THE POSSIBILITY OF APPLICATION ACOUSTIC EMISSION METHOD FOR CONTROLLING FRICTION STIR WELDING OF AW-5083 ALUMINUM ALLOY SHEETS

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Abstract

The article presents the research results on acoustic emission (AE) generated by process of friction stir welding of sheets made of AW-5083 aluminum alloy. Nowadays acoustic emission method is used in many fields of science, including in the diagnosis of machining and joining processes such as turning, grinding, milling, welding, etc.

Friction Stir Welding (FSW) - a new technology can be successfully used for butt welding of different types of aluminum alloy sheets. FSW method can be an alternative to traditional arc welding methods i.e. MIG or TIG. The joining process was carried out on laboratory stand built on the basis of universal milling machine FWA-31. Joining parameters chosen after optimization of the FSW process were presented.

The research was carried out on a laboratory test stand using an acoustic emission set made by Vallen System. This set included: 4 channel signal recorder AMSY 6, two measurement modules ASIP-2/S, preamplifier with a frequency range 20 kHz - 1 MHz and the strengthening of 34 dB and AE signal measurement sensor type VS 150M, with a frequency range 100 - 450 kHz. During the study, the acoustic emission (AE) generated by rotating tool and friction between joining materials and tool surface was recorded. The following parameters were determined: amplitude, number of events - hits, the effective value of the signal (RMS).

The study can be the basis for the use of acoustic emission method to monitor the process and determine the parameters of the friction stir welding for obtaining a high quality joint.

Keywords: Acoustic emission, friction stir welding (FSW), aluminum alloys, joining, welding parameters

1. INTRODUCTION

The interest growth of the ship designers in aluminum alloys used for hull and whole vessels construction gives an opportunity of a considerable reduction of its mass. This allows to increase the ship displacement with simultaneous increase of her dead-weight tonnage or her speed. Weldable aluminum alloys for plastic processing, the most popular in shipbuilding industry is still the group of Al-Mg (5xxx series) alloys, with good weldability and relatively good operating properties. The advantage of these alloys is their relative insensitivity to layer corrosion and stress corrosion, the disadvantage - low strength of welded joints, below 300 MPa. Nowadays the most common aluminum alloy used in shipbuilding is AW-5083 (AlMg4.5Mn0.7) alloy [1, 2, 3].

Joining aluminum and its alloys by welding methods is difficult due to its specific properties. The main problems that can occur during welding result from the following factors: high similarity of aluminum to oxygen, the creation of high-melting (2060 °C) oxide Al_2O_3, high thermal conductivity, high thermal expansion of aluminum alloys, big casting shrinkage (being the reason of welding strains and stresses), considerable decrease of resistance at welding temperatures, the loss of alloying elements such as magnesium, zinc, or lithium during welding. The above mentioned main drawbacks related to aluminum alloys welding provoke searching other joining methods for these materials. An alternative to traditional arc welding is a method known as friction stir welding (FSW) [4].

The method of friction stir welding FSW (Friction Stir Welding) was worked out and patented in 1991 in Welding Institute (TWI) at Cambridge University in Great Britain. For this method of heating and plasticizing a material, a special tool with rotating pin placed in the joining point of pressed down sheets was used. After setting the tool in rotating motion, heating with friction heat and plasticizing sheets material in the direct contiguity - a slow displacement of the whole system alongside the contact line takes place [4, 5, 6]. FSW is a method of welding in a solid state of mainly aluminum alloys, copper alloys and stainless steel. Compared to traditional arc welding methods used in the shipbuilding industry (MIG, TIG), this method does not require such time-consuming preparation of joined plates and the use of additional materials, such as filler material and shielding gases. The main advantage of this method is the fact that it is easy to obtain welds of high, repeatable properties [5, 7].

