Study on Analysis between Friction Stir Welding Process and Hybrid Friction Stir Welding Process

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Abstract. Friction Stir Welding (FSW) is increasingly required, more than traditional arc welding, in industrial environment because it is a simple process in solid state. Despite these feature there are restrictions regarding welding materials with high hardness, like steels. This leads to considering Hybrid Friction Stir Welding (HFSW) with local heating. The next paper briefly presents similarities and differences between Friction Stir Welding (FSW) and Hybrid Friction Stir Welding (HFSW). From point of view of the description of the process HFSW is different from FSW through additional local heating immediately before the weld zone and however for both process results a similar visual appearance of the weld. Nevertheless additional pre-heating source heat from HFSW leads to more refined grains in microstructure, show a general reduction of the longitudinal residual stress in comparison with the normal FSW for weld zone (WZ) and the mechanical properties such as the microhardness and tensile strength of the materials were increased by the increasing temperature in the weld area. From all arguments listed above results that the HFSW process it is a improved version from FSW process and have a wide range of application for various materials.

Keywords: FSW, HFSW, macrostructure, microstructure, residual stress, microhardness and tensile properties.

Introduction

In terms of appearance, solid state welding processes have emerged in the 1956 in the Soviet Union, but Friction Stir Welding (FSW) was found in 1991 at the Welding Institute – TWI Cambridge. This innovative welding process gained wider industrial applicability in last decade [1]. Initially, FSW process was developed to weld pieces of aluminium alloys [2], but with time it was developed for materials similar or dissimilar such as: cooper, brass, magnesium, titanium, steel [3], polymeric materials [4] or metal matrix composites (MMCs), consisting of different base materials such as aluminium, copper, titanium and different reinforcements, such as Al_2O_3, SiC, Si_3N_4 or B_4C [5].

This process has many advantages, including the following: the welding procedure is relatively simple without consumables or filler metal, edge pieces do not need additional preparation, oxide removal prior to welding is not necessary, the procedure can be automated and performed in all positions, FSW can be used for alloys that cannot be welded with traditional methods [6] and is termed "green technology" due to its energy efficiency and environmental friendliness [7]. On the other hand FSW process has several disadvantages such as: a great tool wear, weld speeds are slower, equipment is massive and expensive, friction stir welding for high melting temperature materials have limitations [8]. Therefore Hybrid Friction Stir Welding (HFSW) process has been developed, this is a combination between FSW and other welding technologies, with FSW being the dominant process and the second process playing a supporting role with the aim of pre-heating the parts [8]. Until now FSW was combined with: YAG laser beam, TIG arc and plasma arc, but the most common hybrid couple is: FSW with laser welding named Laser Assisted Friction Stir Welding (LAFSW).

Laser assisted friction stir welding (LAFSW) is considered a new process because it was developed during the last decade [6]. The use of the laser beam introduces additional local heating, in front of the weld zone, so the process needs little mechanical energy produced by the tool [8]. This process has attracted considerable attention because it has some advantages: deeper penetration of weld, higher efficiency of welding, and fewer weld defects. A recent study showed that HFSW is faster than the FSW for materials with high melting points, such as steels, because through heating, the force between material and tool is reduced [9].

Processes description

The main principle of the friction stir welding (FSW) is based on heating by the rotation of a cylindrical tool on the clamped work piece [10]. A rotating tool, made of a pin with different profiling and a shoulder, is rotated and forced down into the material until the shoulder meets the surface of the material. Under these steps, the material is thereby frictionally heated to temperatures where it is easily plasticized. In next step the tool starts translational movement forward, material is forced to flow from the front to the trailing side of the pin, and a joint is formed. All this time the pieces have a very good clamping system in order to obtain good joints [11]. The schematic diagram of the FSW process is presented in Fig.1.

In addition to the FSW, HFSW introduces additional local heating, without melting of the material, immediately in front of the weld zone so that less mechanical energy, produced through the tool, must be converted into heat. This stuff improves the weld process as such: reduces the tool forces, reduces deflections in the machine and fixture, and may enable higher weld speeds [12]. The schematic diagram of the HFSW process is presented in Fig.2.

