

Ultrasonic Joining (U-Joining)

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Ultrasonic joining (U-Joining) is a new direct assembly technique developed by Helmholtz-Zentrum Geesthacht (patent application EU 15163163.7). U-Joining uses ultrasonic energy to join fiber-reinforced thermoplastics to surface-structured metallic parts produced, for instance by metal injection molding (HZG's patent EP 2 468 436 B1). Ultrasonic vibration and pressure create frictional heat at the materials interface, which softens the composite matrix and allows the reinforcement (structured on the surface of the metallic part) to penetrate the composite. As a result, a metal-composite hybrid joint with improved out-of-plane strength is achieved.

Principles of the technique

The U-Joining process can be divided schematically into five steps (Figure 1). In the first step, the parts are fixed between the sonotrode and the anvil, with the MIM-structured elements (pins) touching the composite surface (Figure 1-1). Next, the sonotrode moves down and applies a clamping pressure, while ultrasonic vibration (in this example by back-and-forth motion parallel to the contact surface) begins (Figure 1-2). This vibrational motion is transmitted to the interface, which combined with the joining pressure (applied pneumatically and perpendicular to the contact surface) produces frictional heat that locally softens the polymer matrix. Then, pins are inserted into the composite (Figure 1-3). After the pins are completely inserted, the metallic surface is wetted by the molten polymer and the sonotrode vibration stops (Figure 1-4). At this point a consolidation pressure can be applied to compensate for any shrinkage of the polymer matrix. Finally, the sonotrode is retracted from the now joined hybrid joint (Figure 1-5).

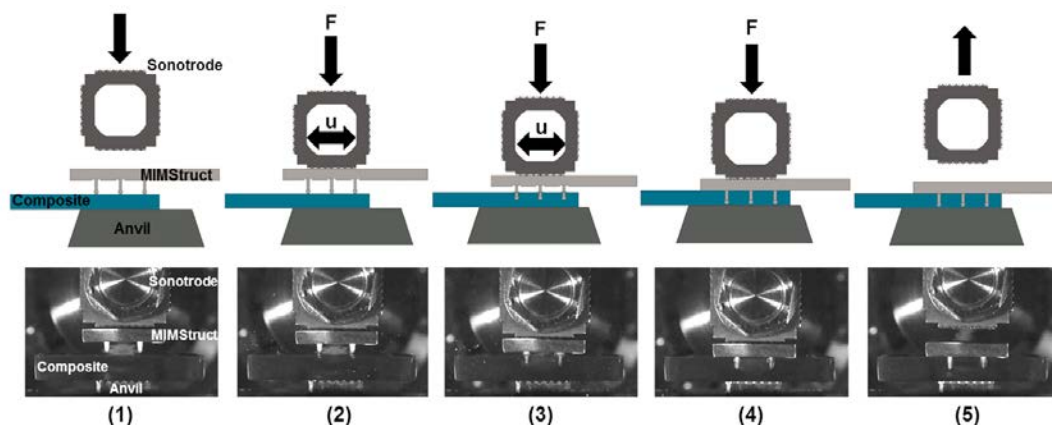
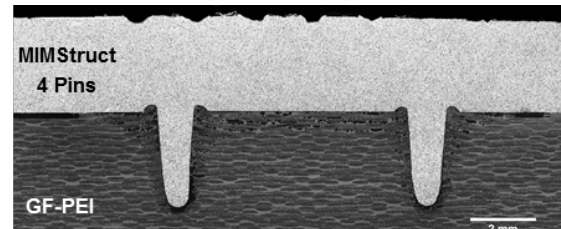


Figure 1: Schematic representation of the U-Joining process. (1) Positioning of joining parts, (2) application of ultrasonic vibration and axial force, (3) softening of polymer by frictional heat at the interface and onset of pin insertion, (4) polymer consolidation and (5) end of the process and sonotrode retraction.

Ultrasonic joints are strongly held by a combination of mechanical interlocking (due to the reinforcement elements) and adhesion forces created at the interface metal-composite after the consolidation of the molten polymer layer. A typical microstructure of ultrasonically joined Ti-6Al-4V/GF-PEI hybrid joints is presented in Figure 2. Apart from the positive gain in terms of mechanical properties, the use of ultrasonic energy induces a very efficient transformation of mechanical work into thermal energy resulting in a very fast joining cycle (usually less than 2 s).



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Figure 2: Cross-sectional view of a ultrasonically joined Ti-6Al-4V/GF-PEI joint.

