Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Friction Spot Joining of Polymer-Metal Hybrid Structures

S. M. Goushegir

Nowadays, there is a growing trend of using rivet-free joining technologies, appropriate to join dissimilar materials to be used in transportation industries. Friction Spot Joining (FSpJ) patented by Helmholtz Research Center in Geesthacht (S. Amancio and dos Santos EP 2 329 905 B1), is a potential technique to produce hybrid structures by joining lightweight alloys (such as aluminum and magnesium) with high performance thermoplastic composites. In this process, a three-pieces non-consumable tool is used to generate frictional heat. The tool comprises of a stationary clamping ring, as well as a pin and a sleeve which can rotate and move independently (Figure 1).

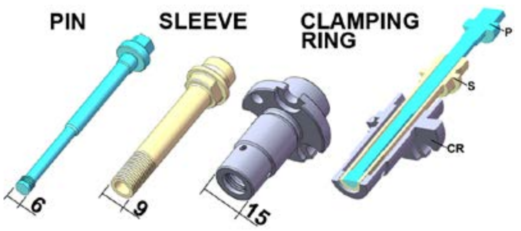

Figure 1: Schematic illustration of FSpJ tool comprised of a pin, sleeve and clamping ring (dimensions are in mm).

Description of the Technique

The explanation of the technique is illustrated in Figure 2. Prior to the joining process, the joining partners are clamped together in lap configuration (metal piece on top of the polymer) against a backing plate. There are two variants for this technique; “Pin Plunge” and “Sleeve Plunge”. In the sleeve plunge variant, the tool approaches the metal sheet at the same time as sleeve and pin start to rotate in the same direction. Then, sleeve plunges into the metallic sheet to a pre-defined depth while the pin retracts upwards. Due to the friction between sleeve and the metal, the temperature rises locally, hence causing metal softening in a volume around the sleeve. The plasticized metal alloy is squeezed into the reservoir left behind by the retraction of the pin (Figure 2-1).

In the second step, the pin is forced against the soften metal to refill the key-hole in the metallic sheet (Figure 2-2). In this step, sleeve and pin return to their original position. Finally, the tool is retracted and the joint consolidates under pressure. Note that the sleeve plunges

Helmholtz-Zentrum Geesthacht • Max-Planck-Straße 1 • 21502 Geesthacht • Phone +49 (0)4152 87-2038 • Fax +49 (0)4152 87-2033 • www.hzg.de
Contact: MEng. Seyed M. Goushegir •Email: seyed.goushegir@hzg.de

shallow into the metal piece without reaching the interface avoiding any damage to the fiber network of the composite and degradation of the polymer matrix.

In the pin plunge variant the pin penetrates the metal piece while the sleeve is retracted. The remaining process steps are equal to the sleeve plunge variant.

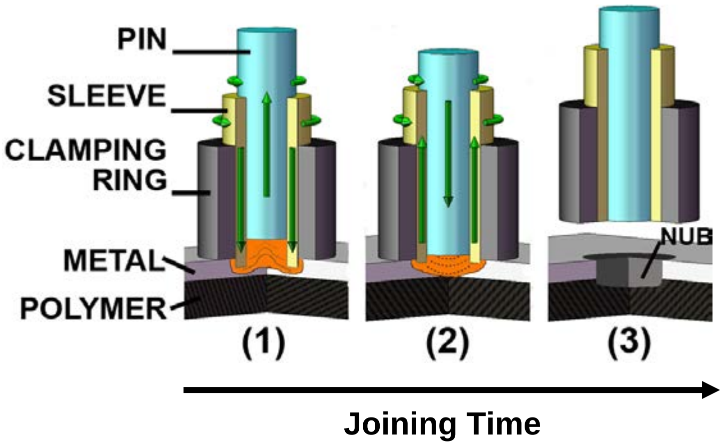

Figure 2: Schematic explanation of the FSpJ technique (sleeve plunge variant). (1) Sleeve plunging soften the metal alloy, (2) spot refilling, (3) joint consolidation.

During the joining process, the plasticized metal is deformed by tool plunging and forms a geometrical undercut in the form of a “metallic nub”. In addition, heat flows by conduction from metal to the thermoplastic piece, melting a thin layer of the polymer at the interface.

The thermo-mechanical phenomena involved in the process lead to two bonding mechanisms. Firstly, mechanical interlocking due to the created metallic nub at the metal-composite interface; secondly, adhesion forces, since a thin layer of the molten polymer is formed in the spot region, and spreads throughout the overlap area due to the low viscosity of the molten polymer.