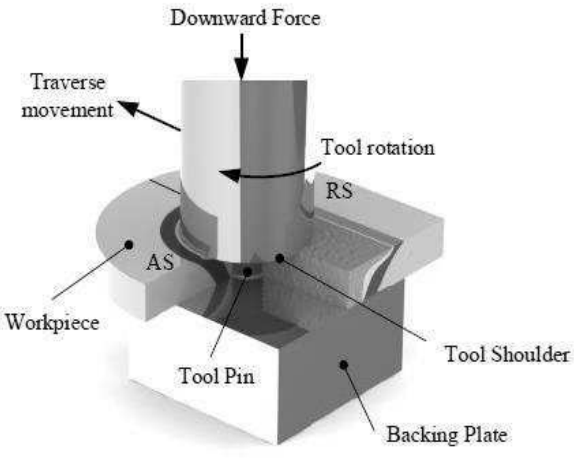

Fig. 1. Schematic diagram of the FSW process [3]

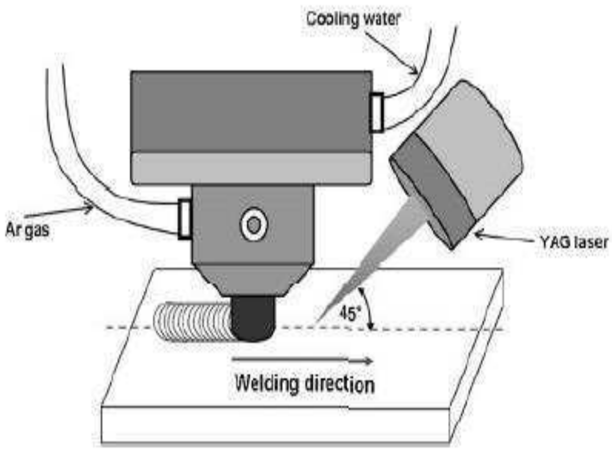

Fig. 2. Schematic diagram of the HFSW process [13]

As FSW and HFSW can be performed on a special FSW machine or a traditional mill, to whom it is attached a pre-heating laser system, positioned directly in front of the welding direction of the tool.

Common process parameters for FSW and HFSW are: tool rotation speed (rpm), travel speed (mm/min), axial force (KN) and tilt angle (^{0}). HFSW has in addition dwell time (s) and laser power (W) [8]. Another important characteristic that influences the processes is the tool geometry, this can be the same for both types of process. The shape of the pin can be: cylindrical, hexagonal, square, triangular, column pin, taper pin, cylindrical threaded, tapered threaded and other shapes.

This two processes are used in many industrial sectors throughout the world such as: shipbuilding and marine industries, automotive industry, aerospace industry, railway industry, nuclear industry, military and more [10, 14].

Macrostructure and microstructure

Because FSW and HFSW are similar processes, visual appearance of the weld is similar, such as: on top presents semi-circular traces because welding material comes in contact with tool shoulder [15] and on the opposite surface does not show evident surface modification. For both processes it is expected as traces vary depending on process parameters and materials. Visual appearance for HFSW between aluminium alloy parts is presented in Fig.3. Visual appearance for FSW is very similar.

As visual appearance, the macroscopic appearance of the welded joint is similarly for both processes, Fig. 4, highlighting the following areas: base material - note with BM, heat affected zone - note with HAZ, thermo-mechanically affected zone - note with TMAZ and weld zone - note with W

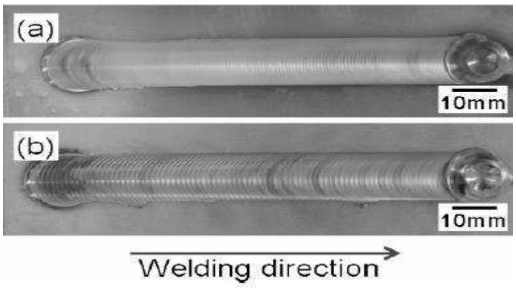

Fig. 3. Visual appearance for HFSW (a) 300 mm/min and (b) 450 mm/min [13]

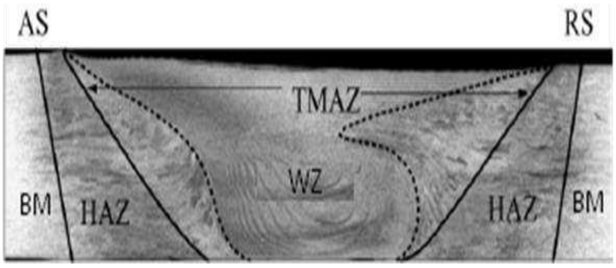

Fig. 4. Macrostructure of the FSW and HFSW [3]

