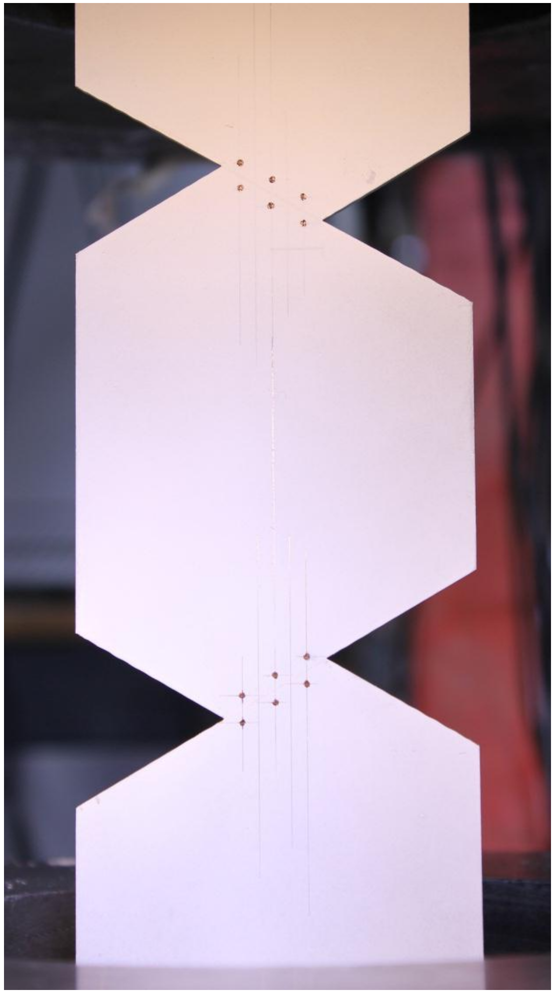
The University Of Sheffield.

OUTOKUMPU

Notched strip tensile tests to determine the yield characteristics of stainless steel

Jurgen Becque Maurizio Guadagnini

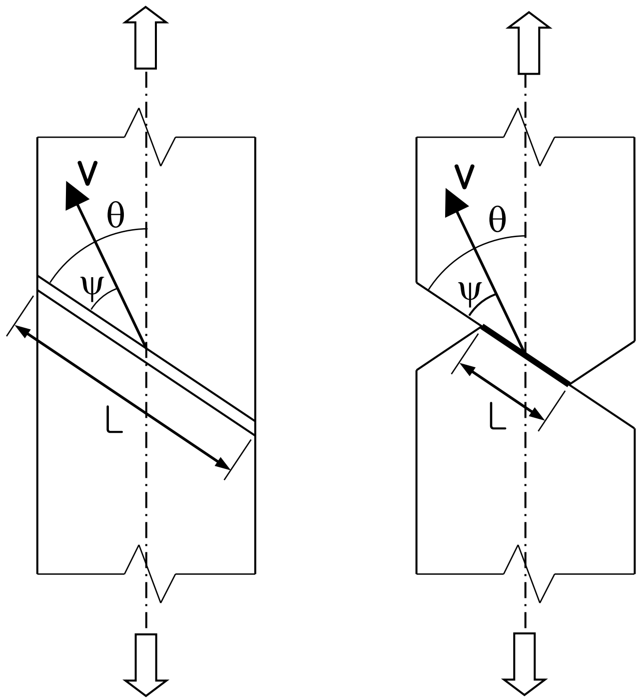
Ajibola Oyawoye Shan-Shan Huang



4th International Stainless Steel Experts Seminar Ascot, UK, 6-7 December 2012

How to subject a material to tension + shear ?

- tube under internal pressure + torsion
- tube under axial load + torsion
- grooved or notched strips (Bijlaard 1940; Hill 1953)



$55^o \leq \theta \leq 90^o$

Theory

- rigid-plastic material
- isotropic material
- uniform state of stress and strain in the neck

$$\frac{\dot{\varepsilon}_1}{1+\sin\psi} = \frac{\dot{\varepsilon}_2}{\sin\psi - 1} = \frac{\dot{\varepsilon}_3}{-2\sin\psi}$$

$$\frac{\sigma_1}{\sin(\theta-\psi)+\cos\theta} = \frac{\sigma_2}{\sin(\theta-\psi)-\cos\theta} = \frac{P}{tL\cos\psi}$$

