Development of a Concept Out-of-Autoclave Carbon Fibre Reinforced Polymer Part-Manufacturing Process

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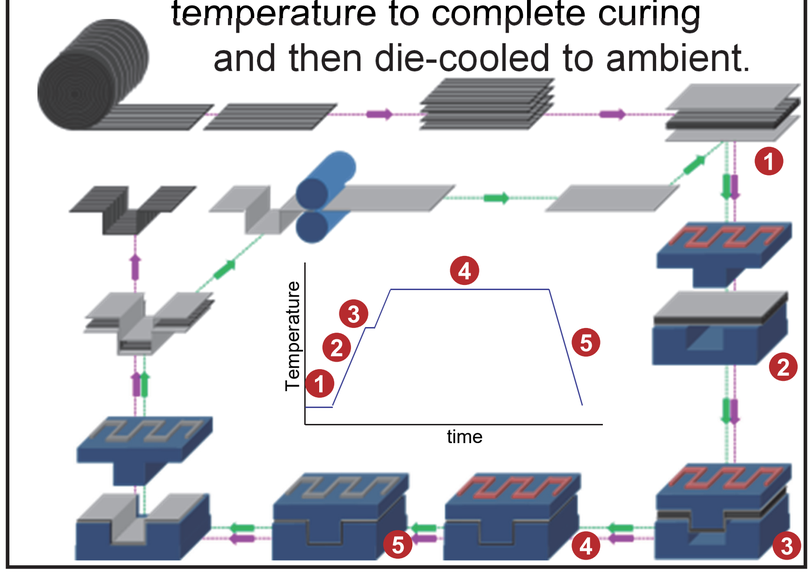
1. Introduction

Carbon Fibre Reinforced (thermoset) Polymer (CFRP) has become an illustrious structural material in lightweight automotive engineering over the past 40 years. However, the high-cost and environmental implications of traditional autoclave-based CFRP part-manufacturing have limited application to niche-market vehicles such as supercars, racing cars and racing motorcycles. The Out-of-Autoclave Resin Transfer Moulding (RTM) process developed by BMW, used extensively in manufacturing the BMW i3 production car and BMW S1000RR HP4 Race production motorcycle, illustrates the desire within the automotive industry to reduce cost of CFRP part-manufacturing and direct application towards high-volume production vehicles. However, the RTM process is still costly and environmentally unsustainable compared to traditional sheet metal forming processes. Thus, further development of Out-of-Autoclave CFRP part-manufacturing processes is in high-demand.

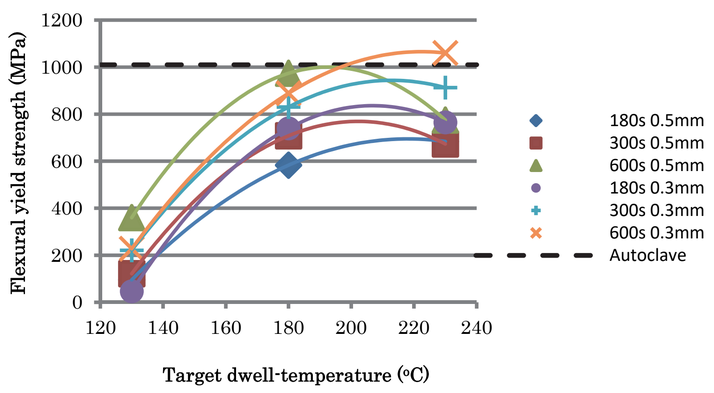
2. Concept Process

Prepreg plies are laid-up, sandwiched between dummy metallic sheets, induction-heated to the intermediate forming-temperature, hot formed, induction-heated to the dwell-temperature, held under tool-pressure at the dwell-temperature to complete curing and then die-cooled to ambient.



