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FACULTY OF MECHANICAL ENGINEERING
Department for Production, IT and Management

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FOREWORD

The first Scientific conference on production engineering of ex Yugoslavia was held in Belgrade, in 1965, initiated by Prof. Vladimir Šolaja. This also marked the forming of the Association of scientific and research institutions in production engineering, which included faculties of mechanical engineering and research institutes of almost all major cities of the former federation. The Association of scientific and research institutions in production engineering was reinstated, under new circumstances, in 1994. In 2009, the Executive Board of the Association delegated the organization of 34rd Conference to the University of Niš, Faculty of Mechanical Engineering in Niš.

The organizer of this Conference, the Department for Production, IT and Management of the Faculty of Mechanical Engineering, University of Niš, has ambitiously approached the task of organizing this Conference, setting two primary goals: (1) to point to the current state of research in the area of production engineering in the region of SEE as well as rest of Europe, (2) to use presence of highly competent professionals to initiate discussions on boosting of production in SEE.

In order to meet these goals, the organizing committee has made efforts to attract production engineering community to present the results of their research. A total of 180 papers were registered. All papers submitted for presentation passed through a double blind review process and were evaluated by two reviewers. After peer review process 119 papers were accepted for presentation. Those authors whose papers were chosen for presentation at the conference submitted manuscripts to be published in these Proceedings. The authors are from 16 European countries: Austria, Bosnia and Herzegovina, France, Germany, Montenegro, Slovenia, Slovakia, Czech, Croatia, Poland, Romania, Belarus, Macedonia, Greece, United Kingdom and Serbia.

Also, four invited lectures will be given by distinguished professors. One of these lectures is an introduction to a roundtable on the theme: "Boosting production in SEE".

The Ministry for Education and Science of Serbia, together with donors from industry, have financially supported the organization of this Conference, for which the organizer wishes to express gratitude on this occasion.

On behalf of the organizing committee, I wish to express my gratitude to all domestic and foreign contributors, as well as the editing board for the performed reviews.

Niš
September 20, 2011

President of the organizing committee	President of the Executive Board of the Association
Prof. Dr. Miroslav Trajanović	Prof. Dr. Velibor Marinković

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AN OVERVIEW ON FRICTION STIR WELDING OF THE AL 2024 T351

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Abstract: *Friction stir welding is a solid state welding technique used for joining soft metals such aluminium and its alloys are. Alloy 2024 is a representative of conventionally unweldable alloys but fully wieldable by friction stir welding. In this case, welding is possible only when proper geometry of the welding tool, welding speed etc. are selected. Like for other welding techniques, results of the welding have to be evaluated by testing given by requirements of appropriate standards. However, it is a challenge to select proper parameters and paper presents some successful experimental results on this topic and announces further developments in the technology of the friction stir welding.*

Key words: *Friction Stir Welding, 2024 aluminium alloy*

1. INTRODUCTION

Friction stir welding (FSW) is a solid state welding process predominantly used for joining materials difficult to weld by applying some of conventional processes. Its application is mainly connected with the welding of aluminium alloys and other soft metals/alloys. In comparison to other welding processes, FSW delivers the smallest amount of energy to the base metal, which results in the smallest deformation in the structure of the base metal. However, FSW is still an unconventional welding process because of the complexity of application and the need for long welds in order to have great productivity. FSW is used for plate-shaped parts [1].

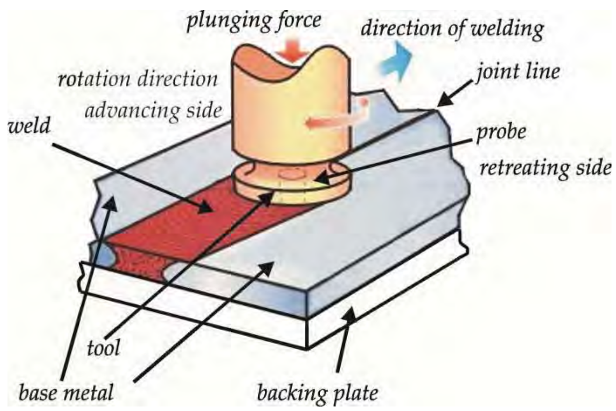

Figure 1 Schematic of the FSW process

In FSW, a cylindrical, shouldered tool (Figure 1) with a profiled threaded probe is rotated at a constant speed and fed at a constant traverse speed into the joint line between two plates, which are butted together. The parts have to be clamped rigidly onto a backing plate to enable welding.

