Dissimilar friction stir welding of EN AW 6082 - EN AW 5083 aluminium alloys

R. Gabor [1], R. Cojocaru [2], C. Ciucă [2], L. Boţilă [2]

[1] University Politehnica of Timişoara, Faculty for Civil Engineering, Romania

[2] National R&D Institute for Welding and Material Testing Timişoara, Romania

E-mail: rcojocaru@isim.ro

Keywords

Friction stir welding, dissimilar materials, aluminium alloy, welding procedure

1. Introduction

Welding of the materials with low melting points is realized mostly using the traditional arc welding processes.

The environmental friendly friction stir welding (FSW) provides a technological alternative to the arc welding procedures.

FSW process allows the connection of an important number of similar and dissimilar materials, which are difficult or impossible to be welded using other welding procedures [1].

The aluminium alloys from the 5xxx and 6xxx classes are more frequently used for the fabrication of complex structures or structural elements that need proper fatigue resistance (including civil engineering). Based on this issue the need to develop new joining methodologies to join these alloys represents a world wide interest.

Previous experiments have been demonstrated a good behaviour of FSW joint for both EN AW 6082 [2] and EN AW 5083 [3] alloys.

The experimental programs have been shown that by using a serial of optimized parameters sets may be achieved good dissimilar welded joints of EN AW 6082- EN AW 5083, with remarkable structural and mechanical properties, much better than for the standard welding procedures.

2. Materials

The material behaviour to FSW is given especially of its properties, ductility and toughness, the weld tool geometry and the welding parameters [4], [5].

The alloy EN AW 5083 is often used for applications in civil engineering, especially to the bridge construction, because of good corrosion behaviour and the good weldability.

Table 1 presents the chemical composition of EN AW 5083 alloy. Table 2 presents the mechanical characteristics.

Table 1. Chemical composition of EN AW 5083 alloy

Chemical composition [%]									
Mg	Mn	Fe	Si	Zn	Cr	Ti	Cu	Diff.	Al
4.0 - 4.9	0.4 - 1.0	≤0.4	≤0.4	≤0.25	0.05 - 0.25	0.15	≤0.10	≤0.15	92.4 - 95.6

The aluminium alloys from the 6xxx series, which have in composition Si and Mg in percentages that leads to Mg_2Si component, are heat treatable.

Table 2. Mechanical characteristics of EN AW 5083 alloy

Rm [MPa]	$Rp_{0.2}$ [MPa]	A5 [%]	HV
315	228	16	96

The alloying elements give to the EN AW 6082 alloy a good mechanical resistance, the good behaviour during extrusion process, highly corrosion and fatigue resistance. These qualities indicate the material to be used for rail train structures, truck frames, naval ships, bridges, bicycles, platforms, hydraulic systems, mining equipments, nuclear systems etc.

Table 3. Chemical composition of EN AW 6082 alloy

Chemical composition [%]						
Si	Fe	Cu	Mn	Mg	Zn	Al
1.06	0.385	0.066	0.62	1.2	0.011	96.66

Table 4. Mechanical characteristics of EN AW 6082 alloy

Rm [MPa]	$Rp_{0.2}$ [MPa]	A5 [%]	HV
322	297	11	110

The chemical composition of the alloy EN AW 6082-T651 plates is presented in Table 3 and the mechanical properties are presented in Table 4.

3. Experimental program

The experimental program for the FSW welding of the alloys couple EN AW 6082-T651 and EN AW 5083-H111 has been developed together with GKSS Institute from Germany (today HZG Institute), the welds have been realized with a portal welding machine. The characterisations of the welded joints (samples cutting, macro-analysis, hardness measurements, tensile and bending tests) have been realized at the ISIM Timisoara.

The welding experiments have been realized on plates with 600x90 mm dimensions, with a thickness of s = 6 mm (Experiment I).

The obtained results have been compared with the world wide results (Experiments 2÷7) [7].

