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COMPUTATIONAL ANALYSIS OF FAILURE MODES IN COMPOSITE JOINTS

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SAFEJOINT

Enhancing structural efficiency through novel dissimilar material joining techniques

CONTENTS

- GENERAL REMARKS
- FRACTURE MECHANICAL ANALYSIS
- COMPUTATIONAL ANALYSIS
- CONCLUSIONS

GENERAL REMARKS

•The purpose of the present work is:

a) The numerical investigation of failure of composite joints under flexural and axial loading

•In composite structures interfacial defects have been studied by many researchers [1-3]

•On the other hand only a limited amount of data are evaluated about the crack growth in the composite beams, T-joints and dissimilar metal matrix joints [4-13]

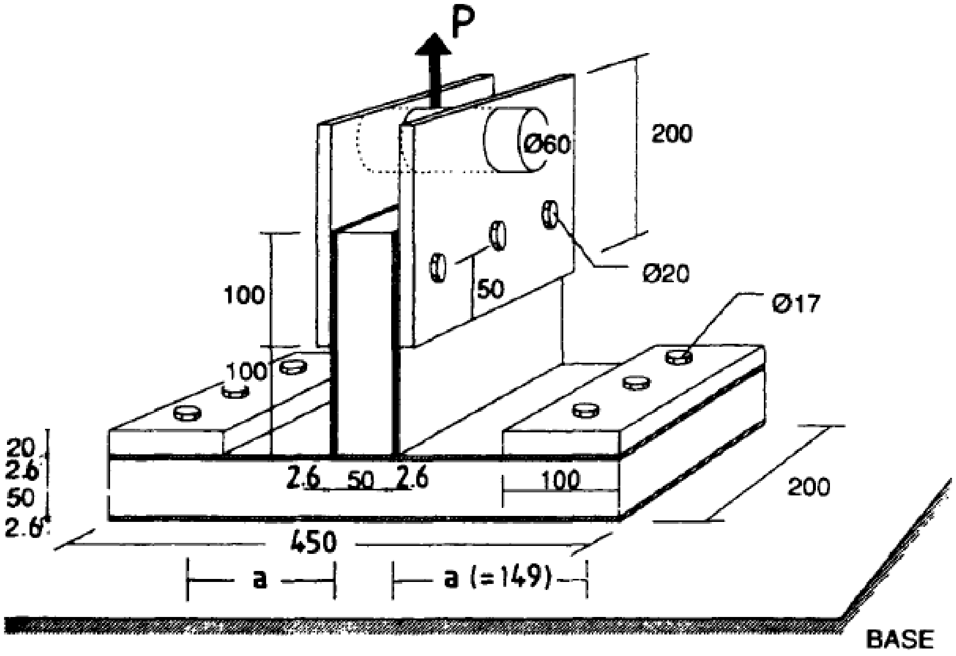
•The mechanical behaviour of such joints is complex due to the complicated geometry, materials constitutive behaviour, non linearities.

•and b) Study of crack propagation in composite joints produced by FSW

•FSWelds aluminium alloys, showing by far higher fatigue properties with respect to the conventional fusion welding techniques.

COMPOSITE T- JOINTS

- T-joints play a vital role in the hulls of ships and bulkheads made of sandwich materials [5,9,10].
- Their design aspects and crack detection are important in preserving the safety of ships navigating through violent sea waves.
- The design aspects are focused on estimating static and quasi-static failure loads, fracture and fatigue characteristics.



COMPOSITE METAL MATRIX JOINTS

- Friction Stir Welding is a solid-state joining process, which has proved to be ideal for creating high quality welds in high strength alloys that were extremely difficult to weld by conventional joining techniques and can be used to weld dissimilar alloys and metals

