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Friction Stir Welding of Aluminum Alloys. Possibilities of Application

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Abstract

Friction stir welding (FSW) can be used that a new technology which allows development of new concepts, thought and designing some of manufacturing processes.
Through high development of FSW and important advantages, on international level, mainly efforts for implementing of new techniques (FSW) in industrial applications are made.
This paper shows ISIM results in FSW field, for some of 1xxx, 6xxx and 7xxx series of aluminum alloys.
Possibilities and conditions for FSW application in different prior fields, at economical agents from Romania, are presented.

Key words: *FSW, aluminum alloys, industrial applications*

Introduction

Aluminum based alloys are light alloys.

The increases of utilization grade of light metals represent an actuality subject, of the actual trends concerning increases and extend of utilization at manufacturing products which have two major technical characteristics: light weight and high corrosion resistance.

Light metals represent a category of materials in which the main property is the light specific weight (2700 Kg/m3, approximately three times less than iron), and are indispensable, for example, in the manufacturing of components and structures from transportation industries, aeronautics and civil constructions [1], [2].

Welding metals at low temperatures are realized, generally, using traditionally arc welding technologies (MIG; TIG). To apply these procedures for aluminum and its alloys welding special conditions are necessary, such as: border conditioning, oxides layers remove before welding, shielding gases in welding processes, right choice of filler metals, utilization of specifically operating parameters (alternating current), as well as programming and memory facilitation. Moreover, if arc welding procedure is applied to aluminum parts, where long joints are necessary, important deformations are produced, and post welding mechanical working are necessary for initial shapes obtaining [3], [4].

Friction stir welding offer a technological alternative for arc welding procedure, allows joining of similar and dissimilar materials which are difficult or impossible to joint using other welding techniques, facile processing, as well as majorities precaution elimination.

Materials

The applications where the weight diminution is important or some electrical and magnetically characteristics are numerously. These products frequently work in corrosive medium or at extreme temperatures. For these requirements assessed for products, the nonferrous metals and alloys are recommended. Aluminum, magnesium, titanium and them alloys are more used.

In this paper, results obtained at welding of aluminum alloys with low (Al 1200), medium (Al 6082) and high (Al 7075) hardness, are presented. These materials were selected trough different mechanical characteristics and important field of application:

- Al 1200: metallic structures, kitchen tools, packing foils, storage boxes, bends for heat exchangers, radiator tubes, applications in food industry, number plates, identification plates.
- Al 6082: railway structures, trucks chassis, naval construction, pedestrian bridges, platforms, hydraulic systems, mining equipment, nuclear field, bikes.
- Al 7075: Components from aircraft and military area used at high loads, nuclear applications area, bearing balls, tools, bolts and screw, sport articles (tennis rackets).

Chemical composition of these materials is presented in Table 1 and mechanical characteristics in Table 2.

Table 1. Chemical composition of materials

Material	Chemical composition [%]								
	Si	Mg	Mn	Fe	Cr	Zn	Ti	Cu	Al
Al 1200	< 1,0	–	< 0,05	< 1,0	–	< 0,10	< 0,05	< 0,05	> 99,0
Al 6082-T651	0,7-1,3	0,6-1,2	0,4-1,0	< 0,5	< 0,25	< 0,2	< 0,1	< 0,1	Rest.
Al 7075-T651	≤ 0,4	2,1-2,9	≤ 0,3	≤ 0,5	0,18-0,28	5,1-6,1	≤ 0,2	1,2-2	Rest.

Table 2. Mechanical characteristics of materials

	Mechanical characteristics			
Material	Mechanical strength R_m, [MP_a]	Yield limit $R_{p\,0,2}$, [MP_a]	Fracture elongation A, [%]	Hardness [HB]
Al 1200	108	97	28	49
Al 6082	322	297	11	104
Al 7075	570	505	10	160

Experimental Program

Rolled plates of high-strength aluminum alloy 6082-T651 with dimensions 360x110mm, s= 5 mm, 6mm and 12 mm thickness were used for the experiment. The FSW processes were carried out using a welding machine for FSW (Fig. 1).

The welds were realized perpendicularly on the rolling direction. The plates to be welded were placed for butt welding and rigid fixed on a steel backing plate, with grinding machined disposal surface.

Two types of welding tools were used (Fig. 2):

- with pre-heating shoulder of 20, 22 and 24 mm in diameter;
- smooth conical pin tool (Fig.2a), threaded pin tool (Fig.2b), conical threaded pin (Fig.2c), respectively.

