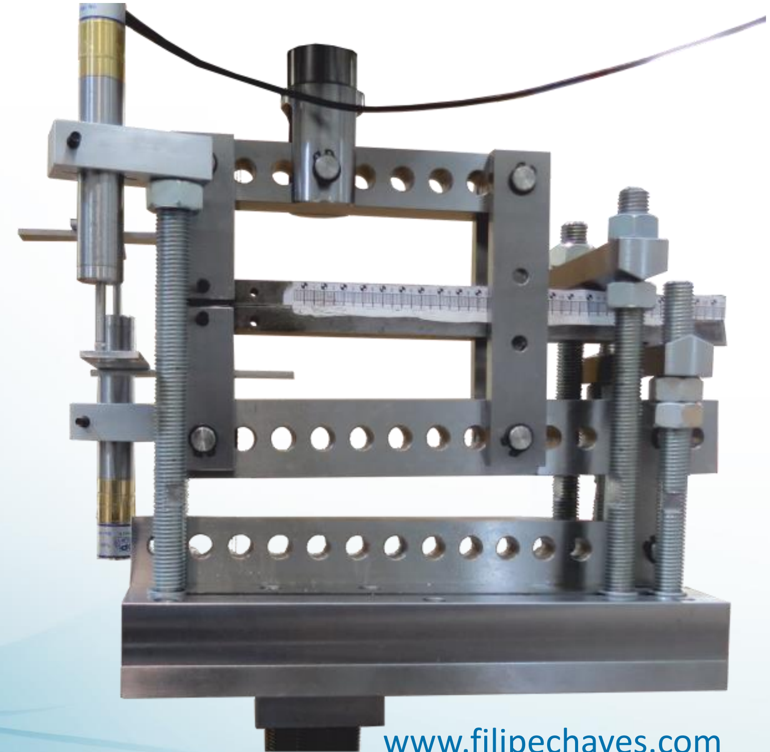


www.filipechaves.com
/apparatus

Apparatus and Method for Characterization of Bonded Joints Mixed Mode I+II Fracture

F.J.P. Chaves | L.F.M. da Silva | M.F.M. de Moura | D. Dillard

idMEC DEMec FEUP Faculdade de Engenharia VirginiaTech

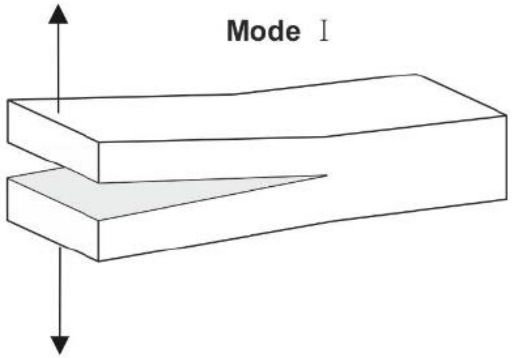
motivation

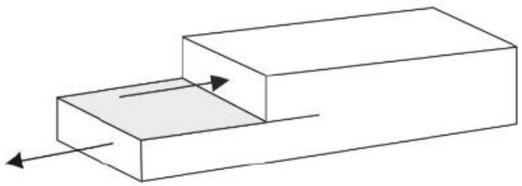
predict the structure toughness

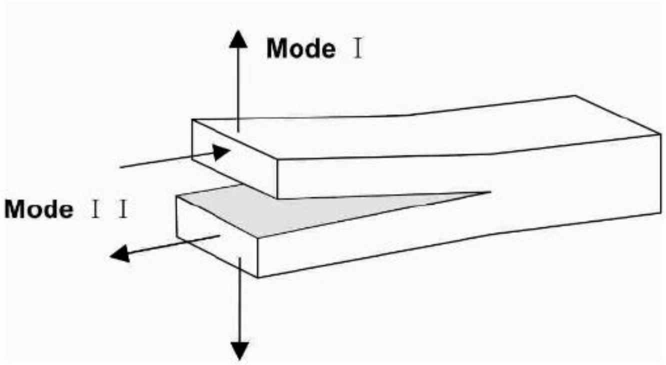
joint mechanical behavior

strain energy release rate
in mode I , mode II and
mixed-mode I+ II

problem definition





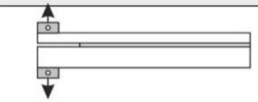
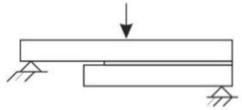
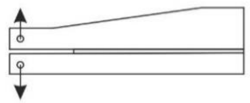
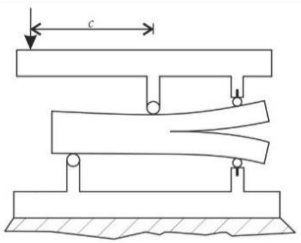
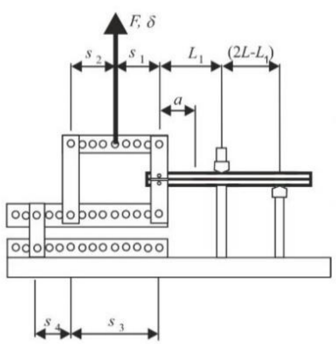


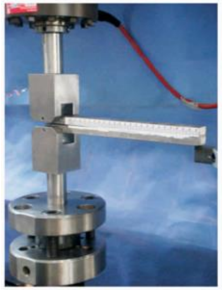
determination of the strain energy release rate in mode I, mode II and mixed mode I + II

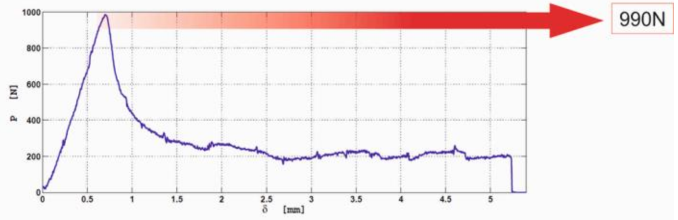
$$\psi = \arctan\left(\sqrt{G_{II}/G_{I}}\right)$$

problem components

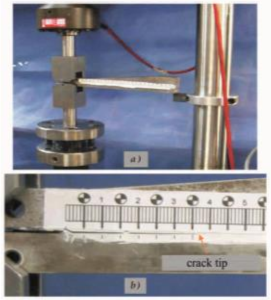
data collection

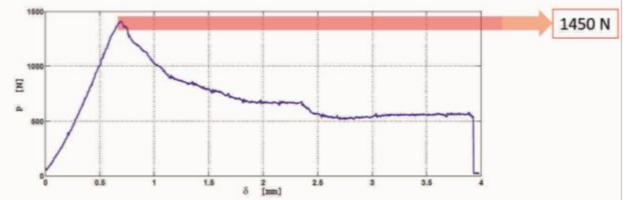
Test name	Test scheme	Global Mixity, Ψ (Degree)
Asymmetric Double Cantilever Beam (ADCB)		≈ 0 - 34°
Single Leg Bending (SLB)		≈ 41°
Crack Lap Shear (CLS)		≈ 49°
Asymmetric Tapered Double Cantilever Beam (ATDCB)		≈ 20°
Mixed Mode Bending (MMB)		$\Psi = f(c)$
Spelt Loading Jig (SPELT)		$\Psi = f(S_1, S_2, S_3, S_4)$