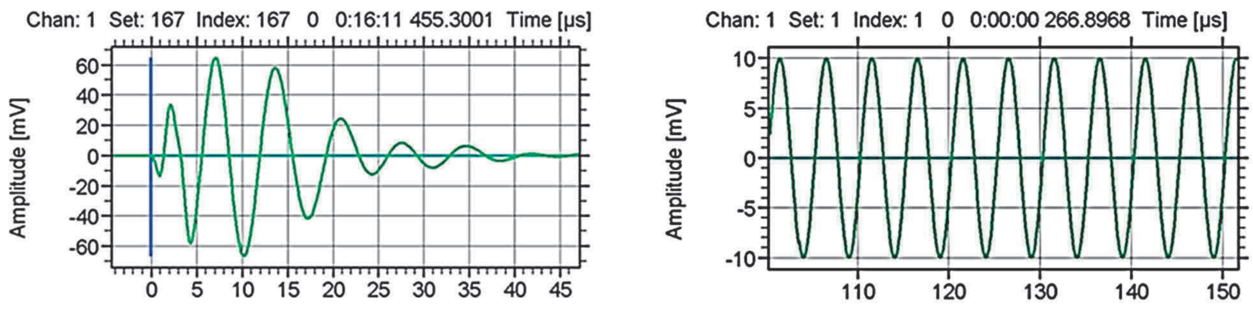
One of the methods for monitoring friction stir welding of metal sheets is the acoustic emission (AE) method. According to the definition acoustic emission (AE) is an evanescent elastic wave, which is the result of rapid release of the energy stored in the material by propagating a micro-damage (increase in micro-cracks, the movement of groups of dislocations) in the material or by a process (friction, leakage, etc.) [8, 9]. The typical frequency range of the acoustic emission is normally determined within 20 kHz - 2 MHz [8].

Acoustic emission is a passive non-destructive method. Its main advantages are:

- the high sensitivity,
- the possibility of continuously research,
- the possibility to locate the source of the AE signals (damages, leaks, etc.),
- the possibility of carrying out research without having to shut down equipment out of service [9].

The stimulus causing the release of energy and the formation of elastic waves can be: load operation, environment, temperature change, and the processes which are accompanied by AE changes both at the micro and the macro scale, such as: cracks, friction, plastic deformation, corrosion, leaks, structural and phase changes, chemical reactions, delamination, cracking of the fibers and matrix in composites, etc. [10].

The acoustic waves propagate in all directions from the source, thus can be recorded by one or more sensors mounted on an object or component. During the propagation of the AE waves they are damped by several physical effects. Therefore the waves can only be detected within a limited distance. These distance dependents on many factors, mainly on properties of the material, the geometry of the object and the level of interference from background noise [10]. According to PN-EN 1330-9: 2009, AE signal can be characterized by parameters such as: amplitude, frequency, energy, rise time, duration, number of exceedances of the threshold of discrimination - hits, RMS of the signal, etc. Examples of AE signals are shown in **Figure 1**.



a) b)

Figure 1 Examples of typical acoustic emission signals: a) burst signal, b) continuous signal [8]

The aim of this study was to determine the possibility of monitoring the friction stir welding process using acoustic emission. AW-5083 alloy sheets were joined by FSW method using different welding parameters. During optimization of welding process the acoustic emission was recorded and then analyzed.

2. THE RESEARCH METHODOLOGY

The study used EN AW-5083 H321 aluminum alloy. The chemical composition of the alloy is given in **Table 1**.

Table 1 Chemical composition of 5083 aluminum alloy (wt.%)

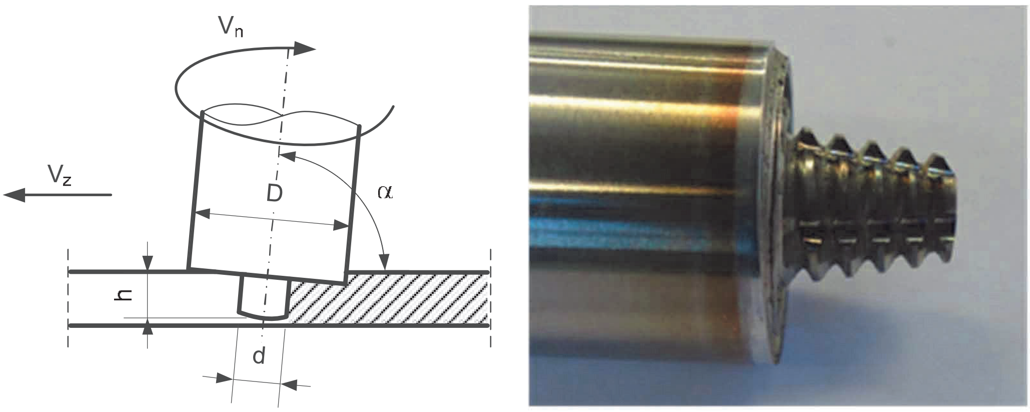
Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr	Al
0.195	0.180	0.090	0.662	4.745	0.111	0.042	0.025	0.037	The rest

