New possibilities of applying the friction stir welding process

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1. Introduction

FSW welding technique in an inert gas environment FSW-IG represents an unconventional joining technology, derived from the conventional friction stir welding process, which is given special attention in the international scientific world, generating considerable interest in several industrial sectors: shipbuilding, road and rail transportation, aeronautical, etc. [1] – [5].

FSW-IG welding method in inert gas environment (e.g. argon) is useful for improving the quality of welded joints made of materials with high mechanical strength and high melting temperature (e.g. steel, titanium, etc.) by shielding against oxidation the tool and welding zone [1] - [8]. For example, when welding reactive materials, with high affinity to oxygen (e.g. titanium alloys), the application of welding in an inert gas environment is required.

Within this paper some preliminary results are presented, regarding the application of the FSW-IG welding process, obtained by ISIM Timișoara. The results refer in particular to providing the necessary techniques for applying FSW welding in an inert gas environment. There are also presented some welding experiments on pairs of similar materials, as titanium TiGr2, respectively steel DD13.

2. Ways of applying the shielding gas to the FSW-IG welding

In order to be able to weld by FSW in an inert gas environment, respectively to obtain a complex FSW-IG welding system, one of the three shielding gas flow systems that are presented lower is located on the welding system. The three variants were designed and made at ISIM Timisoara.

2.1. The solution for the variant 1 of shielding gas application

In this embodiment, the supply of shielding gas is realized unidirectional onto the advancing side or retreating side of the FSW welding tool. Figure 1 shows an image of the technical solution for the variant I adapted on the FSW welding machine.

Composition: FSW welding machine - (pos. 1); gas nozzle (pos. 2); fastening element for the clamping support of the shielding gas system (gas nozzle) - (pos. 3); gas supply system (gas cylinder with pressure reducer and flow meter, gas nozzle, accessories) - (pos. 4). The constructive solution allows the active element, which provides the gas supply, to be adjusted in relation to the FSW welding tool, as follows: vertical adjustment- c = 40 mm, respectively angular adjustment ± 30°.

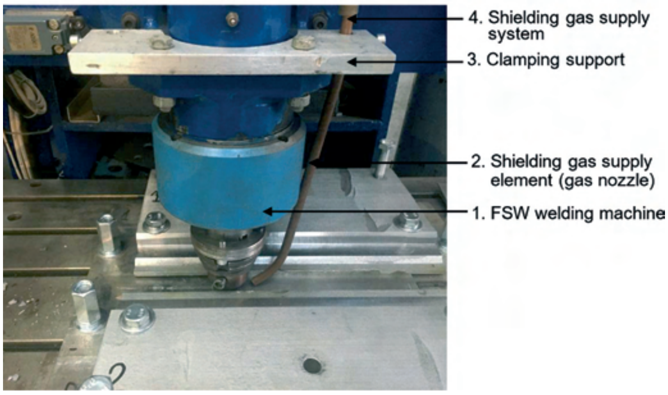

Figure 1. Variant 1 of shielding gas supply

The gas supply can be made, depending on the application, in two ways: in front of the FSW welding tool (on the advancing side of the tool), respectively behind the FSW welding tool (on the retreating side of the tool).

The constructive solution regarding variant 1 was functionally tested / verified by developing an experimental program for welding TiGr2 titanium sheets, of thickness s = 4 mm.

The results of the preliminary welding experiments are presented in Chapter 3.

2.2. Constructive solution for the variant II of shielding gas application

The constructive solution designed and realized for the variant 2 is shown in Figure 2.