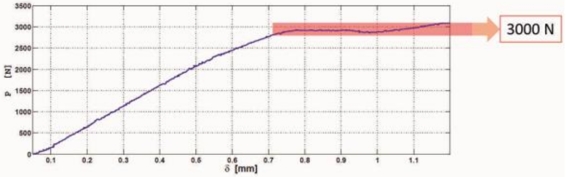


ADCB (P-δ) Load Displacement curve





ATDCB (P-δ) Load Displacement curve

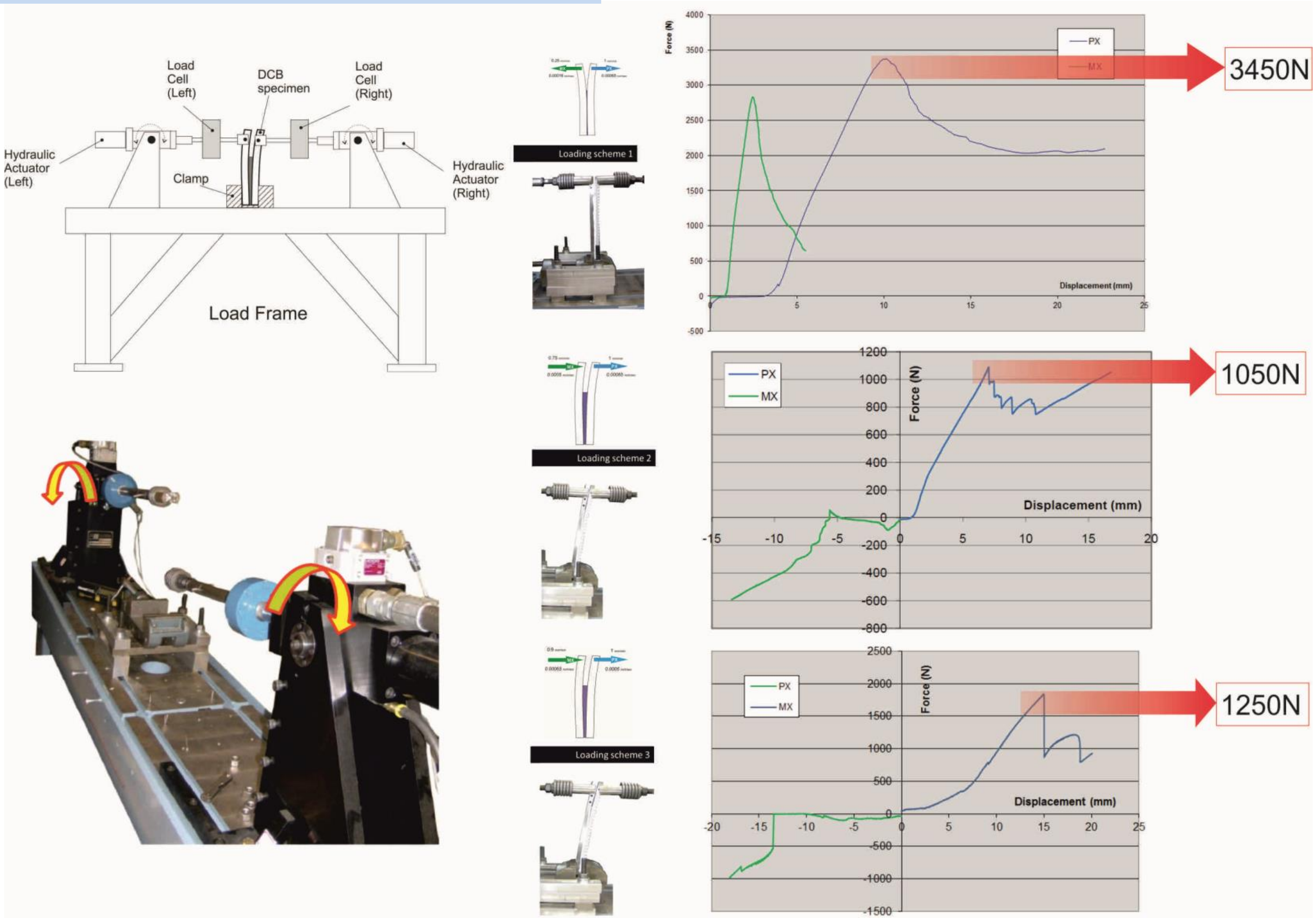


SLB (P-δ) Load Displacement curve

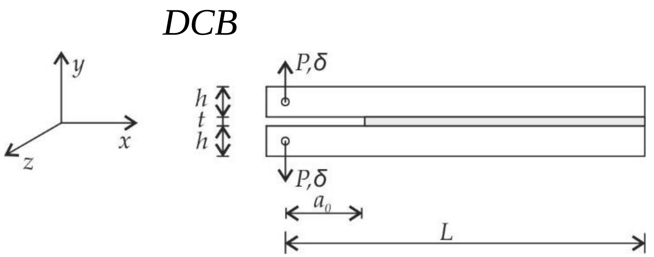
Fracture toughness of a structural adhesive under mixed mode loadings, Mat.-wiss. u.Werkstofftech. 2011, 42, No. 5, 460-470

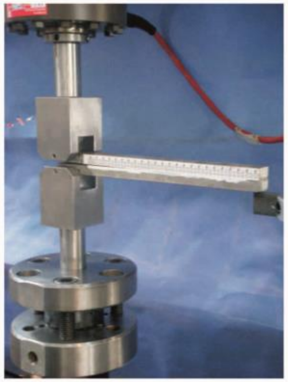
Virginia Tech's Dual Actuator Loading Frame

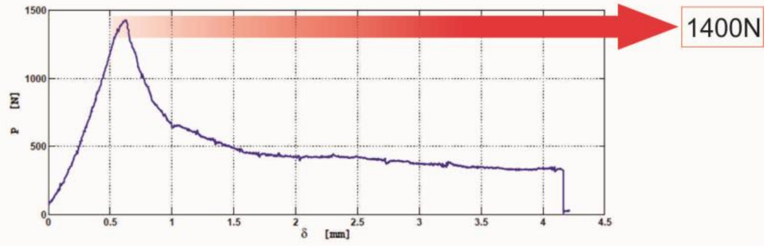
Numerical analysis of the dual actuator load test applied to fracture characterization of bonded joints,
International Journal of Solids and Structures 48 (2011) 1572–1578



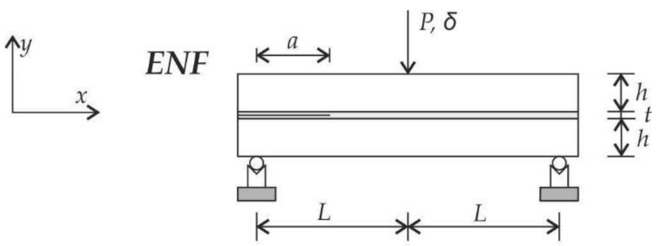
Pure modes [I and II]

