Mechanical Performance of Prefabricated Hybrid Joints

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ABSTRACT

The mechanical performance of prefabricated hybrid joints, a novel concept which is manufactured by free forming of titanium, including protruding pins that are entangled within the composite reinforcement, are evaluated within this study. The metal part and reinforcement are vacuum infused in a single step so that both the composite part and the joint are manufactured simultaneously. The titanium part is free formed using Electron Beam Melting (EBM®) method, an additive manufacturing technology, unlike conventional machining processes where material is removed. The EBM® method gives geometrical freedom to designers, which enables building of complex metal structures without any manufacturing constraints, creating a unique combination of mechanical and chemical adhesion, increasing the joint strength. Preliminary finite element analyses (FEA) of such joints have shown that there is a smooth transition of stress in the prefabricated hybrid joints compared to a standard adhesively bonded lap shear joint. Experimental testing of these joints indicate approximately a fourfold increase in failure stress compared to standard joints.

Addition of carbon nanotubes (CNT) to enhance both composite and joint strength is another focus area of this paper. Chemical bonds formed between nanotube and resin is an effective way to translate the superior properties of nanotube to composites. Moreover, the presence of nanotube enhances the adhesion of fibres to the resin increasing the toughness of the composite.

Electrophoretic deposition (EPD) technique is used to incorporate CNT in both the adherent and reinforcement. EPD is an inexpensive process which ensures uniform coating of CNTs on carbon fabric reinforcement with good microstructure homogeneity. EPD is also conducive for scaling up to large dimensions. Preliminary testing shows that composites made from these CNT coated reinforcement shows 37% improvement in interlaminar shear strength. EPD parameters were optimized for the chosen carbon fabric reinforcement and CNT type. The EPD parameters optimized were sonication conditions to disperse CNTs in water, concentration of CNT, voltage, distance between electrodes and deposition time.

Combining prefabricated hybrid joint approach and EPD technique to improve the mechanical performance of the joint is one of the main aims of this paper. In order to optimise the performance of such joints it is important to be able to model the joint response for different pin configurations and geometries.

During manufacturing of joints, pushing the reinforcement onto the titanium pins for entanglement results in fibre damage. The extent of damage depends on geometrical features like diameter and spacing between the pins. Manufacturing trials have been conducted to find out which pin configurations and geometries suggested by modelling are amenable for fabric layup. Based on design

optimization and manufacturing trials, the arrangement of pins and spacing are decided for joint geometries for different load cases. Surface treatment is a necessary requirement for a strong and durable adhesive joint between different substrates like metal and composite. Sodium hydroxide anodization (SHA) is chosen as an appropriate surface treatment based on literature survey and previous experimental work. Prefabricated hybrid joints for various load cases like tension, bending, pull off, fatigue and impact are manufactured. These joints are tested to assess their performance under different loading conditions. Existing testing standards are modified at appropriate places to accommodate prefabricated hybrid joint testing. The experimental results are used for modelling the response of joints.

The response of a prefabricated metal composite joint tested using a single-lap test configuration is predicted using nonlinear finite element analysis. While the co-curing of the composite parts on the metal adherend results in a stronger joint, it also implies that potentially large residual stresses are introduced in the composite during curing and that these stresses will impact the final structural performance of the joint. This means that in a structural analysis, the cure induced residual stresses have to be included. The importance of including curing simulation into the structural analysis chain of composite structures is highlighted.

The curing is simulated as a sequential coupled heat transfer analysis including cure kinetics followed by a residual stress analysis. The result from the heat transfer analysis is degree of cure and temperature as a function of time in the composite part of the joint. The material model in the residual stress analysis is a special form of a CHILE (Cure Hardening Instantaneously Linear Elastic) model which together with degree of cure and temperature predicts cure induced residual stress in the composite part.

The residual stresses from the cure analysis are then used as the starting point for the structural analysis, in which a progressive damage model is used. This model relies on the LaRC05 failure criteria to predict damage initiation, while damage growth is handled using continuum damage mechanics.

Mechanical performance of prefabricated hybrid joints are thus optimized from three perspectives, namely materials, manufacturing and modelling. An iterative and holistic approach is used to optimize the critical process parameters. A summary of guidelines for materials, manufacturing and modelling approaches is presented in this paper.