Journal of Trends in the Development of Machinery
and Associated Technology
Vol. 21, No. 1, 2018, ISSN 2303-4009 (online), p.p. 17-20

MEASUREMENTS OF FORCE IN NON-CONVENTIONAL METHOD OF JOINING MATERIALS

Nikola Šibalić
University of Montenegro
Faculty of Mechanical Engineering
Dzordza Vasingtona bb, 81000 Podgorica
Montenegro

Milan Vukčević
University of Montenegro
Faculty of Mechanical Engineering
Dzordza Vasingtona bb, 81000
Podgorica
Montenegro

Milanko Damjanović
University of Montenegro
Faculty of Mechanical Engineering
Dzordza Vasingtona bb, 81000
Podgorica
Montenegro

ABSTRACT
One of the most used non-conventional methods of joining metal is a method of Friction Stir Welding - FSW. Theoretical foundations of the used non-conventional procedure are given in this paper. The essence of the process is in joining alloys of various metals (primarily aluminium alloys) using a rotating tool, with the release of heat. The material is plastic deformed and joins in the solid state. This papers presents the equipment for measurement components of welding force: Fz - Down Force, Fx - Longitudinal Force, and Fy - Side Force. Reliable results are obtained because the precise analogue-to-digital measurement equipment, related to information measuring system is used.
Keywords: Non-conventional method, Welding Force

1. INTRODUCTION
The non-conventional method of joining the similar and dissimilar materials, FSW, was patented by The Welding Institute (TWI) from Great Britain in December 1991, and was found by Wayne M. Thomas, who successfully joined aluminium alloys [1, 2]. The new method of joining is performed in a solid state without melting the material. It is an ecologically clean process, it does not pollute the environment, there are no harmful fumes as in conventional procedures, and no a light flash that characterizes all conventional procedures. Also, the process is energy efficient because energy is not consumed for melting metals, but only for starting the rotary electric motor of the machine in our case milling machine. Therefore the application of this process for industrial purposes is extremely cost-effective and significant savings in electricity are achieved.
The FSW procedure starts with the tool positioned above the machine's (milling machine) working table, and its axis is normal on the joining line of sheet metals. The rotating tool slowly accesses line of the joint and heats up into the material - workpieces. Consequently, in the material (workpieces), the initial hole is formed, whereby the heat is being generated. The pin is screwed into the material until the shoulder makes the contact with the upper surface of the workpieces. The tool must to retain the material inside the welding zone with sufficient pressure and to create sufficient temperature for the FSW process to run with no interruption. In this position, the tool heats the material up to the point of melting and becomes plastic. Due to the shape of the pin the heated material moves around it and thus stirs. Then the horizontal translational longitudinal movement of the machine's working table starts. In the further course of the FSW process, the pin practically "slides" between the sheet metals in the direction of welding, the new material is heated, becomes plastic and is continuously stirred. In

the same time, behind the shoulder, a groove of smooth warmed material, which is cooled and solidified, is formed, and between the sheet metals (workpieces), a monolithic compound is formed, while the lower plane is formed by the substrate on which the working pieces stand and it is smooth and straight. By turning off the translational movement of the machine's working table and pulling out the tool from the material, the welding process ends. Instead of the machine's working table, translational movement can only be performed by the tool, or by the machine's working table and tool at the same time.
Therefore, in the process of joining materials with the FSW process, it is very important to know the force components that occur during the process. In order for the FSW process to work properly, it was necessary to create auxiliary accessories for clamping workpieces, as well as to measure the parameters that affect the process the most, which is a force in three normal directions.

2. WELDING FORCE

The forces acting on the tool during the FSW process are: down (axial), longitudinal and side forces. Down force - *Fz* is required to maintain the position of the tool and material beneath the surface of shoulder. Some FSW welding machines work under load control, but in many cases the vertical position of the tool is pre-set and thus the loads will vary during welding. The axial or vertical force in the FSW process is actually the force with which the tool acts on the material. It is the largest in the initial period of penetration of the pin through the material, and then decreases, till the moment the shoulder reaches the top surface of the material being welded. Then it starts to increase again until a certain temperature is reached when it begins to decline and retains its constant value until the completion of the FSW process. However, unlike the rotational friction stir welding, the size of the axial force in the FSW process is much lower, due to the method of generating heat, it does not depend on the surface of the welded parts. It depends on the properties of the materials of the welded parts and the geometrical characteristics of the pin and the shoulder and can range up to 200 kN. As the component of the vertical force is dominant in the FSW process, it is often also called the Welding Force [3]. Longitudinal - *Fx* acts parallel to the direction of the tool movement, and the positive direction is defined with the direction of the tool movement. Since this force occurs as a result of the resistance of the material to the movement of the tool, it can be expected that this force, if the temperature of the material around the tool decreases, will be higher [3]. Side force - *Fy* can act normally on the direction of the tool movement, and a positive direction is defined toward the same-direction side of the seam. In Figure 1, a display of the forces acting during the FSW process is given.