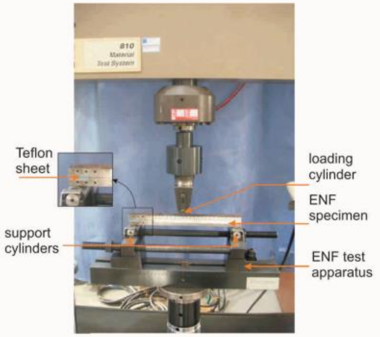


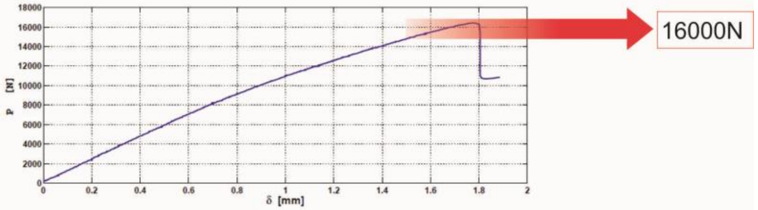




DCB (P-δ) Load Displacement curve

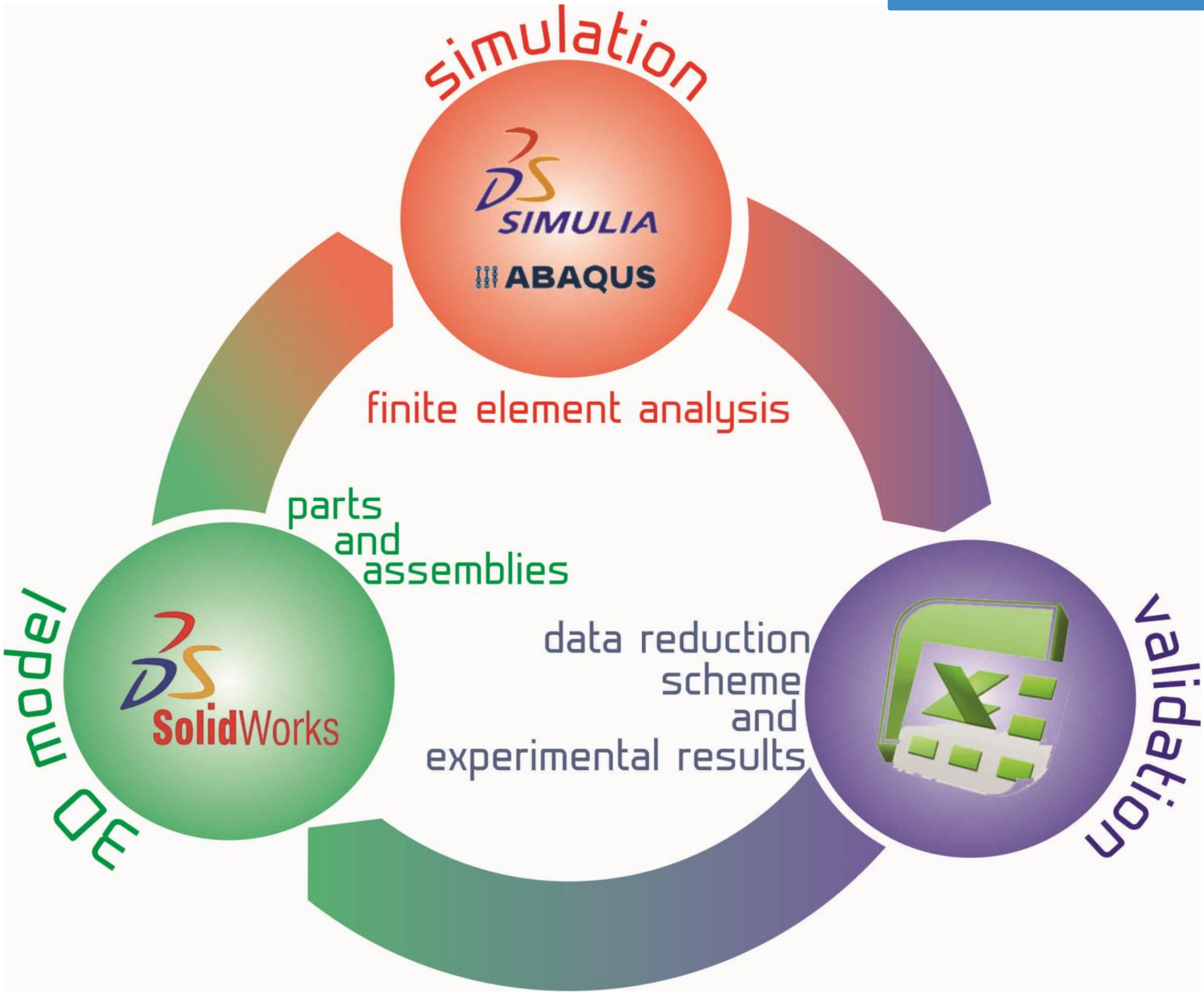






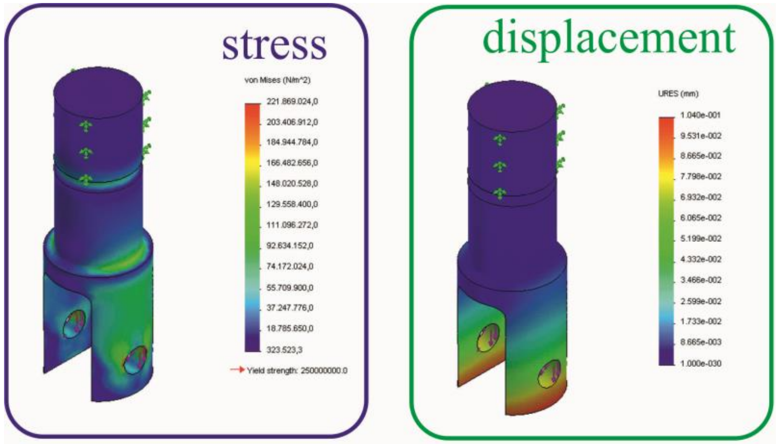
ENF (P-δ) Load Displacement curve

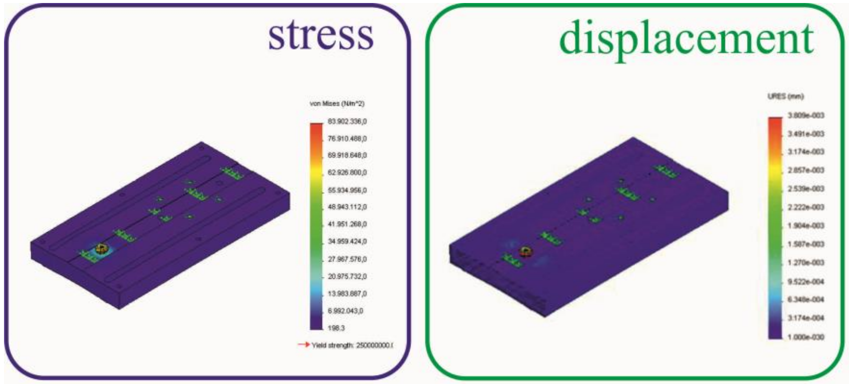
Mode II Fracture Toughness of a Brittle and a Ductile Adhesive as a Function of the Adhesive Thickness, The Journal of Adhesion, 86:889–903, 2010

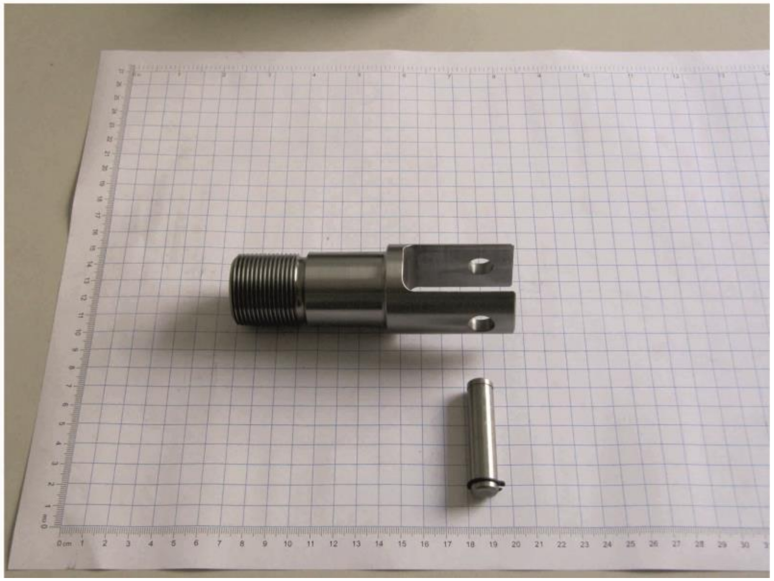

simulation
SIMULIA
ABAQUS
finite element analysis
parts
and
assemblies
3D model
SolidWorks
data reduction
scheme
and
experimental results
validation