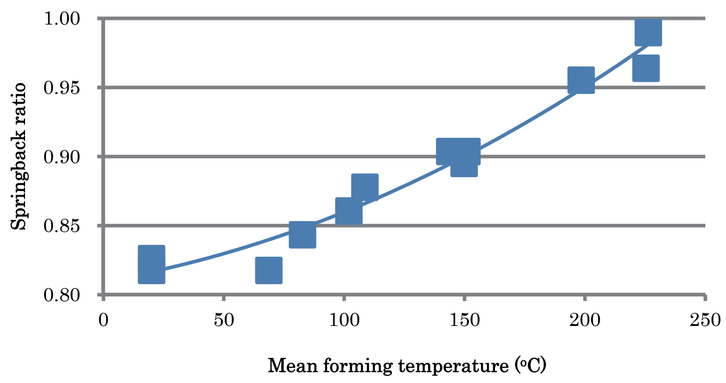
3. Dwell-Temperature & Time

Flexural properties approach those of benchmark parts produced via the autoclave. Small difference in properties given dwell-temperature of 180 or 230 °C; and given dwell-time of 180, 300 or 600 s at dwell-temperature of 230 °C. Low process sensitivity and opportunity to reduce dwell-temperature and dwell-time for increased process efficiency.



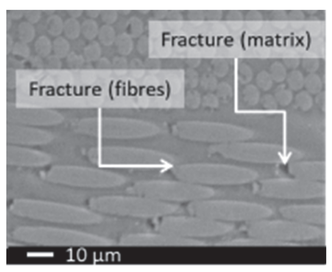
4. Forming Temperature

Progressive decrease in springback with increased forming temperature. Attributed to reduction of interfacial shear strength between matrix and fibres enabling fibres to undergo more plastic yielding and decrease the elastic to plastic ratio. Higher forming temperature also reduces oozing of resin due to increase in viscosity, promoting dimensional control.

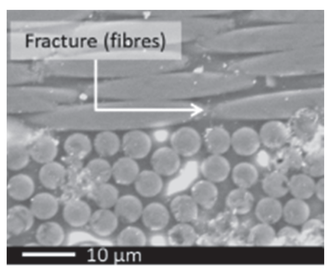


5. Multi-Stroke Forming & Rate

Matrix-fracture significantly reduced by three-stroke forming combined with lower stroke-displacement rate, enhancing formability. Attributed to lower viscosity of resin and enhancement of inter-ply slip placing lower shear stresses on matrix at lower strain-rates; and recovery of elastic strain between each stroke.



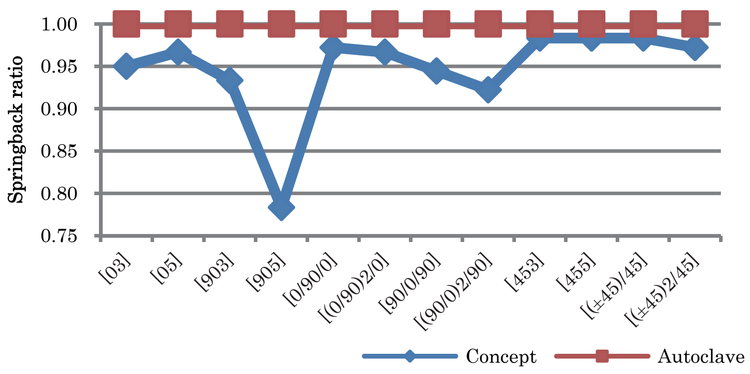
2-strokes, 641 mm/s



3-strokes, 32 mm/s

6. Laminate Configuration

Configurations with fibres orientated at ±45 ° to bending crease the least susceptible to springback and closest to autoclave-parts. Attributed to maximum in-plane shear stress occurring at ±45 ° encouraging free inter-ply slip, minimising residual stress accumulation.



7. Manufacture of Crash-Box

Compressive crash-box testing conducted with displacement rates of 1, 10 and 100 mm/s to a maximum displacement of 25 mm. Specific energy absorption and crush force efficiency of CFRP parts higher than reference aluminium alloy parts across all displacement rates.

8. Conclusions

- Capable of producing high-quality parts.
- Potential for reduced cost compared to current processes.
- Parameters optimised for formability, springback and formed part mechanical properties.
- Applicability of process demonstrated by manufacture of a simulated automotive crash-box.

9. On-Going Research

Integration of CFRP part-manufacturing process with hot sheet metal forming process for metal-CFRP hybrid parts via an integrated hot forming, joining and curing process.