- Dissimilar Metal Matrix Joints [14-16] produced by FSW

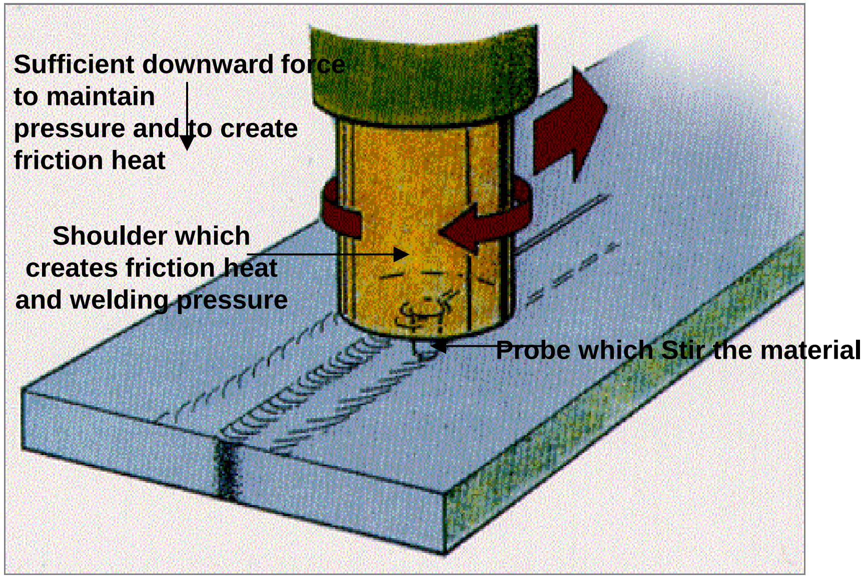
exhibit

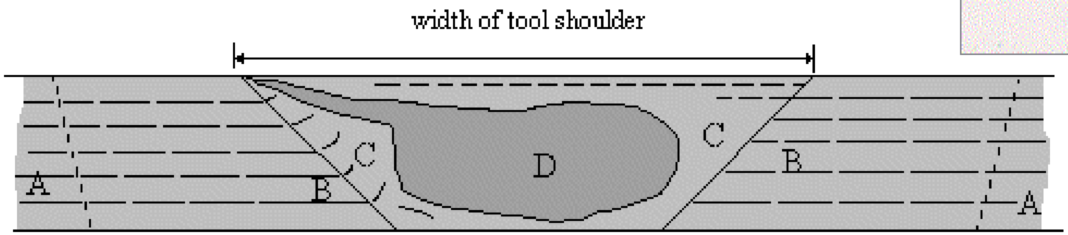
✓higher strength and stiffness,

✓improved tribological characteristics

✓increased creep

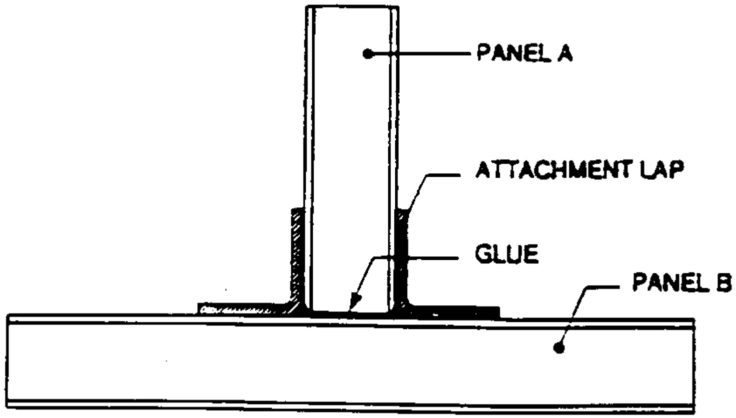
✓fatigue strength





(kg/m^3)

T-JOINT DESIGN



- complex structure
- stress concentrations in T-joints which can initiate interlaminar or fatigue cracks.
- The face sheets of the sandwich panels consist of two layers of each, woven roven E-glass with fibers in directions and Chopped Strand Mat (CSM) on top and on bottom of the laminates.