Fig. 1. Specialized FSW welding machine

a. **b.** **c.**

Fig. 2. Welding tools

The material of the welding tool was tool steel X38CrMoV5 with high temperature resistance and 55HRC hardness, for welding Al 6082 and Al 7075, and OLC 45 heat treated of 45 HRC for welding Al 1200, respectively.

The welding parameters are presented in Table 3.

Table 3. Welding parameters

Material	Rotation speed [rot/min]	Welding speed [mm/min]	Welding tool
Al 1200	600 ÷ 1500	118 ÷ 300	a ; b
Al 6082-T651	1000 ÷ 1300	140 ÷ 220	b ; c
Al 7075-T651	900 ÷ 1200	90 ÷ 150	b ; c

The plates of s=5 mm thickness were welded on one side, and those of 12 mm thickness, alternately on both sides.

In order to obtain good welded joints, with a consolidated nugget through all the material thickness, it is necessary to achieve the optimum plasticization temperature level. Achievement and maintenance of these temperatures can be monitored on-line by using the diagrams obtained with the infrared thermography system.

As the aluminum alloys in system Al-Mg-Si are weldable also with conventional techniques, the comparison of mechanical properties of FSW welds with classical fusion TIG welds was performed. Parameters of FSW and TIG welding processes are reported in Table 4. No post-weld heat treatment was done [5].

Table 4. Parameters of FSW and TIG welding processes [5]

FSW	Pin: M6, H=7 double-side welded, v=180 mm/min, n=1200 1/min
Filler material TIG (AlSi5)	Composition: AlSi5 (W. Nr. 3.2245), "X" weld, shielding gas: Alumix – I3 (50% Ar, 50% He), I=160A-180A, U=22V, v= 18-25cm/min
Filler material TIG (AlMg5)	Composition: AlMg5 (W.Nr. 3.3556), "X" weld, shielding gas: Alumix – I3 (50% Ar, 50% He), I=155A-185A, U=21V, v= 18-25cm/min

The welded plates were tested visually, with penetrant liquid and X-ray in order to assure that no possible macroscopic defects are present. Samples were cut out of as-received base materials, for Al 6082-T651 TIG welded and FS welded plates perpendicularly on the weld line and static tensile tests were conducted in order to obtain the mechanical properties of the welded joints. The results were compared to those of the base materials.

Tests for determination of fatigue resistance characteristics of welded joints were made, for FSW quality and reliability, shows by limit fatigue resistance and durability at variable solicitations (for Al 1200 and Al 6082) [5],[6].

Results. Discussions

Rolled plates of Al1200, Al6082 and Al7075 aluminum alloy with dimensions according to Cap.3 (Fig. 3) were used for the experiment. All welded plates were RX controlled and with penetrant liquids.

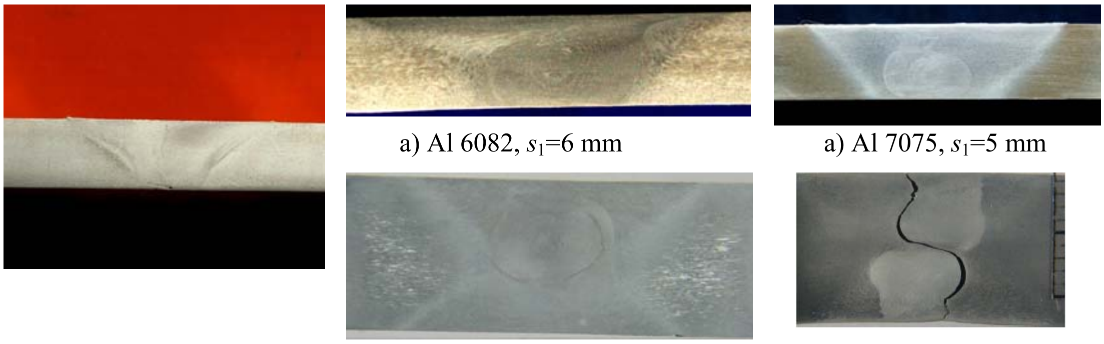
Fig. 3. FSW welded plates (Al 6082)

Welding parameters, welding speed and rotation speed, and also tool dimensions for which it has been obtained defect free welds and good mechanical properties, are shown in Table 5.

