Advanced compressive shear testing and in-situ failure analysis of glass-laminates

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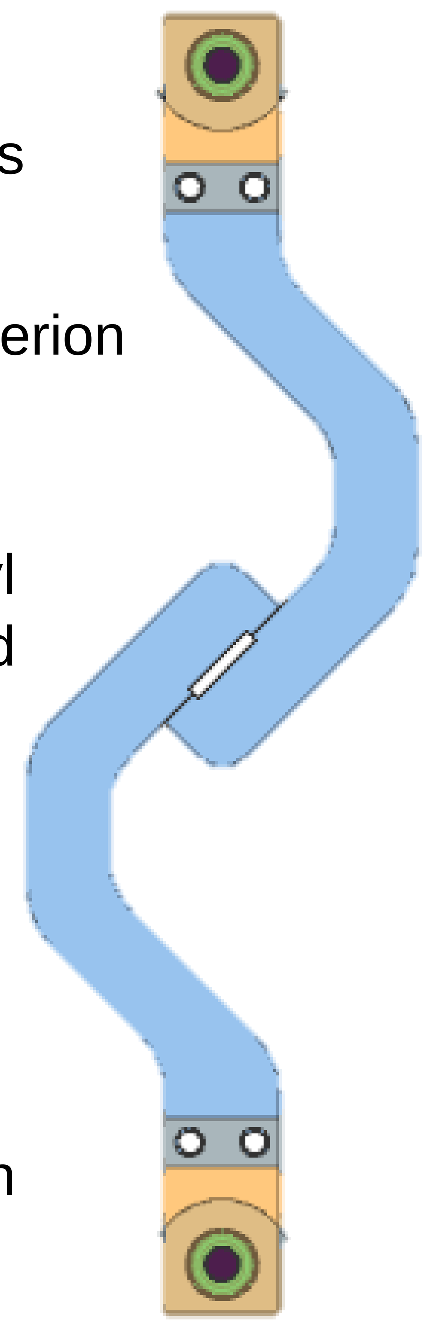
Introduction

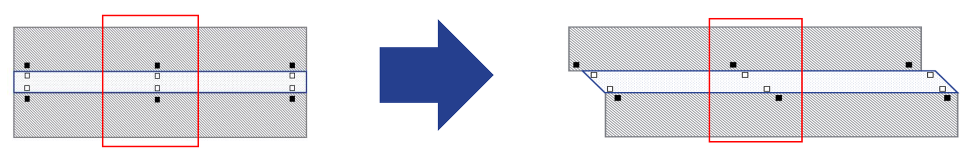
- Compressive shear testing (CST) was applied to characterize the delamination performance of glass-encapsulant laminates
- Digital image correlation (DIC) Aramis (GOM) was used to identify the point of delamination
- Point tracking of DIC generated image series was combined with a finite element model (FEM) to define a delamination criterion



Experimental and Modelling

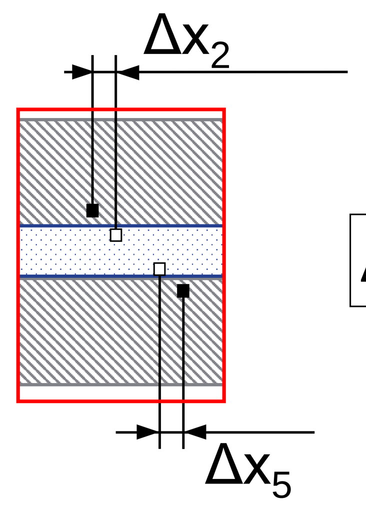
- Glass laminates were manufactured using an UV-transparent, peroxide crosslinking encapsulant (based on ethylene vinyl acetate copolymer (EVA)) at 155°C (curing time: 15 min, pressure: 800 mbar); specimens of 25x25 mm^2 were obtained using water jet cutting
- CST was performed in tensile mode on a Zwick-Roell Z020 equipped with Aramis at a loading rate of 1 mm/min
- GOM Correlate was used to analyse the image series generated by Aramis:
  - Point tracking was performed on 12 (initial) vertically aligned surface points
  - Three regions (left, middle, right) consisting of four points (two on glass and two on EVA) were assessed
  - Output: vertical and horizontal displacement of each point with corresponding shear angles
- Two approaches were developed to evaluate the point tracking data; a FEM was built in order to estimate the delamination load (F_{delam})