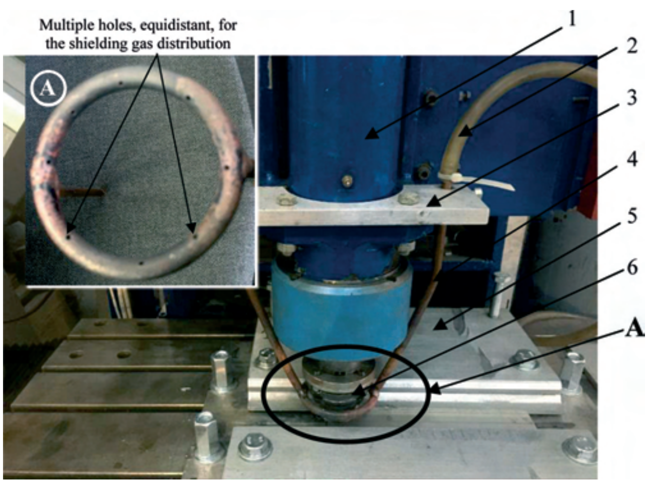

Figure 2. Variant 2 of the shielding gas supply

Composition of the FSW-IG welding system (Variant 2): FSW welding machine (pos.1), shielding gas supply system (gas cylinder, pressure reducer with flow meter, gas distributor, connection hoses) - (pos.2); support plate for positioning and securing the active gas supply element (pos.3); active gas supply element, gas nozzle (pos. 4); fixing device for welding materials (pos.5); FSW welding device and tool (pos. 6).

The technical solution ensures that the work area of the FSW welding tool is supplied by means of a circular system that produces uniform distribution of inert gas around the tool, through holes positioned evenly on a circular contour, as detailed in Figure 2. This variant of shielding gas supply is mounted and fixed on the main shaft housing of the FSW welding machine.

Figure 3 shows how to position the shielding gas supply system, in the functional situation. The circular area of the shielding gas distribution system is located very close to the welding tool, respectively the welding materials (figure 3), to ensure the uniform and efficient presence of the shielding gas, when welding.

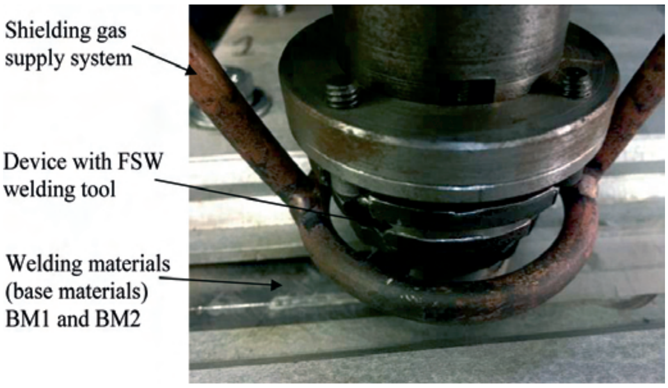

Figure 3. Active element for gas supply

In order to verify the functional skills and the efficiency of ensuring the presence of gas in the working area, an experimental program was developed, in which FSW-IG welding experiments were performed for couples of TiGr2 titanium materials, respectively on DD13 steel. The preliminary experimental results are presented in Chapter 3.

2.3. Constructive solution for the variant III of shielding gas application

This variant ensures the supply of the working area with shielding gas through a gas enclosure (figure 5), located on the main shaft housing of the FSW welding machine (Figure 4).

FSW-IG welding system composition (Variant 3) (Figure 4): FSW welding machine (pos. 1); gas supply system (gas cylinder, pressure reducer with flow meter, gas distributor, connection hoses) – (pos.2); support plate of the active element for gas supply (pos.3); FSW welding device and tool (pos.4); fixing device for welding materials (pos. 5); welding process monitoring system, using infrared thermographic technique (usable only in variants 1 and 2) (pos.6); welding process monitoring system by vertical Fz thrust force control (pos. 7).

The shielding gas enclosure (Figure 5) has the following composition: fixing clamp on the FSW welding machine (pos. 1); adjustable elements for mounting (pos.2); assembly elements (pos.3); shielding gas enclosure (pos.4); sealing elements (pos.5); gas supply nozzle for hose (pos. 6).

