Procedia Manufacturing
Volume 5, 2016, Pages 319–331
44th Proceedings of the North American Manufacturing Research Institution of SME http://www.sme.org/namrc

An Innovative Friction Stir Welding based Technique to Produce Dissimilar Light Alloys to Thermoplastic Matrix Composite Joints

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Abstract
Aluminum sheets can be joined to composite materials with different techniques. Each of them has advantages and weak points over the others. In literature, new techniques and patents are continuously developed to overcome these difficulties. In the paper a new Friction Stir Welding based approach is proposed to mechanically join AA6082-T6 to self-reinforced polypropylene. The aluminum sheet is pre-holed along both the sides of the weld line. A pinless tool generates the heat and pressure needed to activate back-extrusion of the composite. Joints have been produced with varying hole diameter and pitch. The mechanical resistance of the joint has been evaluated and the different failure modes were identified. Finally, a numerical model was set up to study the process mechanics by calculating the distribution of the main field variables, i.e. temperature strain and nodal displacement.

Keywords: FSW, Dissimilar joint, aluminum alloy, Polypropylene

1 Introduction

In the last few years, the use of composite materials has been continuously growing. Increasing pollution as wells as progressive oil reserve depletion has led to energy saving and environmental impact minimization policies aimed to the reduction of fuel consumption and improvement of energy and resource efficiency. These objectives can be pursued by producing light structures made of composite materials and light metal alloys, which enable, at the same time, high mechanical properties of the structures (Duflou et al., 2012). The growing use of these two categories of materials has led to the need of reliable and effective techniques to create dissimilar joints to be used for complex structures. In the aeronautic and aerospace fields, composite materials are used for their light weight,

Selection and peer-review under responsibility of the Scientific Programme Committee of NAMRI/SME

doi:10.1016/j.promfg.2016.08.028

elevated mechanical properties and corrosion resistance. Composites are often used by the automotive industry only for nonstructural components. However, the use of carbon fiber components for race cars showed that the weight saving results in the possibility to reduce the dimension of engines, braking systems and fuel tanks. Finally, in the naval industry several examples can be found of dissimilar joints made of aluminum alloy and composite materials.

As far as joining techniques are regarded, a few alternatives can be taken into account to produce dissimilar metal to composite joints. Among the mechanical joining methods, Di Franco et al. studied the Self Piercing Riveting (SPR) process highlighting the effect of the rivets position on the mechanical properties of joints made of AA2024 aluminum alloy and carbon fiber composite panels (Di Franco et al., 2012). Main drawback of the process is the increase in the assembled part weight due to the presence of the rivets. Lambiase and Di Ilio utilized clinching to produce AA5053/polystyrene hybrid joints. the main failure modes and the effect of the main process parameters on the joints mechanical properties were evaluated. Compared to clinching of metal sheets, additional limitations arise producing hybrid joints due to the lower enveloping effect exerted by the polymer during the upsetting phase which enables crack formation (Lambiase and Di Ilio, 2015). A modification of the clinching process, namely Injection Clinching Joining (ICJ) was investigated by Abibe et al. In the process, a protruding stud is created in the polymeric sheet and a corresponding hole is drilled in the sheet metal. Once the two parts are correctly positioned, the stud is heated by a hot case and a forming punch create a sort of polymeric rivet. In this way, no additional material is needed. The feasibility of the process has been proved for AA2024-T351 and Short glass fiber-reinforced polyamide. The obtained mechanical properties were comparable to the ones known for similar processes. Drawbacks of the process are the further operations needed to produce the extruded stud and the spot joining nature of the process (Abibe et al., 2013).

Hybris metal to composite joints can be obtained also by adhesive bonding. Seong et al. highlighted the effect of a few process parameters, i.e. bonding pressure, overlap length, adherend thickness, and material type on the mechanical properties of the produced joints. AA2024-T3 and three types of prepegs were used to produce the composite adherend, i.e. SK Chemical USN125 carbon/epoxy, WSN-3k carbon fabric and GEP125 glass fabric. Delamination was identified as the major failure mode (Seong et al., 2008). Arenas et al. focused their attention on the correct choice of the adhesive and surface treatment allowing for the best compromise between mechanical properties and adaptation to the manufacturing process. Carbon fiber tissue with an epoxy matrix and AA6160 aluminum alloy were bonded using both highly resistant epoxy and a bi-component polyurethane. Six different surface treatments were considered and a multi-criteria decision tool was utilized to highlight the best combinations of process parameters (Arenas et al., 2013). Although adhesive bonding represents an effective technique in order to produce hybrid metal to composite joints, the degradation of the mechanical properties with time can represent an issue for a number of industrial applications.

Recently, a few different research groups have worked on new joining techniques, based on the solid state welding process known as Friction Stir Welding (FSW), with the aim to produce hybrid metal to composite joints. In particular, Liu et al. used Friction Lap Welding (FLW) to join AA6061 aluminum alloy and monomer casting nylon (MC Nylon-6). In the process, the aluminum sheet is placed on top of the composite one and a pinless tool is used to produce a localized increase of temperature in the plastic. The melting of the plastic and subsequent solidification under the applied load produces the bonding. Different sets of process parameters were considered finding a correlation between the joint resistance and the thickness of melted nylon (Liu et al., 2014). Goushegir et al. used the Friction Spot Joining technique (FSpJ) to join AA2024-T3 and carbon-fiber reinforced poly (phenylene sulfide). In the FSpJ process, the tool is made of three different parts: a clamping ring, which holds the sheets to join, a rotating sleeve, which softens the sheet metal (placed on top of the joint) till its bottoms surface, and a rotating and independent pin which is used to press the extruded material and consolidate the weld. The mechanical properties of the joints were evaluated and the modifications in the structure of the metal and the composite were analyzed demonstrating the