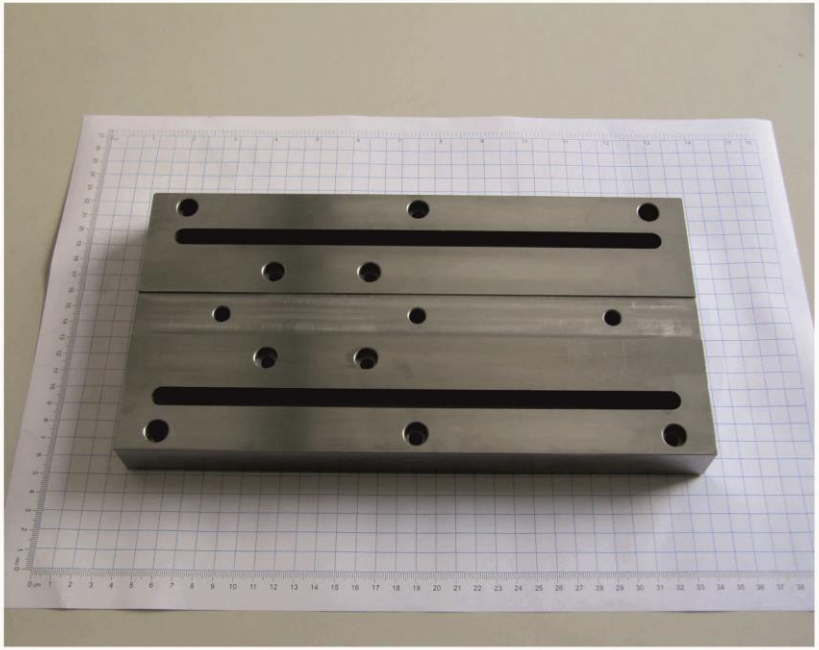
design methodology

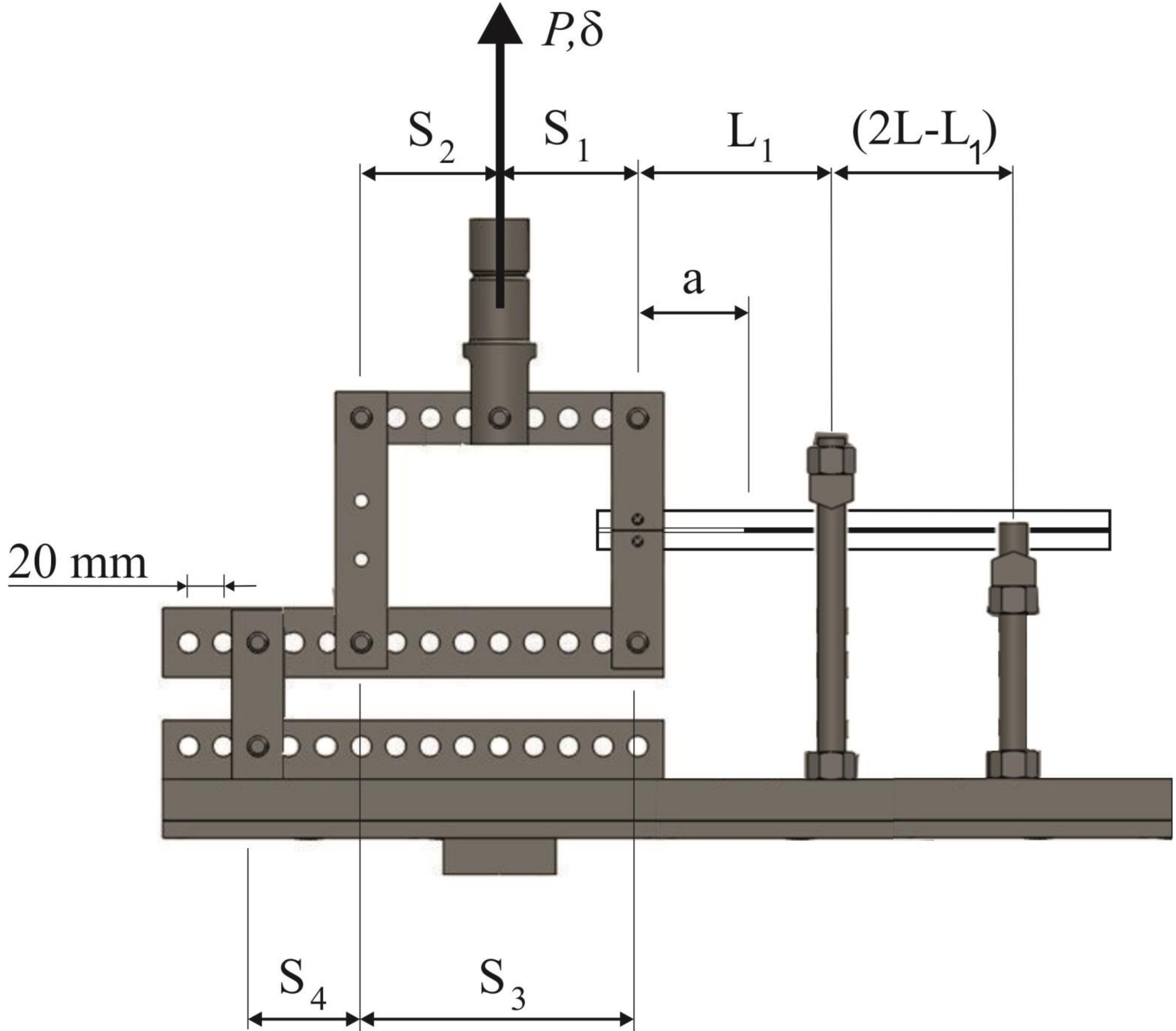
model – Solidworks ®



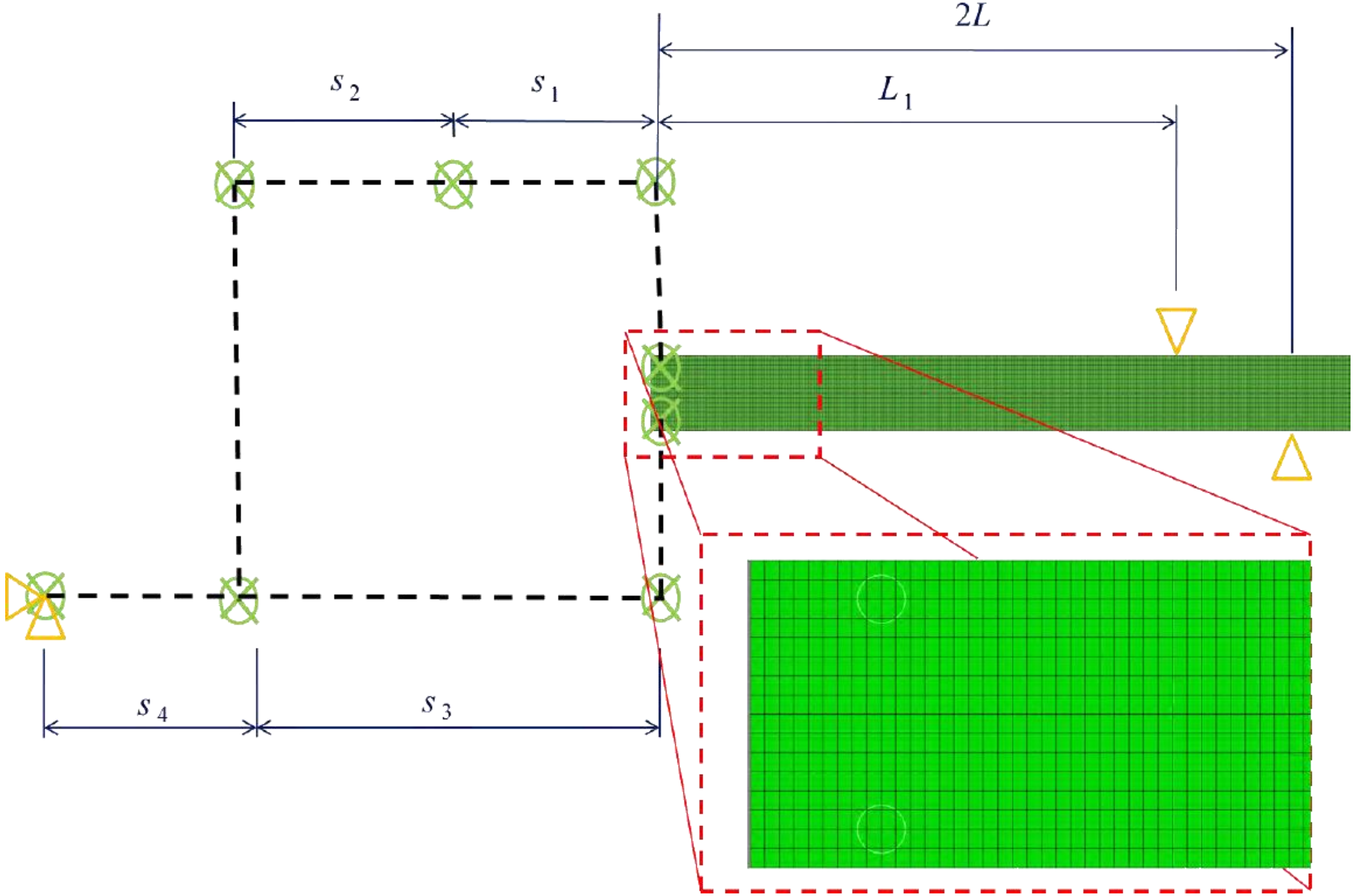




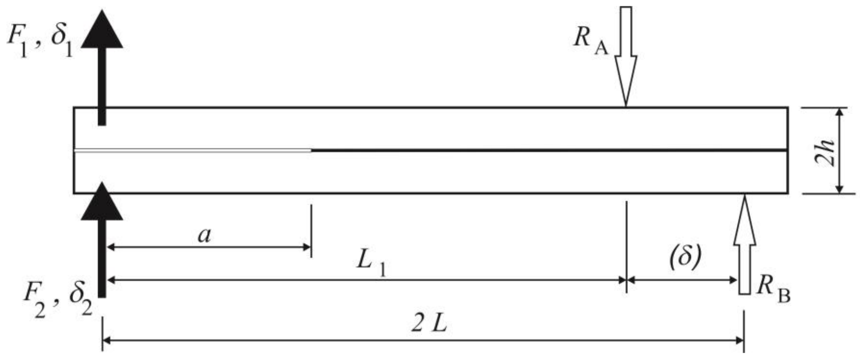



P,δ
S 2
S 1
L 1
(2L-L1)
a
20 mm
S 4
S 3

model – ABAQUS ®



loading scheme



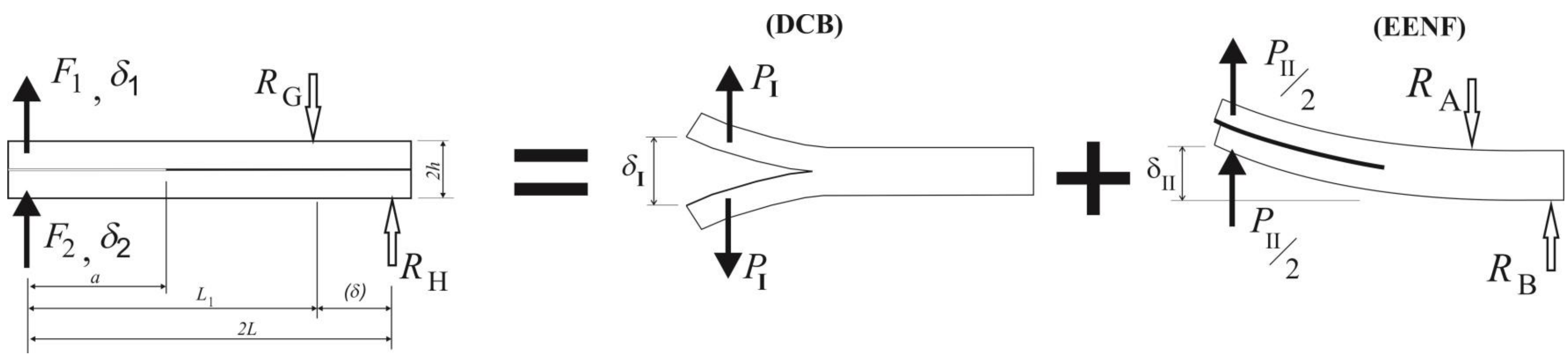
h = 12.7 mm

$2L$ = 260 mm

b = 25 mm

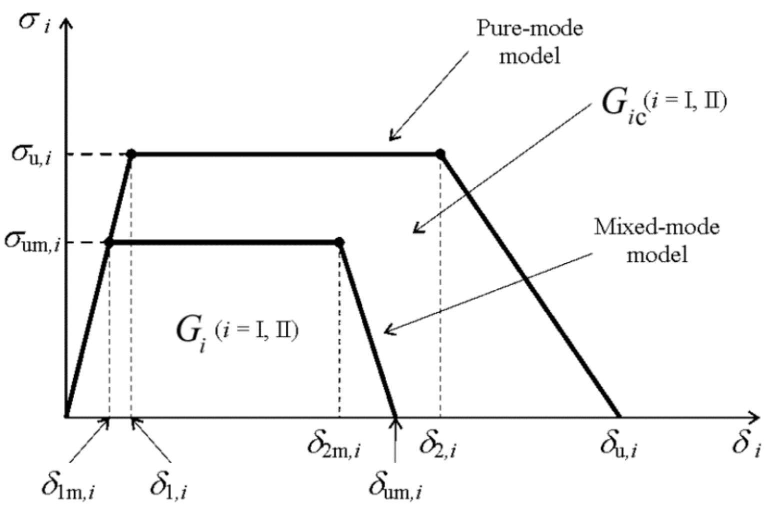
The specimen geometry is in accordance with the ASTM D3433-99

mode separation



model – ABAQUS ®

trapezoidal traction separation law



cohesive law damage parameters

Elastic properties (Steel)		Cohesive properties (Adhesive)					
E (GPa)	G (GPa)	$\sigma_{u,I}$ (MPa)	$\sigma_{u,II}$ (MPa)	G_{Ic} (N/mm)	G_{IIc} (N/mm)	$\delta_{2,I}$ (mm)	$\delta_{2,II}$ (mm)
210	80.77	23	23	0.6	1.2	0.0187	0.2062