2. WELDING TOOL

Welding tool used in FSW is a specialized rotating component that passes entirely through or partially through the workpiece(s) along the joint line, and may or may not have a shoulder [1] and the welding tool always has a probe. The probe is usually cone or cylindrical with the thread on the side. It is common to use left sided thread for clockwise rotation of the welding tool or right sided thread for counterclockwise rotation of the welding tool. The type of the thread is various: metric, profiled, oval etc., with changeable/unchangeable thread step. What type of the thread and thread step will be used depends from the material of workpieces (base metal).

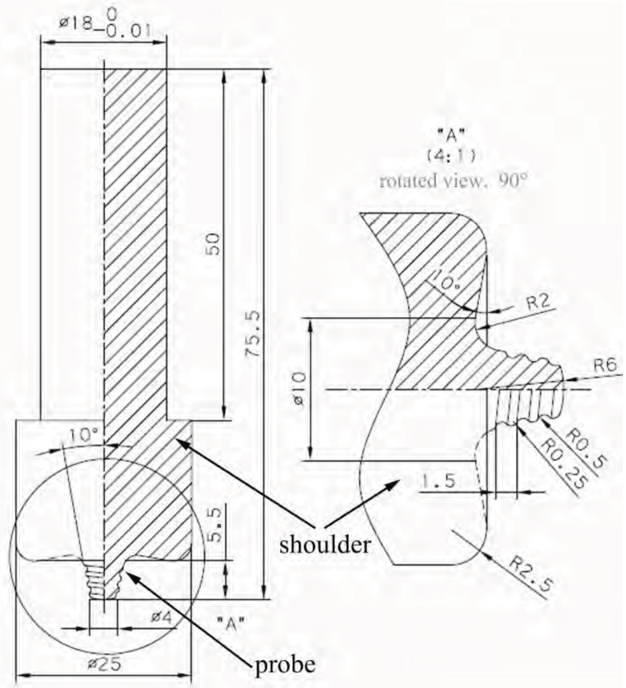

Figure 2 Drawing of the common welding tool [2]

Welding tools must resist high temperatures, and wear and they are manufactured from durable, heat resistant and high strength steels. Active surfaces [1] of the welding tool are usually manufactured by milling or turning, polished and heat treated after machining – annealed and normalized. Hardness of active surfaces on the welding tool should be at least the same as the hardness of workpieces or higher.

3. WORKPIECES

The first application of FSW was on the groove welds on railway vehicles [1] however it was never intended to be used only for the one type. Development of the FSW was tremendous and it expanded on various fields as well as on application on butt welds, spots welds etc. However, groove welds are primary application of the FSW especially on the plate-shaped parts where pipes are included as well.

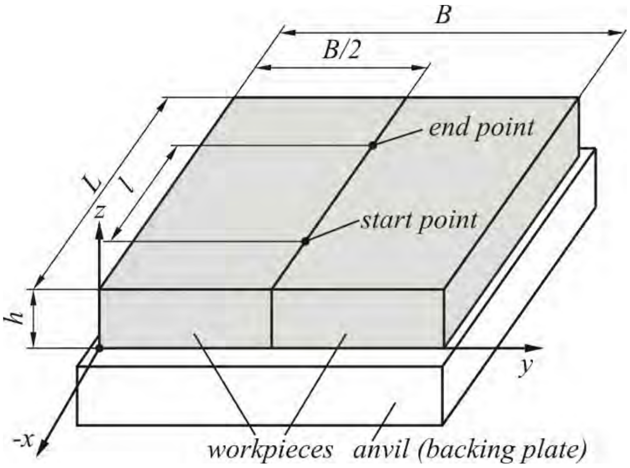

Figure 3 Scheme of the positioned workpieces in position for welding

Before the welding start workpieces are set on an anvil (backing plate), connected to each other on the joint line and clamped to the work table of the machine. Workpieces must be rigidly clamped since forces that appear during welding have to be used for deformation, stirring and mixing of material instead of moving workpieces. Anvil assists in weld root creation and supports workpieces during welding. It has to be manufactured from stiff, rigid, with low thermal conductivity material capable to maintain stability of the system and reduce thermal loses.

