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FLEXIBLE NONCONVENTIONAL HYBRID WELDING SYSTEM FSW-US

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ABSTRACT: Welding and metalworking technologies, which use ultrasonic vibration either as a primary source to achieve the prescribed operation or as an auxiliary source to improve operation efficiency and product quality, are current in international and applied international research. By assisting the ultrasonic vibration welding process, certain advantages are ensured related to the improvement of the components' behavior during the process, as well as the mechanical properties and the final quality of the joints. These advantages which, compared to conventional processes, lead to remarkable and globalized applications of ultrasonic vibration in welding. The research undertaken within ISIM led to the development of an experimental model of friction welding with rotating active element (FSW - Friction Stir Welding), equipped with an ultrasonic assistance system (US). Specialized software programs were used for constructive simulation and sizing of appropriate sonotrodes, for the frequencies of 20, 35, and 40 kHz, developed and tested to interface them in the construction of the experimental model used. The joining parts on which the sonotrodes were tested is the aluminum alloy EN AW 1200.
KEYWORDS: nonconventional joint, ultrasonic vibration, experimental model, sonotrode, aluminum alloy EN AW 1200.

1. INTRODUCTION

Throughout the history of welding technologies, the unconventional approach has always been a way to increase performance. In this sense, the physical phenomenon of friction is known in the art as a cause of energy dissipation; In the variant in which friction is the basis of the friction welding process (FSW), this solid-state joining process can be included in the category of nonconventional welding technologies. Research on the applicability of FSW is estimated to be still in its infancy, although it has been successfully applied to the fabrication of structural components that are difficult to weld in aerospace, rail, automotive, shipbuilding and others [10]. Friction welding (FSW) is considered one of the green manufacturing technologies because it produces minimal emissions to the environment, the sustainability of the technology is enhanced by the hybridization of the process [1]. Manufacturing technologies based on the concentration of energy developed by ultrasonic waves fall into the category of nonconventional technologies [5], [8]. Thus, ultrasonic welding occupies an important place in this processing category [5]. To improve the results obtained by friction welding, there have been concerns of researchers in the direction of stimulating the conditions by the simultaneous use in the workplace of ultrasonic vibrations (ultrasound) [2], [3], [4], [9]. The research focused on some constructive aspects regarding the creation of optimal FSW conditions with US assistance, as well as on the behavior of the metal components subjected to the joint (aluminum alloy EN AW 1200), as well as the welding quality, under the application of different regimes of thing [6]. This paper reflects, in addition to a synthesis of some results obtained in certain customized working conditions, and some ways of constructive design and process simulation, with the application of special software programs, designed and used.

2. EXPERIMENTAL CONDITIONS

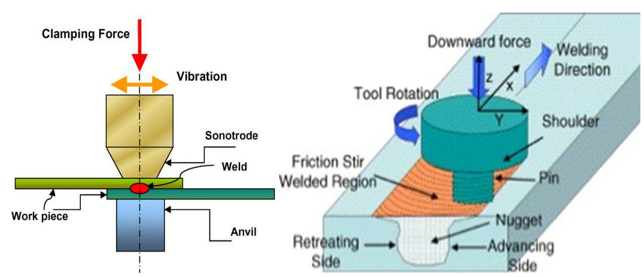


Figure 1. Ultrasonic welding vs. friction stir welding. [10]

The experimental research was carried out in a broader framework offered by the National Research-Development Institute for Welding and Testing of Materials - ISIM Timișoara, with an experience of over 50 years, in which strategic research and innovation objectives of by strengthening technical and technological competence [8], [10]. Following extensive documentation on international concerns about FSW, the laboratory specializing in ultrasound technology recovery, CEX-US, has been expanded, continuing to promote excellence in every direction, developing and capitalizing on hybrid technologies and techniques of bonding materials [7]. To develop an efficient research on the optimization of the technical system and of the conditions of friction welded joint (FSW), in parallel with the own undertaken research, the bibliographic research was continued, the results communicated by other groups of researchers with similar concerns. A comparative study of ultrasonic and friction welding processes was performed. For FSW, the whole process was carefully analyzed, but especially the behavior of the constructive elements. Rotary active element friction welding is a solid-state joining process that uses a non-consumable rotary tool to join the surfaces of the 2 workpieces without melting the material. The active element has 2 parts: pin and shoulder, which has a larger diameter than the pin. The pin is inserted into the adjacent edges of the plates to be welded, and the lower face of the shoulder is in direct contact with the surfaces of the 2 components subjected to welding. Due to this contact and the combination of the movement of the tool along the joint line and its rotation around its axis, the frictional force generates the necessary heat. As the tool moves forward, the pin forces the plasticized material from the main face to the back, where the resulting forces cause the forged consolidation of the weld, resulting in severe solid-state deformation involving dynamic recrystallization of the base material (figure 1) [8], [10].