Evaluation Approaches



Approach 1

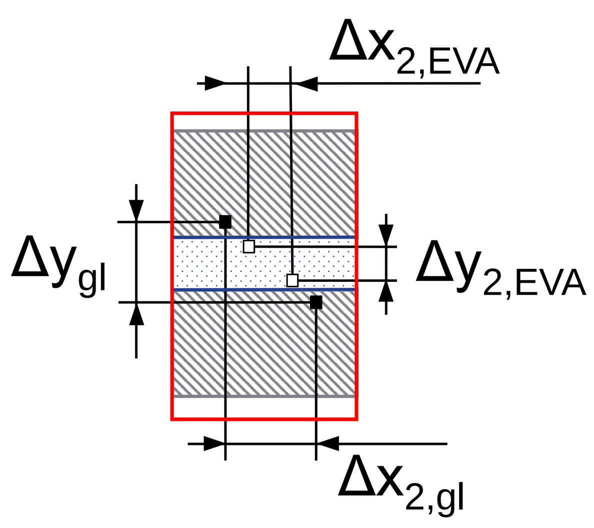
Consideration of the change in x



$\Delta x_i < x_{crit}$

Approach 2

Comparison of the shear angle in EVA (γ_{EVA}) to the shear angle between the glass substrates (γ_{gl})



$\Delta\gamma_i < \Delta\gamma_{crit}$
$\Delta\gamma_i = \gamma_{gl} - \gamma_{EVA}$

$\gamma_{i,j} = \tan^{-1}\frac{\Delta x_{i,j}}{\Delta y_{i,j}}$

FEM

Pure shear of a CST specimen

Linear elastic material models for EVA and glass

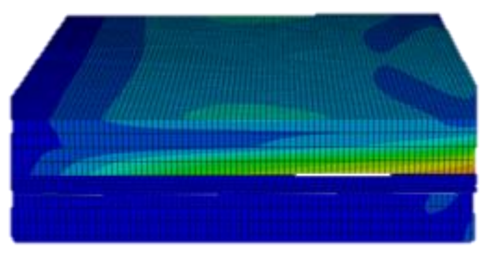
EVA: E*=10 MPa, η = 0.45, ρ= 0.92 g/cm^3 (*obtained from Wallner et al., 2010)

Glass: E=70 GPa, η = 0.23, ρ= 2.5 g/cm^3

Two sets of fracture mechanical (FM) properties (adopted from He et al., 2018) were applied:

- Set 1: $G_{Ic,1}$ = 99 J/m^2; $T_{I,1}$= 0.2 MPa
- Set 2: $G_{Ic,2}$ = 1200 J/m^2; $T_{I,2}$= 4 MPa