3.1. Material of workpieces

FSW is widely used for the joining of softer metals such aluminium and aluminium alloys are. Aluminium alloys are always a challenge for welding, without concern on weldability or unweldability of base metal. Like other arc welding processes, FSW is applicative for welding of 5××× and 6××× series of Al alloys but its advantages over other processes are seeable when welding 2××× class of Al alloy. A representative of the 2××× class is alloy 2024 and it is widely used in FSW processes.
Aluminium alloy 2024 is an Al alloy, with Cur and Mg as the alloying elements. It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. It is not weldable, and has average machinability. Due to poor corrosion resistance, it is often clad with Al or Al-Zn for protection, although this procedure may reduce the fatigue strength. It has a density of 2.73 g/cm³, Young's modulus of 73 GPa across all tempers, and begins to melt at about 500 °C. Due to its high strength and fatigue resistance, 2024 is widely used in aircraft structures, especially wing and fuselage structures under tension. Because the material is susceptable to thermal shock, 2024 is used in qualification of liquid penetrant tests outside of normal temperature ranges.

Table 1. Chemical composition and mechanical properties of alloy EN AW 2024 T351

Chemical composition		Mechanical properties	
Chemical element	Mass %	0.2% Proof Stress $Rp_{0,2}$	266-274 N/mm^2
Al	~		
S	0.12		
Fe	0.28		
Cu	4.52	Tensile Strength R_m	404-424 N/mm^2
Mn	0.65		
Mg	1.60		
Cn	0.01		
Zn	0.09	Elongation A_5	22.00%
Ti	0.016		
B	0.009		
N	0.02		

Data in Table 1 is taken from the Approved Certificate data: Alcoa International, inc, No 47831, for sheet of 2100 mm × 6000 mm × 8mm, material EN AW 2024 T351 used for the FSW process (experiments).

4. TECHNOLOGICAL PARAMETERS

FSW is effective and productive only when the right combination of the welding tool (material, geometry, surface condition etc.) is used on proper workpieces (material, geometry, type of joint etc.) with proper technological parameters of the FSW process (travel speed, tool rotation speed, plunging time, dwelling time etc.). Only in that case appear adequate tribological processes and phenomena (contact pressure, friction, wear, lubrication, heat generation, deformation, adhesion, material exchange etc.) which result with monolith joint between workpieces and qualitative weld.
Technological parameters are the few properties of FSW directly changeable and/or adjustable during welding process. However, selection of proper technological parameters, meaning, travel speed v_{ts} and tool rotation speed v_{rot}, as the most important ones is a difficult task. From the beginning of FSW‟s industrial application (mid 1992.) until present days, selection of travel speed and tool rotation speed is done by „try and error‟ principle. Usable data about the technological parameters for specific processes/materials are usually hidden.
In most of the cases technological parameters of FSW are given over the welding step determined as the ration of tool rotation speed and travel speed v_{rot} / v_{ts}.
Ţivković [2] has estimated that 2024 alloy can be successfully welded for the weld step varying from 30 to 5, where the best results were achieved for parameters given in the Table 2. Welding was performed more than 100 times.

Table 2. Experimental welding step values for successful welding of the 2024 alloy [2]

v_{rot} / v_{ts}			
1180/116=10.17	1180/46=25.65		
750/150=5.00	750/116=6.64	750/93=8.06	750/73=10.27

5. VERIFICATION OF RESULTS

The final result of the FSW has to be a product that must fulfill its projected purpose. Decomposing this statement to the primary level: FSW joint has to be qualitative and should at least maintain properties of the base metal in projected range if not possible to improve them.
According to the existing standards in FSW [3], verification of the results and FSW process has to be done by testing of specimens that have to be specially prepared and extracted from the welded structure (Figure 4).