In the field of ultrasonic welding, considerable research experience has been accumulated, using various constructive and applied variants. The essential components and the role of each are known. In principle, a generator was used that converts the conventional voltage at 50-60 Hz into electricity at 20, 35 and 40 kHz steps, applied to a transducer element (piezoceramic converter, transformer/booster, sonotrode), which converts the electrical oscillations of frequency high in high frequency mechanical vibration, transmitted to the welding device with acoustic softening properties. The mechanical resonator assembly is composed of a piezoceramic converter, an amplitude transformer and a specialized sonotrode. Contact on the work surface must be ensured by means of an adjustable positioning system [9].

The experimental stand used was designed based on the structure in the Flexible joining FSW-US module variant (figure 2) and in its own conception and construction.

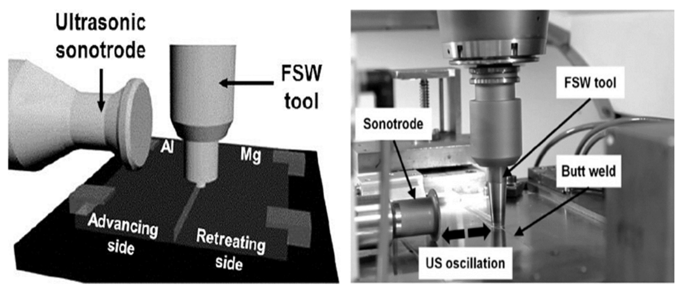
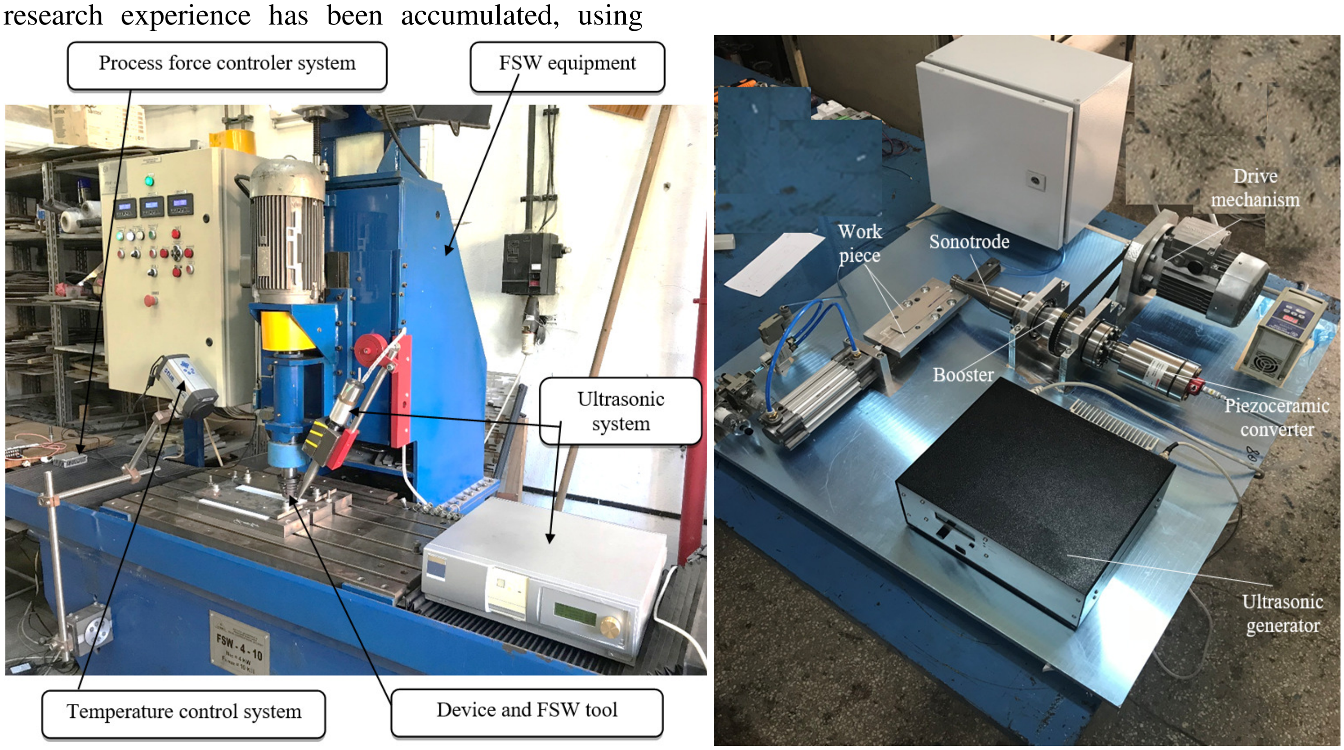