Equipment

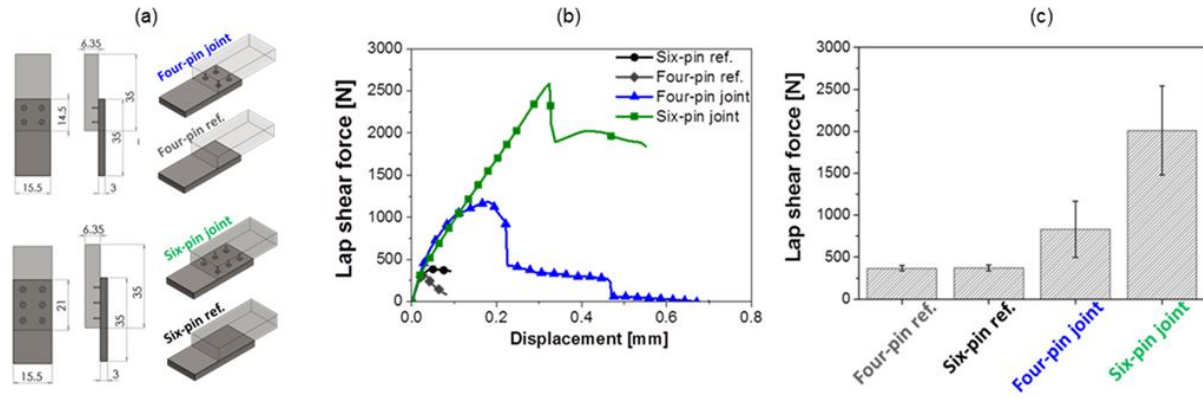
The development of U-Joining has been conducted in a commercially available Ultraweld L20 metal welder from Branson Ultrasonics (Figure 3). This joining system allows the process to be controlled by time, displacement or energy. When the latter is selected, joining energy, amplitude of sonotrode oscillation, clamping force and joining power are the adjustable process parameters. The frequency of sonotrode oscillation is fixed at 20kHz, the joining power can be increase up to 4.0kW and the sonotrode amplitude can be adjusted between 5 – 52 μm . Moreover, the joining system integrates sensors for monitoring of power and sonotrode displacement.



Figure 3: Ultraweld L20 metal welder from Branson Ultrasonics

Mechanical performance

Preliminary mechanical assessment of the ultrasonically joined hybrid joints was performed for Ti-6Al-4V/GF-PEI hybrid joints. Figure 4 (a) shows the specimen geometry and Figure 4 (b) the lap shear mechanical performance of U-joints. Force-displacement curves (Figure. 4 (b)) clearly demonstrate that the through-the-thickness reinforcement increases the quasi-static strength and ductility of the joints in comparison to the non-reinforced reference joints. Moreover, the increase in the number of reinforcement elements positively influenced the mechanical performance of the joint (Figure 4 (c)).



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Figure 4: Geometry of the lap-shear specimens (a), force-displacement curves for the best results for pin-less reference, four- and six-pin joints (b) and, average ultimate lap shear force for each type of joint (c).

Potential applications

Structures designed for applications in the transport sector require high damage-tolerant and crash-resistant metal-composite joints. Therefore, the U-Joining concept offers an extremely wide field of potential applications. The examples presented in Figure 5 comprise potential applications in body-in-white structures in the automotive sector, such as local reinforcement of metallic structures with composite elements to increase crash worthiness (e.g. hybrid metal-composite B-columns, Figure 5 (a)). Other examples are envisaged for primary aircraft structures (Figure 5 (b)), as well as metallic connectors in construction or repair of fiber-reinforced polymer structures applied in lightweight roofs and façades (Figure 5 (c)).

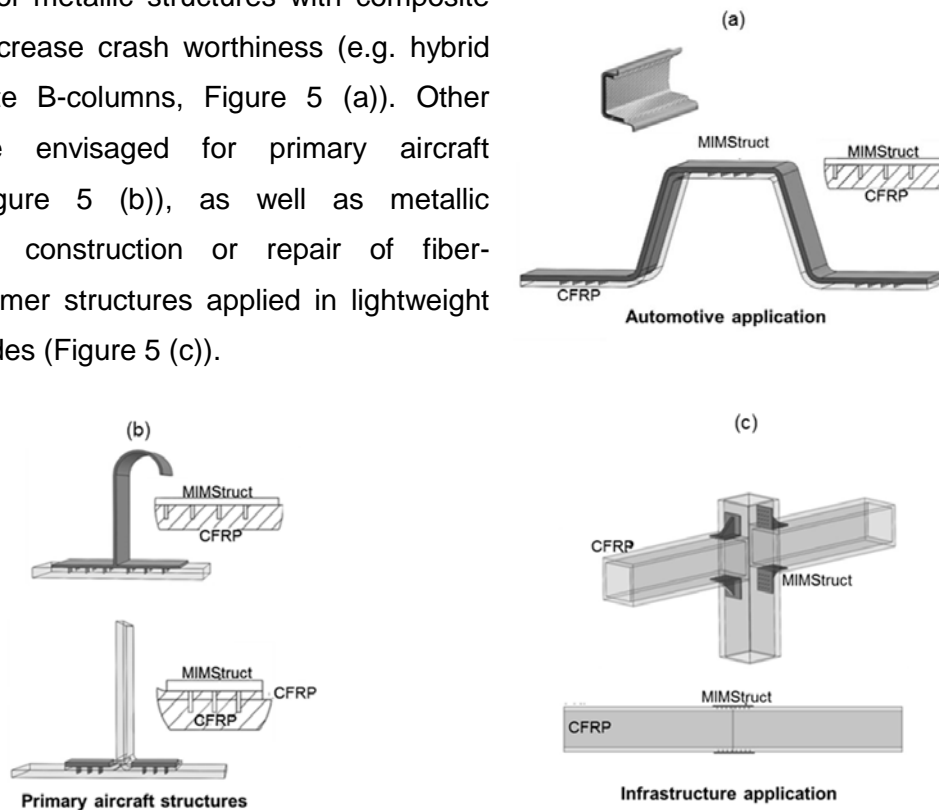


Figure 5: Potential application for the U-Joining are found in the automotive, aerospace and infrastructure sectors.