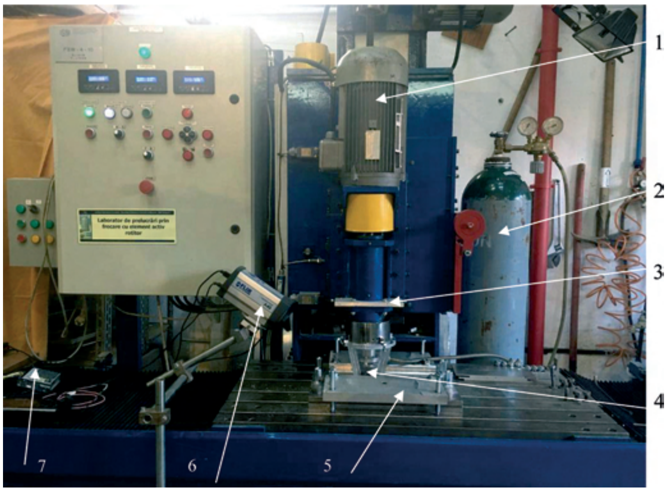

Figure 4. Variant 3 of shielding gas supply on the FSW machine

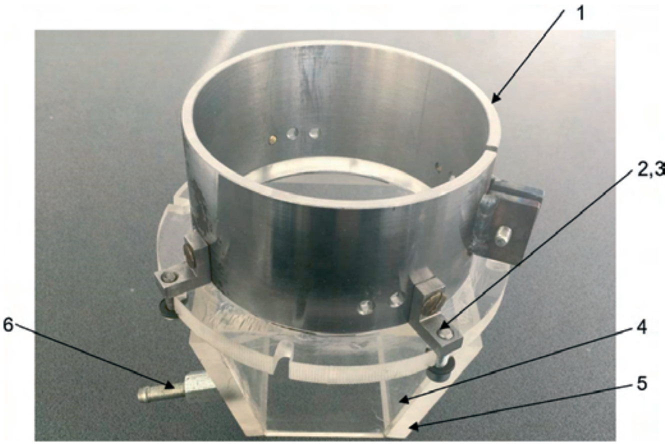

Figure 5. Variant 3 of shielding gas supply

The enclosure ensures that the shielding gas is kept at the pressure level set during the actual FSW-IG welding process (in the impact area between the welding tool and the welding materials). The shielding gas device is located on the main shaft housing of the FSW welding machine. The side walls of the enclosure are made of transparent material, which allows real-time surveillance of the FSW process.

Features of the shielding gas enclosure: the shielding gas enclosure has a volume of approx. 1.4 dm^3 and is made of transparent material; vertical positioning with respect to welding materials ± 30 mm; the supply of shielding gas is made from the inert gas cylinder, provided with a pressure reducer and flowmeter.

3. Preliminary experimental program of welding in a shielding gas environment

3.1. Application technique

The preliminary experimental program had the role of contributing to a first evaluation of the possibilities to apply the FSW-IG process, as well as of the technical solutions for application at the experimental model level.

Figure 6 shows the FSW welding system in shielding gas environment. The FSW welding machine, which is the base of the FSW-IG welding system, is presented, as well as possibilities for monitoring of the welding process, from the point of view of the temperatures and forces developed in the welding process.

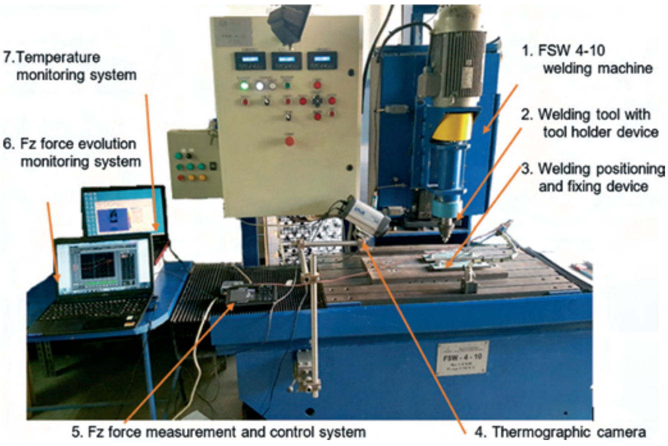

Figure 6. Complex welding system for friction stir welding FSW

For the real-time monitoring of the welding process, two technical solutions were considered:

- monitoring of the FSW process using infrared thermography;
- monitoring of the FSW process by controlling the pressing force of the FSW tools on the welding materials.

The temperature monitoring to FSW-IG welding, using infrared thermography, can be applied without problems in the case of variants 1 and 2 (Figures 1 and 2). In variant 3, the dimensions of the gas enclosure as well as the integration mode on the FSW machine, does not allow the location of the thermographic camera so that the accuracy of the measurements it can be guaranteed in a high percentage.