Figure 2. Flexible joining FSW-US module



a). b).

Figure 3. FSW-US experimental model

a). ISIMs FSW-US experimental model, b). Experimental module for FSW-US at 20KHz

The structure of the experimental stand consists of (figure 3):

- FSW 4-10 - friction welding machine;
- device for positioning and fixing the material to be processed;
- tool and instrument holder;
- tool shoulder pressure force monitoring system on the base material during the FSP process: force transducer mounted in a device on the FSW machine; data logger, modular voltage source and computer for data acquisition, storage, and processing;
- surface temperature monitoring system (BM) to be processed, in the shoulder area of the tool, using an infrared thermography camera mounted on a fixing / positioning device and PC for data acquisition / processing;
- ultrasonic assembly - booster converter and sonotrode, generator.

The determinations were obtained by choosing that the ultrasonic energy be transmitted to the welding area through the parts to be welded. Two different solutions of constructive variants were made (figure 3 and figure 4) for the application of the FSW-US hybrid process.

3. PROCESSING TOOLS

The present study focused mainly on investigating the welding behavior of base materials, such as aluminum alloy.

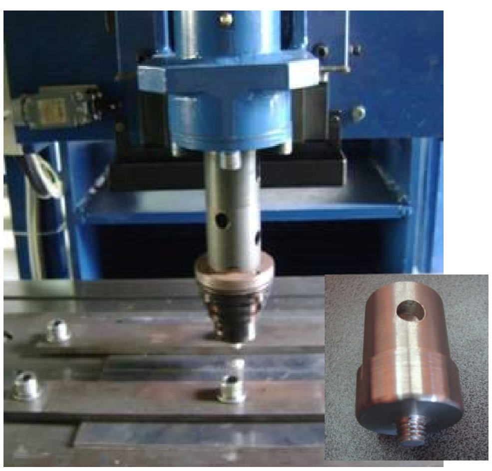


Figure 4. FSW processing tools

Three FSW butt welding experiments were performed with ultrasonic assistance for the aluminum alloy *EN AW 1200*, with *3 mm* thick, using a FSW welding tool with threaded cylindrical pin length $L_{pin} = 2.85$ *mm*. FSW welding parameters used for these experiments were: welding tool speed $n = 1200$ *rpm* - constant for all experiments; variable welding speed, with values of *80, 150* and *230mm / min* respectively; ultrasonic assistance is achieved by applying ultrasonic oscillations in successive cycles with a duration of $t_{US} = 8.5$ *sec*, the frequency of oscillations being *20kHz*.

The FSW welding tool with cylindrical threaded pin is made of *X38CrMoV5* steel, treated at approx. *40-42 HRC*, with shoulder diameter *Ø shoulder = 22.0 mm* and threaded cylindrical pin *M6,* the length of the pin being $L_{pin} = 2.85$ *mm*, correlated with the thickness of the materials to join.

Figure 5. Ultrasonic processing tools

The ultrasonic assistance was performed with sonotrodes designed with specialized software programs (Kreel Engineering) and performed in ISIM Timişoara laboratories and workshops. That ultrasonic assistance was performed by intermittently applying ultrasound (at intervals of maximum *8.5 seconds*, at a frequency of *20kHz*) on the materials to be joined, in front of the welding tool. The joining process was monitored in terms of the temperatures developed in the process, as well as the pressure forces of the tool on the joining materials. For the evaluation and characterization of FSW-US joints, macroscopic and microscopic analyzes, hardness, as well as tensile test tests were performed.