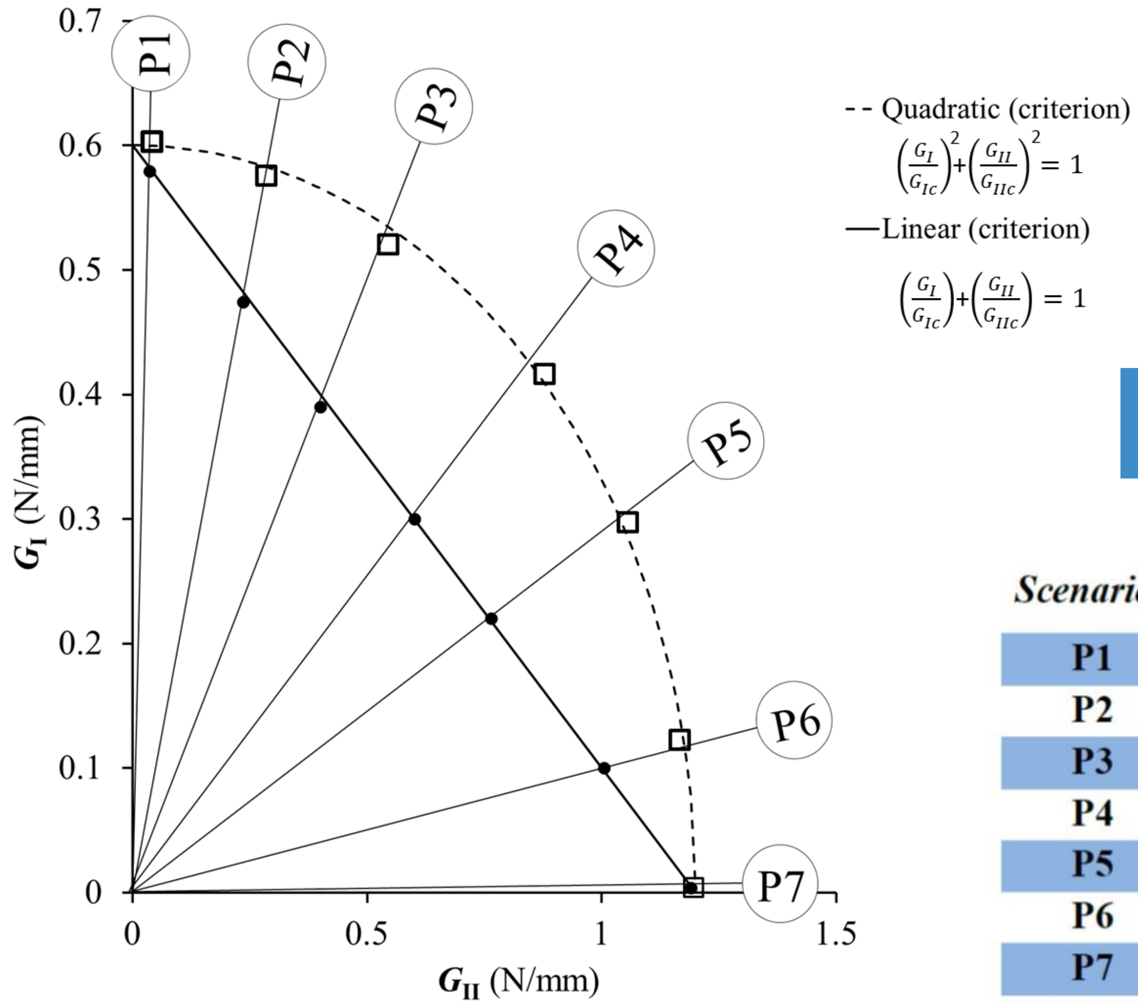
Steel properties used for substrates and Jig base

AISI P20	
Hardness (HB)	290/330
Yield Stress (MPa)	640
Ultimate Fracture Stress (MPa)	993
DIN CK 45	
Hardness (HB)	170
Yield Stress (MPa)	323
Ultimate Fracture Stress (MPa)	578

Spelt problem size in ABAQUS ®

Number of nodes	92199
Number of nodes defined by user	86547
Number of elements	79380
Number of elements defined by user	76551
Internal nodes generated by program	5652
Internal elem. generated for contact	2826
Number of variables in the model	268128

Fracture envelope for the seven scenarios considering the linear (•) and quadratic (◘) criteria.



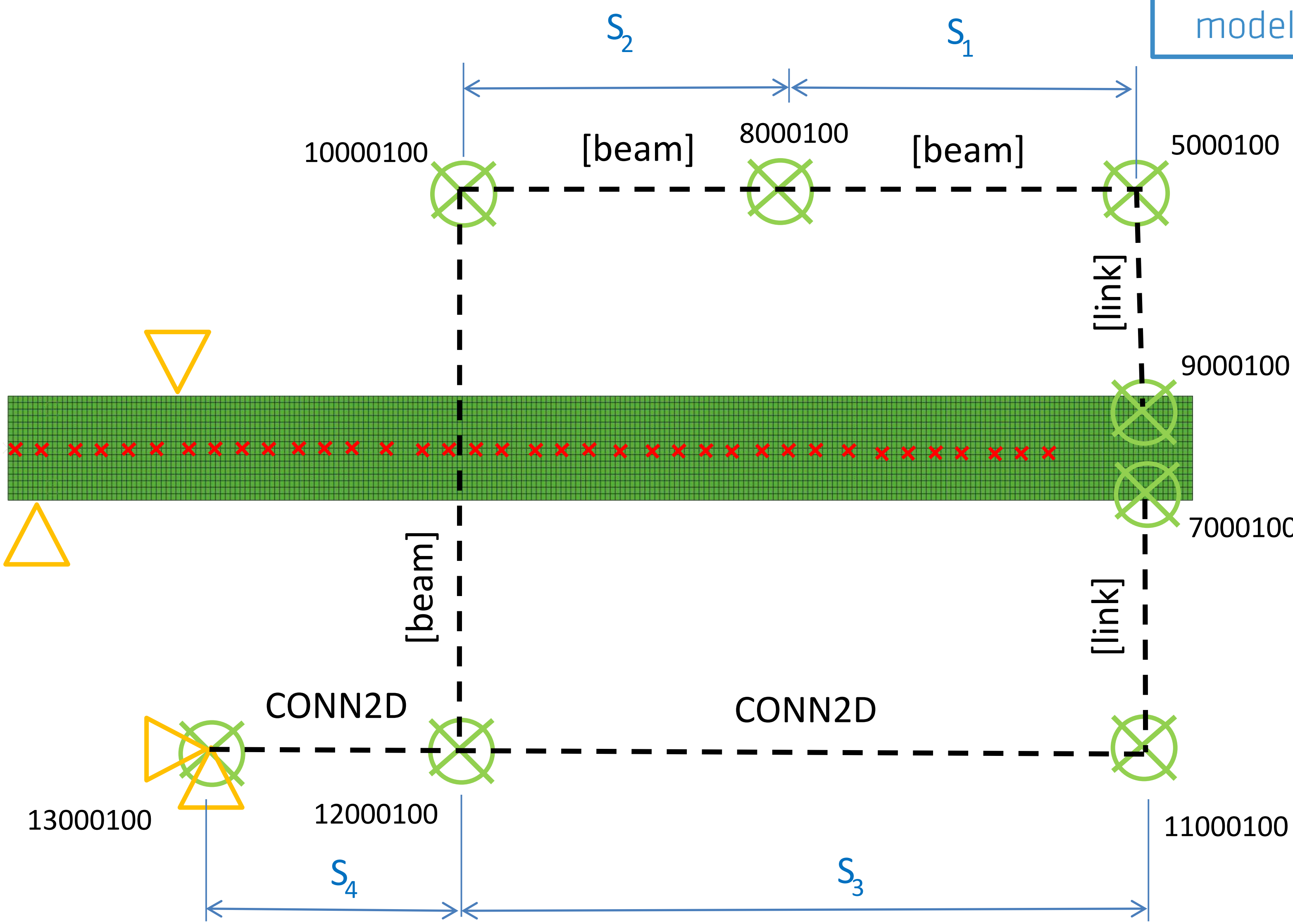
Different scenarios used for the fracture envelope calculation

	Jig arrangement			
Scenarios	s_1 (mm)	s_2 (mm)	s_3 (mm)	s_4 (mm)
P1	100	40	140	-60
P2	120	40	160	-120
P3	40	120	160	40
P4	60	80	140	60
P5	60	80	140	120
P6	40	40	80	100
P7	100	40	140	80

