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# MICROSTRUCTURE AND HARDNESS OF THE FRICTION STIR WELDING

**Ph.D. Nikola Sibalic**
**University of Montenegro**
**Faculty of Mechanical Engineering**
**Dzordza Vasingtona bb, 81000 Podgorica**
**Montenegro**

**Ph.D. Milan Vukcevic**
**University of Montenegro**
**Faculty of Mechanical Engineering**
**Dzordza Vasingtona bb, 81000 Podgorica**
**Montenegro**

**Ph.D. Mileta Janjic**
**University of Montenegro**
**Faculty of Mechanical Engineering**
**Dzordza Vasingtona bb, 81000 Podgorica**
**Montenegro**

**M.Sc. Srdjan Martic**
**University of Montenegro**
**Faculty of Mechanical Engineering**
**Dzordza Vasingtona bb, 81000 Podgorica**
**Montenegro**

## ABSTRACT
*Despite the significant interest in Friction Welding Technology, many aspects of this process are not sufficiently explored. This is, among other things, refers to the quality of the resulting joint. The quality of the joint that is obtained by FSW process is determined through various parameters. In this paper we present an examination of the microstructure and hardness of the joint. The test material was a copper alloy. The results indicate weld quality that is dependent on the values of input parameters.*
**Keywords:** Cu Alloy, Microstructure, Hardness

## 1. INTRODUCTION
Method of FSW (Friction Stir Welding) is patented by "The Welding Institute" - TWI in the UK in December, 1991, and found it was Wayne M. Thomas who has successfully joining aluminum alloys [1, 3, 4]. Shortly thereafter, the FSW welding method is applied to other alloys of copper, magnesium, steel, etc.. as well as the welding of dissimilar materials, such as aluminum and copper, steel and aluminum and so on. The method is very quickly found its application in modern industry and caused a lot of scientific interest. FSW process, is performed on the machine for welding (universal milling machine or CNC machine), using specially designed tools. Tools that are used in the process of welding are cylindrical and consisted of two concentric parts (Figure 1.), which are rotating at the great speed. A larger diameter part of the tool is called the shoulder, while the smaller diameter part is called the pin. Rotating tool slowly approaches the joint line and plunges into material, which creates heat [1, 3, 4].

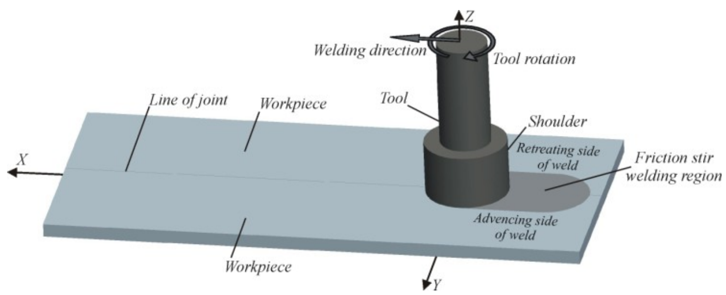


*Figure 1. Tool and workpiece [2].*

Due to that the temperature increases to the heat metal forming where mechanical mixing and joining of materials is performed, enabling the tool to move in the longitudinal direction or along the joint lines. After passing of the tool along the joint lines the solid phase of weld (joint) remains, where the upper plane remains smooth and flat thanks to the tool shoulder, while the lower plane of the work piece is formed from the basis on which the work piece is standing and it is also smooth and flat [1, 3, 4].

## 2. MICROSTRUCTURAL CARACTERISTIC

In literary sources, there are many different terms that describe microstructural changes in the FSW process. The asymmetric nature of the weld metal and the unusual shape of the stepped tool, have caused that, as a result of welded joints have a very characteristic microstructure. The first attempts to the microstructural division of welded joints were performed in 1997 for aluminum alloys. Very quickly it became known as microstructural zones, which were adopted by consensus and covering the microstructure divisions of other metals. Microstructural division is performed on the TWI Institute and it consists of four zones as shown in Figure 2. [2, 3, 4].

