Keller etching, magnification 8x [6]

Hardness test of joints were conducted in accordance with the Polish Standard PN EN 1043-2 [11]. The typical run of the hardness penetration pattern in the cross-section of the joint is shown in Figure 5.

Microstructure examinations showed very good connection between the material of the screw and the material of the cassette's bottom. On the entire length of the welding area, indiscrete metallic connection occurs. No cracks and discontinuities of microstructure of joint were observed. Typical areas of joint are shown in Figure 6.

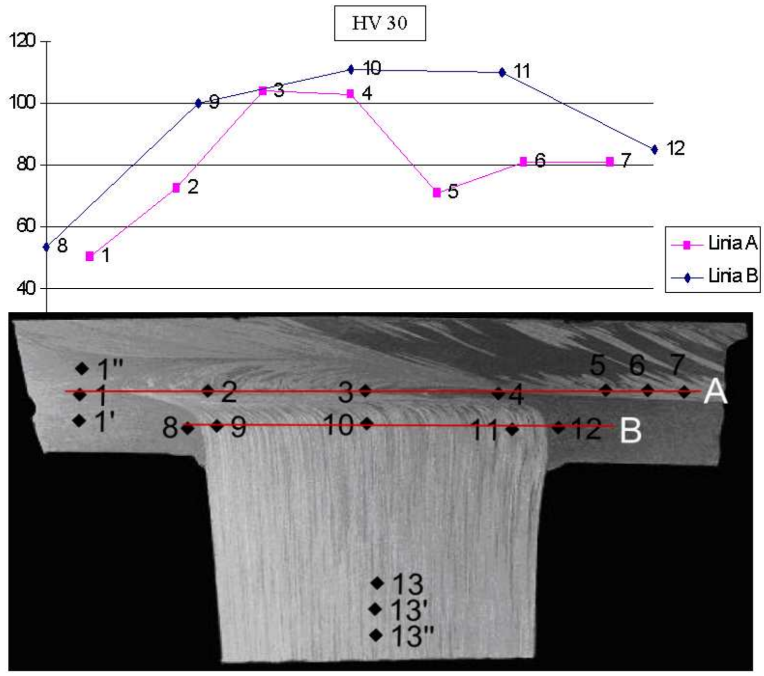
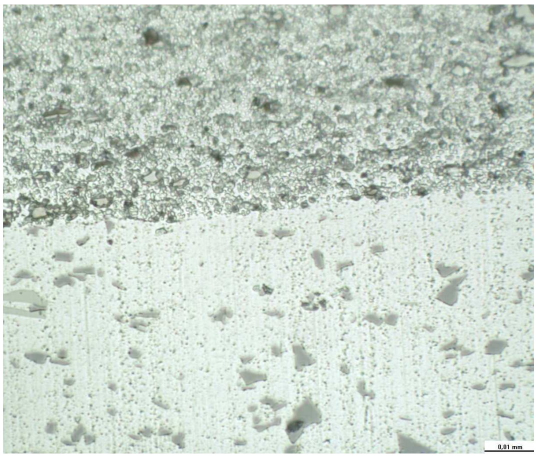
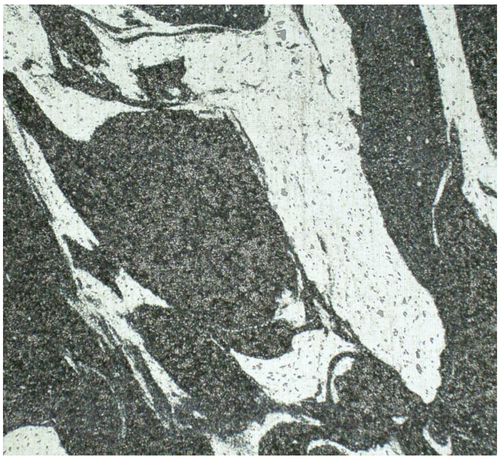


Fig. 5. The hardness penetration pattern in FSW weld: 1 - hardness of the material of the cassette's bottom 54 HV30, 13 - hardness of the screw's material 87 HV30 [6]