Mechanical Properties of E-Glass Polyester Laminate [4]

Longitudinal/Transverse Young’s modulus (MPa)	10000/10000
Shear modulus (MPa)	6200
Longitudinal/Transverse tensile strength (MPa)	95/95
Longitudinal/Transverse compressive strength (MPa)	123/123
Shear strength (MPa)	93

Typical Properties of Crestomer 1152 PA [9,10]

Ultimate tensile strength (MPa)	26
Elongation at break (%)	100
Initial tensile modulus (MPa)	500
Yield stress at 7% strain (MPa)	17

Mechanical Properties of Divinycell PVC H100 at 20oC [9,10]

Density	102
E-modulus compression, ASTM D1621 (MPa)	130
Ultimate compressive strength, ASTM D1621 (MPa)	1.7
E-modulus tension, ASTM D1623 (MPa)	105
Ultimate tensile strength, ASTM D1623 (MPa)	2.8
Shear modulus at 20°C, ASTM C273 (MPa)	40
Ultimate shear strength, ASTM C273 (MPa)	1.5

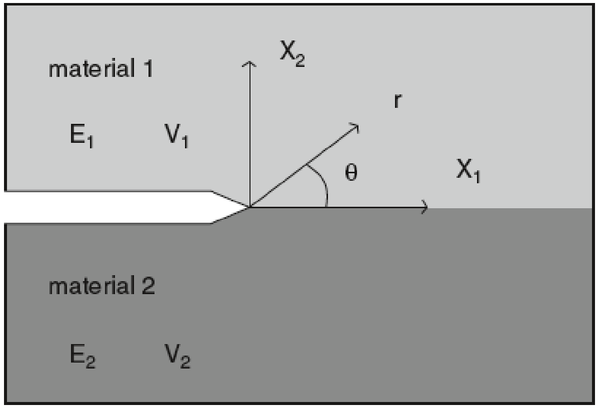
DETERMINATION OF THE STRESS INTENSITY FACTORS

For a crack considered at the interface the stress intensity factors are given by [17,18]:

$$k = k_0 e^{i\beta} = k_I + ik_{II}$$

Where the phase angle depends on the bimaterial constant ε

$$\varepsilon = \frac{1}{2\pi}\ell n\left(\frac{\mu_1 + \mu_2\kappa_1}{\mu_2 + \mu_1\kappa_2}\right) = \frac{1}{2\pi}\ell n(\gamma), \qquad \delta = \tan^{-1}(2\varepsilon),$$



Geometry and local coordinates for analyzing the displacement field close to the crack tip

The complex form of the stress field near the crack tip for a crack at the interface can be expressed as follows

$$\sigma = \sigma_{22} + i\sigma_{12} = \frac{k_1 + ik_2}{\sqrt{2\pi r}} r^{i\varepsilon} \qquad (1)$$

According to Schmelser [18], the complex crack opening $\Delta u = |\Delta u| e^{i\Theta}$ (2)

where the angle is defined $\Theta = \varepsilon \ell n r - \beta - \delta - \pi/2$

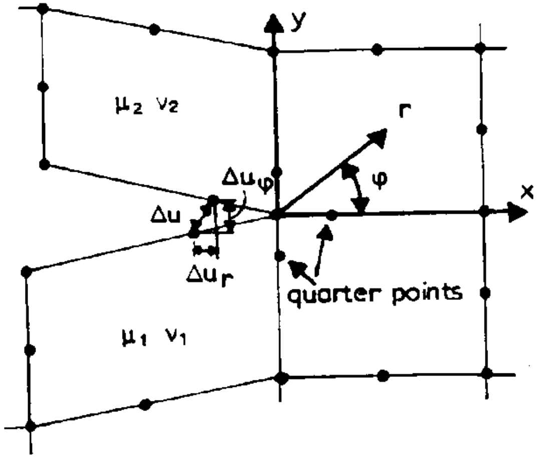
[18] Smelser R.E., Evaluation of Stress Intensity Factors for Bi-material Bodies using Flank Displacement Data, International Journal of Fracture, Vol. 15, 135-143, 1979

DETERMINATION OF THE STRESS INTENSITY FACTORS

By eqs (1) and (2)

$$\Delta u = \frac{1}{4\sqrt{2}}\left(\Lambda_1 + \Lambda_2\right)\frac{k}{\lambda} r^{\lambda} e^{-i\pi/2}$$

$$\Lambda_i = \begin{cases} \dfrac{4(1-\nu_i)}{\mu_i} & plane\ \ strain \\ \dfrac{4}{\mu_i(1+6\nu_i)} & plane\ \ stress \end{cases}$$



