International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2016 Vol. 6 (1) January-March, pp.40-42/Prasanna et al.
Review Article

THE MAIN DEFECTS OF FRICTION STIR WELDING AND PROCESSING: AN OVERVIEW

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ABSTRACT
The paper presents an overview of various types of defects at Friction Stir Welding. In order to explain the reasons for their occurrence a short theoretical background of the process is given first. The main emphasis has been placed on optimising tool design and process parameters to ensure joint quality. However, flaws may still be created in the production environment if the limits of the "process window" are exceeded. The occurring defects are demonstrated on various materials.

Keywords: *Friction Stir Welding, Welding Parameters, Welding Defects*

INTRODUCTION

Friction Stir Welding (FSW) is a solid-state joining process that produces a fully consolidated weld (Thomas *et al.*, 1991). Welds are made by plunging a rotating tapered tool into the joint to be welded. The heat the friction generates is sufficient to locally soften the work pieces, and the rotating motion of the tool stirs the work pieces, together as the tool is advanced along the joint line. Recently there is however a lot of research going on in order to widen the set of materials applicable for FSW (Cam, 2011). As in other welding processes it is very important to choose the right combination of welding parameters in order to get a weld of appropriate quality. In this paper the main parameters of FSW and processing will be presented together with the most common welding defects which occur if an inappropriate combination of these parameters are used (Klobcar *et al.*, 2012).

Theoretical Background

FSW can be characterised as a solid-state joining process which uses a non-consuming tool to join two weld pieces in figure 1. The rate of energy input due to friction and the tool's movement of translational and rotational movements are two primary functions. These are the frictional heating of the work pieces and stirring of material in order to produce a joint (Mishra and Ma, 2005). As there is axial force acting upon the tool, the heating of the work piece is the result of the associated friction between the tool and the workpiece and the plastic deformation of the work piece material.

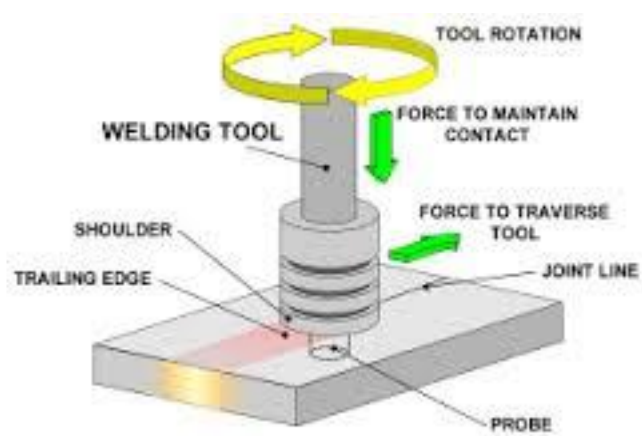

Figure 1: A Schematic Diagram of FSW

Rotational Speed and Translational Speed

Tool rotation and traverse speeds are the two tool speeds to be considered in FSW; how fast the tool rotates and how quickly it traverses the interface. The relation between the welding speeds and the heat input during welding is complex, but in general it can be said that increasing the rotational speed or decreasing the traverse speeds will result in a hotter weld (Dixit *et al.*, 2007). If the material is too cold then voids or flaws or other flaws may be present in the stir zone and extreme cases the tool may break.

Excessive high heat input results in defects the liquation of low-melting point phases. It leads on to the concept of a “Processing Window”: The range of processing parameters (tool rotation and traverse speed) will produce a good quality weld within this window the resulting weld will have a sufficiently high heat input to ensure adequate material plasticity but not so high that the weld properties are excessively deteriorated.

Plunge Depth

The plunge depth is defined as the depth of the lowest point of the shoulder below the surface of the welded plate and has been found to be critical parameters for ensuring weld quality. The plunge depth needs to be correctly set, both to ensure the necessary downward pressure is achieved and to ensure that the tool fully penetrates the weld. Reduction of plunge depth compared to the nominal setting which may results in flaws in the weld.

The Most Common Defects in FSW

The technique leads to several advantages over fusion welding methods since any problems associated with cooling from the liquid phase are avoided. Issues such as porosity, solute redistribution, solidification cracking and liquation cracking are not an issue during FSW. An inappropriate rate of heating can result defects of FSW as lack of penetration, lack of fusion, tunnels, voids, surface grooves, excessive flash, surface galling, nugget collapse and kissing bonds (Qian *et al.*, 2013). These defects are sometimes divided into weld line flaws and volumetric flaws (Threadgill, 2007).

In general FSW has been found to produce a very low concentration of defects and is very tolerant to variations in parameters and materials. However, some distinct defects or flaws can exist if welding parameters or welding procedures are incorrect.

Figure 2: Photo of a Weld Flash with an Additional Surface

Figure 3: Picture of Plunge Depth as Defect in FSW

Definition of Defect and a Flaw

A defect is an imperfection that has been shown to compromise the integrity of the structure, and its presence is therefore intolerable.

A Flaw is defined as an imperfection whose significance has not been established, and which could be possibly tolerated in the structure.

Conclusions

The paper presents the most common defects in the FSW which occur due to an inappropriate combination of welding parameters (mainly translational/ rotational speeds and Plunge depth). This results in either excessive or insufficient heat input. Even if these parameters are selected properly the defects can occur due to inappropriate tilt angle, improper tool geometry.

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