3.2. Welding tools

Welding tools with different geometric and dimensional characteristics were used. Based on the experience gained from welding titanium TiGr2 using the classic FSW process, the dimensional and shape characteristics of the welding tools have been established. The welding tools for the preliminary experimental program have the geometry presented in Figure 7, having 3 variants of pin: a) with smooth conical pin, b) with conical pin having 4 flat chamfers, respectively c) with smooth cylindrical pin.

smooth conical pin   pin with 4 flat chamfers

smooth cylindrical pin

Figure 7. Welding tool geometries for FSW-IG processes

The material used to make welding tools is tungsten sintered carbide, type P20S.

3.3. FSW-IG welding - TiGr2 titanium sheet

For FSW-IG butt welding in shielding gas environment, TiGr2 titanium sheets of 200x100x4 mm size were used, argon shielding gas was locally applied, unidirectional in the welding area, through a gas nozzle. For experiments, P20S tungsten sintered carbide tools were used:

- tool with smooth conical pin, having 3.85 mm pin length and smooth shoulder with diameter $Ø_{shoulder}$ 20 mm;
- tool with conical pin having four flat chamfers, having 3.85 mm pin length and smooth shoulder of diameter $Ø_{shoulder}$ 20 mm.

Table 1 presents the technological parameters of the FSW-IG welding process.

In order to highlight the effect of the use of the shielding gas, in one experiment, a part of the welded joint was made without shielding gas (zone A, figure 8), and for the other part, shielding gas with a flow rate of 16 l/min. was used (zone B, Figure 8).

Table 1 Technological parameters and aspect of weld

FSW-IG welding experiments – TiGr2								
Materials	Thickness (mm)	Tool				Welding parameters		
		Material	Pin type	Pin length l_{pin} (mm)	Type/shoulder diameter $Ø_{shoulder}$ (mm)	Rotating speed n (rot/min)	Welding speed v (mm/min)	Rotation sense
Titanium TiGr2	4	P 20S	Smooth conical pin	3.85	smooth 20	750	20-120	Counter clockwise
			Conical with 4 flat chamfers	3.85	smooth 20	750	40-120	Counter clockwise
				3.85	smooth 20	700	40-80	Counter clockwise
Welding on the rolling direction – using shielding gas – Argon								

In the area where shielding gas was used at the specified flow rate, it was found that the quality of the joint was improved, the welding being without major imperfections (Figures 8 and 9), fact revealed also by the macroscopic aspect (Figure 9). In this case there are no major defects in welding, only a small “break” of material at the root is observed (the plasticized material adhered to the backing plate – zone B.

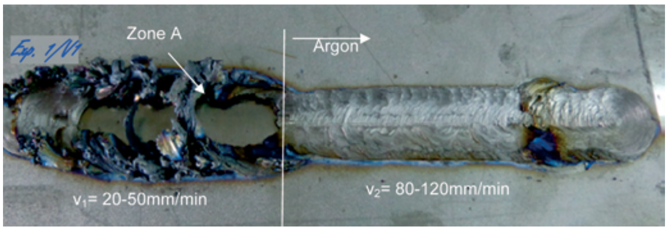

Figure 8. Appearance of welded joint - Ti Gr 2

The temperature developed during the welding process, generated in the area where the welding tool acts on the materials to be joined, is about 1000°C. This fact caused the redness of the tool shoulder and of the welding materials in the welding area (Figure 10).

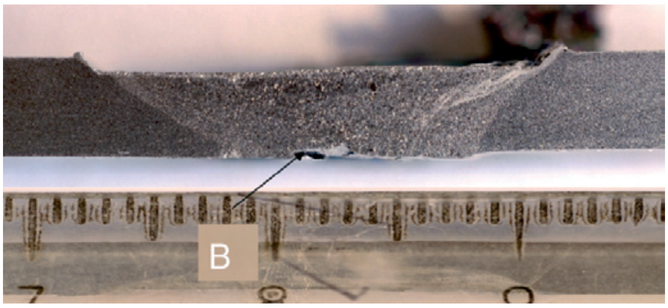

Figure 9. Macroscopic aspect of weld - v = 120 mm/min

The evaluation of the quality of the welded joint was performed by static tensile tests. For example, the results obtained in the static tensile test are presented in table 2.