Lode's parameters

$$\mu = -\frac{\sigma_1+\sigma_2}{\sigma_1-\sigma_2} = -\frac{3\cos\theta - \sin(\theta-\psi)}{\cos\theta + \sin(\theta-\psi)}$$

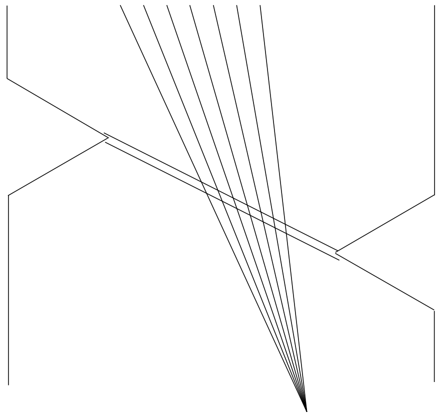
$$\nu = \frac{2\dot{\varepsilon}_2 - \dot{\varepsilon}_1 - \dot{\varepsilon}_3}{\dot{\varepsilon}_1 - \dot{\varepsilon}_3} = -\frac{3(1-\sin\psi)}{1+3\sin\psi}$$

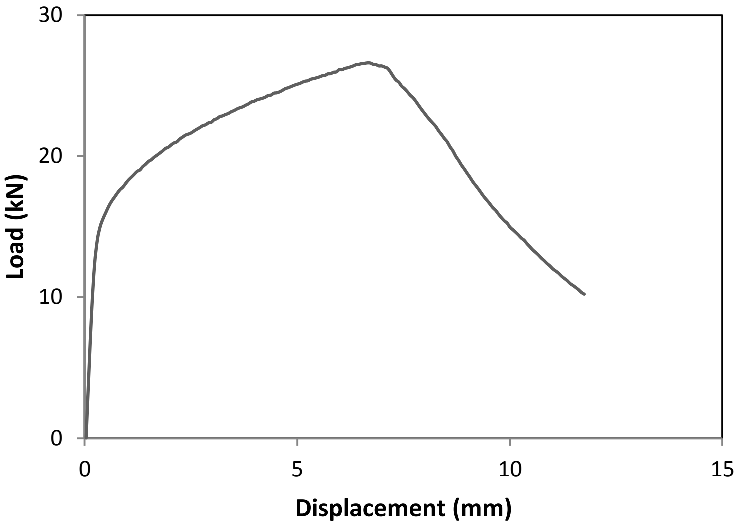
$$\mu = \nu$$

for the Von Mises yield surface

Problems

1 an accurate determination of ψ is difficult





2 an accurate determination of the yield load *P* is difficult

3 brittle fracture originating from the roots of the notches

4 risk of diffuse necking in strain hardening materials

5 theory only applies to isotropic materials

Proposed solutions

1 Digital Image Correlation (DIC)

3, 4 } material related (austenitic vs. ferritic)

⟹ sufficiently deep notches

⟹ laser-cut specimens

2, 5 } new theoretical developments needed

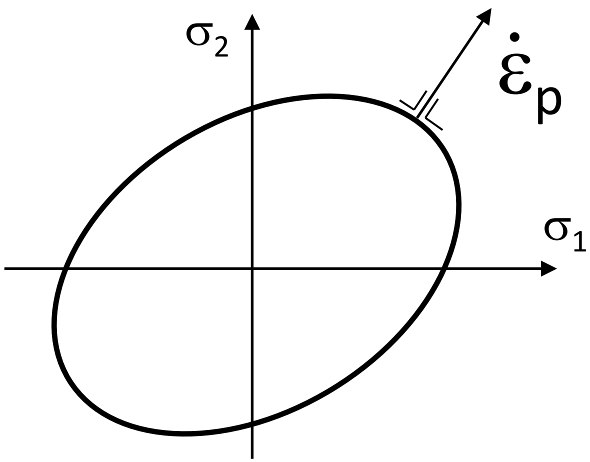
⟹ anisotropic material

⟹ eliminate the need to measure *P*

New theory

$$F\sigma_y^2 + G\sigma_x^2 + H(\sigma_x - \sigma_y)^2 + 2N\tau_{xy}^2 = \sigma_0^2$$

(Hill)



