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INDENTATION METHOD TO EVALUATE METAL-TO-METAL ADHESIVE BOND RESIDUAL STRENGTH

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Factors affecting strength

Strength = *f* (t_a, t_p, E_a, E_p, *others*)

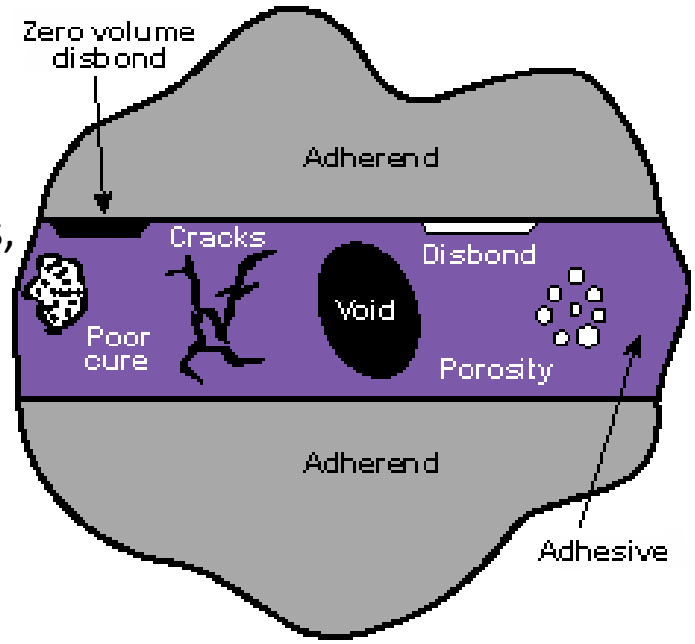
Where

t_a, E_a are the thickness and modulus of adhesive

t_p, E_p are the thickness and modulus of adherends.

Others being the interfacial properties, presence of defects, re-entrant corners and loading conditions.

Defects

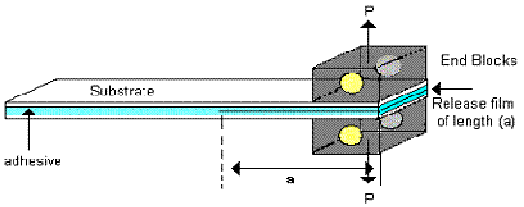


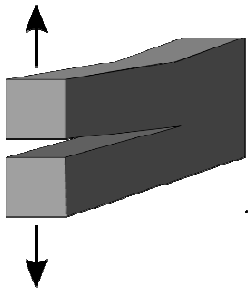
Testing Methodologies

Mode Testing

Mode-I testing (Opening mode)

Double Cantilever beam (DCB)

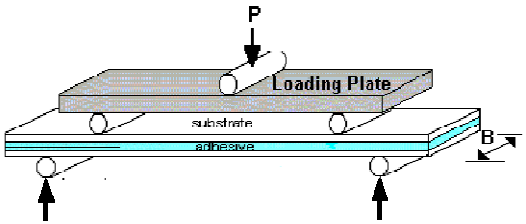


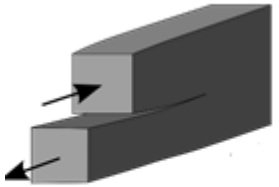


Mode I:
Opening

Mode-II testing (Shear mode)

End Notch Flexure (ENF)

