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Friction stir welding by using counter-rotating twin tool

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ABSTRACT

A twin-tool setup has been designed and fabricated to make a comparative study between twin tool and single tool using double pass in a friction stir welding process. Twin tool helps in generating high heat causing intense plastic deformation in the processed zone. Defect free weld depends not only on the rotational speed, but also on the combined effect of welding speed and rotational speed. Higher hardness profile is observed with higher welding and rotational speeds; defect-free joints are also observed in this combination. Further, SEM results confirm the existence of ductile failure with microscopic voids of different shapes and sizes.

1. Introduction

Friction stir welding (FSW), invented in 1991 by The Welding Institute (TWI) (Thomas et al., 1991), is a solid state welding technique where the peak temperature reached is below the melting point of the material to be welded (Mishra and Ma, 2005). Besides it is seen that there is a significant progress in welding process as well as its properties of the welded joints (Nandan et al., 2008). Further this technique is widely utilized in joining metals like Al, Mg, Cu, Ti and their alloys. Cam and Mıstıkoglu (2014) reviewed and narrated the detailed studies on friction stir welding of different types of aluminium alloys. They highlighted their study mainly on the correlation of weld parameters with the mechanical as well as microstructural properties of the welded joints. Further, Cam (2011) also reviewed their research against different types and grades of metals and alloys in addition to aluminium like Ti, Mg, Cu, steel as well as MMC. They mainly studied on the joint properties with microstructural studies and to some extent on the material selection of the FSW tools. Thomas and Nicholas (1997) used FSW technique to join aluminium alloy with a thickness varying from 1.6 to 12.7 mm and also extended to 75 mm thick plate by using two passes. In contrast to fusion welding technique, surface oxide layer does not create any difficulty to this process. XungHong and Kuaishe (2006) discussed the mechanical properties and microstructural evolution of 4 mm thick AZ31 Mg alloy. Defect-free welds were obtained with enhanced characteristics like fine grains having small intermetallic compound, higher hardness with a joint strength of 93% of that base metal. Similar kinds of studies were explored by Lee and Jung (2004) with copper alloy using an optimum and constant process parameter. Having excellent properties like high melting and specific strength, Ti alloys are being used in many fields like aerospace, nuclear, military applications as well in medical fields. Therefore, it is important to find a solution in joining of those alloys. The use of conventional fusion welding technique over Ti resulted in the formation of brittle structure with distorted residual and mechanical properties. Thus, Lee et al. (2005) also implemented FSW process with water cooling system to weld pure Ti sheet using sintered TiC tool and revealed better properties compared to the conventional one. FSW has also advanced its scope in joining dissimilar alloys (Ipekoglu and Cam, 2014) with dissimilar thickness and also in the welding of steels (Thomas et al., 1999). They used 12 mm and 15 mm thick low carbon steel plates of different grades for welding and revealed that unlike aluminium or non ferrous alloys, a distinctive change in colour in the thermo vision infrared imaging system gave the range of temperature change during welding process. Further, friction stir spot welding (FSSW) is also an elevation in this technology for spot welding of different alloys both in butt as well as lap positions. Bozkurt et al. (2013) studied the effect of sheet locations (up or down) on the joint strength of lap welded dissimilar alloys of AA5754-H22 to 2024-T3 using FSSW.

FSW has a number of advantages over the conventional welding techniques such as very low distortion, no fumes, no consumables (no filler wire), no special surface treatment, no shielding gas

Abbreviations: FSW, friction stir welding; FSP, friction stir processing; GBS, grain boundary sliding; AGG, abnormal grain growth; MPFSP, multi-pass friction stir processing; TT, twin tool; ST–DP, single tool with double pass; YS, yield strength; UTS, ultimate tensile strength; % Elng, percentage of elongation; JOINT EFF, joint efficiency.

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Symbols

v	rotational speed (rpm)
w	welding speed (mm/min)

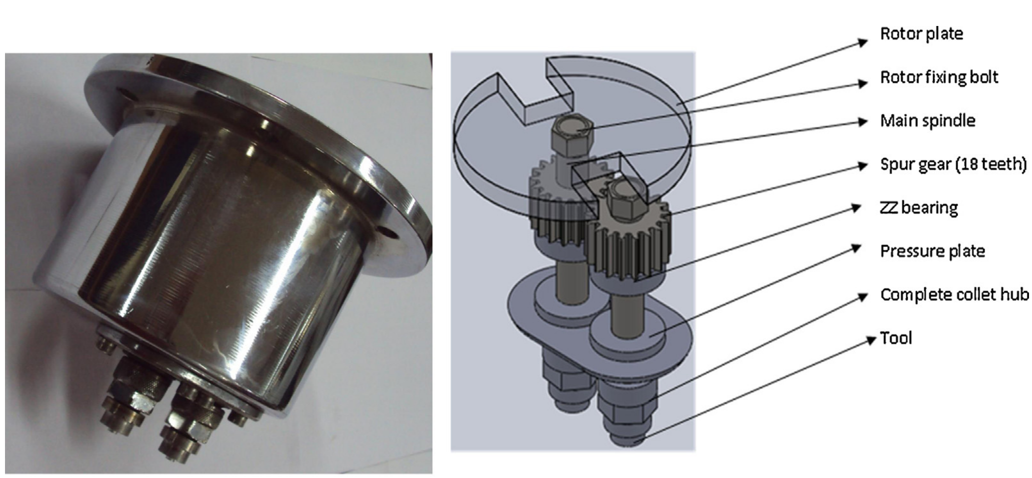
requirements, and no specialized welding skills. Therefore, this is an improved technique of joining with better mechanical properties compared to the conventional welding. Having these advantages FSW is being widely used in the aerospace, automobile industries, ship buildings and many other fields.