$G_{IIc} = G_{IIIc} = 3 * G_{Ic}$
$T_{II} = T_{III} = 3 * T_I$

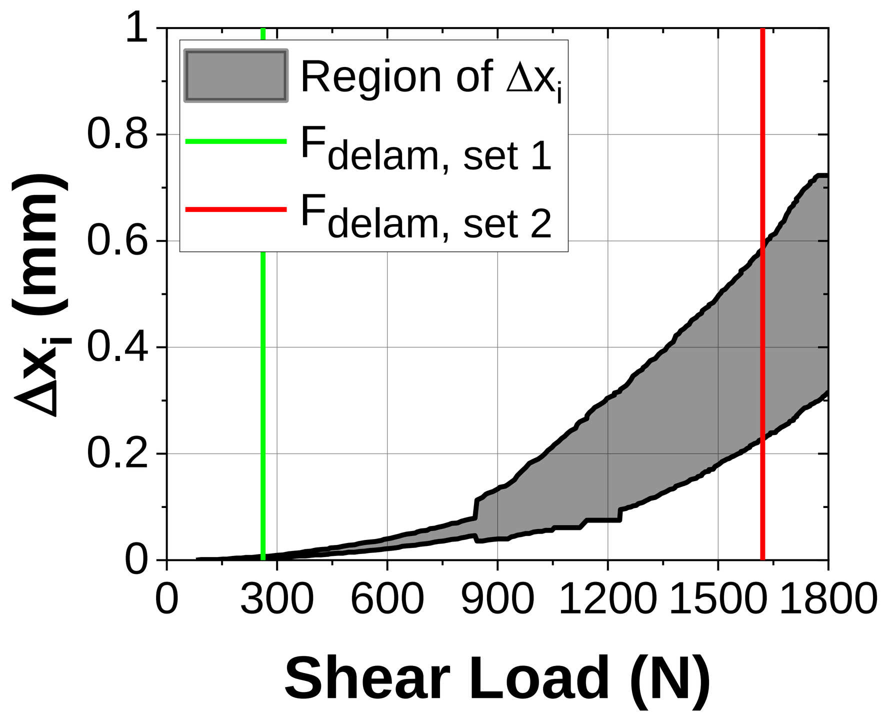


Results & Discussion

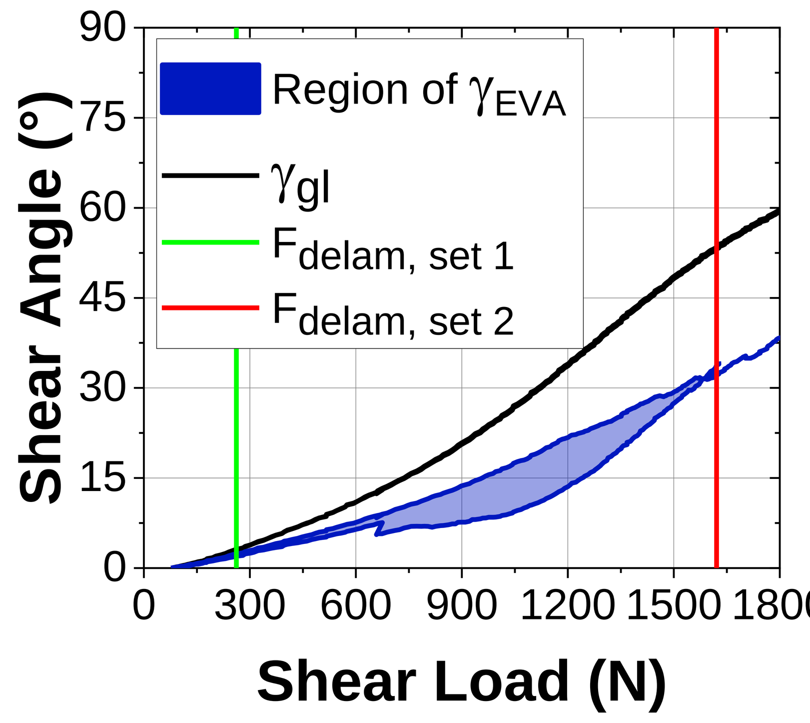
- Point of delamination did not correspond to maximum load
- Complex failure (including glass fracture) of CST specimens
- No delamination criteria could be defined with approach 1 or 2
- Based on the failure loads (262 and 1621 N) deduced by FEM, four delamination criteria were obtained

FEM-Input	FEM-Result	Delamination at	
	F_{delam}(N)	x_{crit} (mm)	$\Delta\gamma_{crit}$ (°)
Set 1	262	**0.01**	**1.41**
Set 2	1621	**0.36**	**19.78**

Approach 1



Approach 2



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Outlook

- Future work will focus on width tapered cantilever beam (WTCB) tests to generate accurate fracture mechanical parameters of the laminates and a study of the effect of damp heat ageing on shear performance

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