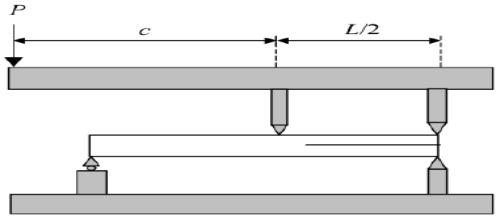




Mode II:
In-plane shear

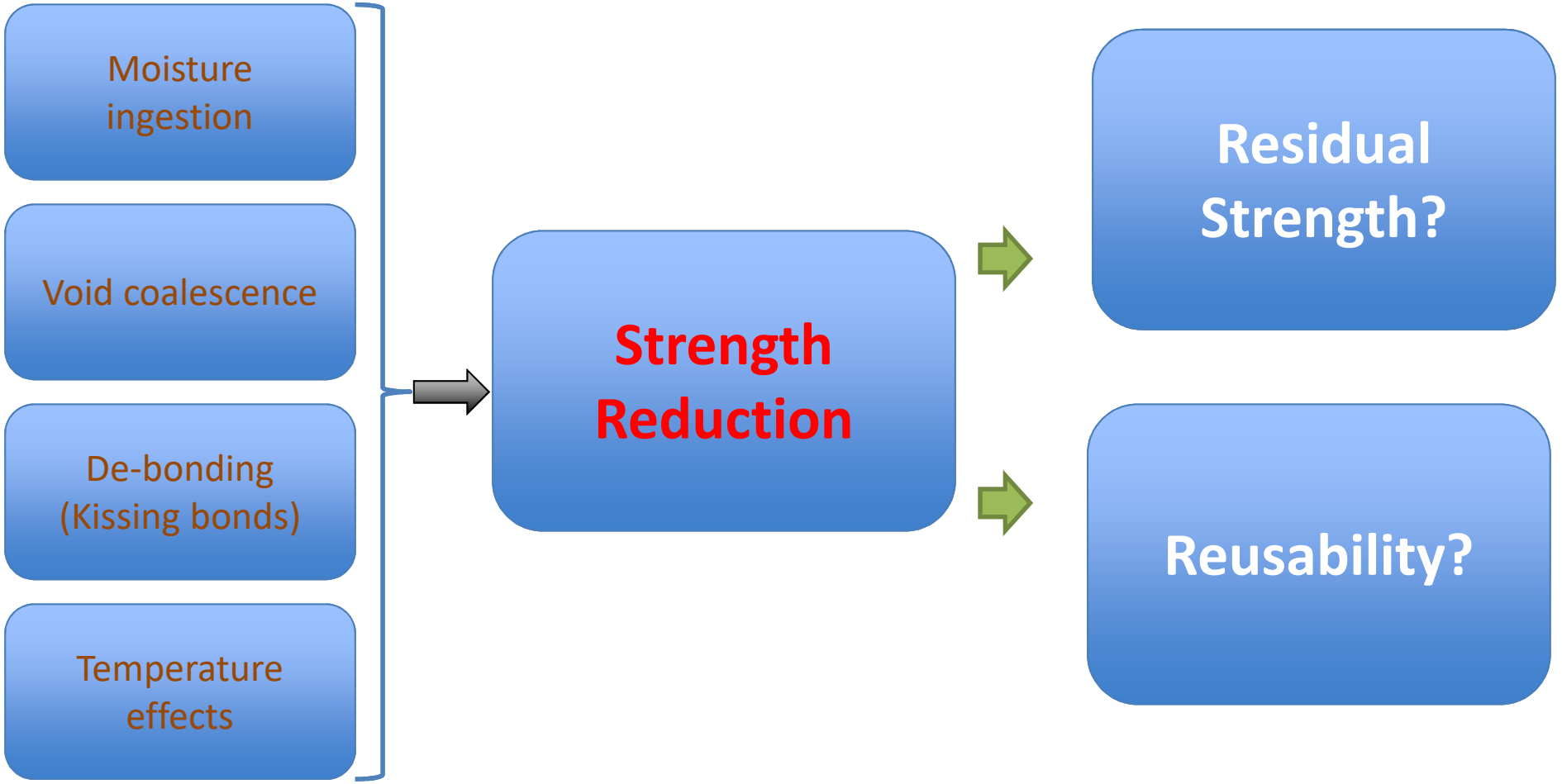
Mixed Mode testing

Mixed Mode Bending (MMB)



