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Friction stir based welding and processing technologies - processes, parameters, microstructures and applications: A review

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ABSTRACT

Friction stir welding (FSW) has achieved remarkable success in the joining and processing of aluminium alloys and other softer structural alloys. Conventional FSW, however, has not been entirely successful in the joining, processing and manufacturing of different desired materials essential to meet the sophisticated green globe requirements. Through the efforts of improving the process and transferring the existing friction stir knowledge base to other advanced applications, several friction stir based daughter technologies have emerged over the timeline. A few among these technologies are well developed while others are under the process of emergence. Beginning with a broad classification of the scattered frictions stir based technologies into two categories, welding and processing, it appears now time to know, compile and review these to enable their rapid access for reference and academia. In this review article, the friction stir based technologies classified under the category of welding are those applied for joining of materials while the remnant are labeled as friction stir processing (FSP) technologies. This review article presents an overview of four general aspects of both the developed and the developing friction stir based technologies, their associated process parameters, metallurgical features of their products and their feasibility and application to various materials. The lesser known and emerging technologies have been emphasized.

1. Introduction

Solid state joining and processing technologies are emerging to be commonplace in industries to join softer metal alloys which are difficult to join using conventional fusion welding techniques. Friction stir welding (FSW), invented in 1991 at The Welding Institute, UK [1], is arguably the most successful solid state joining technology. FSW does not use filler material, leading to considerable weight reduction. Within 26 years of invention, FSW has been proven to be at the forefront of joining high strength aluminium alloys, meant for application in automobile and aerospace sectors, while also savoring partial success in the joining of other metallic alloys [2–10]. Considering the remarkable success of FSW, the friction stir concept has been further modified, improved and refurbished to develop various novel material joining and processing technologies which is gradually enabling transfer of technological feasibility to other high strength structural materials and sophisticated applications [11–21].

This review aims at presenting an overview of all the documented processes and technologies based on the friction stir concept. On the basis of their application, friction stir based operations can be classified into two major categories, welding and processing. The various processes classified under the welding and processing categories are shown in Fig. 1. The operation technologies under the welding category are essentially employed for material coalescence while processing technologies are adopted for applications aimed at improving the quality of the material in terms of its physical, chemical and mechanical properties [18–21].

It is worth mentioning that the friction stir processes involve the rotational motion of a tool in contact with a workpiece. This generates the necessary heat for the operation by friction between the tool and the workpiece. A common notion is that the tool is always non-consumable in the friction stir operations, as in friction stir welding. However, this notion is not necessarily true for some friction stir processes such as friction surfacing where the tool is consumable. The friction stir based technologies operate on the principle of 'third body region' [21,22]. Schematic diagrams of the third body regions in the friction stir operations using non-consumable and consumable electrodes are shown in Fig. 2(a) and (b), respectively.

