Mechanically Fastened Joints in Composite Structures

Composite Engineer's Viewpoint
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Part 10 – Ply Configuration Effects

In this article we consider laminate configuration effects. Configuration effects are both the percentage of fibres in any one direction and the through the thickness placement of the plies. Both of these aspects require an understanding of the effects on structural performance of mechanically fastened joints in composite structures.

Ply orientation percentage effects have been considered on both mechanical property and stress concentration issues. Figures 1 and 2 both show the ply orientation variation effects on bearing and shear strength of specific laminate material. Clearly mechanical joint performance is impacted from ply configuration changes. Likewise the ply orientation percentages changes the stress concentration level for net tension stresses and bearing stresses as seen in Figure 3 and 4, respectively.

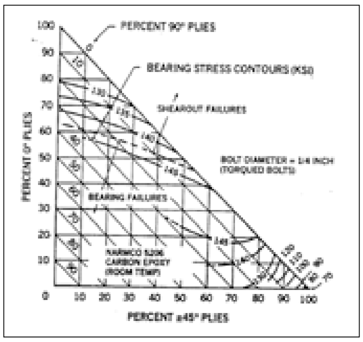

Figure 1: Bearing Strength with Ply Orientation Changes (Hart-Smith)

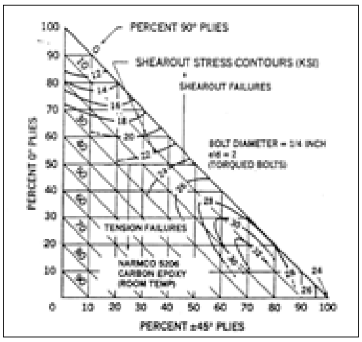

Figure 2: Shear Strength with Ply Orientation Changes (Hart-Smith)

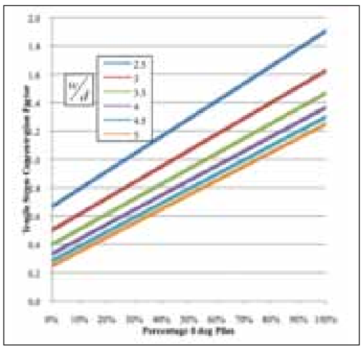

Figure 3: Tensile Stress Concentration Factors with Ply Orientation Changes

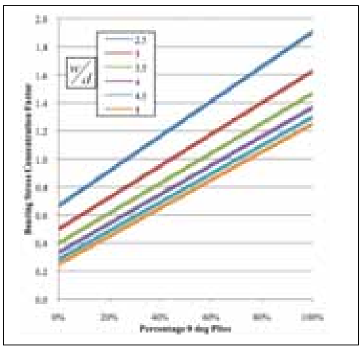

Figure 4: Bearing Stress Concentration Factors with Ply Orientation Changes

Ply stacking sequence has previously been shown to have an effect on the flexural rigidity. As seen in Figure 5 the fastener rests on the elastic bed of the laminate thickness. The positioning of stiffer plies towards the outside of the laminate will change the flexural support bed characteristic. Hence, the deformation and support of the fastener can be then modified by the bending stiffness parameter:

$$k_b = E_1^f / E_1^o$$

Where:
E_1^f – Effective flexural Young's Modulus
E_1^o – Effective flexural Young's Modulus

Changes in the ply configuration by varying the percentage of plies in the various directions not only influences the stress concentration factors, but also modifies the multi-row fastener first and subsequent ply load share. Figure 6 illustrates the relationship between the fastener bending stiffness (K_f) and laminate axial stiffness (K_{plate}) for a 3-row fastened joint. The values of the fastener stiffness and plate stiffness are as follows:

$$K_{plate} = \frac{EA}{L} \propto Et$$

$$K_f = \frac{1}{C}$$

Where: $$C = \frac{8}{t_{av} E_f} \left\{ A\left(\frac{t_{av}}{d}\right)^2 \left[B + \left(\frac{t_{av}}{d}\right)^2 \right] + H \right\}$$

The various parameters are explained in Nui.

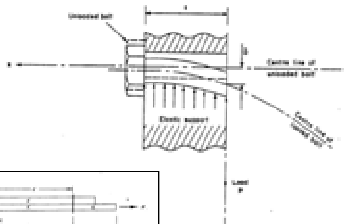

Figure 5: Fastener Bending on an Elastic Bed (Engineering Science Data Unit)

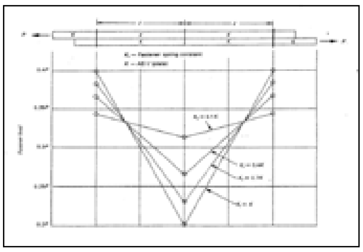

Figure 6: 3-Row Fastener Load Share with Varying Fastener Stiffness to Plate Stiffness Ratio (Michael Nui)

To view all articles in this series go to www.compositesaustralia.com.au. In the next article we discuss off-axis loading – because composite laminates are generally orthotropic, any loading off the material axis results in general orthotropic behaviour. This has significant implications for the laminate design with fasteners that are loaded off-axis. I welcome questions, comments and your point of view. I may publish your questions and comments, and my response in future newsletters.

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