Mode-I + Mode-II

Bond strength deterioration



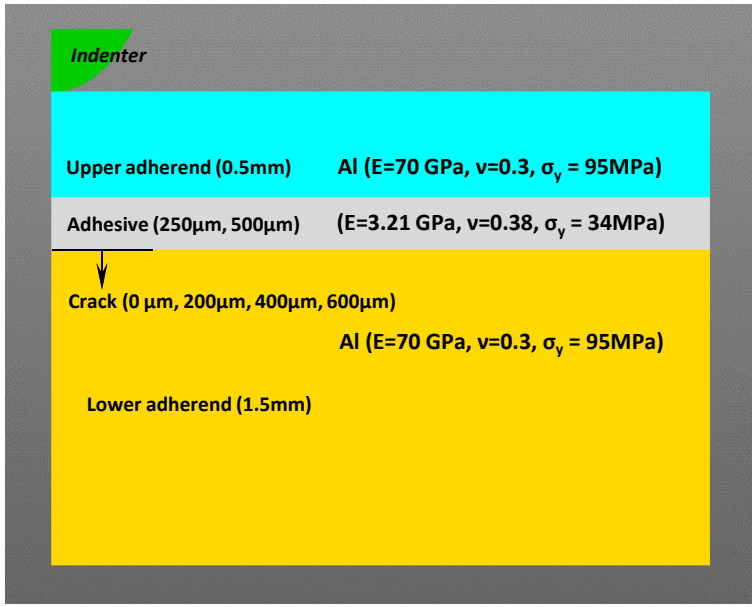
Aim

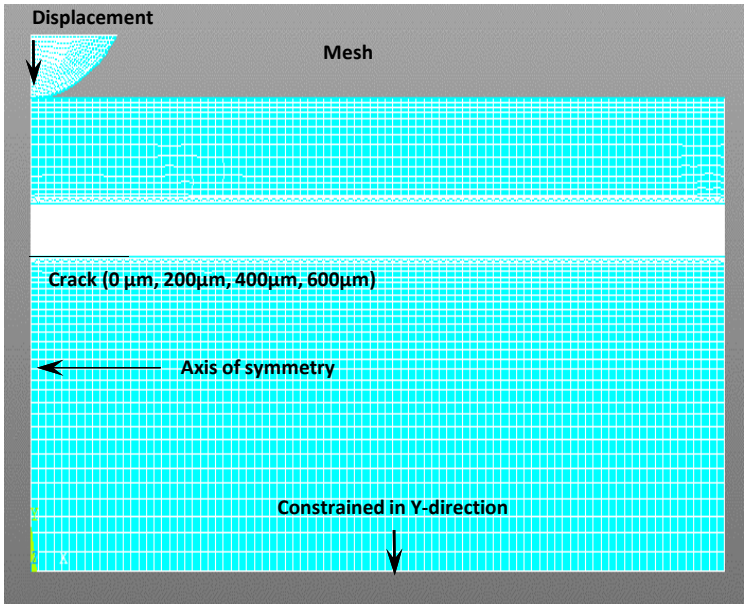
- To understand the failure behaviour of adhesive joints under indentation loading so as to formulate a test methodology for assessing adhesive bond quality.

- To assess the effect of interface strength on the crack propagation behaviour of adhesive joints.

- To assess the effect of interfacial defects on the crack initiation loads of adhesive joints.

Indentation model





- Plane strain conditions.
- **Adhesive thickness** : 250µm and 500µm.
- **Number of nodes** : 22020(250µm) and 37524(500µm).
- **Number of elements** : 23156(250µm) and 38556(500µm).
- **Interfacial crack dimensions** : 200µm, 400µm and 600µm) along the lower interface.
- Displacement controlled quasi-static indentation.

Simulation conditions

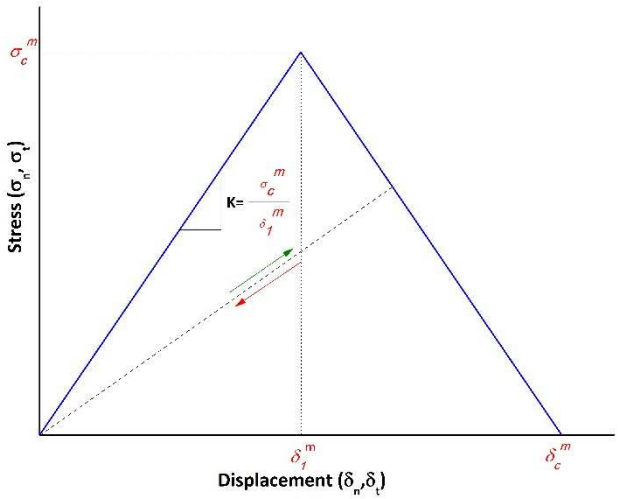
Material Models

- Adhesive and adherends : Bi-linear material model.
- Indenter : Rigid.
- Interfaces : Cohesive zone model using CONTACT 172 and TARGET 169 elements.
- G_{nc} = G_{tc} = 0.1 J/m^2 [1] taken to be equal to the work of adhesion of epoxy adhesives with metals.

[1] P. Feraren and H. M. Jensen, Cohesive zone modelling of interface fracture near flaws in adhesive joints. *Engineering Fracture Mechanics*, 71, 2125-2142, 2004.