Though this reliable technique of joining metals and alloys has a lot of advantages it may be mentioned that complete elimination of defects is not possible. Common defects associated with FSW include lack of penetration, tunnel, worm hole, kissing bond and Lazy S (Chen et al., 2006) and these are all due to improper weld parameters. Kim et al. (2006) also studied three different types of defects formed due to the difference in tool plunging forces. They observed that higher heat input generates the flash formation defects but cavity or groove-like defects were caused due to insufficient heat input. Further, at a combined effect of higher rotational speed and welding speed abnormal stirring occurs at a less plunge force/depth. Hence, mechanical properties usually degrade when welding conditions are not chosen properly. Therefore a careful selection of welding process parameters (such as weld traverse speed, rotational speed, plunge depth or plunge force, tool geometry etc.) is essential to avoid the defects (Leal and Loureiro, 2004).

Researchers are therefore, mainly focussed on the ways to achieve defect-free weld by using multi-pass FSW/Friction stir processing (FSP) with nominal process parameters. By using the rewelding technique, the defective portion of the weld left with the first pass is repaired (Brown et al., 2009) by the second pass. Recent literature reports several examples related to multi-pass FSP/FSW on similar and dissimilar materials.

Brown et al. (2009) performed five overlapping passes and found that there is no need of any adjustment for multi-pass welding. Further, there is a significant reduction in feed force when welding is done over the previous weld. However, grain size, hardness and temperature during welding are unaffected with the number of passes. Again, a gradual reduction of residual stress is noted with increasing number of passes. Nataka et al. (2006) reported a betterment of the mechanical properties in aluminium die casting alloy using multi-pass FSP. Compared to the base metal, hardness value and the tensile strength of the multi-passed specimen are high. The main reason for improvement of mechanical properties is due to the removal of cold flake, uniform distribution of the silicon particles over the aluminium matrix which refines the grain. On the other hand, Ma et al. (2006) reported that there is no effect of overlapping passes on size, aspect ratio or distribution of the Si particle while performing five-pass FSP with 50% overlap on cast A365. Leal and Loureiro (2008) investigated the effect of overlapping FSW passes using two Al alloys (AA5083-O and AA 6063-T6). They found that the quality and strength of the welded joint not only depend on the weld parameters, but also on the type of material used and its heat treatment conditions. Experimentally they also found, weld polishing improves the mechanical joint efficiency.

As FSP is one of the most promising techniques for grain refinement, and removal of flaws and defects, many researchers used multi-pass FSP to improve the properties of as-cast material. Johannes and Mishra (2007) demonstrated the effectiveness of multiple passes to create large areas of materials with super plastic properties. They concluded that, grain boundary sliding (GBS) is the most important mechanism to achieve the super plastic deformation. Similarly, Ma et al. (2009) noted that two-pass FSP shows enhanced super plastic elongation as compared to the single pass. Further, temperature rise in central as well as transitional zone of the second pass is more than the temperature corresponding to the single pass. Surekha et al. (2008) reported that multi-pass FSP showed better corrosion resistance compared to the base metal. This is due to the reduction and dissolution of the $CuAl_2$ particles, which decreases the number of sites available for galvanic coupling. Ipekoglu et al. (2012) studied the effect of temper condition on the weldability of AA 7075 Al alloys along with different parametric conditions. Ipekoglu et al. (2013) further studied the effect of weld parameters as well as the temper conditions on the joint quality and its performance on AA 6061 aluminium alloys. In addition to that Ipekoglu et al. (2014a) enhanced their study to see the outcome of post weld heat treatment (PWHT) on both microstructure as well as the mechanical properties of AA6061-O and AA6061-T6 aluminium alloys. Further, they described the reason behind the formation of abnormal grain growth (AGG) which occurs during PWHT. Severe plastic deformation occurs in case of FSW leading to store higher energy inside the fine grains. Upon subsequent heat treatment inhomogeneous grain size distribution leads to AGG. They observed that PWHT improves the properties of the welded joints though the formation of AGG and it is more in O-temper case as compared to the T6 alloys. Further, Ipekoglu et al. (2014b) highlighted the growth of abnormal grains after post weld heat treatment of 7075 Al plate. They also confirmed that weld parameters



(a) (b)

Fig. 1. Twin tool attachment with schematic diagram.