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Fibre prestressed composites: Theoretical and numerical modelling of unidirectional and plain-weave fibre reinforcement forms

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A B S T R A C T

The objective of this study is to analyse the residual stresses induced in fibre prestressed composites. Both theoretical and numerical methods have been included in the analysis. Macro-mechanical approach of fibre reinforced composite has been developed to include the prestressing effect that suitable for analysing both unidirectional and plain-weave fabric composites. A new simplistic theoretical model was also derived to estimate residual stresses in composite constituents due to releasing the fibre pretension load. This model can be successfully used for composites reinforced by unidirectional fibres. Prestressed composites were modelled numerically in order to validate the theoretical results and estimate the full distribution of residual stresses within the composite constituent more precisely. Good agreement has been obtained between theoretical and numerical results. The results obtained in this study clearly showed that the level of induced residual stresses within the composite constituents depends not only on fibre pretention level, but also on the composite elastic properties.

1. Introduction

Recently, there has been a growing interest in the development and application of composite materials due to their influence on human life, whether it was civilian or military. Composite structures have been confirmed to have less weight and better performance when compared with conventional metallic constructions. Therefore, these materials are most common used in the field of aerospace. Unfortunately, designing and manufacturing of a composite part with improved mechanical performance is usually accompanied with additional cost requirements which is usually very critical parameter [1–3]. The method of fibre pretension could offer such improvements in the mechanical performance of composites without a considerable cost [4].

It is generally believed that when manufacturing of composite materials, residual stresses are generated [5–7]. These residual stresses can be developed in composite materials due to several reasons such as chemical shrinkage of a polymer matrix, different thermo-mechanical properties of the constitutions, humidity absorption, and fibre pretension [5,8]. Residual stresses within the matrix can arise due to phase change of the resin from liquid to solid state (chemical shrinkage). The mismatch in coefficient of thermal expansion between the fibre and the matrix will produce residual stresses in the composite when it cooled from its curing temperature [5,7–12]. Whereas, moisture absorption by the polymeric matrix and the fibre leading to deform and expand the constituents of the composite at different levels depending on the swelling permeability [7,13]. On the other hand, manufacturing process such as the filament winding fabrication technique can add another source of induced residual in the final composite product due to stretching the fibre during the fabrication processes [14–19].

The state of residual stresses in the composite constituents has a great impact on the composite structural performance. When the state of residual stresses within the matrix is tensile, the tensile strength of the composite is reduced considerably. However, compressive residual state of stresses in the matrix could play an important role in impeding the initiation of micro-cracks easily [4,5,20]. One method that can be used to improve the structural properties of fibre-reinforced composites is the method of fibre prestressing (pretension) [21,22]. In comparison with the successful usage of prestressed concrete in the field of civil engineering, application the same principal concept in polymeric matrix composites seems relatively recent and less convenient [4,20,23]. This method approved its ability to reduce the undesirable residual stresses induced by matrix chemical shrinkage and different thermo-mechanical properties of the composite constituents [8,24,25]. On the other side, this method provided a primary solution against fibre waviness during the fabrication process of the composite [8,22]. The method of fibre prestressing is performed by applying a tensile load in the fibre and maintain it along the matrix curing process. Once the matrix has been cured well, the pretension load is released. The elastic prestrain in the fibre tends to return to its origi-

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