Cohesive Zone Model

Traction-separation law:



Governing equations:

Normal traction : $\sigma_n = K_n U_n(1-D)$

Tangential traction : $\sigma_t = K_t U_t(1-D)$

Failure initiation criterion :

$$\left\{\frac{\sigma_n}{\sigma_{nc}}\right\}^2 + \left\{\frac{\sigma_t}{\sigma_{tc}}\right\}^2 = 1$$

Fracture criterion :

$$\frac{G_n}{G_{nc}} + \frac{G_t}{G_{tc}} = 1$$

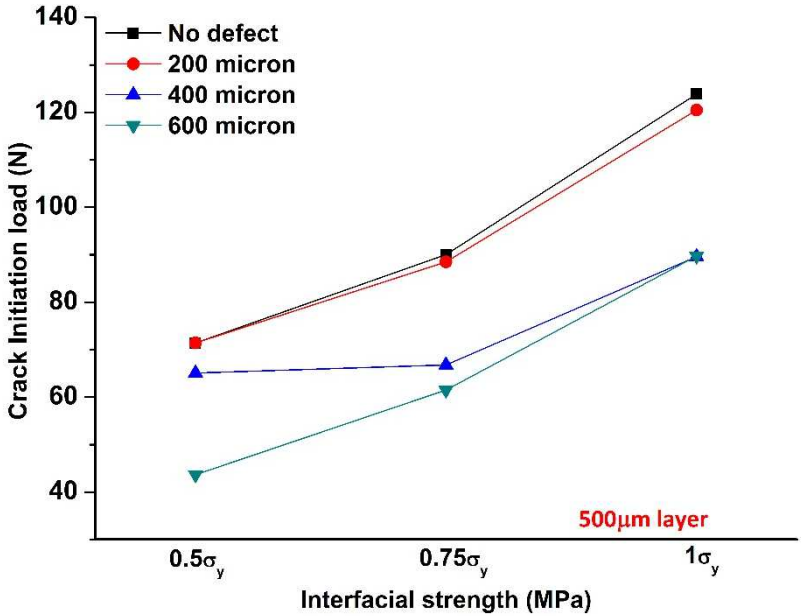
D : Damage parameter varying between 0 to 1.

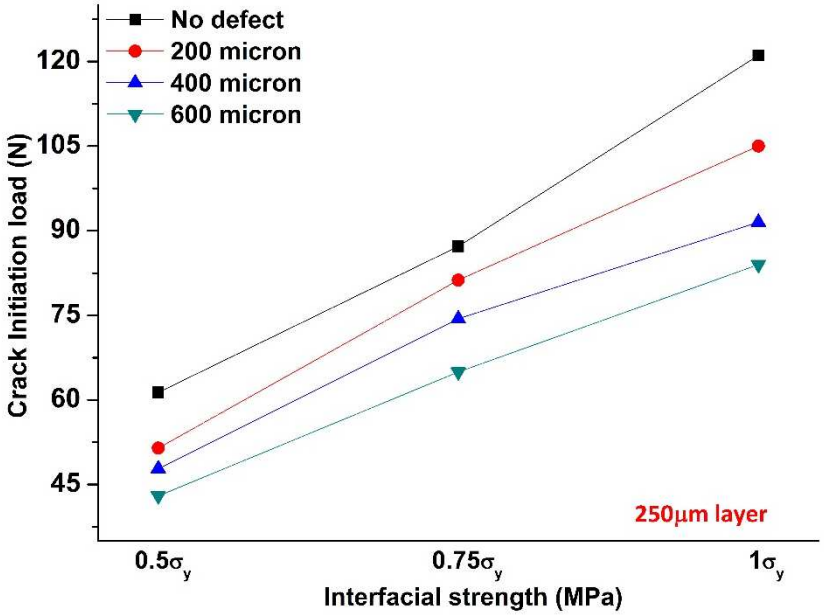
$$G_{n,t} = \int_0^{\delta_{n,t}} \sigma_{n,t}\, d\delta_{n,t}$$

- The interfacial strength (σ_{nc}, σ_{tc}) has been varied as fractions (0.5, 0.75, 1) of the adhesive yield strength (σ_y = 34MPa).
- Crack propagation has been monitored with respect to indentation load.

