Validation of a New Modelling Framework for TSA of CFRP Components

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Abstract. A significant challenge exists in the application of TSA to CFRP components, as it has been shown the stress induced temperature change resulting from the thermoelastic effect, is heavily influenced by heat transfer. The conclusion may be that quantitative TSA on laminated CFRP component is not possible. Both in-plane and through the thickness heat conduction occurs, which is driven by the stress gradients in a structural component. The through thickness thermal conduction occurs in multidirectional laminates mainly because of the step changes in the stresses at the ply interfaces. The conduction is dependent on the ply thickness, the ply orientation, the paint coating thickness and the thickness of the resin rich surface layer (RRL) resulting from the manufacturing process. Even in unidirectional (UD) CFRP materials the paint and the RRL have a significant effect on the response. In components where there are geometrical changes and/or features such as holes and ply drops, additional in-plane conduction occurs because of the stress gradient, but more importantly the stress concentration can change the direction of the through thickness heat transfer locally. It is well understood that cyclic loading at a sufficiently high frequencies minimises heat transfer; for most materials and geometries adiabatic conditions can be achieved at around 15 Hz. However, because of the large degree of anisotropy in both the thermal and mechanical properties of CFRP adiabatic conditions are elusive at achievable loading frequencies.

A finite element modelling framework has been developed that enables quantitative interpretation of Thermoelastic Stress Analysis (TSA) to be carried out on laminated carbon fibre reinforced polymer (CFRP) components [1]. A step-by-step validation procedure has been developed [2], summarised in Figure 1, which shows the experimental inputs required for the model. 72 experimental cases are used to validate the model; these are summarised in Table 1. In the validation procedure both TSA and DIC were conducted on IM7/8552 coupon specimens made in multidirectional lay-ups.

The application of the validated modelling framework is essential to be able to interpretate the thermoelastic response. To demonstrate the utility of the modelling framework, practical applications are presented. It is shown that even for cases where material properties were estimated the model aids in identifying appropriate loading frequencies to obtain a quantitative stress metric.

References

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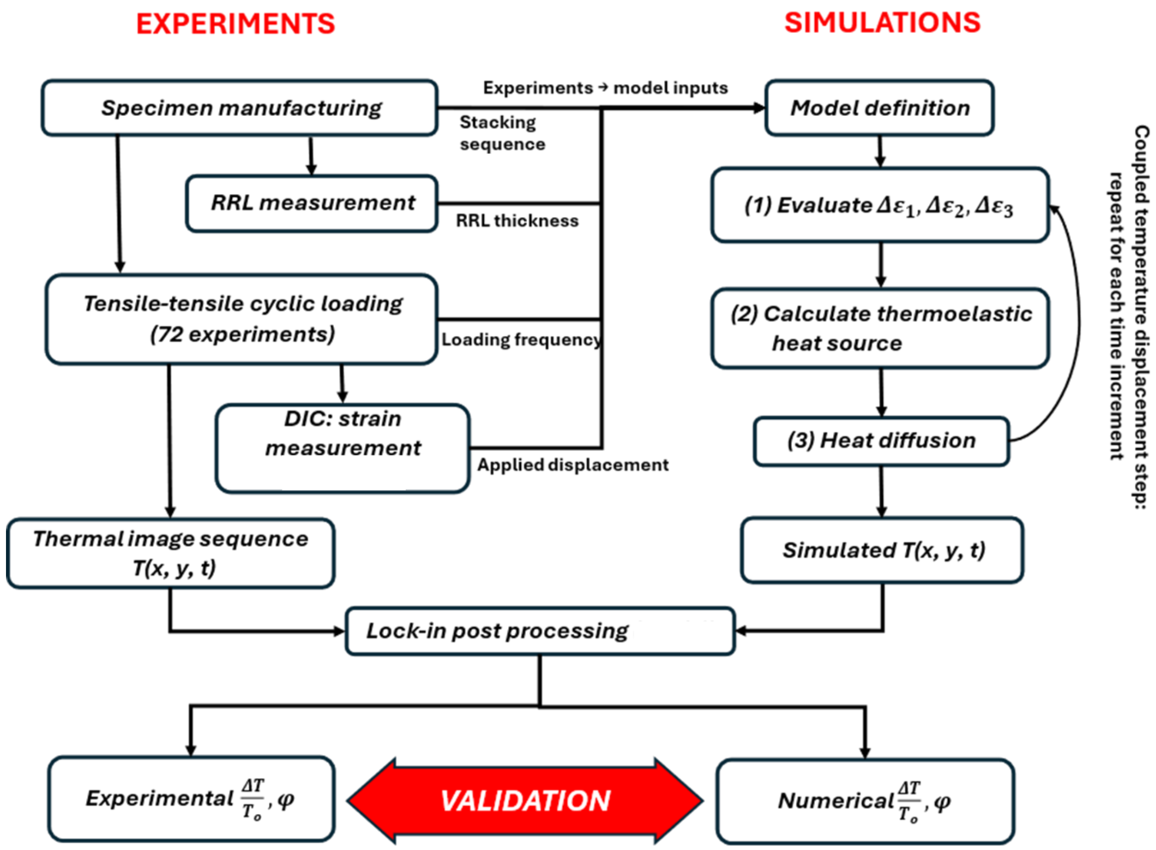

Figure 1 Schematic of modelling procedure

Table 1 Validation cases for the model

Layup	Cyclic Stress [MPa]	Strain amplitude [με]	Loading frequencies [Hz]	RRL thickness [mm]
$[0/90]_{3s}$	104.78 ± 89.06	1750	1.1, 3.1, 5.1, 7.1, 10.1, 12.1, 15.1, 20.1, 22.1,25.1, 27.1, 30.1	1.73 ± 1.10
$[90/0]_{3s}$	94.30 ± 81.20	1590		1.73 ± 1.10
$[\pm45]_{3s}$	52.39 ± 39.29	4250		1.49 ± 1.32
$[0/0/0/45/-45/0]_s$	123.46 ± 111.11	2050	0.5, 1.1, 2.1, 3.1, 4.1, 5.1, 6.1,7.1,8.1,9.1,10.1, 12.1, 15.1, 17.1, 20.1, 22.1,25.1, 27.1, 30.1	37.88 ± 4.48
$[0/45/-45/0/0/0]_s$	123.46 ± 111.11	2050		17.70 ± 6.88