Sudarea şi Încercarea Materialelor

There have been used two types of welding tools:
- one with threaded cylindrical pin and flat shoulder with Ø = 18 mm diameter (Figure 1)

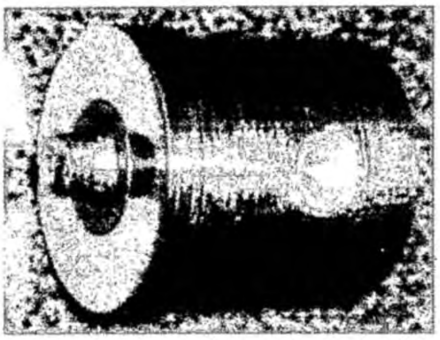
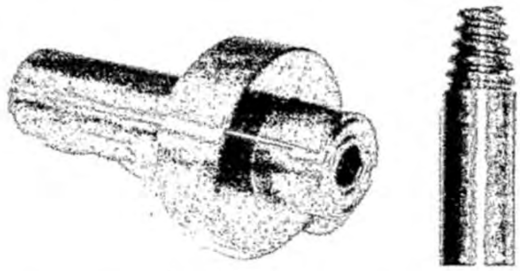


Figure 1. Welding tool with threaded cylindrical pin M6

- one with threaded tapered pin and a shoulder with machined spiral flute, with a diameter of Ø = 18 mm (Figure 2) (GKSS Germany).



a) b)

Figure 2. Welding tool: a) tool shoulder with machined spiral flute; b) tapered threaded pin

The welding parameters [6] that have been used are presented in Table 5, and the position of the welding materials is presented in Figure 3 (EN AW 5083, on the advancing side).

Table 5. FSW welding parameters for EN AW 6082 / EN AW 5083

Exp.	Materials	Thickness s [mm]	Tool			Welding process parameters		
			Type	Pin length l_{pin} [mm]	Shoulder diameter $Ø_{shoulder}$ [mm]	Rotational speed n [rot/min]	Welding speed v [mm/min]	Position of materials
1	EN AW 6082 + EN AW 5083	6	Threaded tapered pin	5.87	15	1200	180	EN AW 5083 on advancing side
2		3	Threaded cylindrical pin	2.87	18	840	300	
3		3			18	560	300	
4		3			18	280	300	
5		3			18	840	300	EN AW 5083 on retreating side
6		3			18	560	300	
7		3			18	280	300	
Position of pin axes - on the joint line								

The welding direction was parallel to the rolling direction of the plates.

For the evaluation of the FSW welded joints have been realized macro analysis, tensile and bending tests, hardness measurements.

For the tensile and bending tests, the samples have been cut with water jet and mechanical processed (on both sides) to a thickness of s=5 mm.

4. Results. Discussions

The macroscopic image of the Experiment 1, presented in Figure 4, shows the characteristic FSW welded joint, without defects/ imperfections, with a well defined nugget. It is obvious the way how the two aluminium alloys have been "mixed".

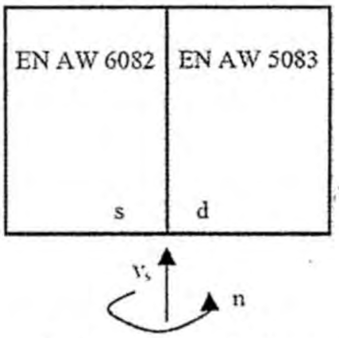


Figure 3. Scheme of the welded materials EN AW 6082 and EN AW 5083

Figure 4. Macroscopic image of the welded joint

Figures 5 and 6 present the macrostructures from the mixed zone of the welded joints, realized in different conditions, with EN AW 5083 on the advancing side and on the retracting side, respectively [7].

The modification of the welding speed or of the rotational speed may have an important effect to the material flow in the stirred zone. The material mixing grade increases with the increasing of the rotational speed and with the reducing of the welding speed. From this point of view the rotational speed has a more significant influence than the welding speed. As a result, the welds realized with the same welding speed of 300mm/min (welds 2÷7), does not present the same mixture grade of the materials.