Magnification 1000x



Magnification 200x

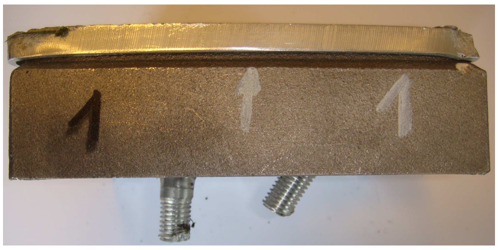
Fig. 6. Characteristic areas of weld (nital etching)

3. Drop tests of the ERAWA-2 cassette

The field investigations of the quality of cassettes were conducted in accordance with the research proceeding no. 38 (LBAR.38) WITU - Zielonka. ERAWA-2 cassettes no.: 1, 6 and 8, filled with the inert material of the weight like in case of the use of explosive, falling down freely from the height of 12 meters hit the concrete from the screw side, the side walls and the cover. During the tests the cassettes underwent plastic deformations (Figure 7÷10).

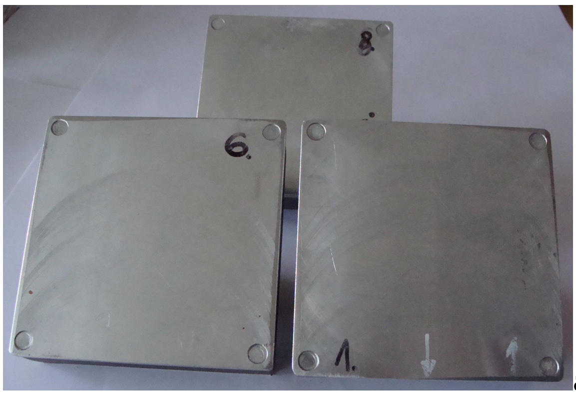
In case of exceed of allowable stresses, cracks occurred in the SWC of the weld or in the areas of corners. Cracks and failures of the rivets, joining the cassettes with the cover, also occurred.

a



b

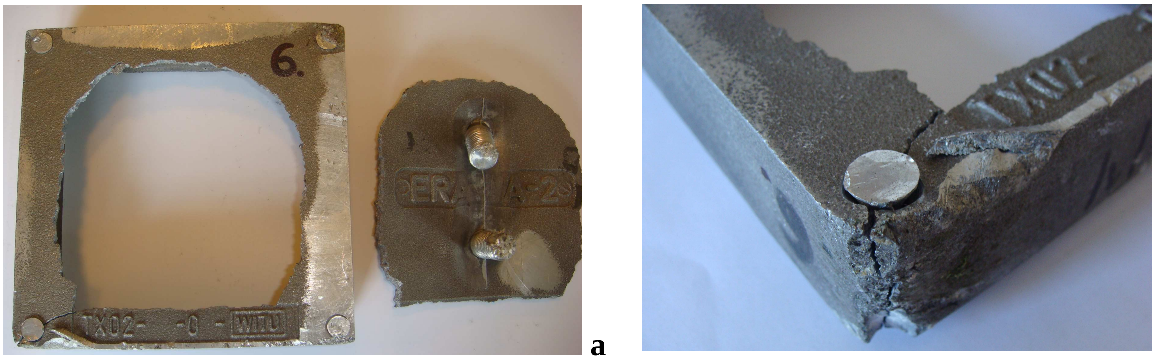
Fig. 7. Cassettes no. 1 after the first drop on the concrete from the height of 12 meters



a

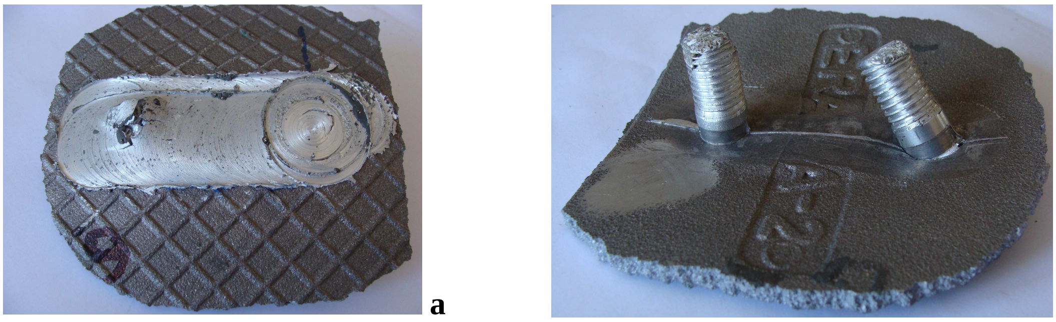
b

Fig. 8. Cassettes no. 1, 6 and 8 after the first drop on the concrete from the height of 12 meters