(θ,ψ) ⇒

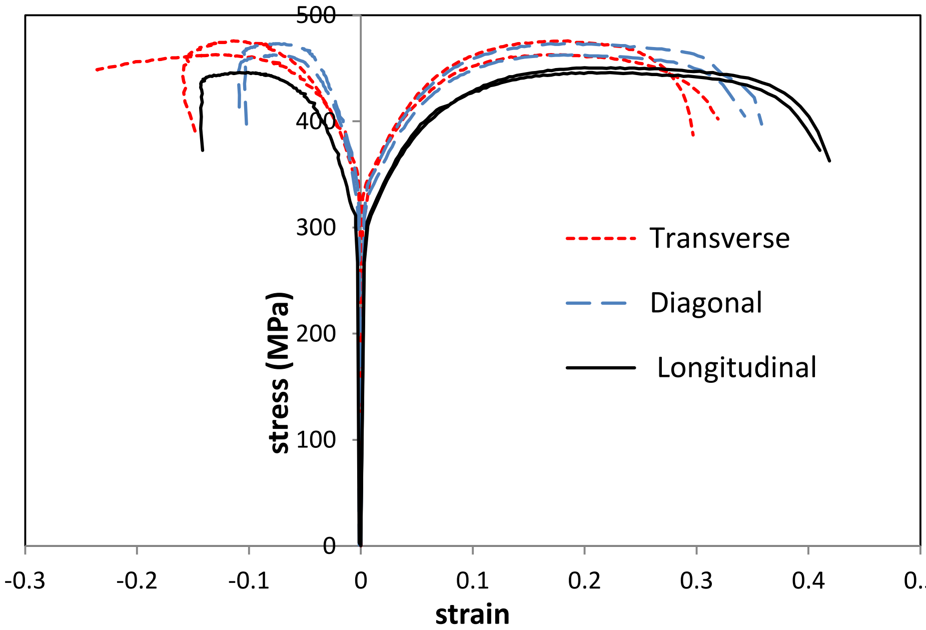
$$A = \frac{\sin\psi}{\sin(2\theta - \psi)}$$

$$B = \frac{2\sin\psi}{\cos(2\theta - \psi)}$$

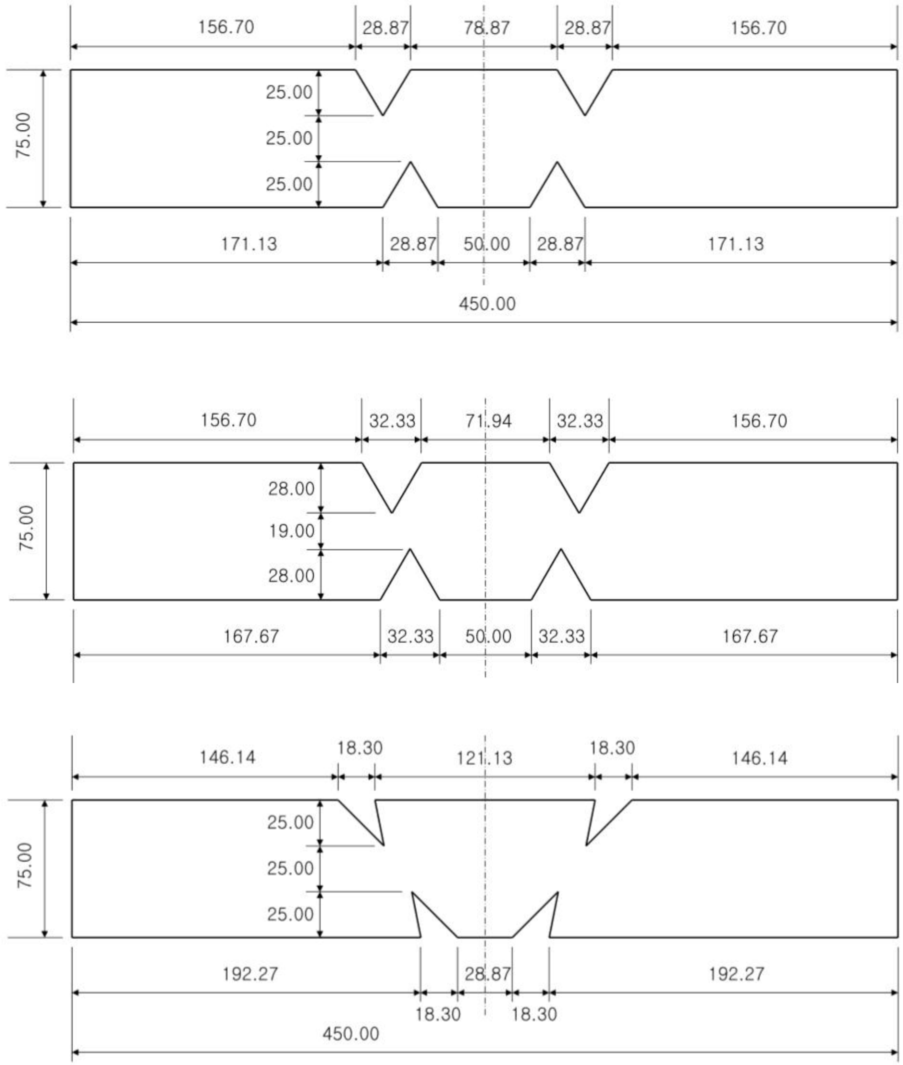
$$\frac{F\cos^2\theta + G\sin^2\theta + NB\sin\theta\cos\theta}{F(1+2\cos^2\theta) - G\cos(2\theta) - NB\cos(2\theta)/\tan\theta} = \frac{F(A-1)\cos^2\theta - G(A+1)\sin^2\theta + 2HA\cos(2\theta)}{F(A-1)(1+2\cos^2\theta) + G(A+1)\cos(2\theta) + 8HA\cos^2\theta}$$