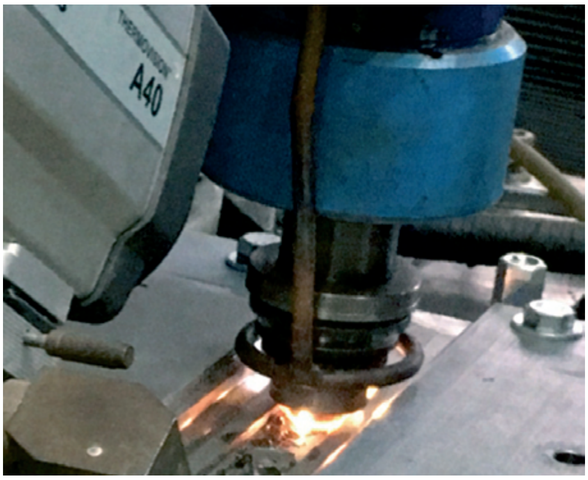

Figure 10. FSW-IG welding process sequence of TiGr2

The following were noted: the ultimate tensile strength of the welded joint represents 72.3% of the mechanical resistance of the base material; the initiation of the breaking occurred in the area corresponding to the diameter of the welding tool; compared to classical FSW, when use FSW-IG, the ultimate tensile strength was 10-15% higher.

3.4. FSW-IG welding of DD13 steel sheets

Table 3 shows the technological parameters of the FSW-IG butt welding process of the DD13 steel, using variant 2 to provide the shielding gas in the action area of the welding tool.

The appearance of the welded sample is shown in Figure 11.

A uniform appearance is observed on the surface of the welded joint. The evaluation of the welded joint will be carried

Table 2 Tensile tests results

Test		Tensile tests of welds					
Type of equipment		MU 100KN, ZD 10/90 Electronic caliper					
Test conditions:							
Temperature		22°C					
Material	Samples No.	a (mm)	b (mm)	a x b (mm^2)	F_{max} (N)	R_m (N/mm^2)	Breaking place
TiGr2	1/V1	4.2	13.2	55.44	16250	318	weld

Table 3 Welding technological parameters

FSW-IG welding experiments – DD13 steel								
Materials	Thickness (mm)	Tool				Welding parameters		
		Material	Pin type	Pin length l_{pin} (mm)	Type/shoulder diameter $Ø_{shoulder}$ (mm)	Rotating speed n (rot/min)	Welding speed v (mm/min)	Rotation sense
DD13 steel	2	P 20S	Smooth cylindrical Ø5	1.85	smooth 20	800	20 start 40(up to ½ of weld), 60 (after ½ weld)	Counter clockwise
Welding on the rolling direction – using shielding gas – Argon, 16l/min flow rate								

out in the next stage of the researches, when samples will be taken from the joint, from areas where different welding speeds have been used.

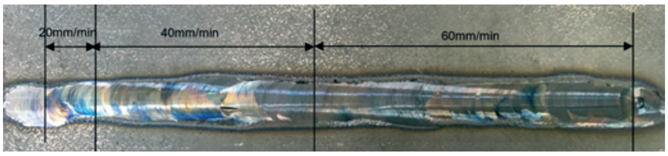

Figure 11. Appearance of the FSW-IG welded joint of DD13 steel

The monitoring of the process temperature, as well as of the forces developed in the welding process, was made possible by using the infrared thermography system, respectively by using the force monitoring system. For each welded sample, process temperature recordings were made, which are processed using the specialized software of the thermographic camera to generate the temperature evolution diagrams throughout the welding process.

4. Conclusions

Preliminary experiments have shown that the use of argon as a shielding gas can improve the quality of welded joints at FSW welding of titanium TiGr2.

The application of the FSW-IG process, requires application techniques that ensure the presence of the shielding gas in the action area of the welding tool on the welding materials.

Three variants of constructive solutions to provide the protection gas in the welding area were presented:

- variant 1 - the local, unidirectional supply of the shielding gas in the working area;
- variant 2 - the shielding gas supply of the working area of the FSW welding tool is made using a system that ensures a uniform, circular distribution of the shielding gas around the tool;
- variant 3 - supplying of the working area (around the welding tool) with shielding gas through a gas enclosure, placed on the main shaft of the FSW welding machine.

Preliminary experiments have shown that there is the possibility of improving the process conditions and the quality of the welding of couples of materials where the classical FSW application presents problems. In order to formulate some of the most accurate and complete concepts, regarding the advantages of the use of shielding gases in FSW welding, it is necessary to deepen the experimental researches on some couples of representative materials.

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