Results

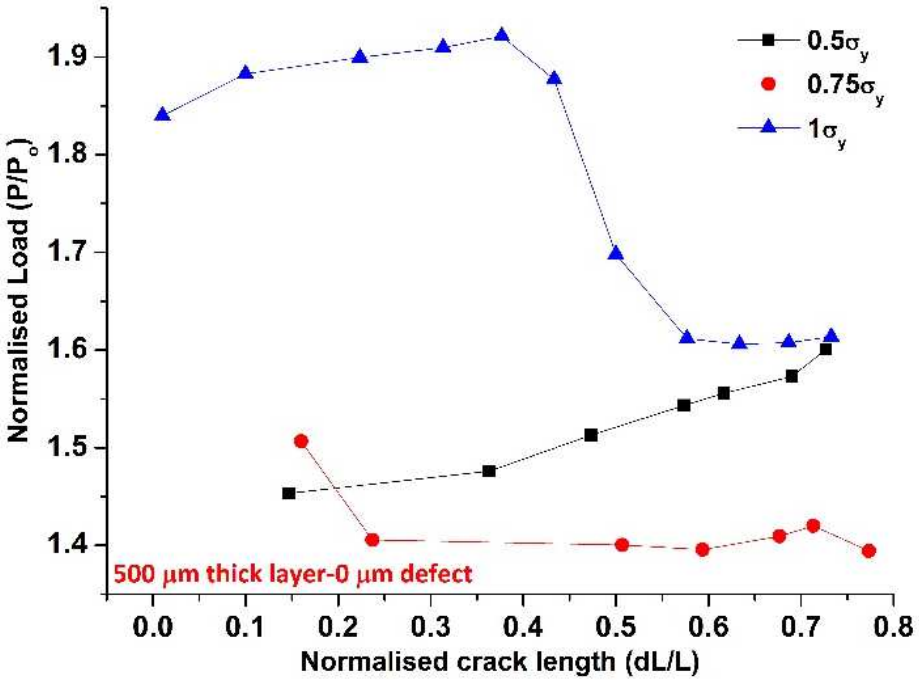
Crack initiation loads

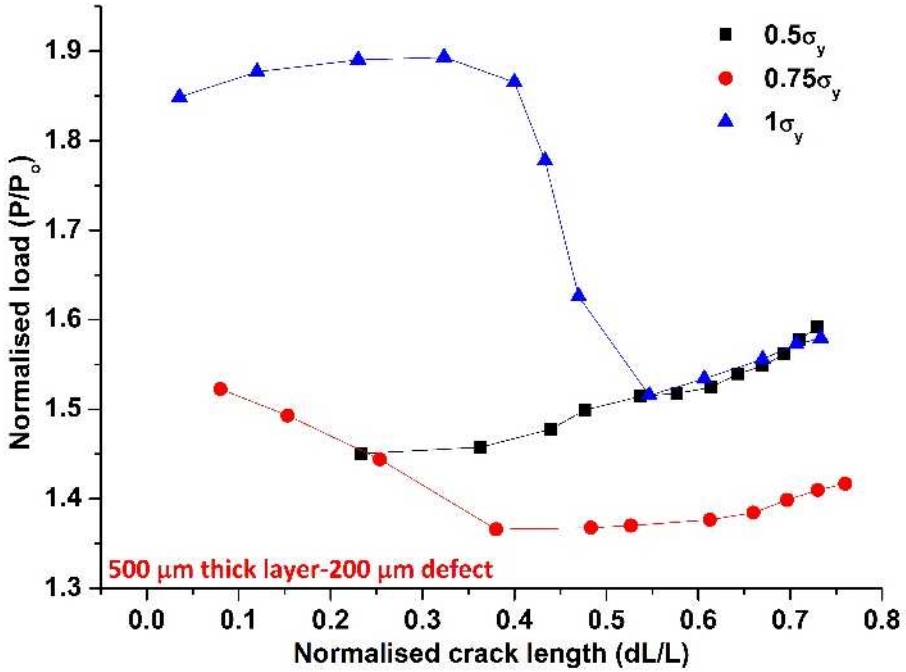




- Increase in the interfacial strength increases the crack initiation load.
- Increase in the defect length decreases the crack initiation load because in the apparent interfacial length.
- The crack initiation location is usually away from the tip of the defect because of the crack tip being in the compressive zone of indentation with no shear load.