Microstructure and Mechanical Performance

Figure 3-a shows the top view of a composite-metal friction spot joint. The cross-sectional view of the joint is also shown in Figure 3-b. The deformed metal feature, i.e., the metallic nub, is visible in the cross-sectional image of the joint (indicated in the figure with an ellipse). The slight insertion of the metallic nub into the composite is believed to increase the mechanical interlocking, and hence the shear strength of the joint.

Helmholtz-Zentrum Geesthacht • Max-Planck-Straße 1 • 21502 Geesthacht • Phone +49 (0)4152 87-2038 • Fax +49 (0)4152 87-2033 • www.hzg.de
Contact: MEng. Seyed M. Goushegir •Email: seyed.goushegir@hzg.de

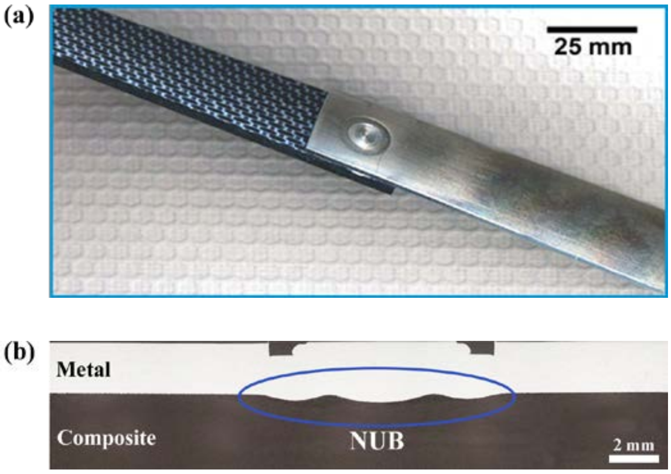

Figure 3: (a) Top view of a sound FSp joint, (b) cross-sectional macrograph of a joint, in which ellipse indicating the formed metallic nub.

Detailed analysis of the nub region illustrates a portion of the carbon fibers which are entrapped by the plasticized metal (Figure 4-a), thereby creating a micro-mechanical interlocking. Furthermore, the molten polymer fills the pores and crevices on the surface of the metal (as a result of the surface pre-treatment and texture changes induced by plastic deformation) which after consolidation increases the micro-mechanical interlocking and the global shear strength of the joint (Figure 4-b).

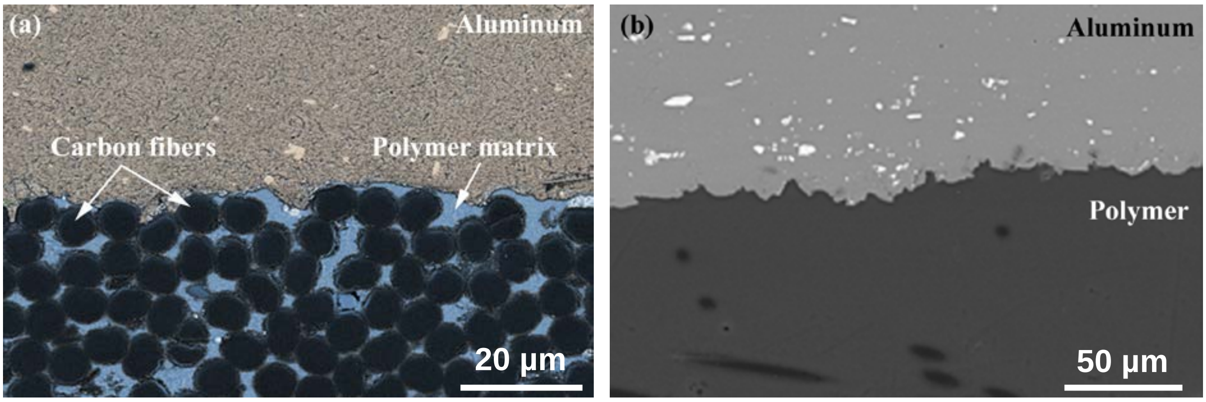

Figure 4: SEM image (a) of the nub region showing carbon fibers embedded by aluminum, (b) showing aluminum surface crevices filled by the molten polymer.

Mechanical performance of the joints depends on the joining materials and joint geometry. Figure 5 depicts, as an example, the ultimate lap shear strength of the friction spot joints between aluminum alloy 2024 (AA2024-T3) and carbon fiber-reinforced poly(phenylene sulfide) (CF-PPS). The strength of the joints varies between 14 to 127 MPa depending on the surface pre-treatment of the aluminum, which is similar or better than state-of-the-art adhesive bonding and welding-based joining technologies.