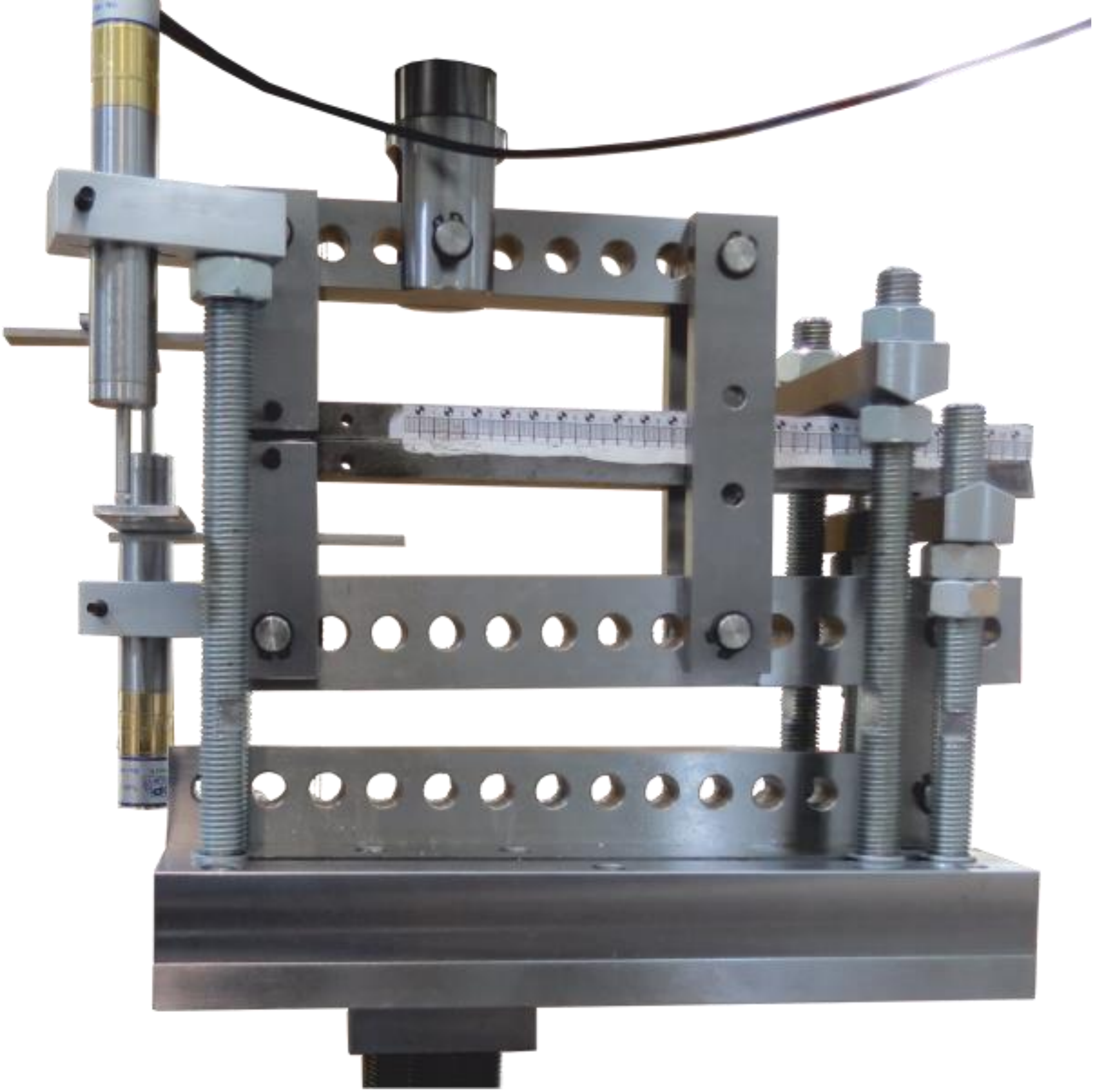
improved geometry for a smaller size spelt apparatus using the same DCB specimen

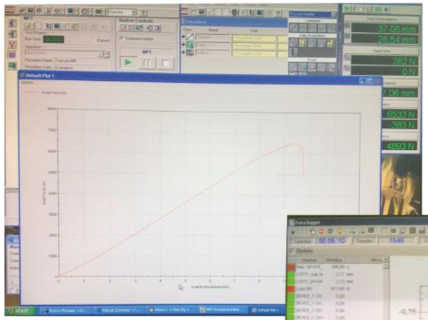
New Spelt

model – ABAQUS ®

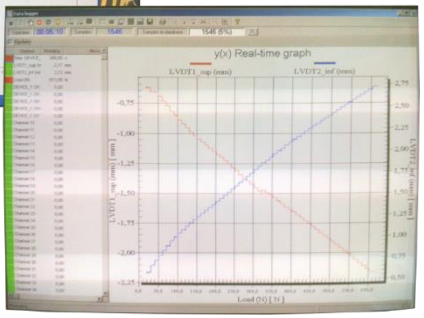


New Spelt
apparatus





load: F



displacements: δ_1 , δ_2

data reduction scheme

using CBBM

inputs

Obtained from the Universal Testing Machine

load F

Obtained from LVDTs attached to each specimen beam

displacements δ_1 , δ_2

Geometry & Material

s_1, s_2, s_3, s_4
B, h, E, G

load components

$$F_1 = F\frac{s_2}{s_3} \quad ; \quad F_2 = F\frac{s_1 s_4}{s_3\left(s_3+s_4\right)}$$

$$P_{\mathrm{I}} = \frac{F_1 - F_2}{2} \quad ; \quad P_{\mathrm{II}} = F_1 + F_2$$

displacement components

$$\delta_{\mathrm{I}} = \delta_1 - \delta_2$$

$$\delta_{\mathrm{II}} = \frac{\delta_1 + \delta_2}{2}$$

equivalent crack length

$$a_{e\mathrm{I}} = \frac{1}{6\alpha}A - \frac{2\beta}{A}$$

$$a_{e\mathrm{II}} = \left[\left(C_{\mathrm{II}} - \frac{6LL_1}{5BhG\left(2L-L_1\right)}\right)\frac{2Bh^3E}{3} - \frac{2LL_1^2}{3}\right]^{1/3}$$

compliance components

$$C_{\mathrm{I}} = \frac{\delta_{\mathrm{I}}}{P_{\mathrm{I}}}$$

$$C_{\mathrm{II}} = \frac{\delta_{\mathrm{II}}}{P_{\mathrm{II}}}$$

outputs

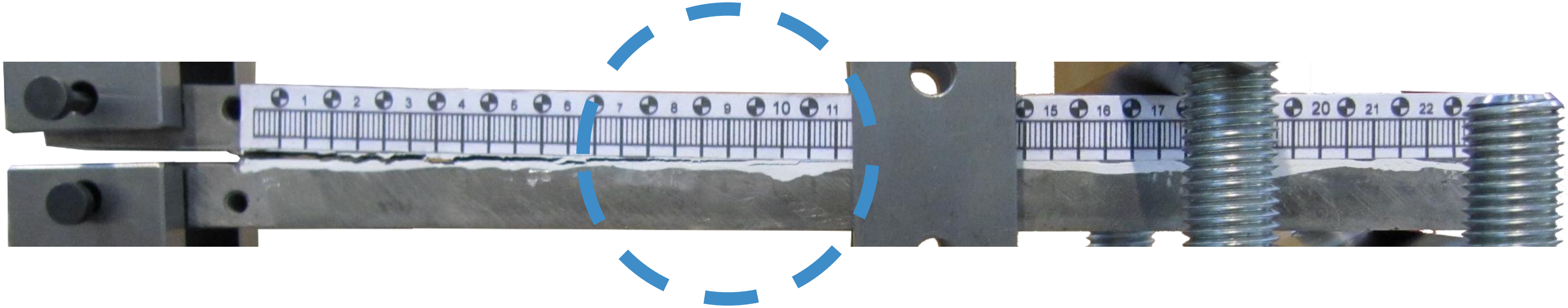
$$G_{\mathrm{I}} = \frac{6P_{\mathrm{I}}^2}{B^2h}\left(\frac{2a_{e\mathrm{I}}^2}{h^2E} + \frac{1}{5G}\right)$$

Mode I

$$G_{\mathrm{II}} = \frac{9P_{\mathrm{II}}^2 a_{e\mathrm{II}}^2}{4B^2h^3E}$$

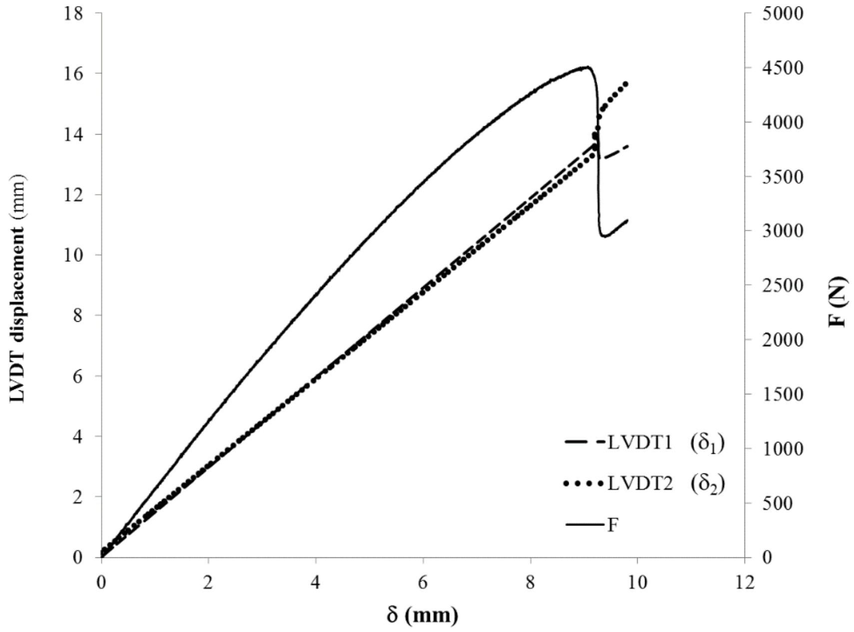
Mode II

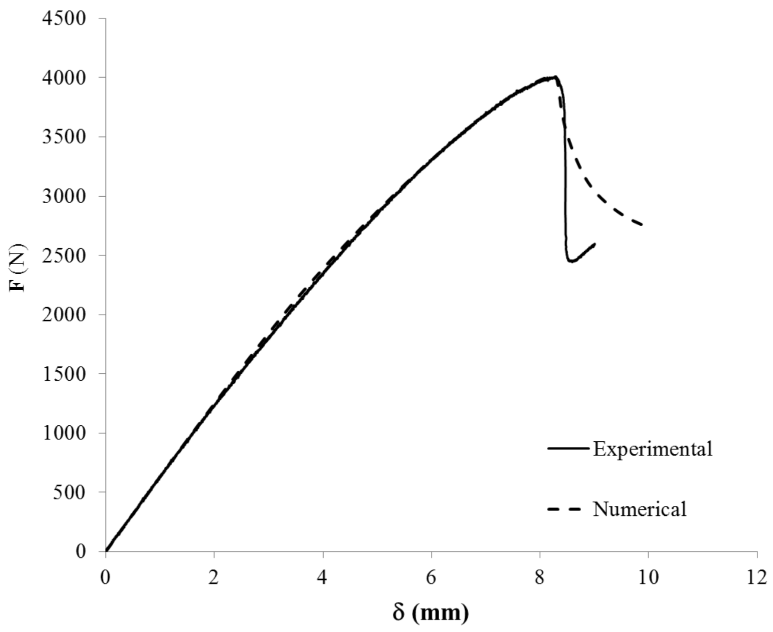
Numerical validation of a crack equivalent method for mixed-mode I + II fracture characterization of bonded joints, Engineering Fracture Mechanics. 2013, Vol. 107, pp. 38–47 crack length is dificult to read