Geometry and local coordinates for analyzing the displacement field close to the crack tip

The strength of the singularity for a crack between the two dissimilar media is given by [17,18]

$$\left.\begin{aligned} \lambda &= \frac{1}{2} + i\varepsilon \\ \lambda &= \lambda_0 e^{i\delta} \end{aligned}\right\} \quad \lambda_0 = \sqrt{\frac{1}{4} + \varepsilon^2}$$

$$|\Delta u| = \frac{1}{4\sqrt{2}}\left(\Lambda_1 + \Lambda_2\right)\frac{k_0}{\lambda_0}\sqrt{r} \qquad \Theta = \tan^{-1}\left(\frac{\Delta u_{\varphi}}{\Delta u_r}\right)$$

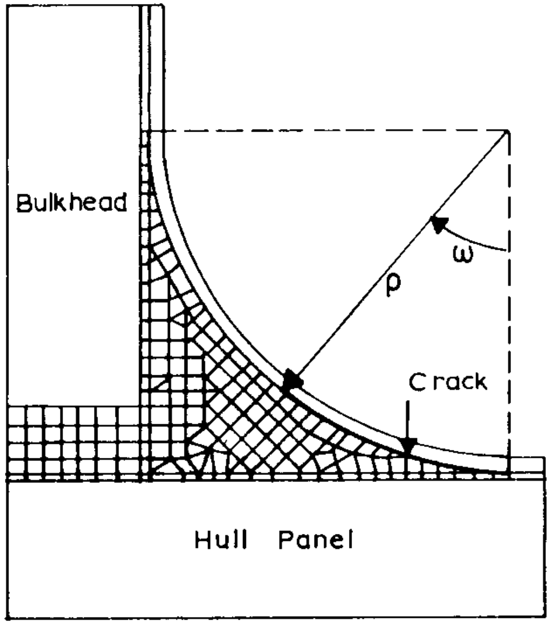
FINITE ELEMENT ANALYSIS

•The finite element analysis is performed with the use of the general purpose finite element program ANSYS [19].

•Plane strain is assumed throughout and the finite element mesh consists of plane isoparametric elements with eight nodes.

•Quadrilateral Quarter Point elements are used close to the crack-tip to get a proper stress distribution [10]

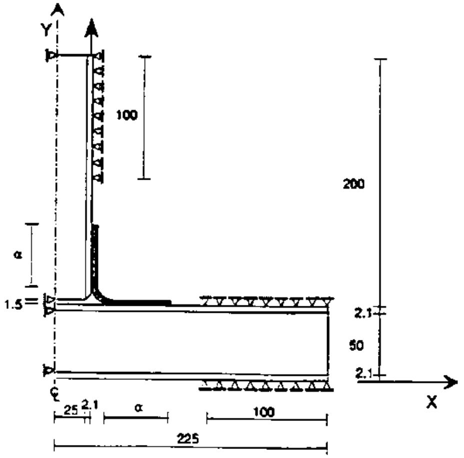
•Taking into consideration the symmetry only the half of the T-joint is analyzed using the Finite Element Method.



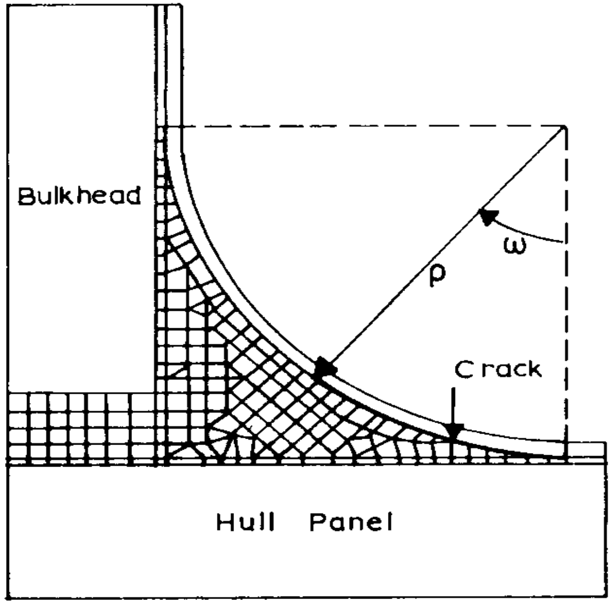
[10] Theotokoglou, E.E., "Study of the Numerical Fracture Mechanics Analysis of Composite T-Joints", Journal of Reinforced Plastics and Composites", Vol. 18, pp. 215-223 (1999).