Butt joints of AW-5083 alloy sheets were made using FSW. Sheet thickness was *g* = 12 mm. With exception of provided general cleanliness of the sheets there wasn't used any degreasing agent interfaces connected elements.

The diagram of friction stir welding (FSW) and view of the tool are shown in **Figure 2**. For joining sheets made of 5083 alloy were used tools with conical pin. For optimizing quality of joints were used different parameters: angle of tool deflection, mandrel's rotary speed and welding speed. The welding parameters are shown in **Table 2**.

Table 2 FSW parameters of 5083 aluminum alloy sheets

Kind of tool	Tool dimensions			Angle of tool deflection α (°)	Mandrel's rotary speed V_n (rpm)	Welding speed V_z (mm/min)
	D (mm)	*d* (mm)	*h* (mm)			
With conical pin	20	10 - in the top 6 - in the bottom	7.5	88.5 - 89.5	150 - 750	52 - 180



a) b)

Figure 2 The diagram of FSW (a) and view of tool used in research (b)

The view of laboratory stand used in research is shown in **Figure 3**. The stand was built on the basis of universal milling machine FWA-31. Research of acoustic emission (AE) accompanying the friction stir welding process was performed using a kit consisting of 4-channel signal recorder type AMSY 6 and two measuring modules ASIP-2/S from Vallen System. The kit includes pre-amplifier with a frequency range of 20 kHz - 1 MHz and the strengthening of 34 dB and a sensor signal measurement AE, VS 150M, with a frequency range of 100 - 450 kHz. The system includes a data recording module - 8 MB per channel and software for recording and analyzing AE data. The sensor was mounted on the surface of the sheets fixing equipment by means of a magnetic holder MAG4M - dedicated to the sensor used. Between the sensor and the surface the coupling fluid was used.

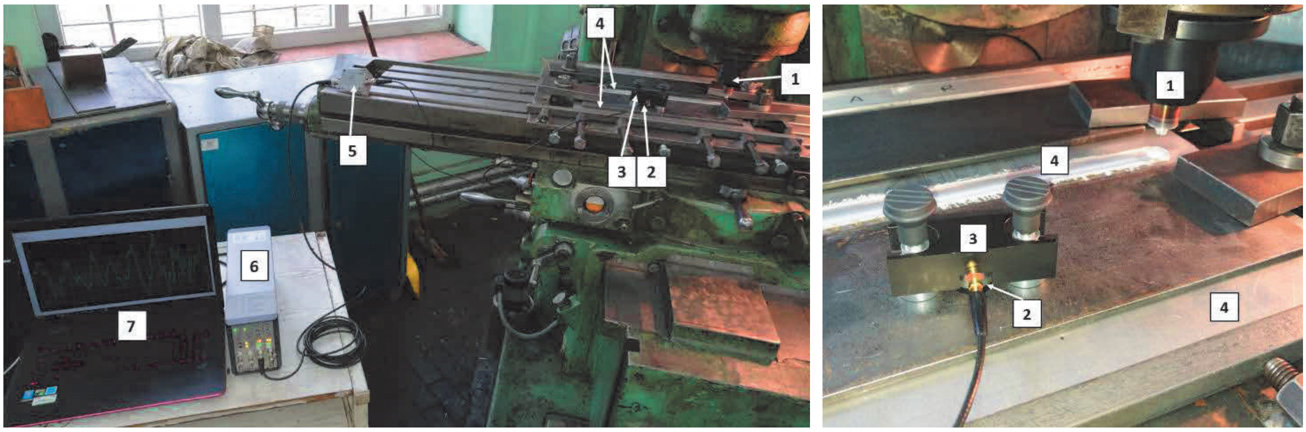
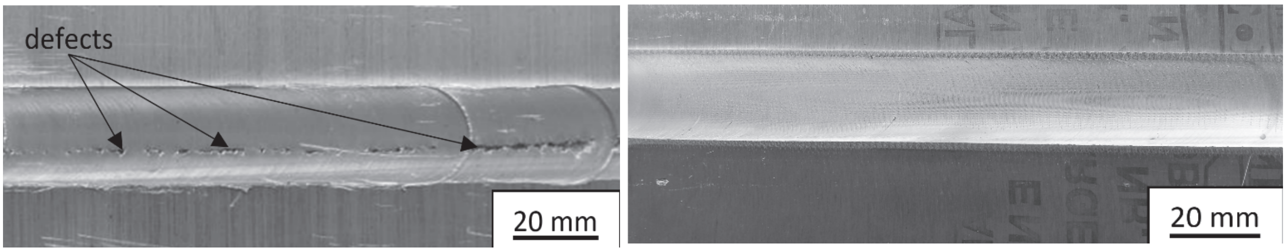