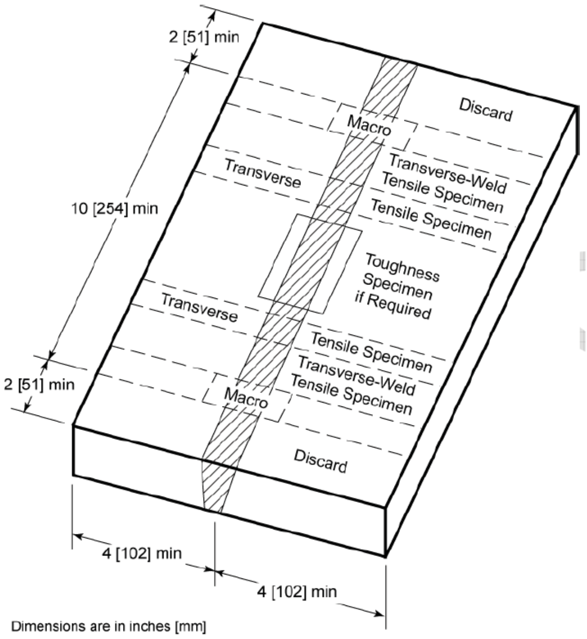

Figure 5 Location of Square Groove Weld Test Specimens—Plate [3]

5.1. Mechanical properties

Welded structures can be overmatched or undermatched from the aspect of the weld joint˝s strength. FSW process applied on 2024 alloy mostly gives overmatched structures: values of the strength, yield stress, hardness, elongation etc. slightly drop in the area of the weld or heat affected zone (HAZ) (Table 3).

Table 3 Experimental values of mechanical properties of FSW processed 2024 alloy in HAZ [2]

Test Nº.	$Rp_{0,2}$, MPa	R_m, Mpa	A_5 ,%	v_{rot} / v_{ts}
1	323	398	6,0	1180/116=10,17
2	316	319	7,1	1180/46=25,65
3	324	330	4,8	750/150=5,00
4	318	395	7,5	750/73=10,27
5	/	210	2,2	750/150=5,00
6	313	365	4,2	750/73=10,27

The common hardness diagram of 2××× class has a specific W-shape: hardness of the material on join (center) line has some median value and distancing from the center line it gradually drops until the center of the HAZ than it rises and stabilizes its value outside the HAZ.

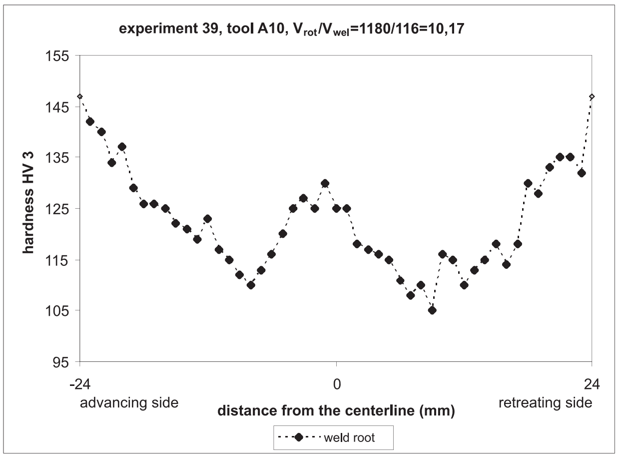

Figure 5 Hardness distribution in FSW, for 2024 alloy [2]

Hardness peak on the centerline is a result of the nugget zone (N). Nugget is the zone of fully recristalized material that appears on the very center of the joint line and it is a product of intensive plastic deformation initiated by the welding tool and heat treatment of material (during the welding process) (Figure 6).

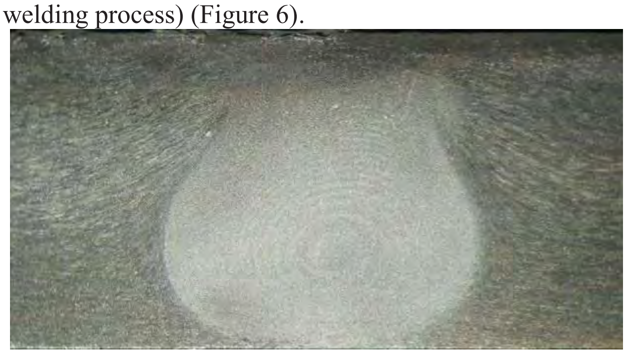

Figure 6 Macroscopic section on nugget zone of the FSW weld on 2024 alloy [2]

6. FUTURE WORK, DISCUSSION AND CONCLUSIONS

During past 20 years of application of FSW, science has given the great tribute to its improvement and better understanding the process itself. Numerous researches on the FSW application were aimed in recognition of dominant parameters that influence the process and the possibilities of their adjustments in order to reach optimal or desired characteristics of welds [4].
As mentioned earlier, some parameters of the FSW process are adjustable and simple to change since they depend only on possibilities of the system or fabricator. Challenge is to manipulate with other, nonadjustable or difficult to be adjusted parameters that depend not only from the process but from various physical phenomena as well. From the early beginning of application it is recognized that dominant processes in weld creation during FSW are deformation and heating. Literature explains differently these two processes: somewhere this

is stirring and heat generation, somewhere adhesion, diffusion, wear and friction, and some authors explain it as a pure mechanical process with the influence of other processes.