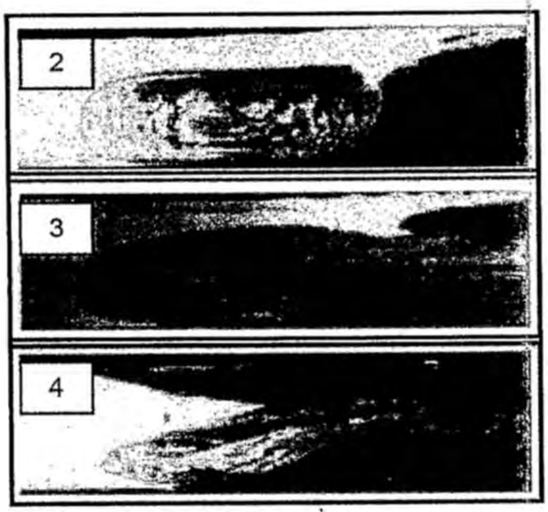


Figure 5. Macrostructures - EN AW 5083 on the advancing side [7]

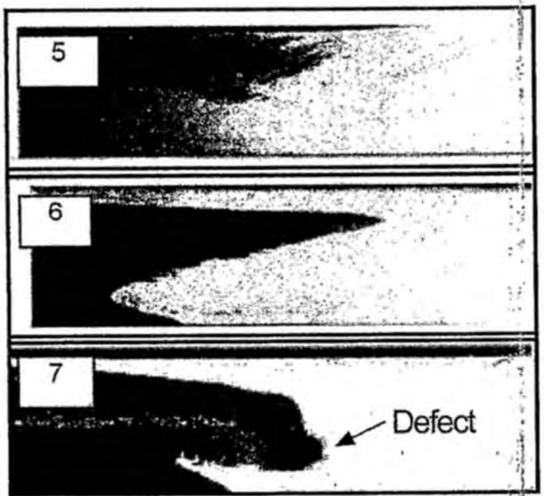


Figure 6. Macrostructures - EN AW 5083 on the retracting side [7]

Then again, for a given welding parameters combination, the welds realized with EN AW 6082 situated on the advancing side, present a reduced mixture grade of the materials (in the stirred zone), that for the samples with EN AW 6082 on the retracting side of the welding direction. Reducing of the mixture grade affects the defects formation (voids or tunnell deffects) in the welded joints(ex. Weld 7), defects which are not present in the weld 4, although they have been realized with the same welding speed [7].

The evaluation of the joints has been realized also through the comparison of the mechanical strength, static tensile tests of base material (R_{mBM}) and welded joints (R_{mWJ}). The testing conditions and the static tensile tests results of the couple EN AW 6082 - EN AW 5083 aluminium alloys, for experiment 1, are listed in Table 6, and the samples are presented in Figures 7 and 8.

There have been observed that the ultimate strength of the 4 samples cut of from the different zones of the welded joints, are very appropriate (differences under 1%), which demonstrates the stability of the welding process using the specified parameters along the entire weld lentgh.

It has been analyzed [7] the effects of the reduced mixture grade, in the cases presented above, on the ultimate strength

Table 6. The testing conditions and the static tensile tests results

Test	Tensile tests of the weld FSW EN AW 5083- EN AW 6082					
Equipment	MU 100KN ZD 10/90					
Testing conditions:						
Temperature	16^0C					
Humidity	42 %					
Sample Nr (pierced)	a (mm)	b (mm)	a x b (mm^2)	F_{max} (N)	R_m (N/mm^2)	Failure position
CEAB3 SN5	5.2	12.1	62.9	15800	251.2	HAZ+ W
CEAB3 SN8	5.2	12.1	62.9	15850	251.9	HAZ+ W
CEAB3 SN10	5.2	12.2	63.4	15900	250.8	W
CEAB SN12	5.2	12.1	62.9	15750	250.4	HAZ+ W

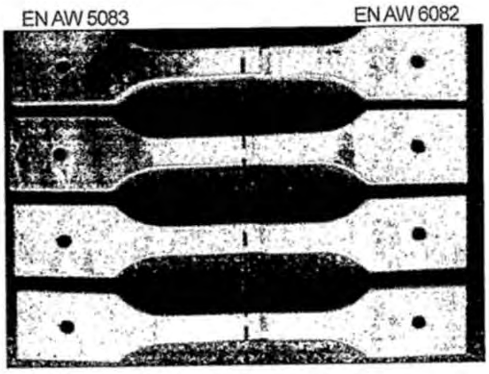


Figure 7. Welded samples after the tensile tests

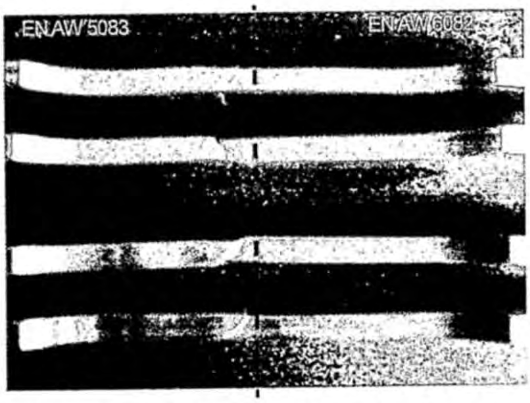


Figure 8. Welded samples after the tensile tests, perpendicular on the plates surface