Table 5. Welding parameters and tool dimensions

Material	Welding speed v_s[mm/min]	Rotation speed n[rot/min]	Welding tool		
			pin	shoulder	pin length *l* [mm]
Al 1200, *s*=6mm	190	1180	Threaded M6	Smooth, ∅ 24mm	5.85
Al 6082, *s*=5mm	180	1200	Threaded M6	Smooth, ∅ 22mm	4.80
Al 6082, *s*=12mm	180	1200	Threaded M6	Smooth, ∅ 22mm	7.00
Al 7075, *s*=5mm	110	1000	Threaded M6	Smooth, ∅ 20mm	4.85
Al 7075, *s*=12mm welded on both sides	110	1000	Threaded M6	Smooth, ∅ 24mm	5.85

The macro graphic structures (Fig. 4) shows a free defects weld seam section and also that the weld nuggets are well built in the middle of the welding section, as concentric circles, for the plates of 5 and 6mm thickness, but also nugget fusion for the 12mm thick plates.



Al 1200, s=6mm

a) Al 6082, s_1=6 mm

b) Al 6082, s_2=12 mm

a) Al 7075, s_1=5 mm

b) Al 7075, s_2=12 mm (after tensile tests)

Fig. 4. Macroscopic structure

The evaluation of welded joints quality has also been carried out through a comparison between the values of the breaking resistance for static tensile tests for of base material samples (R_{mMB}) and the results of tensile tests for the welded samples (R_{mIS}). Results are shown in Table 6.

Table 6. Comparison between breaking resistance for static tensile tests Rm_{IS} / Rm_{MB}

Material Thickness	Al 1200 s=6mm	Al 6082 s=6mm	Al 6082 s=12mm	Al 7075 s=5mm	Al 7075 s=12mm
Rm_{IS} / Rm_{MB}	75-80 %	70-73 %	~70 %	75-77 %	65-68 %

Researches demonstrated that the welding speed can have an important influence on the statically tensile tests, using the same rotational speed and the same characteristics of welding tools. For example, for Al 6082, experiments and welds evaluations denoted that at 1200 rpm and the welding speed between 150 and 190 mm/min, using a threaded cylindrical pin, good results for tensile strength can be obtained [5].

The bending test has been carried out in order to underline the plastic deformation performance of the base material and also of the friction stir welded material, using the fracture bending angle principle.

The Al 6082 – T651 alloy shows a good ductility and certifies a maximal deformability, but bending tests for Al 7075 as base material at $\alpha \cong 40^0$ were fractured.

Test results of welded joints, for all investigated materials, show a very good behavior of the weld, for optimum welding parameters. The welded joints were constrained to the most sever bending test, with the root of the weld on the side with the maximum deformation.

It has been observed that for welded joints the plastic deformation capacity may be influenced by the welding speed.

In order to relieve the quality of friction stir welded joints, a comparison between FSW welded joint properties and TIG welded joints properties was made, for a 6082-T651 aluminum alloy plate with the thickness of 12 mm.

Static tensile tests demonstrated that fracture resistance of the FSW welded specimens is better than that of TIG welded specimens and it represents 70 - 72% of the base material fracture resistance.

The test carried out it has been shown that FSW joints have a good fatigue resistance. FSW joints have a fatigue resistance of 92 MPa, close to that of the base material that is 125 MPa. The frequency of resonant voltage was 115Hz with sinusoidal wave and transformation ratio

R=0,05. A limit at 10^7 of fatigue cycle was ascertained. In comparison with fusion TIG welding, FSW joints have o higher fatigue resistance with 30%. At higher tensile, fracture initiation takes place in the center of the weld, and at lower tensile the fracture is located in the lowest hardness welded zone.

It must be mentioned that using decrease of welding speed (the same rotation speed) at friction stir welding of Al 7075, a improvement of strength resistance has generated, but in the same time reducing of plastic deformability grade of the welded joint .

Possibilities of Application

For a good period of time, the transport sector was the biggest market of final users for aluminum and it's alloys (aprox. 25% from total). Needful in aerospace industry, for it's low weight, aluminum is used more and more for vehicle, bus, wagon, trucks, trains, ships, planes and bicycle building.

Research results fundamented FSW welding application in different industry sectors: aerospace (Airbus, Boeing, EADS), automotive (Toyota, Ford, Rover, Honda), railway (Shinkansen high speed train).

World wide results regarding FSW welding process implementation in industrial activities can form the base of implementing the new technologies in the Romanian industry, especially in prior domains:

Naval constructions
Introducing friction stir welding in shipbuilding, impulsed the use of aluminum in welded structures, especially where thin or semi fabricated extruded sheets are used, and the dimensions are limited due to fabrication process (section of few hundred mm^2 max.). Naval industry and shipbuilding are two of the first industries that used FSW for commercial applications.