visual assessment does not account for the FPZ

Load vs. Displacement curves for a ψ = 85° combination

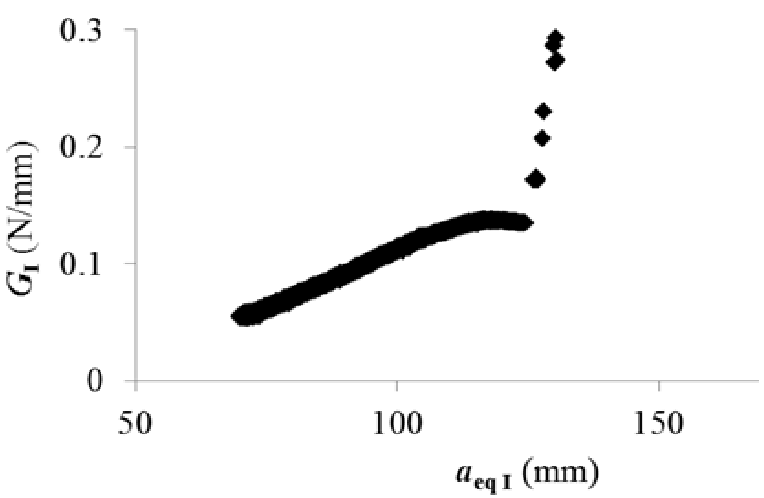


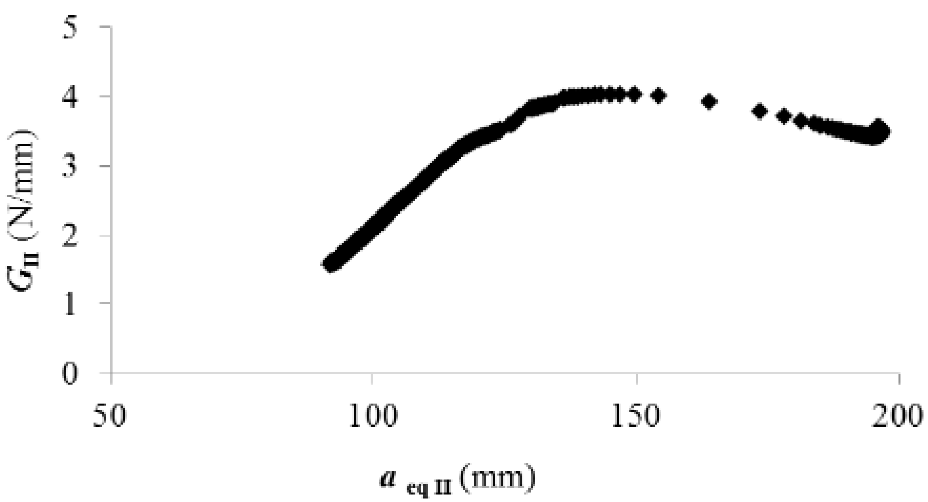


$$\psi = \arctan\left(\sqrt{G_{II}/G_{I}}\right);\ \ \psi = \arctan\left[\frac{\sqrt{3}}{2}\frac{\left(\frac{F_1}{F_2}+1\right)}{\left(\frac{F_1}{F_2}-1\right)}\right]$$