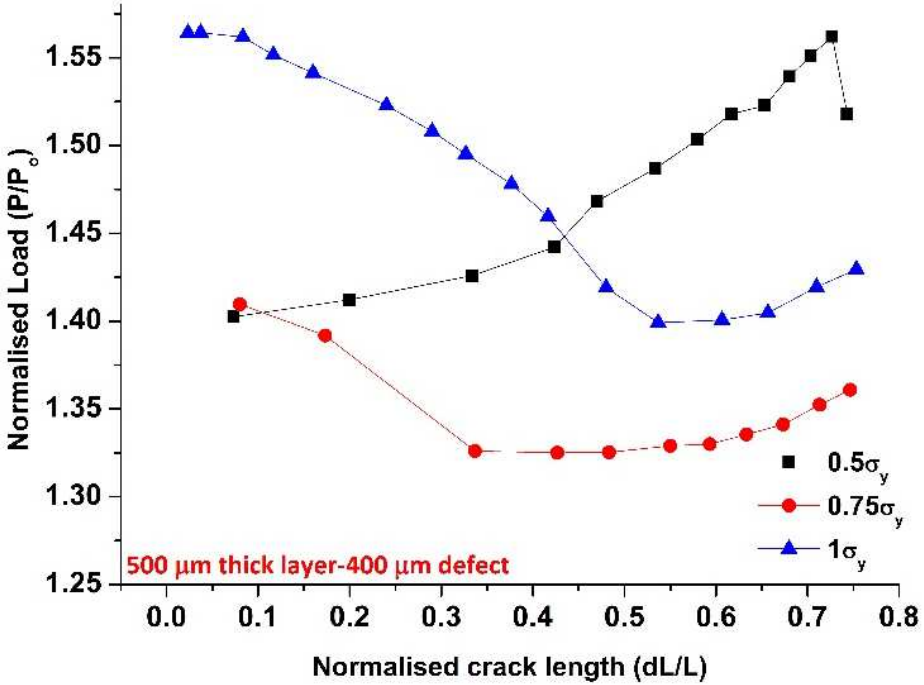
500 µm thick adhesive layer

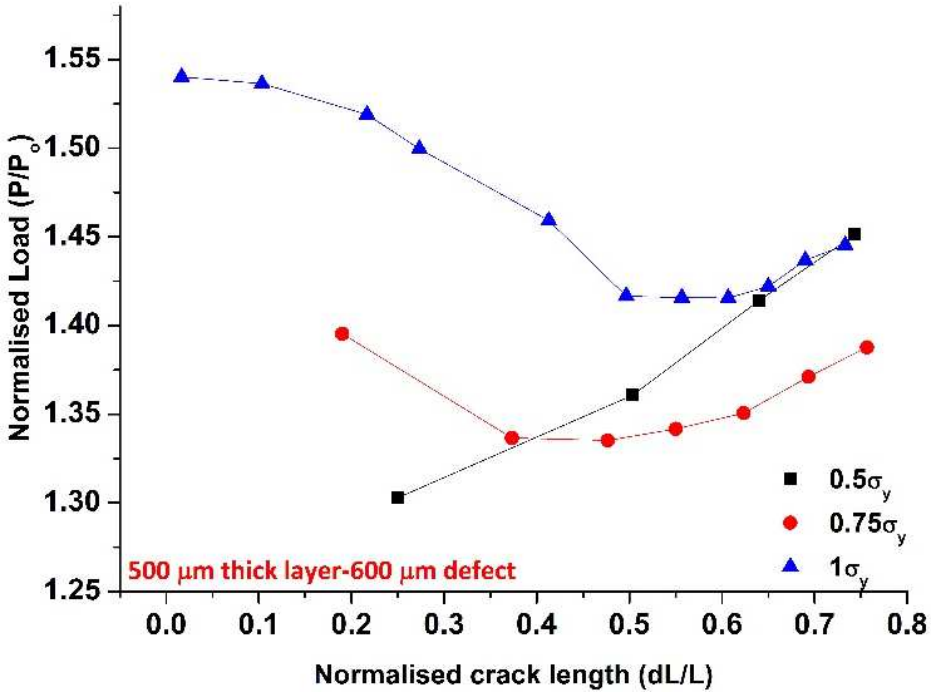




- Loads have been normalised with respect to the load for an un-bonded joint at the corresponding indentation depth.
- Crack lengths have been normalised with respect to the length of the interface.
- Interfaces with higher strengths exhibit unstable crack propagation. Lower strength interfaces exhibit stable crack propagation.

500 µm thick adhesive layer





Higher interfacial strength ➡ Higher crack initiation load ➡ Higher strain energy accumulation