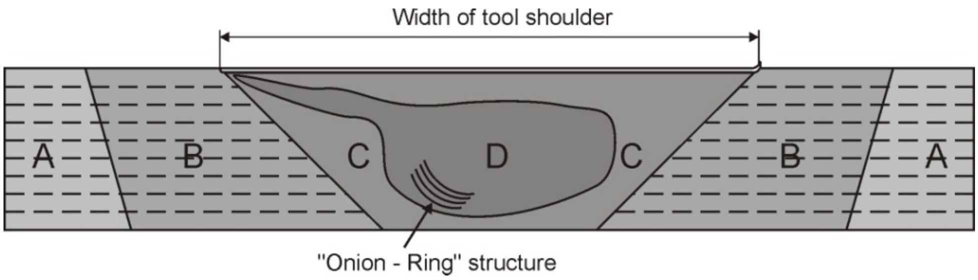


*Figure 2. Structure of the welded joint in the process FSW.*

- A - *Unaffected material or parent metal - PM (Base material).*
- B - *Heat Affect Zone - HAZ.*
- C - *Thermo-Mechanically Affect Zone - TMAZ.*
- D - *Stirred Zone or Nugget Zone - NZ.*

In the zone of the base material has no plastic deformation of the material, nor the influence of heat, which can affect the mechanical properties, so that in the zone of the base material has no microstructural change. Heat affected zone is common to all welding processes, so there is in FSW. This zone is exposed to the effects of heat, but it is not deformed during the welding process. During the welding process, it passes through a suitable temperature cycle that leads to changes in mechanical properties and microstructure. Size heat affected zone depends directly on the heat input. The temperatures in this area are lower than those in TMAZ zone, but still have a significant effect if the microstructure of thermally unstable [2, 3, 4].

In the area of thermo-mechanical influence of heat, the material is exposed to plastic deformation and temperatures between tools that can occur on both sides of the stirred zone. The microstructure in this zone due to the deformation and developed temperature is different from the microstructure of the base material. Microstructural changes were more expressed in the stirred zone.

## 3. EXPERIMENTAL PROCEDURE

### 3.1. Experimental research

The material used in the experiment was a copper alloy sheet thickness of 5 mm. For experimental research vertical milling machine was used. The tool is axisymmetrical and consists of the workpiece and body of the tool. The body of the tool is adjusted to the jaws of the machines, used in the experiment. The general appearance of tools for FSW process is given in Figure 3.

For input values, factors of the welding regime: $v$ = 100 *mm*/*min* (welding speed), $\omega$ = 800 rpm (rotation speed of tool) and geometrical factors of tools: $\alpha$ = 5$^{o}$ (angle of pin slope), $d$ = *5* mm (diameter of the pin) and $D$ = *20 mm* (diameter of the shoulder), are adopted. Figure 4, presents the welded workpieces on the upper side or the side from which the welding is performed.

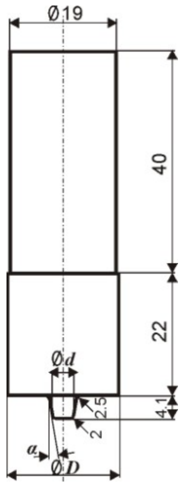


Figure 3. Tools of welding process [2]

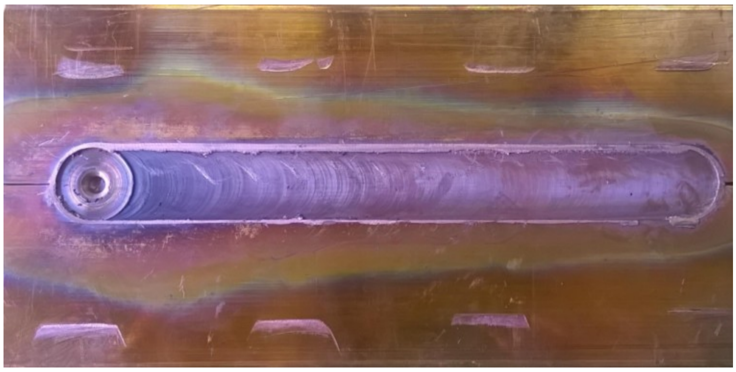

Figure 4. The appearance of the welded joint with the upper side of the welded workpieces

Specimens for welded workpieces are taken by the standards of the examination of welds. All cropped specimens are presisely machined to the dimensions and shapes that require standards [2, 3, 4] using a modern CNC machine for cutting (Wather Jet). In Figure 5 a scheme excision of samples (specimens).