Measurement of process forces, mechanical testing and defect analysis were used to study the influence of ultrasonic vibrations on the conventional FSW process. The experimental program was carried out in several sections, which had as main objectives:

- experimental validation of the new hybrid welding method proposed in the project.
- verification and validation of the techniques for applying the FSW-US procedure, designed, and implemented within the project. During the FSW-US hybrid welding process, the variation of the values of the pressing force of the FSW tool on the joining materials was followed, through the force monitoring system.

The maximum values of the forces recorded for the experiments performed are shown in table 1.

Table 1. The maximum values of the forces recorded.

	V [mm/min]	**F_{max} [N]**	**F_{medium} [N]**
Experiment 1	80	5500	2500÷2450
Experiment 2	150	6200	2040÷2000
Experiment 3	230	6600	4050÷4000

Analyzing the values of the pressing force for experiments 1, 2, 3 it is observed that for *Experiment 2* its lowest values were recorded during the actual welding process (excluding the stage of penetration of the welding tool in the joining materials). Monitoring of the FSW hybrid ultrasonic joining process with ultrasonic assistance in terms of temperatures developed in the shoulder area of the welding tool. The evolution of temperatures during FSW-US hybrid welding, related to experiments 1, 2 and 3 is shown in figure 6.

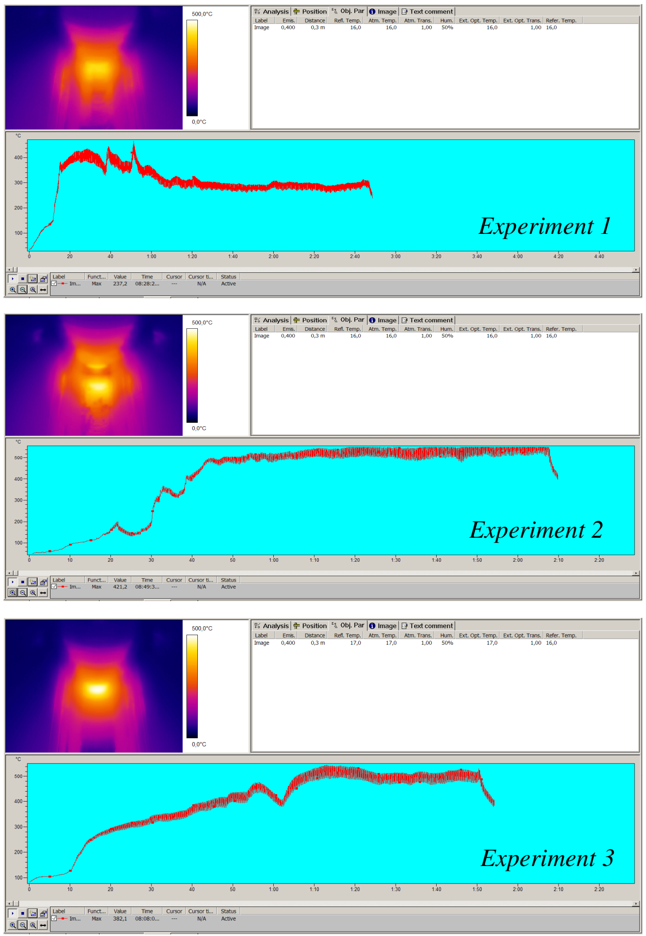


Figure 6. Temperature evolution during the FSW-US welding process (Experiment 1, 2, 3)

Given that the welding speed values increased significantly from *Experiment 1* to *Experiment 3*, the temperature values are expected to be inversely proportional to the welding speed. This may be true for conventional FSW welding. Given that ultrasonic oscillations are also applied during the welding process, the graphs in Figure 6 show that the recorded temperature values for experiments 1,2 and 3 were:

- when using the speed *v = 80 mm/min*: - classic FSW temperature ≈ *400* ^0C - FSW-US temperature ≈ 300 ^0C
- when using the speed *v = 150 mm/min*: - classic FSW temperature ≈ *500* ^0C - FSW-US temperature ≈ *540* ^0C
- when using the speed *v = 230 mm/min*: - classic FSW temperature ≈ 400 0C - FSW-US temperature ≈ 500 ^0C.