of the welded joint and the location of the failure place in the samples, regarding the characteristic zones of the FSW welding process. During the tensile tests the maximum deformation was focused in HAZ, on the EN AW 6082 side and the failure took place mostly in this area. Exceptional was the failure of the Experiment 7 where the breakage took place on the welding line, because there were defects.

To the Experiment 2-7 the failure strength fluctuate between 200-240 MPa, smaller that for the base material of EN AW 6082-T6 (≈330 MPa). The values of the failure strength are comparable to that for the WIG weld of dissimilar welds of EN AW 5083-O / EN AW 6061-T4, where the failure took place mostly in the HAZ on the side of 6XXX alloy [7].

Analyzing the experimental data, it could be observed a smoothly increase of the R_m from 200 MPa to 240 MPa and the ultimate elongation from 2.3 to 3 mm, in case of increasing the tool rotation and also the welding speed, for the Experiments 2÷7 [7].

For the experiment 1, the average failure strength was aprox. R_{mWJ} = 251 MPa, bigger than for the other experiments (because of the high rotational speed of the welding tool, n=1200 rot/min). The ratio between the failure resistance of the welded joint and the base material failure resistance for EN AW 5083 alloy is R_{mWJ}/R_{mBM} (EN AW 5083) ≈ 0.8 (failure resistance of the welded joint represents 80% from the base material failure resistance of EN AW 5083 alloy). For the alloy EN AW 6082, the ratio between the failure resistances was R_{mWJ}/R_{mBM} (EN AW 6082) ≈ 0.78 .

The bending test intended to define the plastic deformation capacity of the base material and also of the FSW weldments, based on the bending to failure angle.

The static bending test, for the experiment 1, demonstrated that the samples without defects, the welded joint presented the maximum deformation grade ($\alpha = 180^o$) for both FBB and RBB tests.

The tests results of the welded joints indicate a good behaviour, for the optimal welding parameters, considering also the most sever bending test, meaning the bending test with the weld root on the side of maximum deformation.

The Vickers hardness measurements (HV2) has been realized perpendicular on the tool movement direction along the welding elements, on three levels of depth in plate thickness, on 1.5 mm, 3 mm and 4.5 mm from the weld surface (Figure 9).

Figure 9. The place of the hardness measurements prints

With the measurements results have been sketched the hardness evolution graphics, presented in Figure 10.

In the nugget, on the joint line for the two materials, de average value of the three measurements is around 82 HV0.2.

From this zone, in the EN AW 5083 alloy direction, the hardness presents a slow drop until achieve the heat affected zone (HAZ), where the values are more close to the values for EN AW 5083 base material, around 78-80 HV0,2.

In the direction of EN AW 6082 in the weld nugget, on the first measurements line the hardness measurements increase slowly (max. 90 HV0.2) until reach the TMAZ and then appears a drop in the HAZ, the maxim value in this zone is 75 HV0.2. After that the values of the hardness measurements increase until reach the base material values (110 - 115 HV0.2).

On the second line, the hardness measurements evolution is closely as for the first line, with the different value in the nugget zone and TMAZ, with a smooth drop, the average value is about ≈ 83 - 84 HV0.2. In the HAZ the minimum value is ≈ 72 HV0.2.

On the third line (in the weld tool pin peak) the drift is descending, starting from the weld nugget until reach the TMAZ, with an approximate value of 70 HV0.2, afterwards the hardness values start to increase, inclusive in HAZ, until reaches the values from the base material hardness (EN AW 6082).

