Mechanically Fastened Joints in Composite Structures

Composite Engineer's Viewpoint by Rik Heslehurst PhD, MEng, BEng(Aero) FIEAust, FRAeS, CPEng

Part 2B – Bearing Strength, continued

In the last newsletter I commented on the bearing strength of composite laminates that considered the requirements of fibre form and the ply orientation. This discussion led to the understanding that bearing strength is influenced by angled fibre direction more than axial fibre direction. Further to the fibre direction issue is the ply (fibre) position through the thickness of the laminate. The position of the ply through the thickness influences the flexure stiffness of the laminate which in turn influences the bearing strength.

The axial stiffness or longitudinal Young's modulus of a laminate is determined by fibre direction. The derivation of the laminate in-plane stiffness is based on the percentage of the plies on the various directions. The simplest approach uses the 10% rule for the determination of the longitudinal modulus estimated:

$$\frac{E_{lam_1}}{E_0} = \left[P0 + 0.1\left(P45 + P90\right)\right]$$

$$\frac{E_{lam_1}}{E_0} = 0.9P0 + 0.1$$

Where: PX represents the ply percentage in the 0 or 90 or ±45 degree directions

E_{lam}/E_o is the Young's modulus ratio for the laminate to 0° ply

Flexural rigidity in isotropic materials (i.e. metals, plastics) is based on the Young's modulus and unit second moment of area, being:

$$D = \frac{Et^3}{12\left(1-\upsilon^2\right)}$$

However, the flexural rigidity of a composite structure is influenced by the position of the various plies and is determined from:

$$D_1 = \frac{1}{6}\sum_{k=1}^{n/2} Q_{1_k} z_k^3$$

where k = the k^{th} ply,

n = the total number of plies,

Q_1 = longitudinal ply stiffness, and

z = ply distance from the mid-plane

Thus the further the ply is placed towards the outer surface the more influence it has on the flexural rigidity of the laminate. For example, if a 8-ply quasi-isotropic graphite/epoxy laminate has one of the following ply configurations; [0/90/±45]s, [+45/0/-45/90]s, [±45/0/90]s, [±45/90/0]s, each laminate has a longitudinal Young's modulus of E_1^{o} = 55 GPa, but the equivalent Young's modulus for the flexural is; E_1^{f} = 87 GPa, E_1^{f} = 57 GPa, E_1^{f} = 37 GPa, and E_1^{f} = 28 GPa, respectively. By observation, whilst the in-plane longitudinal Young's modulus remains constant the equivalent longitudinal Young's modulus flexural is a function of the position of the 0 degree ply through the thickness of the laminate. This effect will impact bearing strength through fastener bending because of fastened flexibility (Figure 1). With stiffer fibres towards the outer surface of the laminate the bearing load will be greater due to flexural resistance improvement.

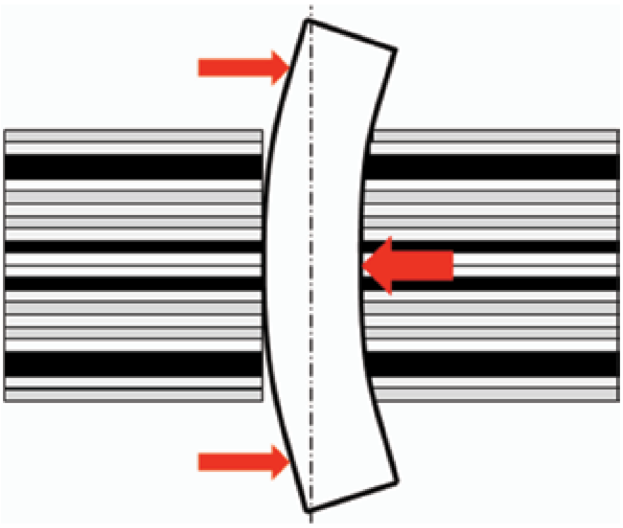

Figure 1: Fastener Bending and Ply Position.

An approach to the modification of the bearing strength and stiffness can be adjusted by using the laminate bending stiffness parameter k_b, which is the ratio of the equivalent longitudinal flexural Young's modulus to the longitudinal in-plane Young' modulus:

$$k_b = \frac{E_1^f}{E_1^o}$$

Thus for the example laminate configuration presented the laminate bending stiffness parameter k_b is 1.58, 1.04, 0.67 and 0.51 respectively. For the relatively thin laminate used in the example the effects of ply position variation are large, but with thicker laminates the variations in kb are generally between 1.25 and 0.8.