Figure 3 The view of laboratory stand used in research: 1- FSW tool, 2 - AE sensor, 3 - AE sensor holder, 4 - joined metal sheets, 5 - preamplifier, 6 - AE recorder, 7 - computer

3. THE RESEARCH RESULTS

Changed parameters: rotary speed (V_n), welding speed (V_z) and angle of tool deflection (α) affect the properties of the joints. Very large forces associated with the welding process, especially during the first phase of welding cause that high rigidity of the entire system is required - mainly mounting joined sheets. Insufficient downforce of joined plates results formation of the gap between them. Both the incorrect selection of welding parameters and insufficient downforce of joined plates caused the occurrence of discontinuities (welding defects) in the joints.

An example of the welded joint by different welding parameters is shown in **Figure 4a**. Visible discontinuities of joint points lead to incorrect welding technology. The optimizing process of welding parameters selection enables obtaining proper joint without flaws. View of an exemplary joint without visible welding defects is shown in **Figure 4b**.



a) b)

Figure 4 Examples of friction stir welded joints: a) with incorrect parameters - visible welding defects, b) with correct parameters - lack of welding defects

During the study, the acoustic emission (AE) generated in the friction stir welding process carried out on a test, recorded a number of parameters which were analyzed. These parameters were e.g.: amplitude, number of events - hits, energy, RMS of the signal. The analysis of these parameters was made using Visual Vallen AE software. Examples of graphs recorded in the tests for correct and incorrect joining parameters are shown in **Figures 5, 6**. For analysis were chosen two parameters: amplitude and RMS (Root Mean Square) of the signal, recorded during friction stir welding when the joining process was with stable conditions. Average values of chosen parameters are shown in **Table 3**.

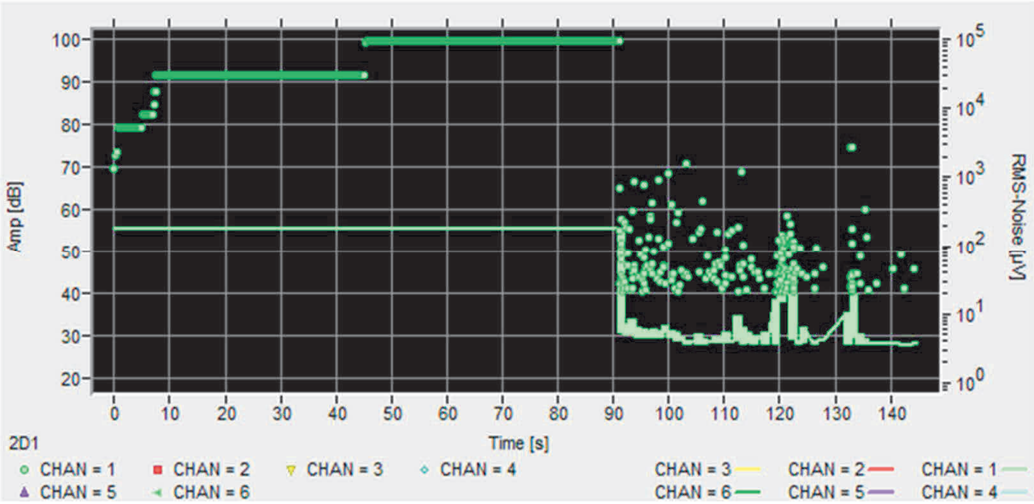


Figure 5 Chart of number of hits and their amplitude changing as a function of time, incorrect joining parameters, weld with defects