In the *Experiment 1*, in the case of FSW-US welding, the temperature decreased due to collateral reasons (a malfunction of the welding equipment). Experiments 2 and 3 showed that by applying the US, the process temperatures increased by ≈ *8-25%*. It is observed that the most stable process was in the case of experiment 2, where the evolution of temperature was relatively constant (after the stabilization of the process). Also, in this experiment were recorded the highest values of the process temperature in this series of experiments, which shows that using that combination of process parameters (for FSW and FSW-US) a temperature increase is obtained which it is favorable to obtain a better welded joint, by increasing the degree of plasticization of the materials to be joined.

The appearance at the joint surface for experiments 4-6 is shown in Figure 7.

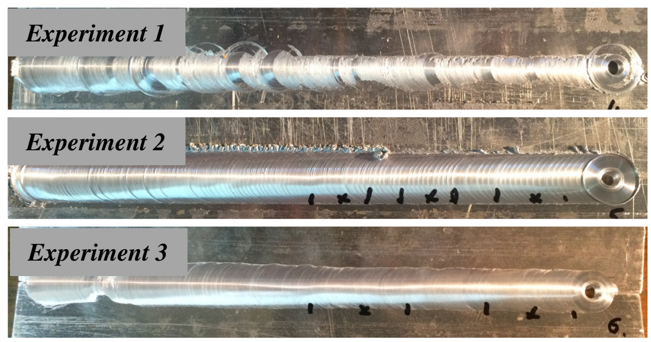


Figure 7. Appearance at the joint surface (experiment 1, 2, 3).

For the evaluation and characterization of FSW-US joints, macroscopic and microscopic analyzes, hardness, as well as tensile test tests were performed. The macroscopic aspect of the samples taken for the three experiments is shown in Figure 8.

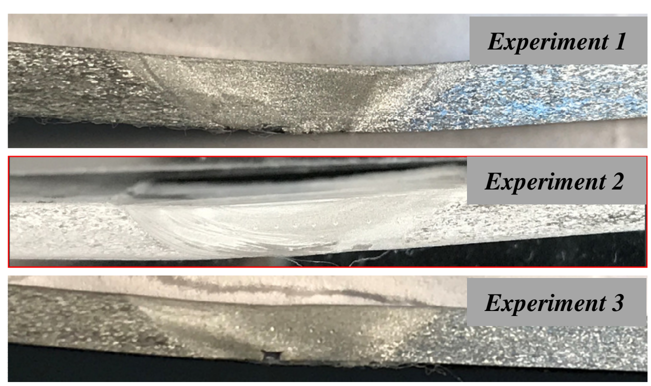


Figure 8. Macroscopic appearance of the samples (experiment 1, 2, 3)

4. CONCLUSIONS

Considering the characteristics of ultrasonic vibrations, FSW – US ultrasonically assisted FSW welding of aluminum alloys allows to reduce the welding force and improve the mechanical properties of the welded part, especially in terms of elongation at break and yield strength. It has been shown that the integration of ultrasonic application on welding materials provides promising results in welding quality assurance, helping to reduce the possibility of welding defects. Ultrasonic treatment during welding ensures additional plasticization of the metal and a better efficiency of its mixing, serving to eliminate defects such as root defect and refining of grains in the mixing area. In all cases, superior mechanical properties were obtained by applying the FSW-US hybrid process, compared to the classical FSW process. Breaking strengths were higher, as appropriate, with values in the range of 2-10%.

The results of this study will have an impact on new research applied in unconventional joining processes by reducing and optimizing the technological parameters of welding and combining unconventional technologies. All studies to date suggest that this technology will improve the mechanical properties of joints, namely increase their resistance to wear, breakage, shrinkage of oxide layers, eliminate casting defects, increase welding speed, and improve anticorrosive properties. It believes that we have managed to create an efficient green technology alternative to those existing in the field of joining materials that manages to reduce production and material costs by increasing the productivity and quality of the joints made.

Effects:

- reduction of oxide layers
- improving the mechanical characteristics of the joint (increasing the tensile strength, fatigue strength)
- increase of welding speeds;
- improving the anticorrosive properties.

The performance of this flexible nonconventional hybrid welding system FSW-US can be extended to other metal pairs for welding.

5. ACKNOWLEDGEMENTS

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