The microstructure of the FSW process is affected by the tool rotation speed because it determines temperature variations within the weld zone: the grain size within the weld tends to decreases near the weld zone and grow with increasing distance from this area [16]. Considering this finding and the fact that HFSW process has an additional pre-heating source, result that the grains in the material subjected to HFSW were more refined than those in the material subjected to conventional FSW for the same rotation speed (and equal downward forces exerted by the tool) [13] For example the grain size for FSW process can be seen in Fig. 5 and for HFSW can be seen in Fig. 6. However, in a research was found difference in nugget's structure of FSW and HFSW just for process performed with a laser power of 2 kW, for this the grain size appears smaller and with regular shape just under the weld surface [8]. It follows that for major differences in grain size is needs to major differences in temperature from weld zone.

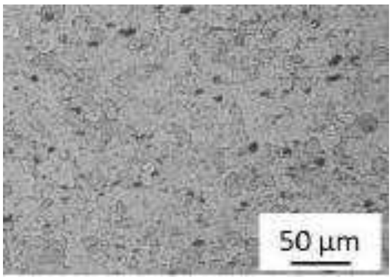

Fig. 5. FSW microstructure for the 5754 H111 aluminium alloy [8]

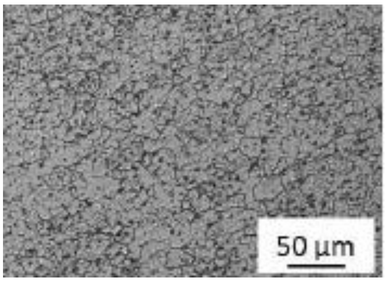

Fig. 6. HFSW microstructure (200W laser power) for the 5754 H111 aluminium alloy [8]

It is certain that the microstructure within the weld nugget consists of grain much smaller when compared to the parent metal microstructure for both the FSW and also HFSW processes [8]. Also HFSW is accompanied by high strain rate (stored energy) and frictional heat between the material and the tool, and the strain rate increases by increasing the welding speed [13]. It results from this that the variation regarding microstructure between FSW and HFSW depends on the temperature reached during the weld process.

Residual stress

During FSW process, the welding tool motion induces frictional heating and plastic deformation, therefore important residual stresses can be generated [17]. HFSW has frictional heating and plastic deformation during the welding process, as FSW process, so significant residual stresses can be generated in this process.

Because these processes are similar, according to the geometry of the welding process, the largest residual stresses are identified parallel to the welding direction [17] in the TMAZ, for both processes. Also, the higher stresses were identified on the advancing side than on the retreating side [17] and also transverse residual stresses do not display a direct dependence with the welding process [8]. All three arguments, the largest residual stress in the TMAZ, the higher stress on the advancing side and transverse residual stress do not depend on the welding process, can be substantiated by Fig.7, where it is presented transversal and longitudinal residual stresses for FSW process.

Due to additional pre-heating source heat contribution the hybrid friction stir welding plates show a general reduction of the longitudinal residual stress in comparison with the normal friction stir welding for weld zone (WZ), Fig.8. These differences are insignificant in the zone away from the weld line, and are less influenced by the laser power [8].

It follows that, for both processes, the residual stresses are influenced by the temperature distributions and the thermal histories, especially in the weld zone (WZ).

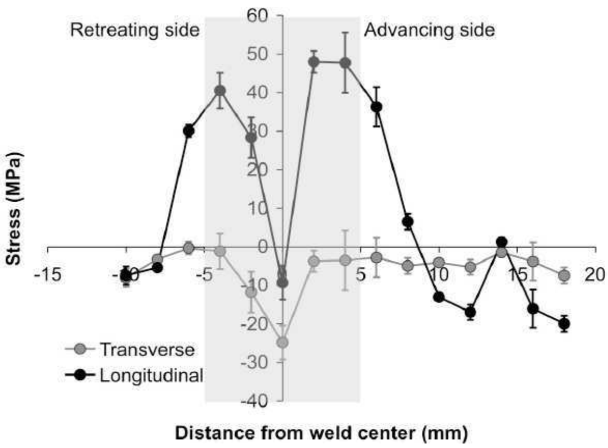

Fig. 7. Transversal and longitudinal residual stress in FSW for AZ31 magnesium alloy [17]

