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Review

Friction stir processing – State of the art

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ABSTRACT

Increasing demands for operating properties of fabricated elements on one hand, and a necessity of reducing mass of a structure on the other, triggers materials engineering research into producing surface layers representing required functional properties. Methods commonly used in the production of surface layers, such as surfacing, spraying or re-melting with a laser beam have been known for years. A new method is the friction stir processing (FSP) of surface layers. The FSP process is primarily used for the modification of microstructure in near-surface layers of processed metallic components. In particular, the process may produce: fine grained structure, surface composite, microstructural modification of cast alloys, alloying with specific elements, improvement of welded joints quality. The chapter is composed of a few main parts. In the first part, based on literature review the main application and achievements of FSP processes are presented. In the second part: analysis of the process. The third part is focused on microstructure refinement and the last part provide information about friction stir alloying as well as friction stir processing with ultrasonic vibration.

1. Introduction

Friction stir processing (FSP) utilizes the same process principles as FSW (friction stir welding) [1]; however, instead of joining samples together the process modifies the local microstructure of monolithic specimens to achieve specific and desired properties by surface modifying the microstructure (Fig. 1). As in FSW, the tool induces plastic flow during the process, but depending on the selection of process parameters, i.e. applied force, travelling speed and rotational speed, the material flow can yield a modified microstructure that is beneficial to the performance/requirement of the material. Developed by Mishra in 2000, the modified process is a relatively new and exciting technique for microstructural development and modification as well as property enhancement [2].

During the FSP process, a pin is plunged into the modified material with the shoulder of the rotating tool abutting the base metals. As the tool (Fig. 1) transverses the modified direction, the rotation of the shoulder under the influence of an applied load heats the metal surrounding the modified area and with the rotating action of the pin induces metal from each section to flow and form the modified area. The microstructure that evolves during FSP results from the influence of material flow, plastic deformation and elevated temperature and is characterized by a central stir zone surrounded by a thermomechanically affected zone (TMAZ) and heat affected zone (HAZ). The deformed material is transferred from the retreating side (RS) of the tool pin to the advancing side (AS) and is forged by the tool shoulder, resulting in a solid state modification of the material. In the FSP process the most important area is between stir zone and

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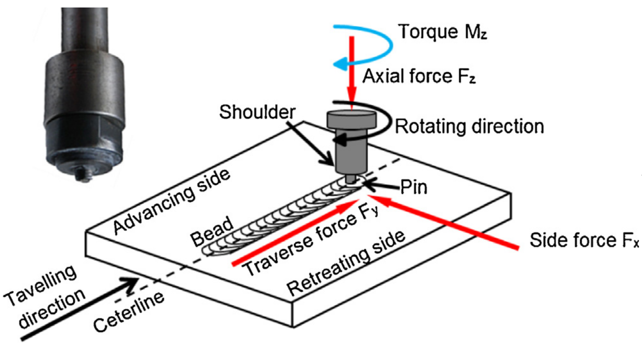

Fig. 1 – Schematic drawing of friction stir processing process and a tool.

thermomechanically affected zone. This area will determine properties of modified area, especially adhesion. In FSW the most important area is stir zone, and these can be noted as a one of the differences between FSP and FSW processes. The second difference is that for FSP the important area is zone direct below pin, and for FSW is does not matter because basically the welding technology consist in joint throughout thickness of materials.

The main technological parameters of the FSP process are the following:

- rotational speed,
- travelling speed,
- tilt angle,
- penetration depth of the tool,
- kind of the tool (pin length, diameter and shape of the pin, diameter and shape of the shoulder).
- alloying material (SiC, Al_2O_3, etc.),
- cooling system,
- clamping system.

The detailed analysis of these parameters as well as prospective tools are presented in earlier publication [3].

The width of the processed zone by the single-pass FSP is slightly wider than the pin diameter. The traversing pattern may involve only a single linear or curvilinear processing pass as shown in Fig. 2a. Such a narrow processed zone might not be suitable for all practical engineering applications. Therefore, two approaches to increase the width of the processed zones are available [4]. The first one is to use a large diameter pin and the second one is to process the sample using multi-run FSP. In the first case the increase in the tool dimension causes the increase in the torque acting on the tool and this increases the demand for power of the machine. The second one with a certain level of overlap between the successive passes can guarantee the demanding properties of the modified material. Hence, it is important to understand the microstructure evolution during the multiple-pass FSP. The multi-pass techniques are illustrated in Fig. 2b–d. A wider surface of material can be subjected to the FSP thermomechanical cycle using a series of linear traverses, offset from one another by stepping over by a designed distance as presented in Fig. 2b. Due to tool rotation the deformation field near the tool pin is not symmetric to the axis of tool advance and therefore the variation in microstructure from the advancing side to the retreating side can be observed. Microstructure gradients are typically more pronounced on the advancing side than on the retreating side. A series of parallel traverses as suggested in Fig. 2b result in successive replacements of the advancing interfaces with retreating interfaces in the processed volume of material. In contrast, a raster pattern as shown in Fig. 2c results in a pattern of advancing/advancing and retreating/retreating interfaces in a direction transverse to the local direction of tool advance. Such a pattern may leave long-range gradients in microstructure in the stir zone and lead to strain localization with attendant low transverse ductility. The use of a spiral pattern such as that illustrated in Fig. 2d results in the replacement of the advancing interface with a retreating interface on successive passes and thus may mitigate gradients in stir zone microstructure. The step over distance is typically based on the pin diameter in order to assure overlap of stir zones on successive passes in multi-pass processing. As mentioned before, the stir zone is generally wider at the work piece surface due to the effect of the tool shoulder, and an excessive step over distance may result in incomplete overlap in lower regions of the stir zone on successive passes. Again, microstructure gradients within the stir zone may result in strain localization and reduced ductility. Using a step over distance that is ≈½ of the pin diameter at the mid-length of the pin generally eliminates such microstructure gradients [5].

Owing to its simple concept, various applications of FSP technology have been presented in the literature [6]. These include improvement in the corrosion resistance, mechanical properties, grain refinement in the microstructure, production of superplastic materials, reduction of the porosity of castings, or production of special alloys. Many different materials can be subjected the multi-run FSP technology, these include: cast and wrought aluminium alloys, copper, magnesium alloys, titanium and many others.

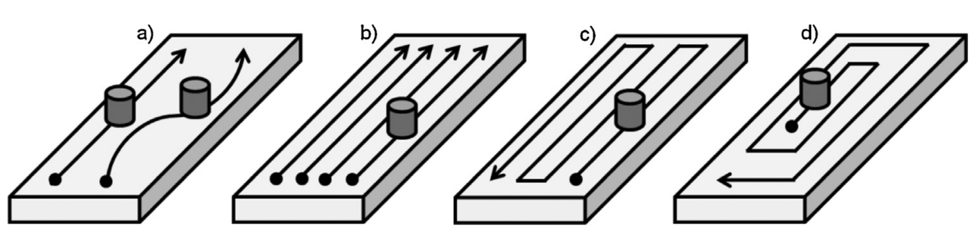

Fig. 2 – Traversing patterns for FSP: (a) a single linear or curvilinear pass, (b) parallel passes offset by a step over distance, (c) raster pattern, and (d) spiral pattern [5].