The process is recommended for the following applications: platform, walls, panels, bulkheads, floor panels; halls and superstructures; helicopter landing platforms; naval structures; refrigerating installations; naval platforms.

Panels with high dimensions, formed from extruded profiles, are mass produced, with open or closed profile, used as platforms, bridges, walls, floors, walkways etc.

In naval constructions and for superstructure platforms of naval drilling systems, 5xxx and 6xxx series aluminum alloys are used.

Using FSW process, a large variety of constructive forms for components, with high length, high cross section, cased beams, longerons, extruded or cast materials, can be welded [1].

Vehicle industry
Vehicle industry, especially, and road transportation domain, generally, are characterized by a high competition between constructors, in order to increase technical performances and to reduce fuel consumption.

One way to achieve this desideratum is to reduce vehicle weight, especially for the car body. This can be achieved by using high strength materials with low section or using materials with a low specific weight.

The FSW process can be used for car body construction, central console, suspension cars and car wheel cylinders welding.

Friction stir welding process is an alternative for riveting joining, due to high cost of the rivets and also because of the riveting machines dimensions. Vehicle producers estimate that the FSW process will have a high impact regarding the possibilities of using aluminum in vehicle construction domain.

In present time, the FSW welding process is highly experimented and applied by vehicle construction companies, for manufacturing motors and chassis, wheel bandages, truck components, mobile cranes from transport vehicles, fuel tanks, trailers, motorcycle frames and bicycles, etc.

Aerospace industry

Friction stir welding process can also be used in aeronautics domain. The process drastically reduces assembly time and eliminates the need of thousand of rivets, and the results are reflected in assembly costs, high quality, resistant and light joints.

As an application, FSW welding is used for manufacturing commercial aircrafts modules, replacing the riveting process. At aircrafts, longitudinal butt welding can be made for fuselages, floors, girders, wings etc., circumference lap welds for fuel tanks, but also other type of welds.

Railway transport

FSW welding is used for manufacturing high speed trains wagons.

Wagon manufacturing processes imply welding components of great length (15-20mm). By using friction stir welding for different train wagons structures manufacturing, welds with minimum post welding deformations can be obtained.

By manufacturing the wagon body from aluminum, with double walls, a simple structure cand be obtained, that doesn't require an additional resistance frame/structure.

As a result for using FSW process in welding wagon structure elements, high quality and resistance joints can be obtained. The joining is clean, without drops and no gasses during the welding process. The welded surface is plane, without deformations, and the final operation can be just to paint the exterior of the wagon.

Also, beside the mentioned domains, the FSW welding process can be used in civil constructions and bridges, nuclear waste containers, heat exchangers manufacturing, medical technique, military technique, electronics, etc.

Conclusions

Al is a light metal, strong and durable. From these 3 base properties, Al becomes the preferred metal for applications in prior domains.

Metals with low melting temperatures welding, in general it is done with conventional electric arc welding process.

Ecological friction stir welding process (FSW), is a good alternative to the conventional electric arc welding methods.

Through the experimental program it has been demonstrated that using optimized parameters superior FSW joints can be obtained with better characteristics than those of conventional welding methods, for low hardness (Al 1200), medium hardness (Al 6082) and high hardness (Al 7075) aluminum alloys, for one side welded plates having s=5-6mm thickness, as well as both sides welded plates having s=12mm thickness.

Static tensile tests demonstrated that fracture resistance of the FSW welded specimens is better than that fusion welding (TIG).

Using optimized welding parameters, at static bending test, the welded joint exhibited a maximum degree of deformation.

The tests carried out it have been shown that FSW joints have a good fatigue resistance.

Experimental results demonstrated that analyzed aluminum alloys, have a good behavior in FSW process and can be used for manufacturing of welded structures in different industrial applications.

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Sudarea prin frecare cu element activ rotitor a aliajelor de aluminiu. Posibilitati de aplicare

Rezumat

Procedeul de sudare prin frecare cu element activ rotitor (FSW) poate fi utilizat ca o noua tehnologie ce permite dezvoltarea de noi concepte, gandirea si proiectarea unor procese de fabricatie.
Datorita dezvoltarii rapide a procedeului de sudare FSW si a avantajelor importante pe care prezinta, pe plan international, se depun eforturi deosebite pentru implementarea in aplicatii industriale a noii tehnici (FSW).
Lucrarea prezinta realizari ISIM in domeniul sudarii FSW a unor aliaje de aluminiu din seriile 1xxx, 6xxx si 7xxx.
Sunt prezentate posibilitati si conditii de aplicare a procedeului FSW la agenti economici din Romania, din diferite domenii prioritare.