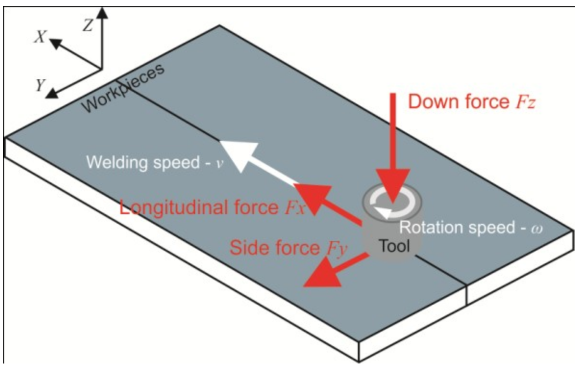

Figure 1. Display of the forces Fz, Fx and Fy [3]

3. EXPERIMENTAL EQUIPMENT

In the FSW process, a rigid machine is required to perform experimental research, with a working table that has the ability to move in space in three normal directions, or with an "automatic moving head" on which the welding tool is located, and the workpieces are stationary. Due to the specificity of the FSW process and in order to perform the envisaged tests in this paper, due to the convenience of measuring the force components (down forces - *Fz*, longitudinal force - *Fx* and side force - *Fy*), the machine for the material processing by cutting was used in the experiment, also known as the horizontal milling machine. In Figure 2, a schematic presentation of auxiliary equipment is given, and in Figure 3, there is the survey site with the installed measuring devices for measuring the force that are connected to the information measurement system.

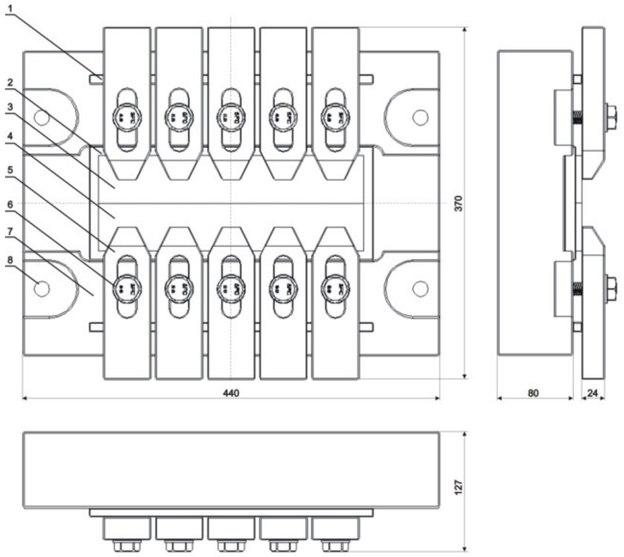

Figure 2. Auxiliary equipment for FSW: 1 - Shim, 2 - Support plate, 3 - Workpiece, 4 - Workpiece, 5 - Workpiece clamp, 6 - Screw, 7 - The base plate, 8 - The place for special carriers of the base plate [3]

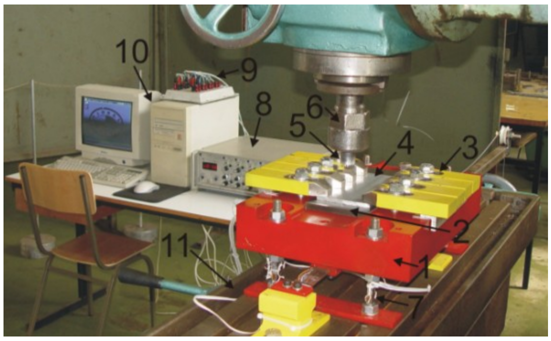

Figure 3. Research site: 1 - The base plate, 2 - Support plate, 3 - Workpiece clamp, 4 - Workpiece of Al alloys, 5 - Tool for FSW, 6 - Clamp part of the milling machines, 7 - Special carrier with glued strain gauge, 8 - Measuring bridge, 9 - BAS, 10 - PC with A/D card and software for data acquisition, 11 - Work table of milling machine [3, 4]

In order to measure the forces components, four special carriers of the base plate (Figures 4 and 5) were made, to which the strain gauge were glued. At the point of the glued strain gauge, the special carrier of base plate is a rectangular cross-section. This allows measuring the bending of special carriers in *x* - longitudinal direction and *y* - side direction. To measure the force in the *z* - vertical direction, pressure strain gauge are also used. The dimensioning of the special carrier was based on the expected loads in *x*, *y* and *z* direction.