FINITE ELEMENT ANALYSIS

- The finite element results for the different lap extensions and the different angles are presented [10]:



Overall model with boundary conditions



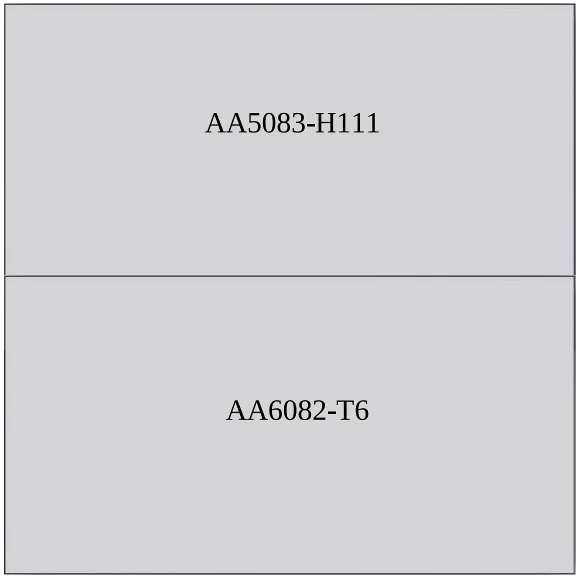
Extension α of the lap (m)	Angle ω	K_I $(MPa\sqrt{m})$	K_{II} $(MPa\sqrt{m})$
0.08	25°	4.50	-0.93
0.06	25°	4.51	-0.92
0.08	35°	4.90	-3.81
0.06	35°	4.90	-3.80
0.08	45°	2.00	-4.90
0.06	45°	2.01	-4.90
0.08	55°	-0.56	-4.00
0.06	55°	-0.56	-3.98

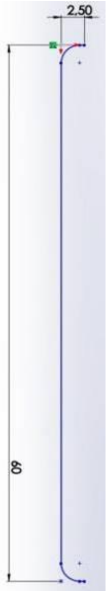
COMPOSITE METAL MATRIX JOINT

- The experimental phase included the welding of specimens and the preparation of specimens for

