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MICROSTRUCTURAL CHARACTERISTICS OF THE WELDED JOINT OBTAINED BY METHOD OF FSW

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ABSTRACT
This paper presents a method for friction welding with mixing materials known under the name (Friction Stir Welding - FSW). FSW welding process is primarily used for connecting plates greater thickness, both of similar and dissimilar materials. In this paper phases of the process and microstructural characteristics are presented.
Keywords: FSW process, macrostructure, microstructural zones, HAZ, TAMZ, NZ

1. INTRODUCTION
The process FSW (Friction Stir Welding) was patented by "Welding Institute" (The Welding Institute - TWI) in the UK in December 1991 and found it Wayne M. Thomas who has successfully joining aluminum alloys [1]. The process of welding FSW, is very fast already in 1994, received his commercial application and drew great attention of researchers in practice. The largest application has in the space industry, shipbuilding, aerospace and automotive industries, as well as in many other industries, where necessary welding thick plates, as of similar as well as dissimilar materials [1, 2, 3].
FSW process is performed so that the working table machines are sheets that need to be joining. Plates must be clamped for the working table machines, which can horizontally translationally moving. Special tool that is used in the welding process is of cylindrical shape and consists of a tool body and two concentric parts that rotate at high speed. Body tools used to attach the tool clamping jaws of the machine. Part of a larger tool diameter is called the shoulder, while the smaller diameter called a pin. Forms shoulder and pin tool may be different. Shoulder may also have a concentric recess in its surface, generally semicircular, while the pin often is conical, which can be profiled threaded or various other grooves. Height pin mainly depends on the thickness of sheet metal to be welded (joining), but it must be a few tenths of a millimeter smaller parts of the sheet thickness [4, 5].

2. WELD METAL
In the FSW process, welding (weld metal) is asymmetric, and are defined and advancing side and retreating side welding. Advancing side of the weld metal is defined as the side where the correspond direction of the vector of angular velocity and rotational velocity vector linear movement tools. An retreating side of the weld metal is defined as the side where the movement direction opposite to the vector speed tools. The leading edges of the front part of the tool and trailing edge is the last part of the tool. The face of the weld metal surface on top of welded steel sheets formed after the passing of

the shoulder, and the root of the weld metal is lower surfaces. On the face of weld metal are typical trace of the tools in the form of semicircular edges. The distance between the two edges corresponds to the path that passes tool rectilinear motion of the workpieces in the direction of welding during a turnaround. Depending on the type of alloy and welding parameters the edges can be more or less obvious. On retreating side cheek weld metal, formed edges of the material that flowed through the base metal. This edge is often called "flash". Correct choice of welding parameters and design tools "flash" can be minimized. At the end of FSW in the metal seam appears "keyhole", which remains after the tool out of the welded workpieces. The "keyhole" has a shape and size that approximates the shape and size of the pin of the tool used in the process of FSW [1, 2, 3, 5, 6].

3. MICROSTRUCTURAL ZONES

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 1 [2, 3, 6].

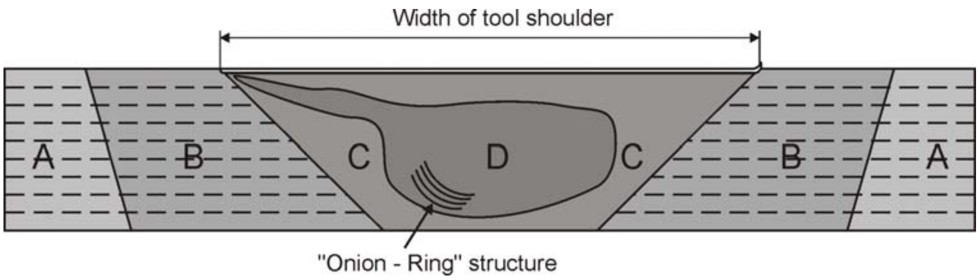


Figure 1. Structure of the welded joint in the process FSW.

- 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 [5, 6].

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.

4. DETERMINATION OF MICROSTRUCTURAL ZONES

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. The reagent is prepared by measuring of 1.3 ml 40 % HF hydrochloric acid in the gauge and gently mixed with 200 ml of distilled water into a suitable glass container. In this way, the reagent is ready for use. Figure 2 shows the specimen, which is chemically treated and ready for testing.

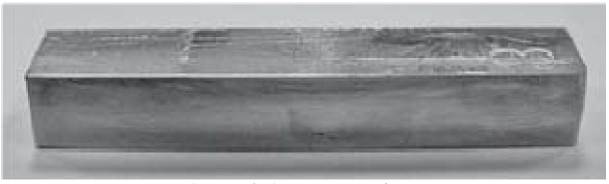


Figure 2. Display of the treated specimen [2, 4].

Examination of macrostructure and microstructure is carried out by methods of light microscopy. Microstructural images of specimens are recorded on the metallographic microscope. Figure 3 shows the metallographic microscope with camera, and recording patterns of the specimen. Metallographic microscope has the ability to zoom magnification up to 500 x, and the camera has the ability to record up to 750 x [2, 4].