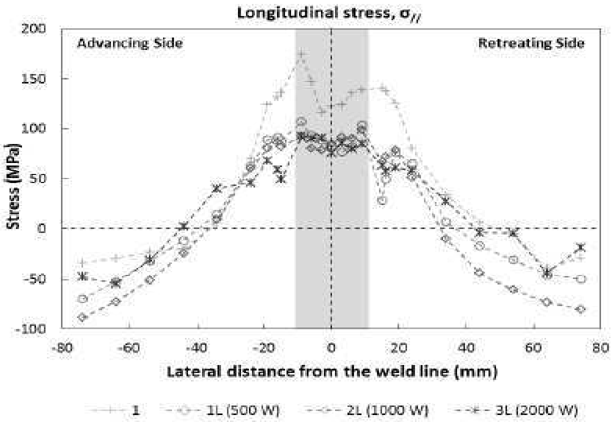

Fig. 8. Longitudinal residual stress for FSW (1) and HFSW (1L, 2L, 3L) on the 5754 H111 aluminium alloy [8]

Microhardness and tensile properties

With the transition from FSW to HFSW, and increasing temperature in the weld area, as expected, the grain refinement and grain size was decreased from base material (BM) to weld zone (WZ) [8, 13]. This modification of grain size leads to improving the mechanical properties such as microhardness. This fact is exemplified in Fig. 9: the microhardness in weld zone (for the 5754 H111 aluminium alloy) increase from 65 HV for FSW process to 73 HV for HFSW process with 2000 laser power (W) [8]. Also, and the ultimate tensile strength (UTS) is influenced by grain refinement from FSW to HFSW. A comparison between two studies regarding tensile strength of materials: inconel (nickel-chromium) 600 alloy and 5754H111 aluminium alloy specimens joined by FSW

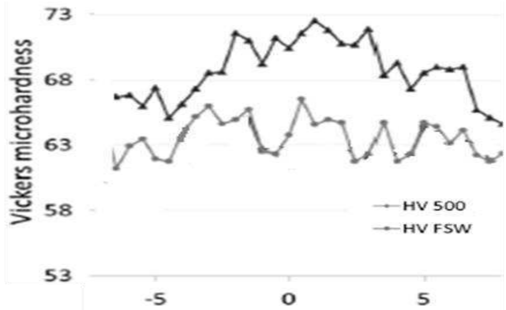

Fig. 9. Microhardness profile across FSW and HFSW welds at 1.5 mm from the top surface [8]

and HFSW (with various process parameters from 300 mm/min to 450 mm/min and from 500 W to 2000 W) is presented in Table 1. Thus, it was observed that the base material was broke under smaller values of tensile strength in the case of FSW specimen joined in similar conditions with the HFSW specimens [13].

Table 1. Comparison between FSW and HFSW regarding tensile strength [8, 13]

Process	Tensile strength (MPa) [13]	Tensile strength (MPa) [8]
FSW	**698**	**201,3**
HFSW - with various process parameters	**730**	**207,3**
	735	**204,1**
	758	**206,9**

In conclusion, the mechanical properties such as the microhardness and tensile strength of the materials were increased by the application of HFSW, thing that can be explained by the increasing temperature in the weld area and therefore good grain refinement.

Conclusions

In this paper, original contribution consists of a brief overview of several bibliographic sources concerning the similarities and differences between FSW process and HFSW process. The principal analyzed elements are: processes description, macrostructure, microstructure, residual stress, microhardness and tensile properties for both processes.

Process steps are similar, with difference as for HFSW process an additional local heating exists. The visual appearance and macrostructure is very similar for both processes, and highlighting four joining specific areas. The microstructure depends on the temperature reached during the weld process: the grains in the material subjected to HFSW are more refined than those in the material subjected to conventional FSW, for the same process parameters. Regarding the residual stress, for both processes the largest are identified in the TMAZ areas, on the advancing side. In addition, the HFSW plates show a reduction of the longitudinal residual stress in comparison with the FSW for weld zone. The microhardness and ultimate tensile strength (UTS) increase from FSW to HFSW due to grain refinement.

As a brief conclusion, for both processes, the temperature distributions and the thermal histories have an important role, they determine if the weld has a good microstructure, residual stress and strength. Because HFSW is a relatively recent process and has more benefits than FSW, new research directions can be listed: development of studies regarding the joining of materials with increased hardness, introduction of welding process in mass production for a wide range of products or development of numerical models to improve the quality of the welded joints.

Acknowledgements

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