✓uniaxial tensile
✓micro-hardness
✓indentation tests

- The weld line joined two different base materials AA 6082 T6 and AA 5083 H111

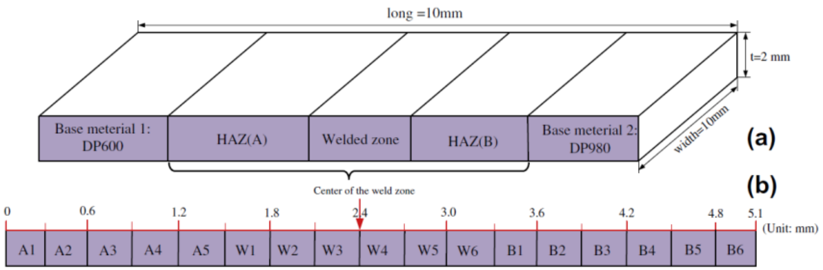


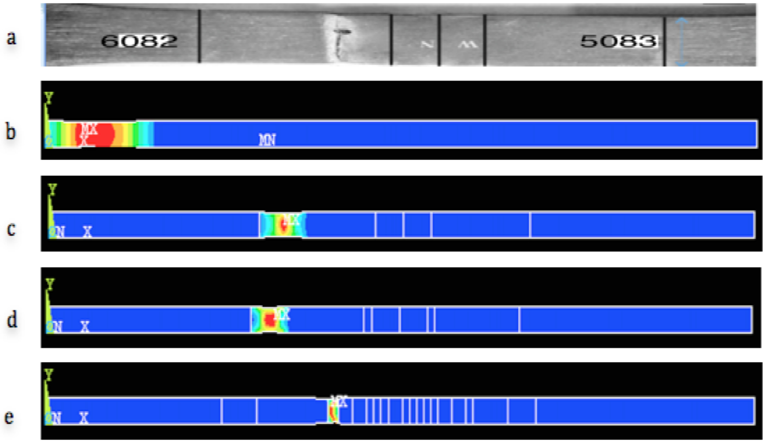


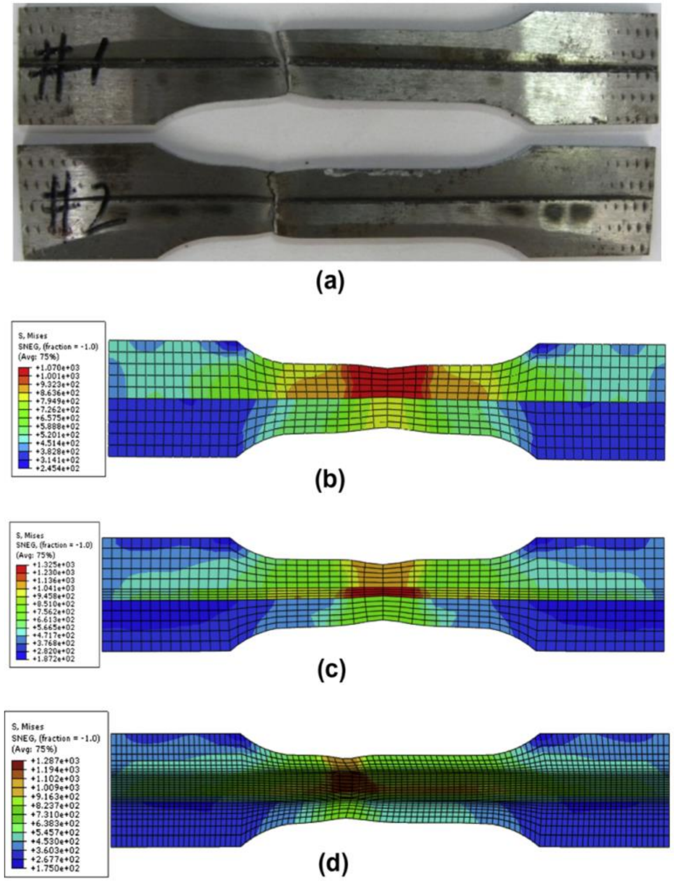
Specimen	Young's Modulus (GPa)	Yield stress (MPa)	UTS (MPa)	elongation (%)	Poisson Ratio	H_v microhardness
AA 6082 T6	71.7	268	320	18	0.33	105
AA 5083 H111	71.7	147	315	24	0.33	80

COMPOSITE METAL MATRIX JOINT

- The physical experiments including the uniaxial tensile and the indentation tests were needed to fully determine the <u>localized mechanical properties.</u>
- Note that the indentation tests were conducted to divide the weld region into several different zones in terms of different hardness values.







CONCLUSIONS

T- Joints

- In the case of static tests, the failure load is independent of the extension of the lap.
- The above numerical analysis is performed considering linear fracture mechanics analysis.
- A similar analysis has been performed by the authors in the case of fatigue loading.
- Glue is a material that yield plastically, so further research is required in order to predict the overall behavior of the T-joint more exactly.

FSW- Joints

- Since the base materials undergoes significant microstructural changes under the welding process, it is essential to characterize the true properties of different zones through nanoindentation.
- The scope of this work is to provide a comprehensive study on determination of mechanical parameters in the weld zone and heat affected zone by using indentation and inverse modeling techniques.
- In order to improve the simulation accuracy of finite element (FE) modeling for such complex welded structures, it is critical to characterize the detailed mechanical properties of the weld line.

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