⬇

Unstable crack propagation

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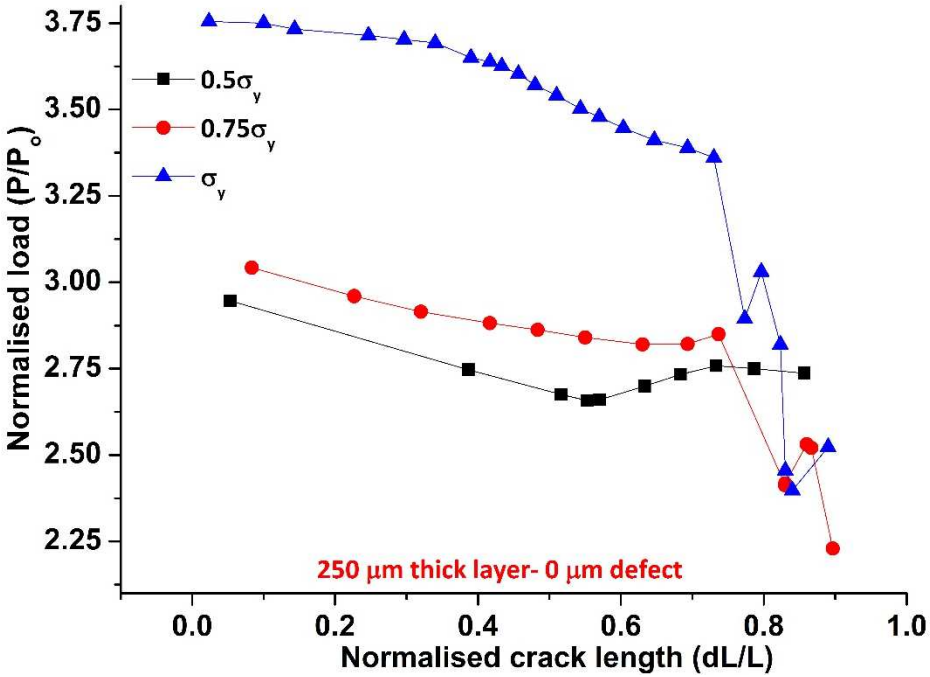
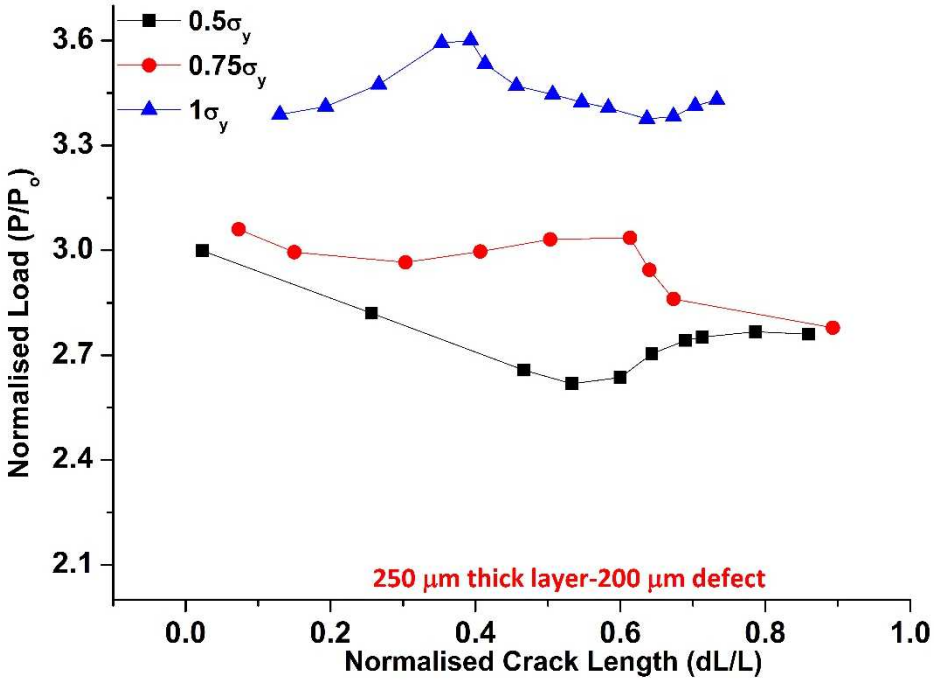
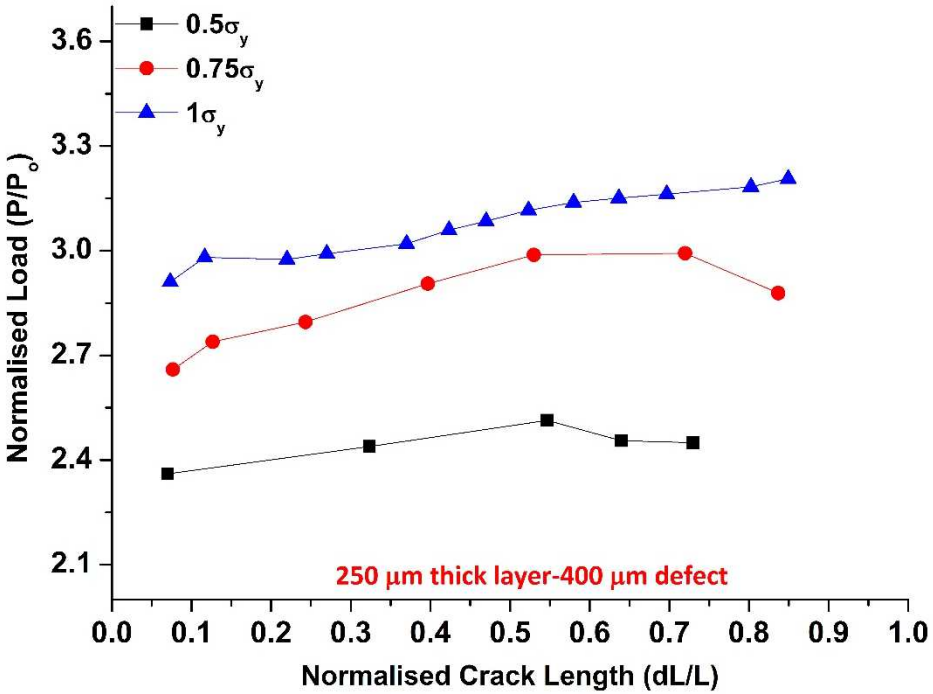
250 µm thick adhesive layer

