Feasibility Study of Friction Stir Welding Application for Kevlar Material

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***Abstract*—**Friction stir welding (FSW) is a joining process in the solid state, which eliminates problems associated with the material melting and solidification, such as cracks, residual stresses and distortions generated during conventional welding. Among the most important advantages of FSW are; easy automation, less distortion, lower residual stress and good mechanical properties in the joining region. FSW is a recent approach to metal joining and although originally intended for aluminum alloys, it is investigated in a variety of metallic materials. The basic concept of FSW is a rotating tool, made of non-consumable material, specially designed with a geometry consisting of a pin and a recess (shoulder). This tool is inserted as spinning on its axis at the adjoining edges of two sheets or plates to be joined and then it travels along the joining path line. The tool rotation axis defines an angle of inclination with which the components to be welded. This angle is used for receiving the material to be processed at the tool base and to promote the gradual forge effect imposed by the shoulder during the passage of the tool. This prevents the material plastic flow at the tool lateral, ensuring weld closure on the back of the pin. In this study, two 4 mm Kevlar® plates which were produced with the Kevlar® fabrics, are analyzed with COMSOL Multiphysics in order to investigate the weldability via FSW. Thereafter, some experimental investigation is done with an appropriate workbench in order to compare them with the analysis results.

***Keywords*—**Analytical modeling, composite materials welding, friction stir welding, heat generation.

I. Introduction

FRICTION stir welding (FSW) is particularly suitable for the non-ferrous metals which have low melting point. Additionally, some compound materials such as aluminum alloys and steels can also be readily welded. During welding, a rotating cylindrical pin is traveled throughout joint line of the materials and resulting from heating the materials to a plasticized state and stirring the workpieces together, a joint is formed.

Thanks to advances in FSW, hardly weldable steels or dissimilar materials such as aluminum, magnesium, copper, and titanium can be welded to each other. This technology is can be applied in many industries such as automotive, aviation, defense and electronics.

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II. Process Review

Fig. 1 shows that the process applies plunge force, torque and traverse force on the workpieces to be welded via a nonconsumable rotating tool with a specially designed pin and shoulder [1].

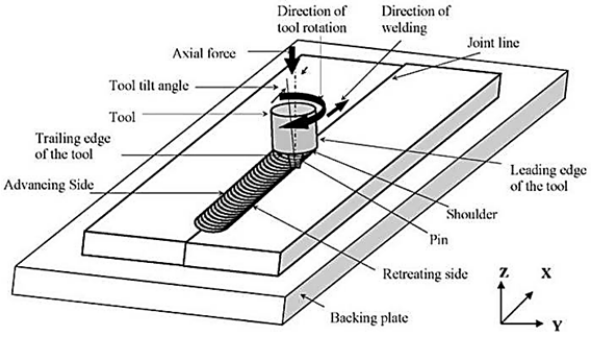


Fig. 1 Schematic drawing of FSW process

Fig. 2 illustrates that along the joint line, two square butt grooved plates without any welding groove preparation can be welded via a tool with a specially designed pin and shoulder under applied specific process parameters such as tilt angle (θ), plunge force (F), rotating speed (ω) and travelling speed (v) [1].

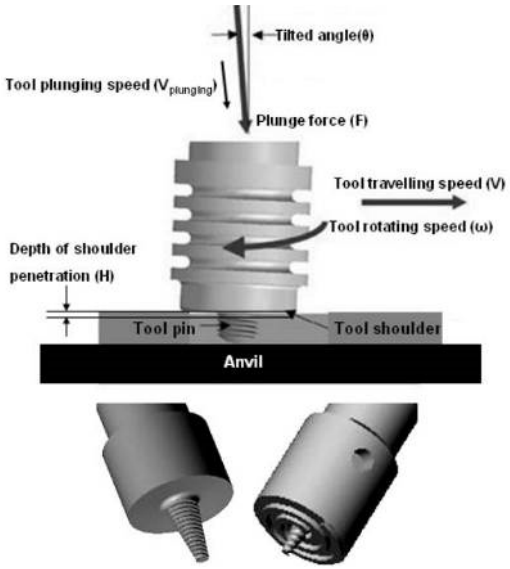


Fig. 2 Schematic of a FSW tool and processing parameters

3. Whorl Pin and Applications

Fig. 12 represents the applications of whorl pin and experimented welding parameters used for FSW of several alloy materials [3]-[5].