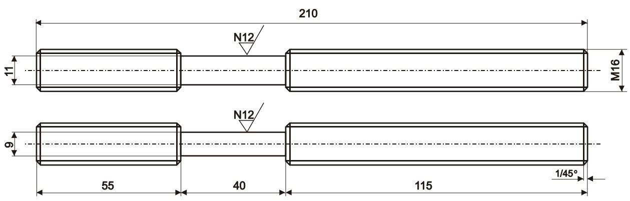

Figure 4. Special carrier of auxiliary equipment [3]

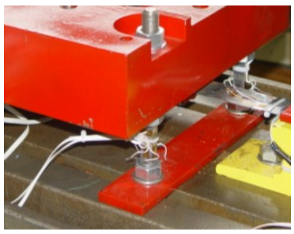

Figure 5. Special carriers of the base plate on which the sensors are places (strain gauge)

4. INFORMATION MEASURING SYSTEM FOR FORCES MEASUREMENT

When measuring forces, the analogue signal from the sensor units - strain gauge (Figure 3, pos. 7), through the digital six channel amplifier - the measuring bridge (Figure 3, pos. 8) and the portable device (Figure 3, pos. 9), is brought to an AD/DA card, where it is converted to digital and stored on a computer with the software download package installed (Figure 3, pos. 10). The diagrams obtained in this way are in the function of the current (*V*) and time (*s*), of which the diagrams of force (*N*) in the function of time (*s*) [3, 4] are obtained on the basis of known relations and values of the calibration of measuring equipment. In Figure 6, a block diagram of the information measuring system is given [3].

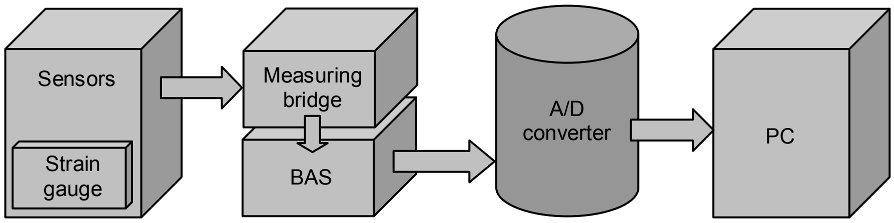

Figure 6. Block diagram of the information measuring system for forces measurement [3]

When measuring the force, special type KMR, installed below the base plate, are used and serve to check the measurement results obtained. Resistance sensors for measuring the FSW process forces are strain gauge connected in full Vitston's bridges, which give a change of electrical signal based on the elastic deformation of special carriers that are load by pressure and bending. All used strain gauge are of type: HBN 6/120LY11, resistance 120 Ω ± 0.2% and *k* - factor 2.05 ± 1%.

5. FORCE MEASURING IN THE PROCESS OF FSW

Within the phase of experimental research, the measurements of the components of the welding force were performed: the down force *Fz*, the longitudinal force *Fx* and the side force *Fy*. The researches were carried out in accordance with the adopted experimental plan. Figure 7, shows the obtained diagrams of forces components in the function of the FSW process time at the central point of the experimental plan number 36.

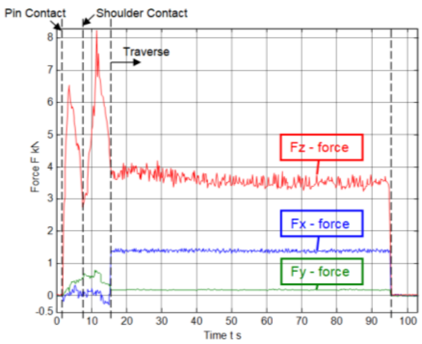

Figure 7. Diagram of forces obtained using the sensor (strain gauge) [3, 4]

6. CONCLUSION

Figure 7, shows that the welding force *Fz* has the highest values when the rotating tool with its pin is screwed in the material. The material is warmed up due to the friction of the tool pin and material. Then the force *Fz* decreases until the moment of the contact of the shoulder and the surface of the workpieces, when the force *Fz* reaches its highest value, since the large surface of the shoulder starts digging into the material. The workpieces are even more heated due to the friction caused by the shoulder and tool pin at the same time, so the force *Fz* starts to decline. When the milling machine is set on the longitudinal movement of the working table i.e. the chosen welding speed, the forces *Fx*, *Fy* and *Fz* retain constant values until the moment when the tool exits the material.

7. REFERENCES

[1] Thomas M. W., Andrews E. R.: High Performance Tools For Friction Stir Welding. International Patent Application, WO 99/52669.,

[2] Thomas W., Threadgill P., Nicholas E.: Feasibility of Friction Stir Welding Steel, Sience and Technology of Welding and Joining, 1999, Vol. 4, No 6, pp. 365-372.,

[3] Šibalić N.: Modeliranje i simulacija procesa spajanja deformisanjem - FSW,, Doktorska disertacija, Univerzitet Crne Gore, 2010.,

[4] Vukcevic M., Savicevic S., Janjic M., Sibalic N.: Measurement in Friction Stir Welding, 15th International Research/Expert Conference - TMT 2011, pp. 133-136.