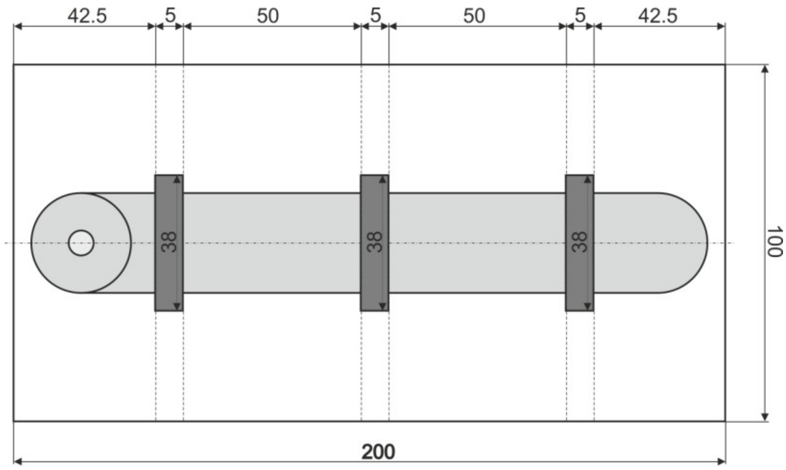


Figure 5. Scheme samples of welded workpieces

### 3.2. Determination of microstructural zones and hardness

The process of metallographic, mechanical specimens preparation is done through a series of successive operations: cutting (sampling), roughing, mounting, grinding and polishing. Chemical analysis of specimens obtained from cuts of workpieces welded by FSW process, is carried out with the appropriate reagent. Figure 6 shows the specimen, which is chemically treated and ready for testing.

Figure 6. Display of the treated specimen.

Examination of microstructure is carried out by methods of light microscopy. Microstructural images of specimens are recorded on the metallographic microscope.

Method of light microscopy was used for providing recordings for all specimens, in elected positions. The aim of metallographic research is to identify the various defects that occur during the FSW, as well as the identifi cation of microstructural changes. Figure 7. shows the macrostructure of the specimen with the positions of microstructural zones [2]. As Figure 8. shows the microstructure.

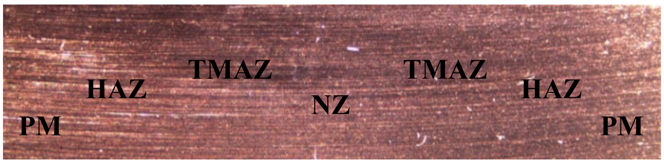

*Figure 7. Macrostructure of the specimen.*

*Figure 8. Microstructure of the specimen.*

Hardness of a material is defined as the resistance to penetration of a body into its surface. The most frequently applied methods of testing by: Brinell, Vickers and Rockwell. Testing of samples was carried out on samples of the Brinell 1, 2 and 3, according to a planned order. Hardness is measured in 16 points whose distance from one point to another is 2 mm. When penetrating balls into the material measured diameter circle on the surface obtained after penetration beads. Then determines the hardness of HB $N/mm^2$. The obtained values are shown in Figure 9.

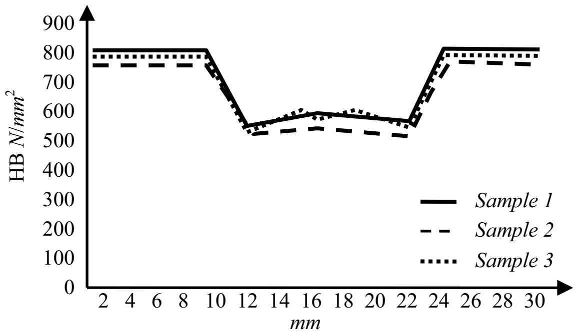

*Figure 9. Hardness in samples 1, 2 and 3.*

## 4. CONCLUSION

This paper presents a new welding process, which is performed in the solid state without melting the material (Friction Stir Welding - FSW). FSW process characterized by complex processes taking place in the welding zone, so that a complex microstructure of the weld is expressed through four zones: Unaffected Material Zone, Heat Affected Zone - HAZ, Thermo-Mechanically Affected Zone - TMAZ and "Nugget" Zone - NZ. The most typical is the so-called. "Nugget zone", which gives a nice fine-grained microstructure, which due to large plastic strain shows excellent plastic properties that correspond to the characteristics superplastic alloys.

Hardness testing of welded joints showed relatively the same schedule for all three samples. At least hardness values were obtained in the HAZ zone, while the hardness values gradually increase towards the NZ zone. This arrangement hardness is caused by a large plastic deformation welded materials.

## 5. REFERENCES


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