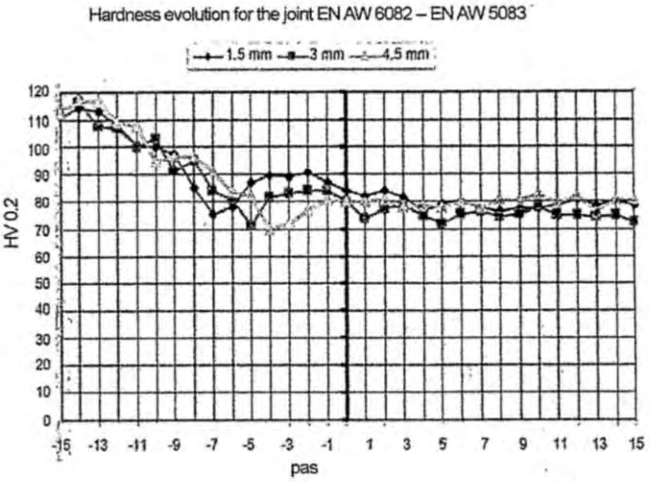


Figure 10. Hardness evolution for the FSW joint EN AW 6082 - EN AW 5083

Analysing the results obtained for the dissimilar FSW welding of EN AW 5083 with EN AW 6082 aluminium alloys, it may be said that these are good, in some cases better than the welding of the similar alloys.

The macro analysis proved the possibility to obtain welded joints without any defects / imperfections, and the statically tests indicated good mechanical properties.

Taking into account the wide use grade of these two aluminium alloys (especially for the naval constructions and for transport industry) and the difficulties that appear by using standard welding procedure and the necessary precautions in these cases, the possibilities offered by the FSW welding procedure are favourable and may offer the base for future industrial applications.

5. Conclusions

- The welding of the aluminium and its alloys is realized by using the traditional electric arc welding procedure, which involves supplementary expensive precautions.
- The FSW welding process allows an easy processing of the similar and dissimilar aluminium alloys is environment friendly and presents advantages from the economical efficient.
- The behaviour of the base material during the FSW process is given especially by its properties, ductility and toughness, welding tool geometry and the welding parameters.
- Dissimilar FSW welding involves some supplementary approaches:
  - The material setup (left or right), depending from the mechanical characteristics, must be correlated with the rotational direction and the movement of the welding
  - The setup of the tool axes related to the joint line
- The obtained results on FSW welding of the EN AW 6082 with EN AW 5083 aluminium alloys demonstrated that these materials are weldable with this procedure, by using of an

optimized welding parameters sets and by using of the welding tool with the geometrical characteristics presented in this paper.

• The results demonstrated that it is possible to obtain good welds for a large field of parameters / welding conditions. By the use lower rotational speed of the welding tool and a high welding speed, and also the positioning of the EN AW 6082 alloy on the advancing side, result unsatisfactory properties (with defects, imperfections) of the welded joint.

References

[1]. Thomas, W. e.a.: Improvements relating to friction welding, European Patent Specification 0 615 480 B1

[2]. Cojocaru, R., Dehelean, D., Zupanc, U., Ciucă, C.: Comportarea la sudarea prin frecare cu element activ rotitor a aliajului Al 6082, utilizat în construcţii civile, Conf. ISIM TIMA 09, Timisoara, 2009

[3]. Gabor, R., Dos Santos, J., Băncilă, R.: Mechanical performances of Friction Stir Welding of the aluminium alloys, Welding and Material Testing, No. 4/2010, pp. 45-48

[4]. Fuller, C.B.: Friction Stir Tooling: Tool Materials and Designs, Friction Stir Welding and Processing, ASM International, 2007, pp.7-37

[5]. Duborg, L., Dacheux, P.: Design and properties of FSW tools: a literature review, The 6th International Friction Stir Welding Symposium, Saint- Sauveur, Montreal, Canada, 10-13 Oct. 2006;

[6]. Gabor, F.R.: Application of Friction Stir Welding in Civil Engineering, PhD Thesys, Universitatea Politehnica din Timişoara, Facultatea de Construcţii, Ianuarie 2010

[7]. Peel, M.J., Steuwer, A., Withers, P.J., Dickerson, T., Shi, Q., Shercliff, H.: Dissimilar Friction Stir Welds in AA 5083-AA6082. Part I. Process Parameter Effects on Thermal History and Weld Properties, Metallurgical and Material Transactions A, Vol. 37A, pp. 2183-2193, July 2006.

Lecture presented at the 5th International Conference "Innovative Technologies for Joining Advanced Materials", Timisoara - Romania (June 16-17, 2011)