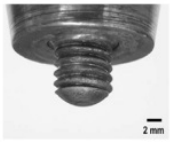
Workpiece Material	Alloys	Material Thickness	Welding Parameters	Advantages	Disadvantages	Schematic View
Al	Al 5xxx (Mg alloy) series (AA 5754 - FSSW: friction stir spot welding)	1.32 mm	1500 rpm, dwell time; 2 s, plunge rate ; 20 mm/s	* This shoulder produces quality welding and decreases significantly welding mistakes in tne microstructure and geometry * It improves the max plunge force and plunge deepth. * Simply designed.	* It produces moderate the flush and welding mistakes.	
	Al 6xxx (Si ve Mg alloys) series (AA 6061-T6)	6.3 mm	286-1150 rpm, 30-210 mm/min			
	Al 7xxx (Zn alloy) series (AA 7020-T6)	4 mm	300-1620 rpm, 100-900 mm/min			
Ti	AA 1050 with 22MnB5 steel	3 mm	1000-2000 rpm, dwell time; 2 s, FSSW lap			
	Ti alloy (cp-Ti, commercially pure Ti)	1.8 mm	200 rpm, 50 mm/min, under Ar shield			
	2024-T3 Al with Ti–6Al–4V alloy	2 mm	800 rpm, 80 mm/min			
Stainless Steel	SAF 2507 super duplex	4 mm	450 rpm, 60 mm/min	* Proper operation of this shoulder design requires tilting the tool 2 to 4° from the normal of the workpiece away from the direction of travel; this is necessary to maintain the material reservoir and to enable the trailing edge of the shoulder tool to produce a compressive forging force on the weld.		
	15-5PH (martensitic, precipitation-hardening material with chromium, nickel and copper)	2.6 mm	300-450 rpm, 60-350 mm/min			
Advanced High-Strength Steels (AHSS)	DP 780 carbon steel (Dual phase, for the automotive industry, consists of a soft ferrite phase with dispersed islands of a hard martensitic phase) - FSSW	1.5 mm	800-1600 rpm, dwell time; 1-10 s			
	DP 590 carbon steel (Dual phase, for the automotive industry, consists of a soft ferrite phase with dispersed islands of a hard martensitic phase)	1.2 mm	3000 rpm, under Ar shield, FSSW lap welding			

Fig. 9 Concave shoulder and experimented applications

4. MX Triflute Pin and Applications

Fig. 13 represents the applications of MX Triflute pin and experimented welding parameters used for FSW of several alloy materials [3]-[5].

5. MX Trivex Pin and Applications

Fig. 14 represents the applications of MX Trivex pin and experimented welding parameters used for FSW of several alloy materials [3]-[5].

6. Threadless Pin and Applications

Fig. 15 represents the applications of threadless pin and experimented welding parameters used for FSW of several alloy materials [3]-[5].

III. Kevlar Material Properties and Applications

Kevlar® is a class strong and synthetic fiber which has a unique combination of characteristics such as high strength, toughness and thermal stability, is characterized from other commercial fibers [6].

Kevlar® is a registered trademark of E. I. Du Pont de Nemours and in the aromatic polyamide (aramids) family. It was developed for aerospace, defense and military industries for demanding applications [6].

There are two types of Kevlar®, Kevlar® 29 and Kevlar® 49 and especially Kevlar® 49 is widely used in aerospace industry [7]. Major applications of Kevlar® are cut, heat, and bullet-fragment resistant apparel, brake and transmission friction parts, gaskets, ropes and cables, composites, fiber-optic cables, circuit-board reinforcement, sporting goods, tires, automotive belts and hoses.

Continuous filament yarn, staple, wet and dry pulp floc, cord are the major forms of Kevlar® [7]. When we look to the properties of special interests of Kevlar®, we can see that how