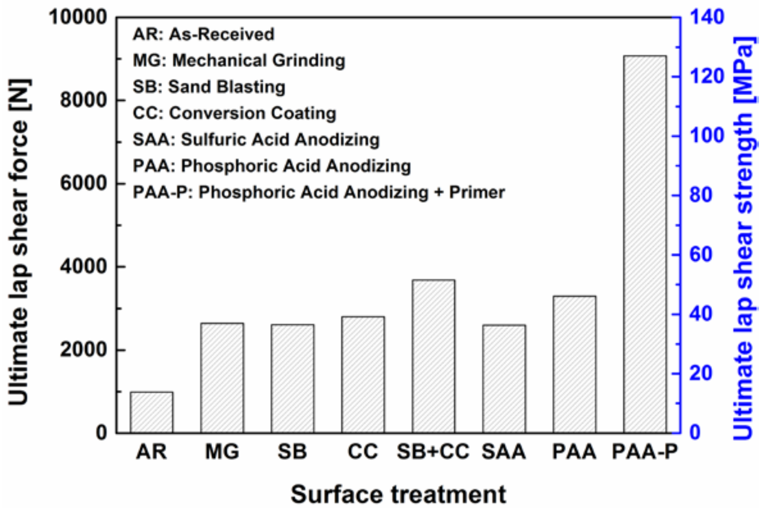

Figure 5: Average lap shear strength of AA2024-T3/CF-PPS FSp joints based on different aluminum surface pre-treatments.

Potential Applications

Polymer/composite-lightweight alloy joints, produced by friction spot joining technique, display high mechanical strength. Furthermore, this technique does not add any weight to the structures. Therefore, hybrid structures produced via FSpJ can be considered to be used along with other techniques in the aircraft structures, for instance in skin/stringer/clip joints, as can be observed schematically in Figure 6-a. Figure 6-b shows an example of a skin-stringer sub-component produced by FSpJ for demonstration purposes.

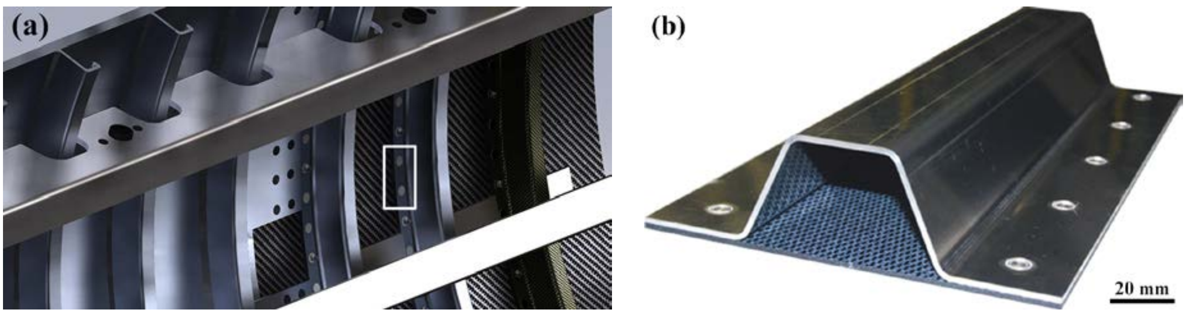

Figure 6: (a) Schematic illustration of potential application of FSpJ in skin/stringer/clip joining of an aircraft, indicated by the white rectangle, (b) skin-stringer demonstration sub-component produced by FSpJ.

In addition to the aircraft industry, automotive manufacturers such as BMW, Volkswagen and AUDI consider to use high amount of polymers and polymer composites in the new generation of the cars to reduce the weight and fuel consumption. Therefore, new joining technologies should be used to be able to join such multi-material structures. Friction Spot Joining has already attracted a lot of attention from automotive industry due its advantages such as high mechanical strength of the joints, no need of filler materials, short joining cycles and being an environmentally friendly technique. The technology recently won the “German High Tech Champions 2013 in Lightweight Design” awarded by the German Federal Ministry of Education and Research (BMBF) in Tokyo, Japan[1].

[1] http://www.research-in-germany.de/dachportal/en/Campaigns-and-Activities/GHTC-Award/2013-Lightweight-Design/Amancio.html

Helmholtz-Zentrum Geesthacht • Max-Planck-Straße 1 • 21502 Geesthacht • Phone +49 (0)4152 87-2038 • Fax +49 (0)4152 87-2033 • www.hzg.de
Contact: MEng. Seyed M. Goushegir •Email: seyed.goushegir@hzg.de