If some accepts any of the proposed explanation to be satisfactory accurate, FSW will still remain elusive from some point of view, either on macro or micro level, and the shade of our (human) no-understanding of the physics keeps us away from perfect deign of the FSW. Anyhow, this challenge is overcome by numerous experiments and researches, and analysis of the processes that appear during FSW – good explanation of these processes helps in understanding the FSW in general.

With the goal of better design of the FSW (meaning: proper selection of technological parameters, geometrical parameters of the welding tool, workpieces" preparation etc.) mathematical model for the heat generation during FSW is developed. Heat is a necessity of the FSW process and its tribute in better weld creation lies dominantly in softening of the workpieces and easing the deformation/adhesion/stirring… process during weld creation.

Mathematical model relies on mathematical analysis, theoretical assumptions, state of the art in measuring techniques, recognition of dominant physical phenomena etc (Figure 7).

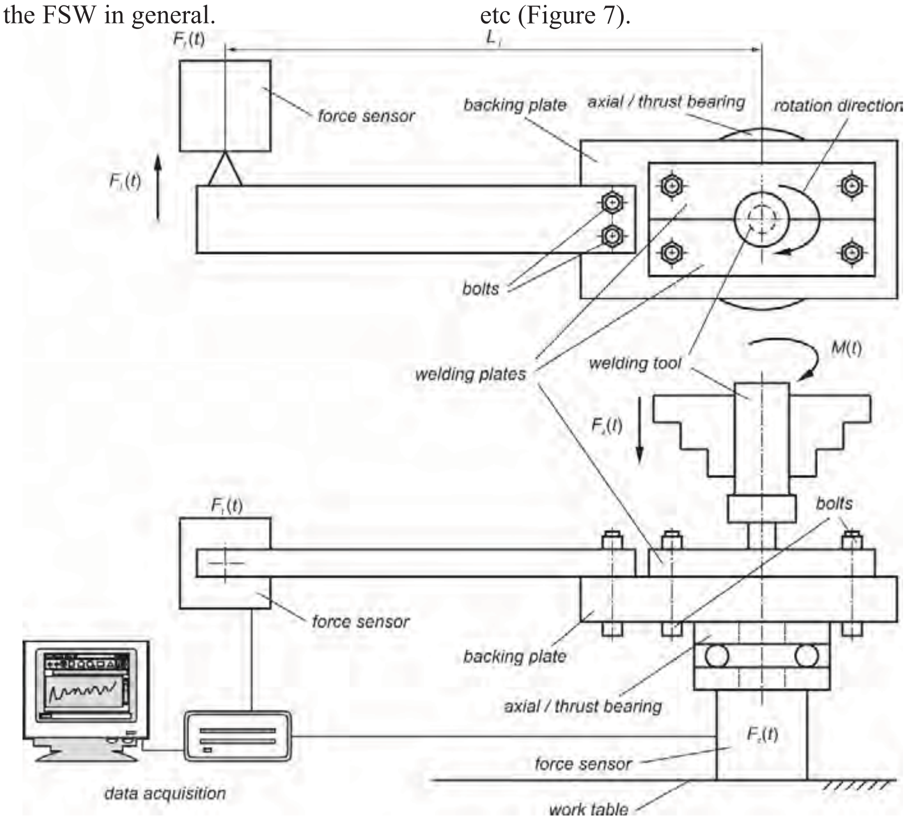

Figure 7 Scheme of the experimental setup for the FSW process

Further research in this area of FSW requires:

1. Recognition and precise determination of active/reactive forces in the system welding tool-workpieces, its influence and possibilities of increase/decrease of their magnitude.
2. Estimation of tribological parameters in contact between welding tool and workpieces (friction coefficient, contact pressure, adhesion, wear, selfaligning, selflubrication etc.)
3. Possibilities of the process efficiency increase (energy consumption, heat losses cuts etc.).

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