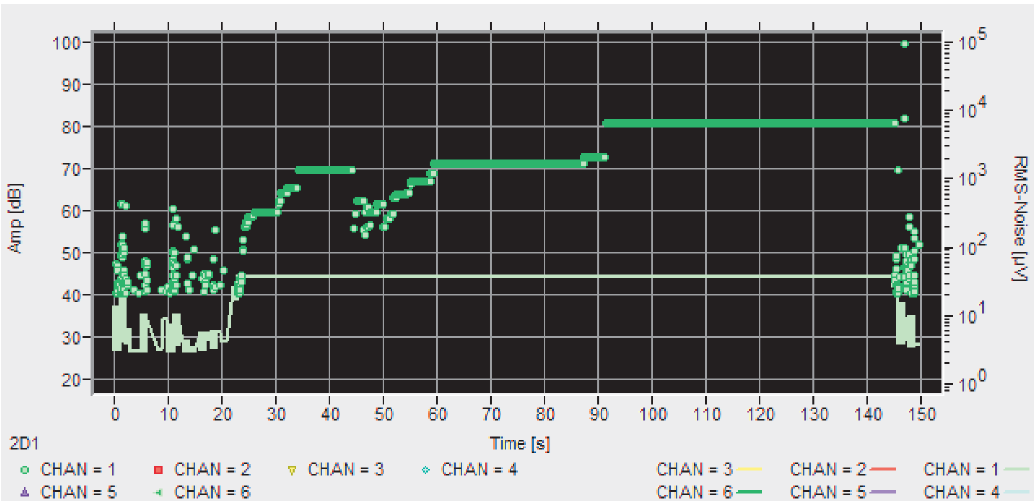


Figure 6 Chart of number of hits and their amplitude changing as a function of time, correct joining parameters, weld without defects

Table 3 Average value of chosen parameters recorded during welding with stable conditions

Correctness of FSW process	Amplitude A (dB)	RMS (µV)
Incorrect parameters	97.2	177.2
Correct parameters	77.3	36.0

The research of acoustic emission, generated during friction stir welding of 5083 alloy sheets, showed that there are significant differences in chosen AE parameters depend of correctness of joining process. Average value of signal amplitude raised up approx. 25 % when the FSW process was incorrect compared to correct. In the same time RMS of the signal increased almost 5 times.

4. CONCLUSION

Application of FSW method for joining metal sheets made of 5083 aluminum alloy allows obtaining good quality of the joints. In order to achieve high quality of joint it is necessary to precisely select the welding parameters. Monitoring of joining process using e.g. acoustic emission could be helpful to achieve correct joints.

The research showed that the welding parameters have a big impact on the quality of joints made by FSW. Changed parameters: rotary speed, welding speed and angle of tool deflection affect for the properties of joint as well as the stiffness of mounting the sheets. Insufficient downforce of joined plates and the incorrect selection of welding parameters caused the occurrence of welding defects (discontinuities) in the joints.

For obtaining joints of high quality continuously monitoring of the welding process can be used. One of these methods is acoustic emission. There is possibility of detecting irregularities in the welding process due to, for example, insufficient metal clamping, incorrect welding parameters, etc. The research has shown that it is possible to monitor on-line the joining process. Analyzing parameters recorded during friction stir welding, e.g.: amplitude and RMS of the signal allows determine the correctness of the conducted process. In the case of joining AW-5083 alloy sheets, acoustic emission emitted during welding with incorrect parameters compared to correct parameters caused increasing the amplitude of the signal from 77 dB to 97 dB and increasing the average RMS value of the signal by almost five times.

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