FAILURE OF LOAD-CARRYING POLYMER COMPOSITES IN FIRE

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ABSTRACT

Fibreglass composite materials are used extensively in the boat and leisure craft industry and are increasingly being used by navies in patrol boats, mine hunting vessels, and large warship structures. In all these applications, flammability is possibly the greatest single factor hindering the wider use of these materials and their applications [1]. Furthermore, the stability, stiffness and strength can be reduced by thermal softening of the matrix, which is due to the onset of the glass transition in the case of thermosetting matrices. While researchers have investigated the composite post fire characteristics [2], little work has been done to date on establishing their properties during the fire event.

Detailed experimental testing is required to predict the degradation of the tension and compression strengths of fibreglass composites during one-sided fire/heat exposure. Time-to-failure predictions require knowledge of the through-thickness temperature profile and the dependence of the mechanical properties on temperature, as well as the failure mechanisms involved.

Temperature profiles were measured by inserting thermocouples into the composite, and the temperature profile was predicted accurately for different heat fluxes using COMFIRE, a program developed by the University of Newcastle. Material properties such as thermal conductivity, specific heat and heat of decomposition are required as input parameters and have been measured for vinyl ester and phenolic resins. The degradation behaviour of the resins was measured with TGA under different atmospheres and heating rates. The kinetic parameters for the mass loss, the activation energy and rate factor, were obtained with a multi-branch least squares fit assuming a first-order Arrhenius equation.

Structural parameters such as strength, modulus, Poisson’s ratio, and thermal expansion were measured under tension and compression for the vinyl ester and phenolic composite laminates for uniform temperatures up to 350°C. For compressive strength, the strength is assumed to further reduce during resin degradation above 350°C. For tensile strength, a further decrease is taken into account because of the glass strength reduction at temperatures up to 500°C. These data are required to predict the structural behaviour of laminates supporting a static tension or compression load exposed to a one-sided heat flux. Figure 1 shows the experimental test set-up for the fire under load testing. The applied temperatures range between 300 and 700°C for heat fluxes of 10 - 75kW/m². The time-to-failure is measured as a function of heat flux and applied load. The mechanical load was applied in fixed percentages of the room temperature failure load.

Both finite element modelling and analytical modelling using composite laminate theory are used to predict deformations and time-to-failure of the laminates. In-plane and out-of-plane deformations are caused by thermal expansion and are compared to the modelling results. The models furthermore investigate the predictions of residual and progressive strength analyses using the temperature-dependent mechanical properties of the material and its through-thickness-temperature profile.
The bulk residual strength is calculated by averaging the mechanical properties in the through-the-thickness direction, while progressive failure models investigate the use of different failure criteria depending on the loading conditions (e.g. buckling failure criteria for compression). The tests reveal that the models can predict the time-to-failure characteristics with good accuracy. Figure 2 shows exemplary results of the residual strength approach in predicting time-to-failure under compressive loading for glass/vinyl ester laminates at different heat fluxes. Further experimental work on sandwich materials and the phenolic resin laminates is currently being undertaken to validate the models for a wider range of composite materials.

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**REFERENCES**