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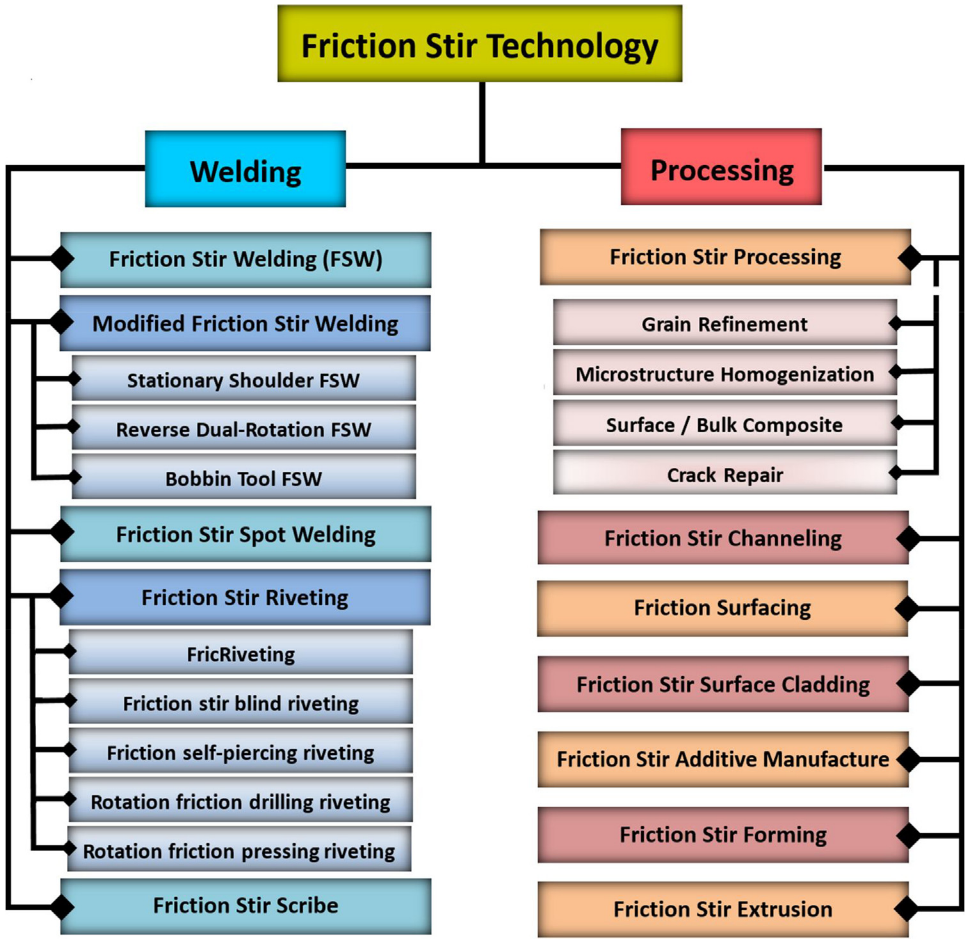

Fig. 1. Classification of friction stir based technologies.

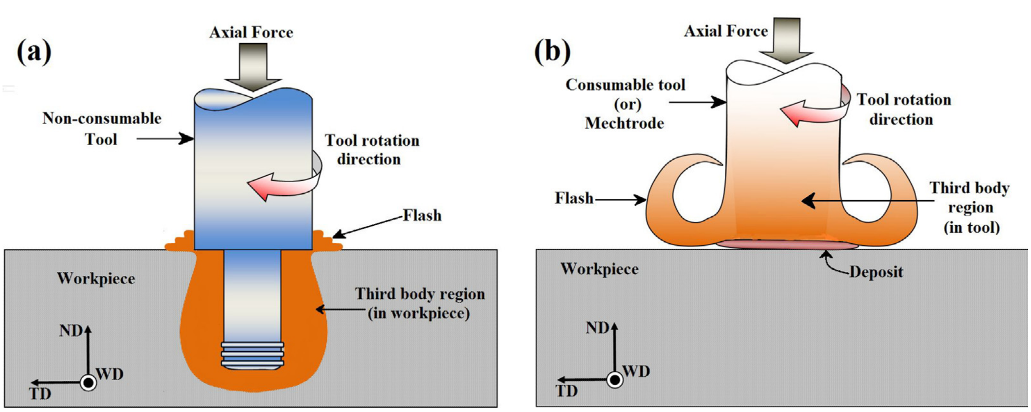

Fig. 2. Third body region in friction stir operations with (a) Non-consumable tool, as in friction stir welding, (b) Consumable tool, as in friction surfacing.

As the term persuades, 'third body region' is a zone physically distinct from both the tool and the workpiece. It is generated either on the workpiece (when the tool is non-consumable) or on the tool (when the tool is consumable) during the friction stir operation. Although still a solid, the third body region exhibits three dimensional fluidity and allows the material in the region to flow and mix with the other material at the interface. Formation of the third body region is driven by frictional heat generation at the working interfaces. This region appears at temperatures between the recrystallization temperature and melting point of material and is characterized by relatively high viscosity and low flow stress. The material in this region closely corresponds to the plasticized or deformed material in the friction stir based operations.

In general, the third body region is typical to all the friction stir based operations while it is nonexistent in fusion technologies because there is no frictional heat generation at the melting point of material. The third body region allows interatomic diffusion and material intermixing at relatively higher temperatures. Thus, the material in the region can produce strong bonding with similar region of another similar/dissimilar material. At lower temperatures or higher pressures, however, interatomic bonding is also a dominating mechanism of joining or processing [21]. Therefore, the main objective of the friction stir based technologies is to gener-

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