Experimental program: tensile tests

	430 (1.4016)	304L (1.4301)
Rolling dir.	315 MPa	290 MPa
Diagonal dir.	340 MPa	292 MPa
Transverse dir.	345 MPa	290 MPa



Experimental program: notched strip tests

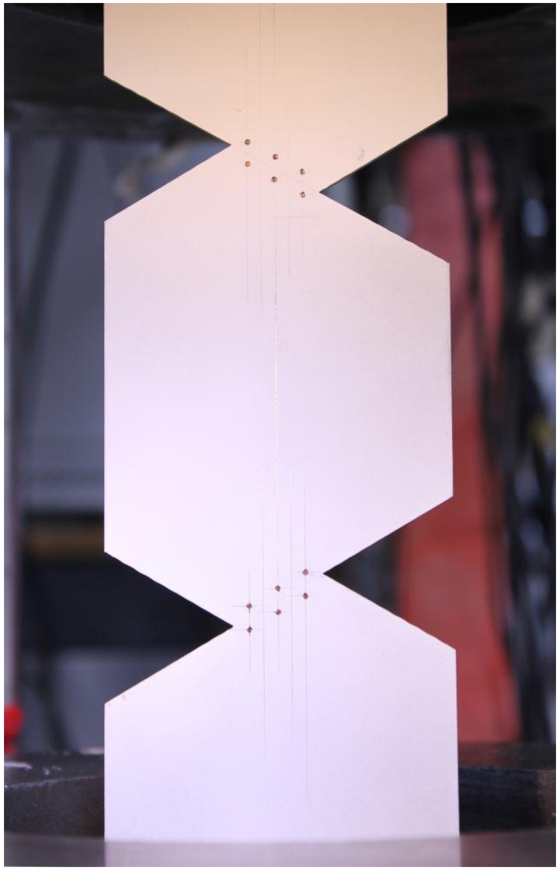


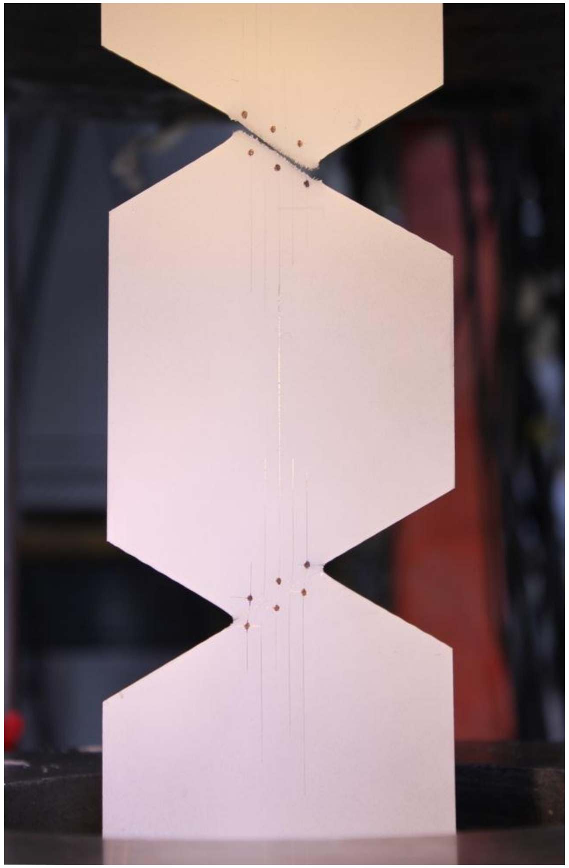
$\theta = 60^o$

$\theta = 70^o$

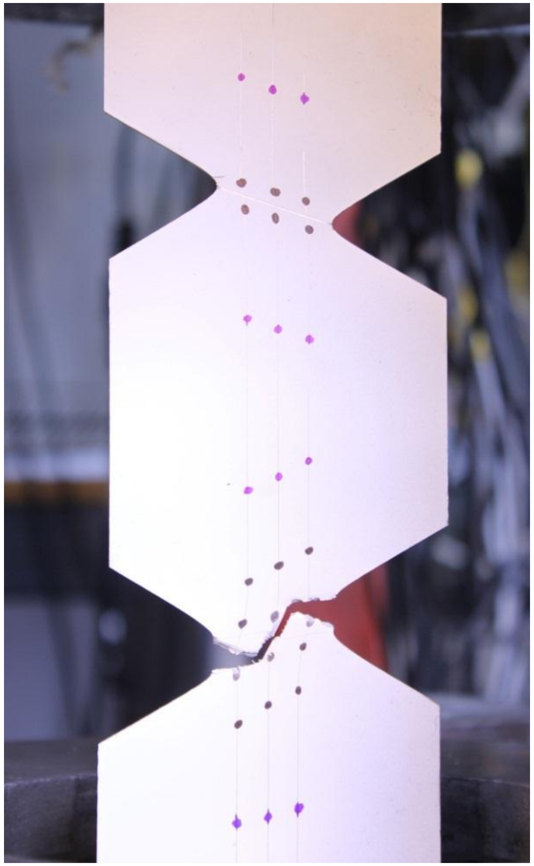
$\theta = 80^o$

Experimental program: notched strip tests



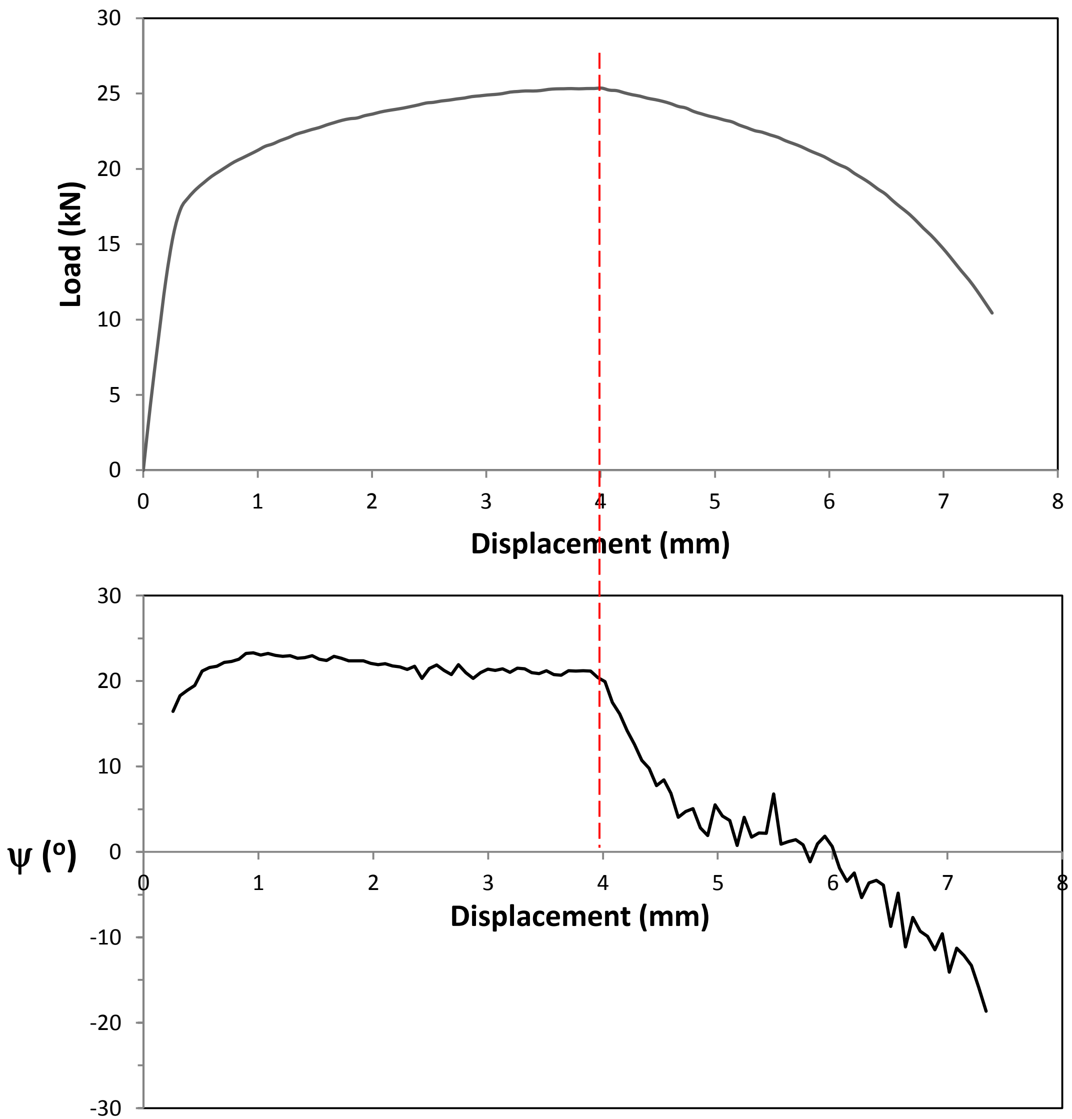


Ferritic



Austenitic

Results



30
25
20
15
10
5
0
Load (kN)
0
1
2
3
4
5
6
7
8
Displacement (mm)
30
20
10
0
-10
-20
-30
ψ (º)
0
1
2
3
4
5
6
7
8
Displacement (mm)

Results: 304L austenitic

Specimen	θ	ψ	ψ (theory)	F	G	H	N
	o	o	o	-	-	-	-
NA-0-60-B	60.31	22.21	23.68	0.464	0.464	0.536	1.508
