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An Advanced Numerical Tool for the Design of Through-Thickness Reinforced Composites for Electrical Applications

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Abstract : Fibre-reinforced polymer (FRP) composites have been extensively utilised in various industries due to their high specific strength, e.g., aerospace, renewable energy, automotive, and marine. However, they have relatively low electrical conductivity than metals, especially in the out-of-plane direction. Conductive metal strips or meshes are typically employed to protect composites when designing lightweight structures that may be subjected to lightning strikes, such as composite wings. Unfortunately, this approach downplays the lightweight advantages of FRP composites, thereby limiting their potential applications. Extensive studies have been undertaken to improve the electrical conductivity of FRP composites. The authors are amongst the pioneers who use through-thickness reinforcement (TTR) to tailor the electrical conductivity of composites. Compared to the conventional approaches using conductive fillers, the through-thickness reinforcement approach has been proven to be able to offer a much larger improvement to the through-thickness conductivity of composites. In this study, an advanced high-fidelity numerical modelling strategy is presented to investigate the effects of through-thickness reinforcement on both the in-plane and out-of-plane electrical conductivities of FRP composites. The critical micro-structural features of through-thickness reinforced composites incorporated in the modelling framework are 1) the fibre waviness formed due to TTR insertion; 2) the resin-rich pockets formed due to resin flow in the curing process following TTR insertion; 3) the fibre crimp, i.e., fibre distortion in the thickness direction of composites caused by TTR insertion forces. In addition, each interlaminar interface is described separately. An IMA/M21 composite laminate with a quasi-isotropic stacking sequence is employed to calibrate and verify the modelling framework. The modelling results agree well with experimental measurements for bothering in-plane and out-plane conductivities. It has been found that the presence of conductive TTR can increase the out-of-plane conductivity by around one order, but there is less improvement in the in-plane conductivity, even at the TTR areal density of 0.1%. This numerical tool provides valuable references as a design tool for through-thickness reinforced composites when exploring their electrical applications. Parametric studies are undertaken using the numerical tool to investigate critical parameters that affect the electrical conductivities of composites, including TTR material, TTR areal density, stacking sequence, and interlaminar conductivity. Suggestions regarding the design of electrical through-thickness reinforced composites are derived from the numerical modelling campaign.

Keywords : composite structures, design, electrical conductivity, numerical modelling, through-thickness reinforcement
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