Visualization study on dissimilar Friction Stir Welding (FSW) technology for lightweight structural manufacturing

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Abstract

Dissimilar friction stir welding has gained significant attention in the manufacturing industry. Simulation modelling for in-depth understanding of heat generation, thermal conduction and material flow in dissimilar FSW is of paramount importance. The authors have sequentially undertaken studies on the FSW of Al alloy/CFRTP and Al alloy/high-strength steel. Numerical simulation techniques are employed to elucidate the underlying interaction between joint formation, microstructure and mechanical property in dissimilar FSW.

Background & Results

FSW is a revolutionary green manufacturing technology that finds extensive applications in lightweight structural manufacturing. High quality joining of dissimilar materials through FSW strongly depends on interfacial macro-/micro-structures. However, how the underlying thermo-mechanical processes affect them and how they can be controlled remains unclear.

For pin-less friction spot joining of silane-treated Al alloy and CFRTP (Figure 1), authors recently investigated the feasibility of tool modification to enhance joint strength [1], compared the interfacial structures and strength of joints manufactured using 3 different tools. In the case of the flat tool, a significant reduction in shear strength occurred due to the extensive formation of micro-scale void defects. This issue was mitigated when using the concave-shaped and ring-shaped tools, as they allowed effective control of heat generation distribution, resulting in more uniform temperature distribution and preventing defect occurrence. Therefore, authors recommend the use of the concave-shaped tool in the friction spot joining process for Al/CFRTP. It offers improved macro-mechanical interlocking, ensures sufficient chemical reactions, provides an effective joint area, and results in lower residual stresses, ultimately achieving the highest shear strength among the tools.

Concerning with Al/steel friction stir lap welding (Figure. 2) [2], authors discovered that material flow recirculated near the shoulder and pin, primarily originating from the advancing side of the Al and the retreating side of the steel. Increasing the rotational velocity intensified the overall material flow, resulting in increased migration on the steel side. At lower rotational velocities, insufficient steel migration around the pin was mainly responsible for the formation of micro-voids and non-bonding defects at the lap interface. At the bottom of the stirring pin, the steel migration flow was altered through shearing and squeezing, changing the dimensions of the hook-like structure and causing steel fragments near the interface. As the rotational speed increased, the peak temperature shifted from the Al-stirred zone to the steel-stirred zone. At high rotational speeds, the temperature at the bottom of the stirring pin approached the solidification temperature of the Al alloy. This led to the formation of a thicker intermetallic compound layer, significantly reducing the interfacial strength.

Significance of the research and Future perspective

By conducting fundamental experiments and utilizing numerical simulations to unveil the joining mechanisms and optimize process conditions, this technology can achieve high-quality joining between various dissimilar materials. The advancement of this technology will drive innovation in the future, particularly in the automotive, aerospace, and other industries, resulting in the creation of more competitive products.

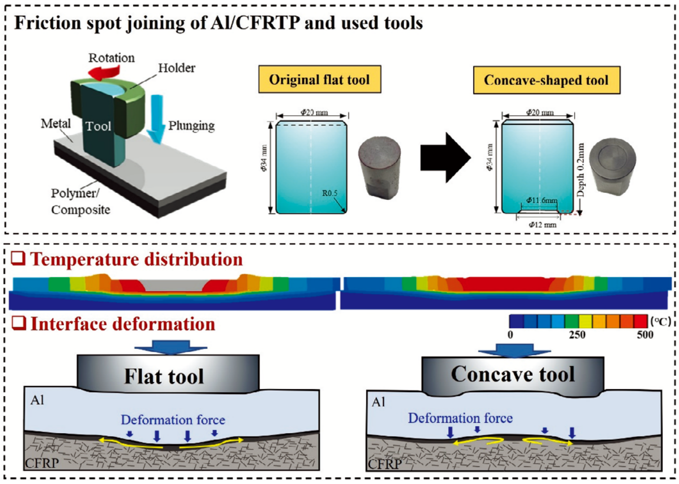

Figure 1 Friction spot joining of Al/CFRTP

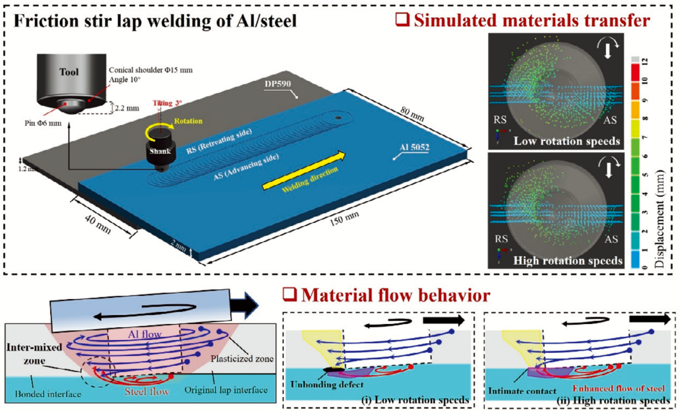

Figure 2 Friction stir lap welding of Al/steel

Patent	Japanese Patent Application No.2021-179991
Treatise	Geng, Peihao; Ma, Hong; Li, Weihao et al. Improving bonding strength of Al/CFRTP hybrid joint through modifying friction spot joining tools. Composites Part B: Engineering. 2023, 254, 110588. doi: 10.1016/j.compositesb.2023.110588 Geng, Peihao; Ma, Yunwu; Ma, Ninshu et al. Effects of rotation tool-induced heat and material flow behaviour on friction stir lapped Al/steel joint formation and resultant microstructure. International Journal of Machine Tools and Manufacture. 2022, 174, 103858. doi: 10.1016/j.ijmachtools.2022.103858
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