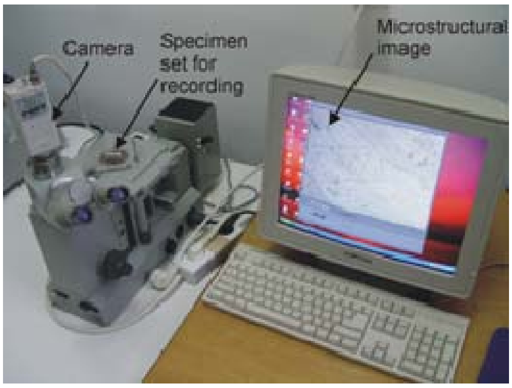


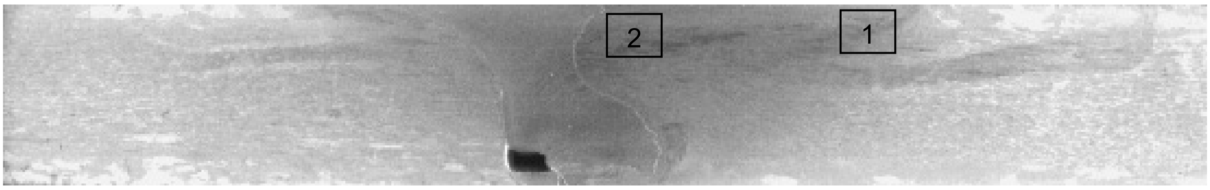
Figure 3. Metallographic microscope used to capture the structure of welded joints.

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 4. shows the macrostructure of the specimen with the positions of microstructural zones [2, 4].

Characteristic structural zones of FSW can be clearly indentified from recorded images of macrostructure, those zones are: unaffected material or parent metal, heat affected zone - HAZ, thermo-mechanically affected zone - TMAZ, and so called "weld nugget" zone - NZ.

The images clearly show defects that are present for certain case. That is so called "tunnel" effect on the advancing side, as a result of insufficient transport material around the pin. This defect is one of the density errors, which can be detected by radiographic images, which are mostly incessant. This error can be avoided by proper choice of geometrical parameters of tools and kinematic parameters of the process. Based on the macrostructure images for certain specific positions, images of microstructure are recorded, which provide a clearer view of the observed structure of welded joints, as well as the grain size. Figure 5. shows the macrostructure of the of the specimen. As Figure 6. and Figure 7. shows the microstructure positions one and two with Figure 5.

When examining the microstructure, one can clearly identify the transition between the zone that was affected with deformation from tools and the unaffected material zone. The material which was deformed by FSW process, shows a well-turbulent grain structure, as well as materials in the vicinity of the heat affected zone - HAZ, which gives the proper arrangement of grains. In the mixing zone, a very fine recrystallized grains are present, due to the large deformation of material and high temperature during the FSW process [2, 4].



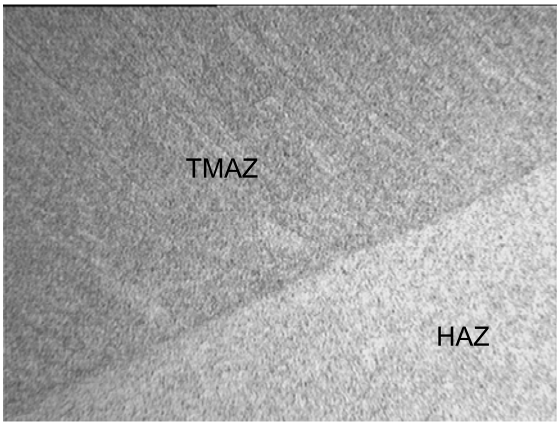


Figure 6. Microstructure of the specimen, positions 1.

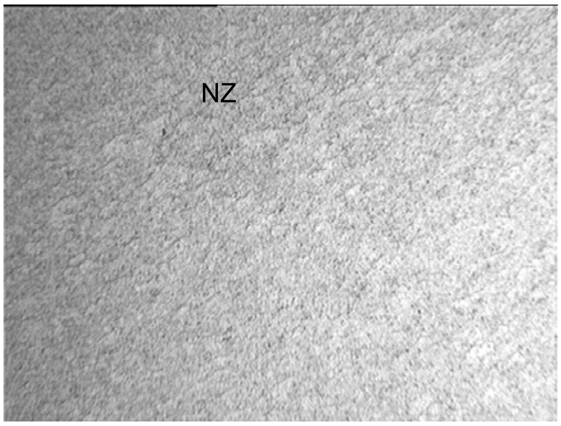


Figure 7. Microstructure of the specimen, positions 2.

Microstructures within the "weld nugget" zone indicates dynamic recrystallized grains, which are much smaller than with the unaffected material, where the larger size grains are present. Dynamic recrystallized "weld nugget" zone is shown in Figure 7.

5. CONCLUSION

This paper presents a new welding process, which is performed in the solid state without melting the material (Friction Stir Welding - FSW). This procedure is very topical in the world, and in modern industry has a great application. FSW process is environmentally clean process with no environmental pollution, which at the present time is an additional motivation for improvement and greater application in the industry. 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.

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