Quality Improvement by Vibrations in Composite Materials Production

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Introduction

This study deals with the effect of mechanical vibrations applied to the curing system of composite materials production, particularly on minimizing void content. ANUQS machine provided vibration-assisted curing at elevated temperatures, along with vacuum, and produced composite laminates with low void content. Range of frequency of vibrations covered was from 2Hz to 8kHz. The laminates were made by hand lay-up using glass fibres and epoxy resin, and examined under microscope to determine types and quantity of defects. Mechanical testing (flexural, tensile and shear), water absorption (7 days @ 45C) and CT scan (3D porosity images) are used for quality characterization of laminates.

Experiments

- ANUQS machine

Theory

- Gas bubble in liquid
  \[ r^* = \frac{2\gamma}{\Delta p} = \frac{2\gamma}{p_i - p_e} \]
- Vibrations
  \[ \sim p_e = \frac{2\gamma}{r} \]
- Pressure fluctuations
  \[ P_g - \rho gh + P_a + P_{vibr} = \frac{2\gamma}{r} \]
- 
  \[ \Delta P > \frac{2\gamma}{r} \Rightarrow \text{Expansion} \]
  \[ \Delta P < \frac{2\gamma}{r} \Rightarrow \text{Collapse} \]
- Buoyancy
  \[ V_B = \frac{2}{9} r^2 g\Delta \rho \]
- Dissipation of work heat
  \[ \Delta T = \frac{W_d}{\rho c_p} \eta \]
- Viscosity
  \[ \eta = \eta_0 \exp\left(\frac{Q}{RT}\right) \]
- Diffusion
  \[ \langle p[R(t)] \rangle_t > p_0 c_\infty / c_0 \Rightarrow \text{Shrinkage} \]
  \[ \langle p[R(t)] \rangle_t < p_0 c_\infty / c_0 \Rightarrow \text{Growth} \]
- Bjerknes forces (2 bubbles)
  \[ F_B = -\langle V(t) \nabla p(t) \rangle_t \]

Results

- Void content, glass-epoxy laminates

- Flexural test before water absorption
- Flexural test after water absorption
- Water absorption after 7 days at 45C

Conclusions

Low frequency (2-50Hz) vibrations-assisted curing improves quality of composite materials, in terms of mechanical properties and void content reduction.