Hybrid joining process to FRP and metallic thin sheets for ultra lightweight applications

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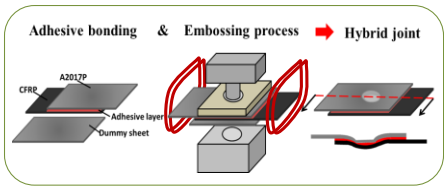
Introduction and Background

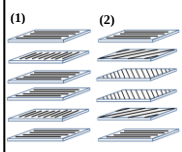
High specific stiffness and strength combined with excellent corrosion resistance of continuous thermosetting fiber-reinforced plastics (FRPs) lead to their widespread applications in aerospace, automotive and marine industries. Joining FRPs with lightweight metals could increase the weight-to-strength structural performance, overcome the drawbacks of FRPs and reduce overall fabrication cost. However, reducing the thicknesses of components for lightweight products makes FRP-to-metal joining a greater challenge. Mechanical fastening, welding and adhesive bonding are three conventional joining techniques for FRP-metal hybrid components. However, bolts and rivets would unavoidably damage the continuous fibers, resulting in stress concentration on joints and the short lifetime of the drill. Furthermore, FRP and metallic thin sheets (less than 1.0-mm-thick) are more susceptible to gentle ply drop-off and bolt/rivet countersinking. The ultrasonic and laser welding methods were utilized for joining a thin thermoplastic FRP sheet to a metallic sheet but not for joining a thermosetting FRP sheet. Adhesive connections are simple to use, weight-effective and capable of uniform load transfer. The high feasibility for thin sheets makes adhesive bonding suitable for ultra lightweight hybrid structures.

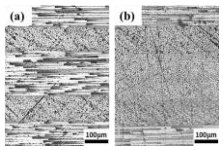
In our study, warm embossing process conducted in air rather than in an autoclave, instead of bolts or rivets, was applied to improve the single-lap adhesive bonding quality for thermosetting FRP and A2017P-T3 thin sheets for the first time. In our study, the effects of a dummy sheet, the relative position of the bonded specimen and the dummy sheet as well as the embossing parameters on the hybrid joining quality were investigated. The applicability of the proposed hybrid joining process to five FRP composites with different ply laminates and different types of fiber and polymeric matrix were also examined. Optical microscopy, SEM observation, tensile shear test and peel test were utilized to evaluate the performance of the adhesive–embossing hybrid joints. The mechanisms underlying the improved joining quality and negative effects of the embossing processes on the mechanical properties of FRP sheets were also discussed. We have verified that adhesive–embossing hybrid joining process which exhibits remarkable superiorities in terms of tensile shear load, displacement and absorption energy is a competitive joining method for ultra lightweight thermosetting FRP-metal hybrid structures.



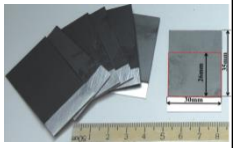
Experiment Procedure

Manufactured A-type and B-type CFRP sheets

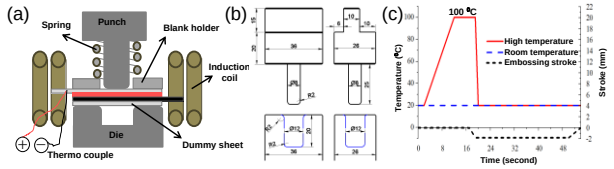




A2017P-CFRP adhesively bonded specimens



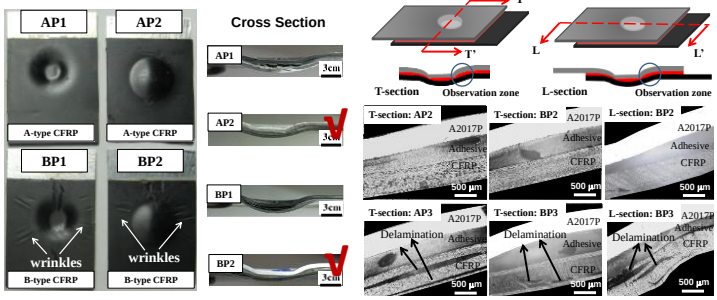
Warm Embossing Process, experimental setup and conditions



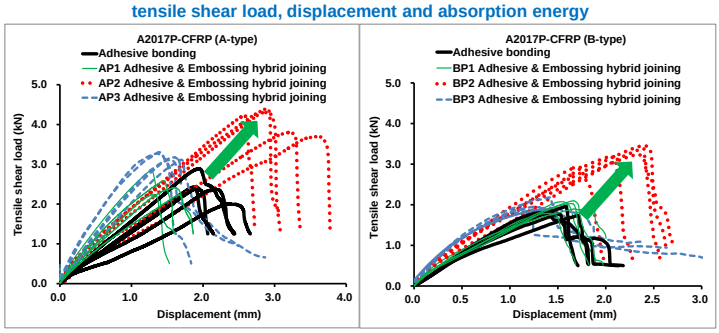
Six embossing sets: AP1, AP2 and AP3 using A-type CFRP; BP1, BP2 and BP3 using B-type CFRP.

Result and Discussion

Cross-sectional observation shows that AP2 and BP2 are two optimal hybrid joints.

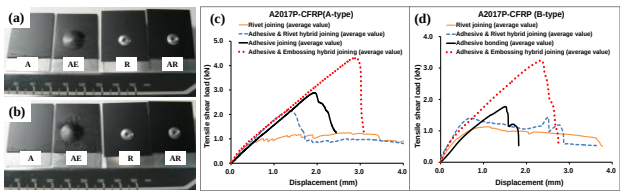


AP2 and BP3 hybrid joints exhibit remarkable superiorities in terms of tensile shear load, displacement and absorption energy

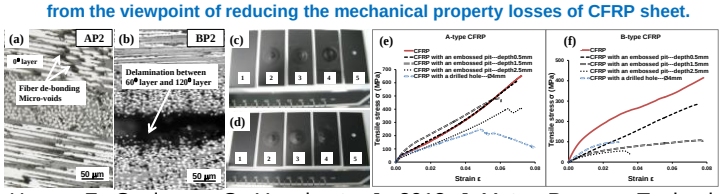


Compare with adhesive-rivet hybrid joining method

Adhesive-embossing hybrid bonding method is superior in terms of tensile shear load and displacement to adhesive-rivet hybrid joining.



The proposed hybrid joining method displays obvious advantages over rivet bonding from the viewpoint of reducing the mechanical property losses of CFRP sheet.



Improvement mechanisms:

mechanical anchor effect of the embossed pit, expanded adhesive area, adhesive concentration at the edge of the pit and the heating procedure, which has been experimentally verified by Huang et al. (2013).

Huang, Z., Sugiyama, S., Yangimoto, J., 2013. J. Mater. Process. Technol. 213, 1864-1874.