Time-temperature dependent adhesive tack and contact area development between prepreg carbon fibre tape and rigid substrate

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Automated material placement (AMP) processes to manufacture large composite components employ robotic equipment with thermosetting resin-impregnated fabrics, known as prepregs, to deposit layers of tape on a tool to form a laminate prior to curing. In order to minimise defect formation such as tow pull-up during AMP, sufficient levels of adhesion, or tack, are required between the prepreg and the tool and between the prepreg layers. Tack is controlled through the AMP parameters, including temperature, deposition speed and compaction pressure.

Crossley et al. developed a test fixture to measure tack with an application-and-peel method for prepregs at a range of temperatures and deposition/peel rates [1]. This method differs from other tack tests in that the prepreg is bonded to the substrate and peeled from it in a single continuous motion, replicating the AMP process with short timescales for tape application and bonding. Prepreg tack is dictated by both the adhesion of the prepreg to the substrate and the cohesive strength of the resin. Adhesive strength is influenced by the substrate surface properties and the contact area between the prepreg and the substrate. The contact area is determined by the viscoelastic resin response that depends on the temperature, application pressure and duration of pressure application. The time-temperature superposition principle (TTS) is used to describe polymer viscoelastic behaviour over extended timescales. TTS parameters obtained from the resin rheological properties are applied to the tack data to construct a bell-shaped mastercurve of tack as a function of the peel rate at a reference temperature [2]. This facilitates estimation of tack levels at deposition rates representative of the AMP process.

In this work, contact area (prepreg-glass substrate) and tack (prepreg-metal substrate) were measured at matching combinations of temperature and feed/peel rate. Using a single set of TTS parameters obtained directly from the prepreg it was possible to construct both the tack and the contact area mastercurves as a function of the shifted rate. While tack peaks at a particular value of shifted rate, contact area starts close to full coverage (100%) at low reduced rate and decreases with increasing shifted rate. It was found that the contact area at the rate corresponding to peak tack is considerably less than 100%. This suggests that during AMP the maximum tack is achieved at a reduced contact area, despite the potential to achieve full intimate contact. Hence, the strategy to reduce defect formation should not focus on maximising the contact area between prepreg and tool.

References

[1] R.J. Crossley, P.J. Schubel and N.A. Warrior. Experimental determination and control of prepreg tack for automated manufacture. Composites Part A: Applied Science and Manufacturing (2012), 43:423–434

[2] R.J. Crossley, P.J. Schubel and D.S.A. De Focatiis. Time-temperature equivalence in the tack and dynamic stiffness of polymer prepreg and its application to automated composites manufacturing. Composites Part A: Applied Science and Manufacturing (2013), 52:126-133