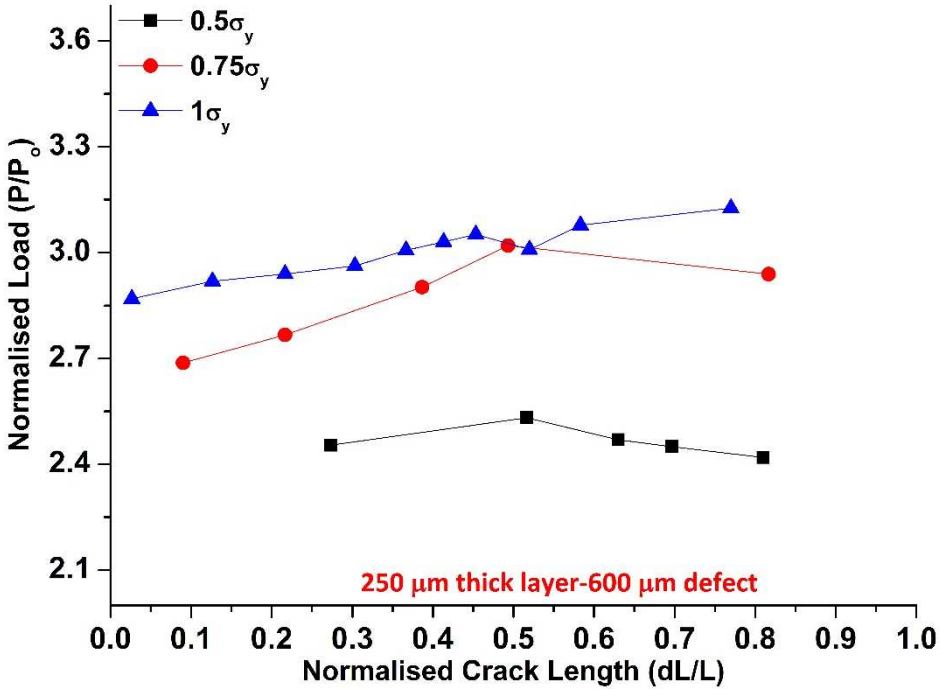




- Stable crack propagation has been observed at 250µm adhesive layer thickness.
- This is because of the lower accumulated strain energy in the bulk of the adhesive layer.

250 µm thick adhesive layer





Lower interfacial strength → Lower crack initiation load → Lower strain energy accumulation

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Stable crack propagation

Conclusions

- Indentation can be used as a testing method to evaluate the strengths (or residual strengths) of adhesively bonded joints of various adhesive layer thicknesses. The crack initiation load decreases with decreasing interfacial strength.

- The effect of presence of defects (at the adhesive bond interface) on the load carrying capability can be seen as a reduction in the load carrying capability. This does not affect the crack initiation or propagation behaviour because of the presence of the crack within the high compressive stress zone (at indentation sub-surface zone). The effect of cracks situated away from this zone can be part of future investigations.

- The adhesive bond interfaces with higher bond strengths exhibit unstable crack growth behaviour and those with lower bond strengths exhibit stable crack growth. This is because of the higher crack length initiation loads at higher interfacial strengths leading to accumulation of strain energy in the bulk of the adhesive and adherends thus increasing the energy available for crack propagation.

- The present work gives an insight into adhesive joint behaviour under indentation loading with different joint configurations. The failure conditions of various joints have been identified and discussed. The scope for future has been identified.

Future Work

- Experimental validation of model.
- Parametric study of the effect of various variables on the adhesive bond strength.
- Investigate the mode mixity of the crack tip.

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Thank you

Questions, Comments or Suggestions?

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