NA-0-70-B	69.86	36.22	34.29	0.534	0.534	0.466	1.438
NA-0-80-B	79.99	56.68	54.77	0.533	0.533	0.467	1.440
NA-90-60-B	59.55	26.84	23.04	0.594	0.594	0.406	1.378
NA-90-70-B	69.63	33.58	33.95	0.490	0.490	0.510	1.483
NA-90-80-B	80.12	55.84	55.13	0.509	0.509	0.491	1.464
			Average	0.521	0.521	0.479	1.452
			COV	0.086	0.086	0.093	0.031

Average difference = 1.08°

Results: 430 ferritic

Specimen	θ	ψ	ψ (theory)	F	G	H	N
	o	o	o	-	-	-	-
NF-0-60-B	60.17	26.43	23.56	0.573	0.411	0.427	1.232
NF-0-70-B	69.90	37.97	34.34	0.582	0.420	0.418	1.224
NF-0-80-B	80.30	57.50	55.63	0.555	0.393	0.445	1.251
NF-90-60-B	60.62	21.06	23.95	0.504	0.342	0.496	1.302
NF-90-70-B	70.04	31.74	34.55	0.497	0.335	0.503	1.308
NF-90-80-B	79.81	58.23	54.28	0.602	0.440	0.398	1.204
NF-0-60-D	60.36	22.72	23.72	0.480	0.318	0.520	1.326
NF-0-70-D	69.85	36.91	34.27	0.563	0.401	0.437	1.243
NF-0-80-D	80.41	54.72	55.94	0.501	0.339	0.499	1.304
NF-0-60-S	59.70	25.96	23.17	0.572	0.410	0.428	1.234
NF-0-70-S	69.92	39.75	34.37	0.616	0.454	0.384	1.189
NF-0-80-S	79.66	60.44	53.87	0.653	0.491	0.347	1.153

	F	G	H	N
Average[1]	0.540	0.378	0.460	1.266
COV[1]	0.082	0.117	0.096	0.035

Conclusions

Notched strip tests have the potential to provide an easy-to-use method to determine the yield surface of stainless steel alloys, provided that:

- DIC is used as a measurement method
- the method is used in conjunction with new theoretical developments which account for anisotropy and eliminate the need for measurements of the applied load