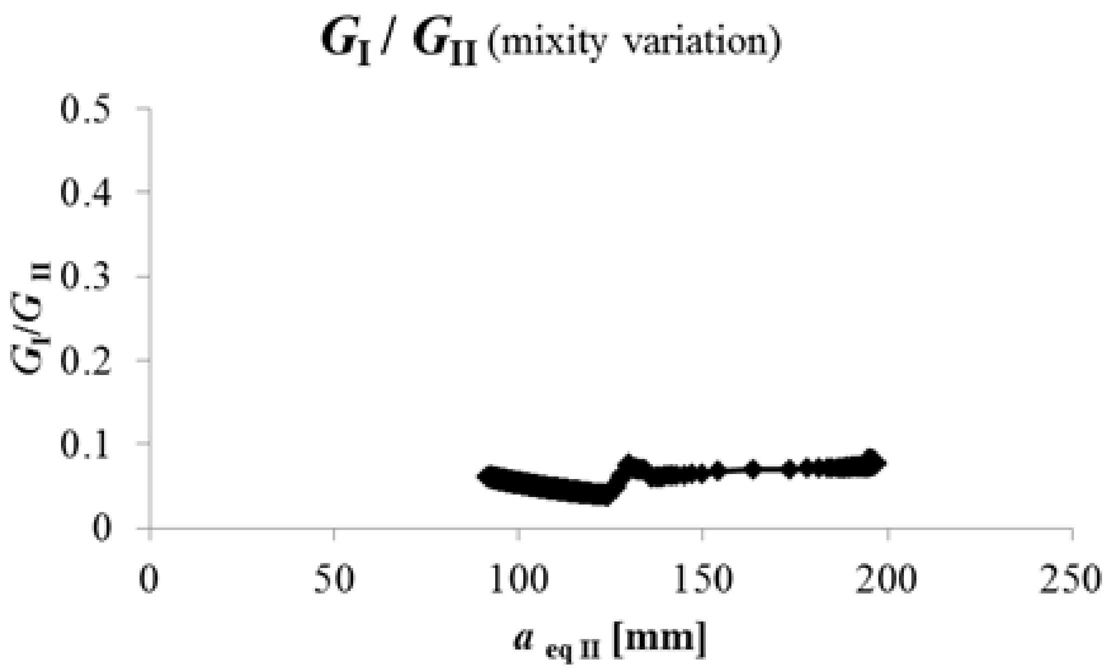
85º

R-curves (G_I and G_{II}) for a ψ = 85° combination



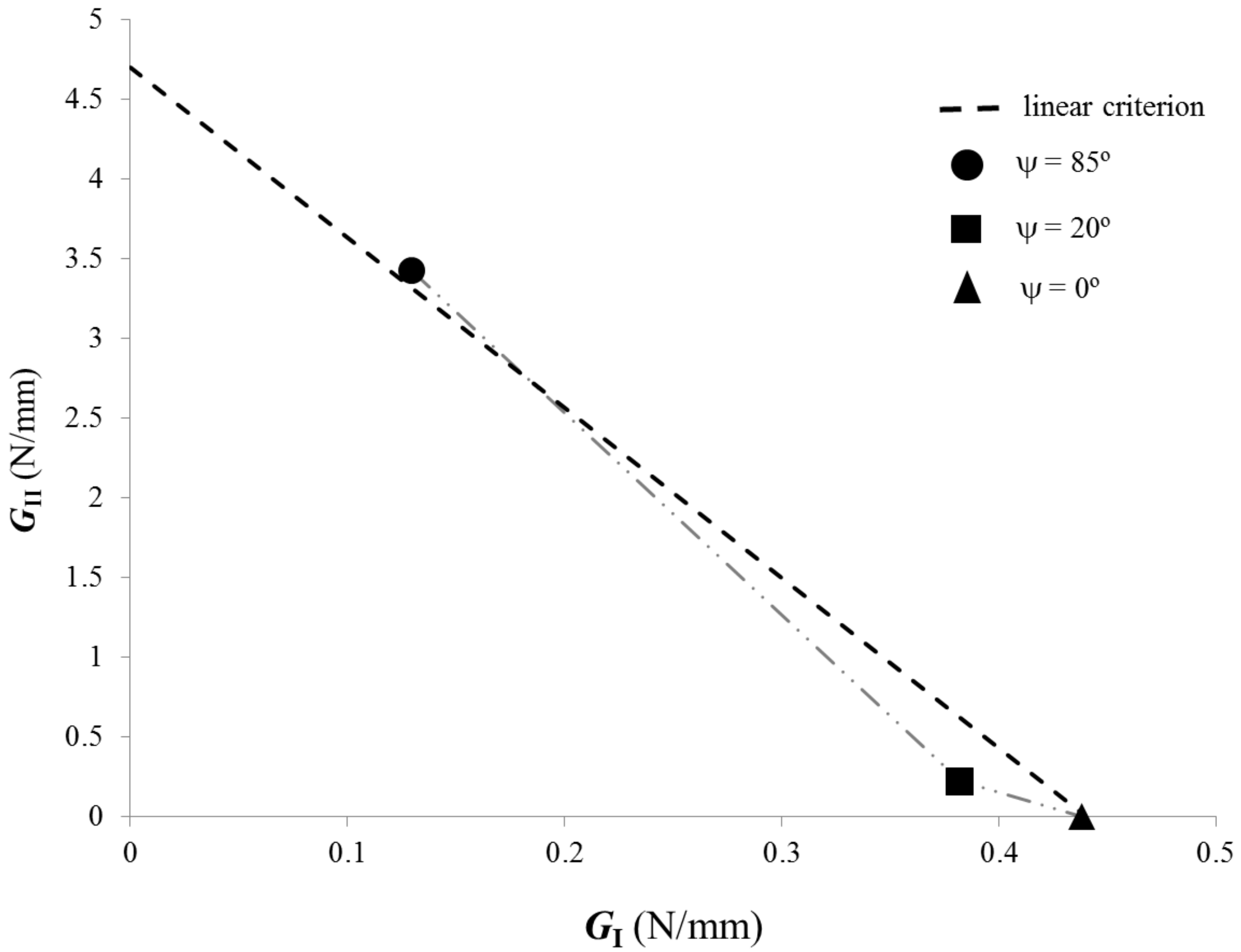


mixity variation (G_I / G_{II}) for a ψ = 85° combination

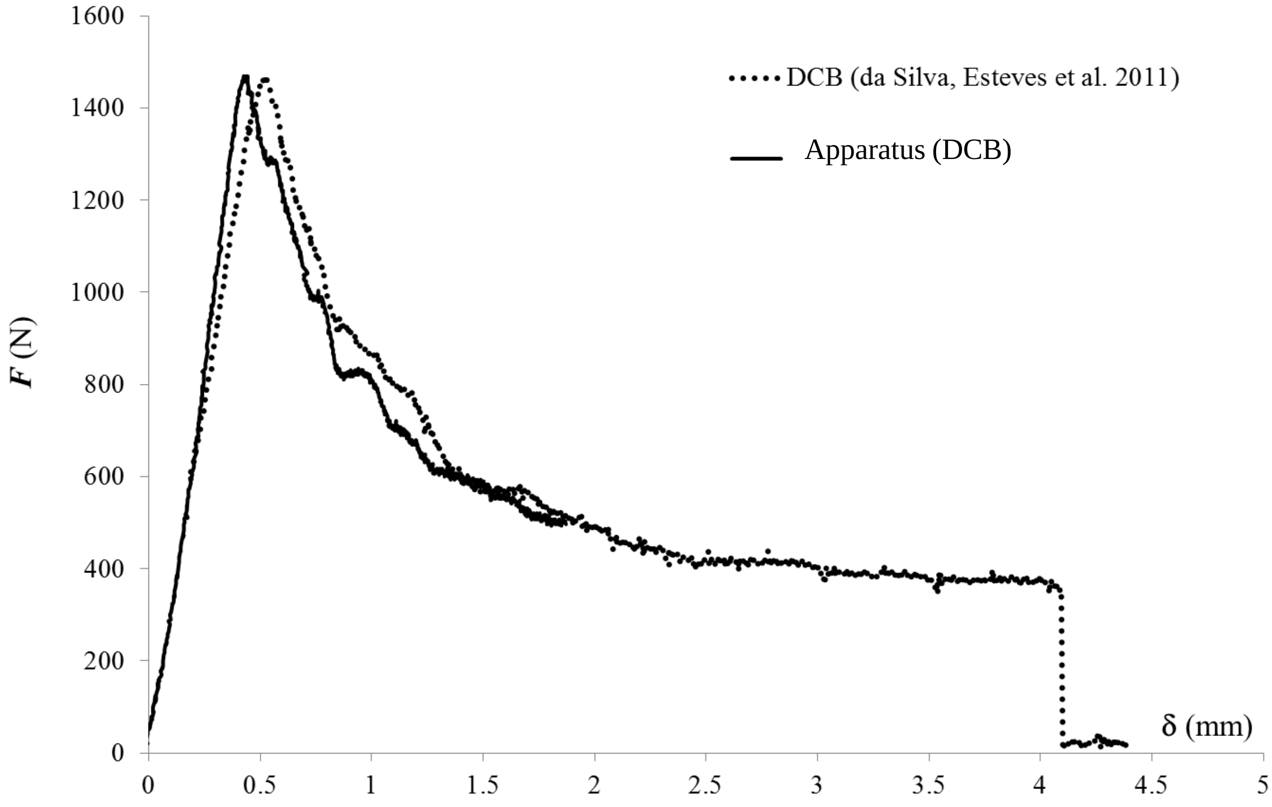


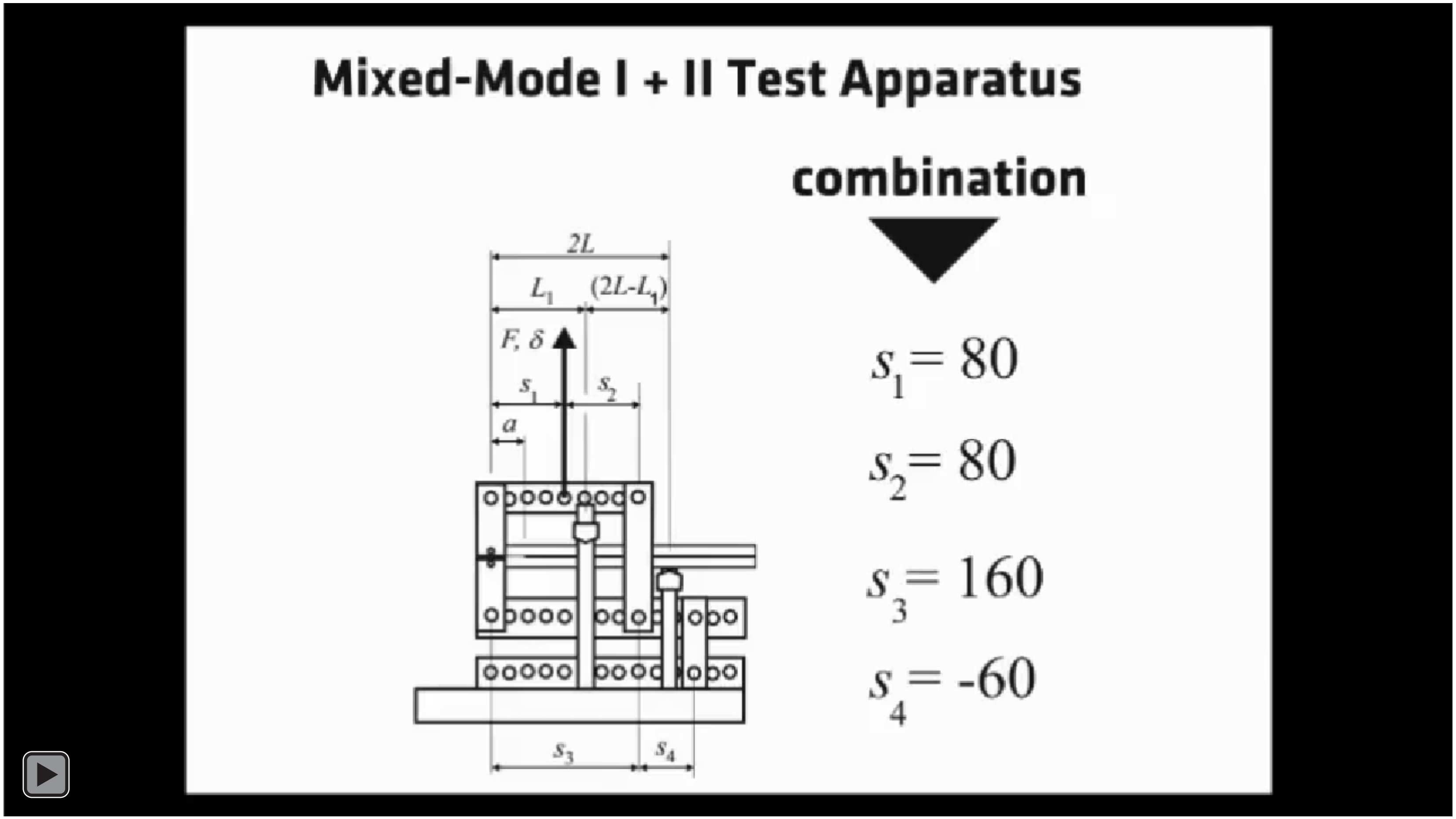
self similar crack propagation

Fracture envelope for three experiments



Load vs. Displacement curve for "classical" DCB and "apparatus" DCB




Mixed-Mode I + II Test Apparatus
combination
$2L$
L_1
$(2L-L_1)$
F, δ
s_1
s_2
a
s_3
s_4
$s_1 = 80$
$s_2 = 80$
$s_3 = 160$
$s_4 = -60$

conclusions

this apparatus represents a compact version of the SPELT JIG:
- using a standard DCB specimen (universal and easy to manufacture);
- covers all range of the fracture envelope from mode I to near mode II;
- promotes a self similar crack propagation.

in combination with the proposed data reduction scheme, accounts for the FPZ and does not requires for the crack length to be measured.

the development of the testing apparatus benefited of a design methodology based in numerical simulation using Finite Element Analysis

validation prior to manufacture, avoided errors and allowed optimization of materials and parts geometry

while at simulation stage a data reduction scheme that improves the efficiency of the test was also developed benefitting of the same design methodology

this data reduction scheme was first validated recurring to numerical results and later used to analyze experimental data with good results

the authors would like to thank "Fundação Luso-Americana para o Desenvolvimento" (FLAD) for the support through the project 314/06 2007 and Instituto de Engenharia Mecânica (IDMEC)

FUNDAÇÃO LUSO-AMERICANA

idmec FEUP engenharia mecânica

we also like to acknowledge the support provided to Virginia Tech by the National Science Foundation (DMR NSF 0415840) in the development of the dual loading frame capable of facilitating mixed mode studies.

NSF

VirginiaTech

thank you

questions ?

filipechaves.com/
apparatus