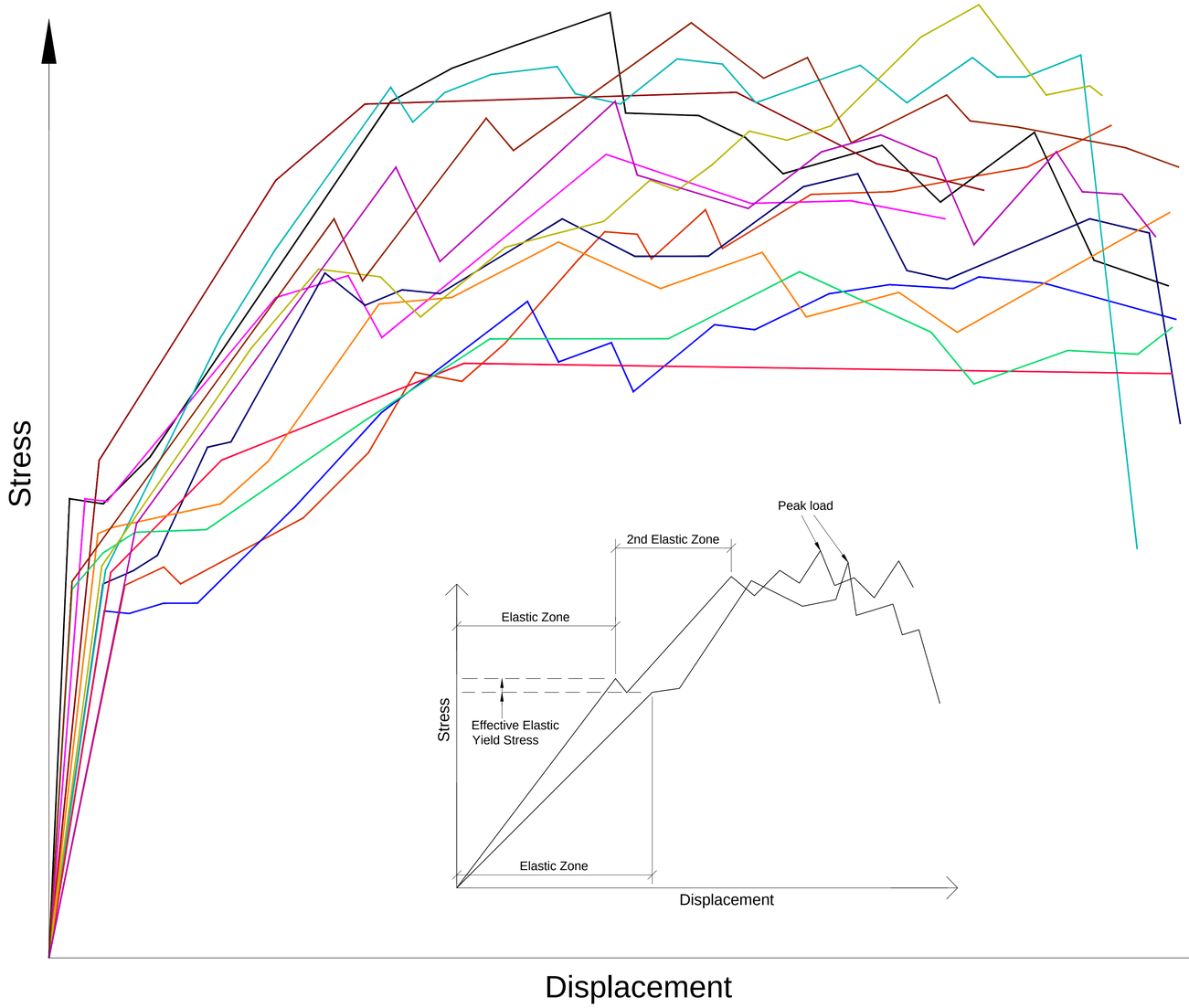
An investigation into the effect of stacking sequence in laminated Advanced Composite Materials on the bearing capacity and ductility of bolted connections

ABSTRACT

Advanced Composite Materials (ACM's) provide the engineer with a material which with care and careful design can provide light and stiff structures with good dampening properties, ACM's are avoided typically through lack of knowledge and understanding of their behaviour. Their potential orthotropic / anisotropic and heterogeneous nature and brittle failure modes mean that lower bound theory does not apply. This research project tested a series of laminates with varying ply stacking sequences to determine the effect on the bearing capacity and quasi-ductility. The effect on the bearing capacity was quite dramatic with yield stress range 219-466N/mm2. The effect on the Factor of Safety between the first yield stress to the peak stress ranged from around 1.15 to 2.3. This paper offers some designers guidance for the use of bolted connections and what types of ply stacking sequences could be used where lower or higher factors of safety are required.



DESIGN RECOMMENDATIONS & CONCLUSIONS FROM RESULTS

From the results, a number of conclusions can be drawn as designers guides when using Advanced Composites in a bolted joint situation.

1) To improve the transmission of load between the fibres and layers a matrix should be used that has a lower elastic modulus and a higher strain failure percentage than the fibre used.

2) The introduction of fibres with a lower elastic modulus and a higher strain failure percentage will increase the factor of safety between the elastic yield load and the peak load

3) In laminates with predominantly woven layers, having layers close to but not at the surface where the fibres are orientated at 45deg to the load path will increase the load transmission through the laminate, increasing the elastic yield load but not significantly increasing the peak load capacity

4) Grouping layers of woven fabrics of similar weight and weave will increase the elastic yield load but may reduce the peak load capacity

5) When using a 10mm dia bolt, using a fabric weight (in these tests Twill) of around 375gsm will result in higher elastic and peak loads. Heavier fabric (650gsm) with this size of bolt results in a weaker and a lower bearing stiffness in comparison to the 375gsm.

6) Mixing woven layers with large differences in weight and weave will result in a non economic design with regards to the strength and stiffness of the bearing

7) Mixing fabrics with smaller "steps" between weights i.e. 200-375-650 will result in a stronger and stiffer laminate

8) Mixing plain woven fabrics with unidirectional fabrics helps to stabilize the laminate at the bearing point resulting in a very strong and stiff bearing (the highest in these tests) but the concession being the lowest factor of safety between the elastic yield and the peak load

9) The end and edge distances suggested by CP1380 and Karakuzu can be applied to laminates of using woven fabrics. All laminates tested at the suggested end and edge distance failed in bearing first and had a zone of "ductile" behaviour before progressing to other forms of failure, whether block shear, tension failure or a complex mix of the previous combined with Interlamina shear.

10) Delaying the elevated temperature cure has adverse effects on the laminate bearing capacity and behaviour, this can be seen in the variation in Layup 17

11) Due to the quasi-ductile behaviour once the elastic yield stress has been exceeded i.e. the ability to sustain load for a duration with a controlled and slow displacement post elastic yield, with care and caution the lower bound theory and safe design theorem can be applied.