a b

Fig. 9. The bottom (a) and the corner (b) of the cassette no. 6 after the sixteenth drop from the height of 12 meters on the concrete



a b

Fig. 10. Fragment of the part of the cassette no. 6 after the sixteenth drop on the concrete from the height of 12 meters

The best results were obtained for the ERAWA-2 no. 6 cassette which was dropped down as many as 16 times till the total destruction was achieved. Break of the rivets and separation of the bottom from the sides of the cassette took place, but the joint of the screw with the bottom of the cassette was not destroyed. The number of drops until the total destruction of the ERAWA-2 cassette was achieved determinates the quality of performance of the cassette and the connection of the screws with the use of FSW method.

4. Conclusions

On the base of carried out tests the following conclusions were drawn:

1. The most favourable friction stir welding parameters for welding screws made of the aluminium alloy EN AW 2017A (screws) to the bottom of the cassette made of the aluminium alloy EN AC-42100 were determined.
2. Welds made with the FSW method have compact and constant structure in entire welding area, free from surface defects and irregularities.
3. FSW method is suitable to joining aluminum screws to the bottom of the cassette made of the cast aluminum alloys.
4. FSW process conducted in the suitable conditions guaranties carrying out joints of the proper and repeatable quality.
5. The use of the FSW method to join the screw to the bottom of the ERAWA-1 cassette and ERAWA-2 cassette ensures that the connections are:
   - Durable in rugged conditions - e.g. driving in the field with high speed, etc.;

- Resistant even during the 155 mm artillery shell burst HE in the vicinity of the vehicle and also during the explosion of the mine 10 kg in weight under the vehicle, in accordance with the standard STANAG 4569 for IV and V protection level:

Protection level	Shot's parameters	Artillery shells	10 kg mine's explosion under:
IVa	Weight		Any wheel or caterpillar
IVb			Center of the vehicle body
V	Distance, m	25	
	Azimuth, δ	360^o	
	Elevation, γ	$0 \div 90^o$	
	Ammunition	155 mm HE	
	Velocity, V_o	960 ±20 m/s	

- corrosion resistant between different materials, like in case of the use of screw made of steel with the cassette made of aluminium alloy;
- tight:
  – during cassettes' filling;
  – in rugged conditions - moisture, rain, snow, overcoming of a water-obstacle.

6. The use of FSW method to join screws to the bottom of the ERAWA-1 and ERAWA-2 cassettes allows reduce their weight in relation to the cassettes with the steel screws.
7. The practical use of the cassette made of the aluminium alloy ERAWA-1 i ERAWA-2 welded with the screws of the aluminium alloy with the use of FSW method can take place after realization of the following tests:
   a) Accelerated ageing test,
   b) Fire with the bullets:
      - 12,7 mm type B-32,
      - 14,5 mm type B-32,
   c) static – evaluation of protection ability during the punching with hollow charge projectile PG-7;
   d) static - evaluation of amount of deformation of adjacent cassettes during initiation of the middle cassette in the set of nine ERAWA-1 and ERAWA-2 cassettes;
   e) static - evaluation of amount of deformation of cassettes during explosion of the mortar bomb in the vicinity of them;
   f) static – evaluation of reaction of cassette in the consequence of burning of petrol;
   g) static - evaluation of reaction of cassette in the consequence of burning of napalm on it;
   h) static - evaluation of reaction of cassette in the consequence of burning of the warhead with termit on it;
   i) operating – during the drive of the tank with cassettes on the surface and unsurface road in accordance with the determined proceeding.

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