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Experimental Determination of Apparent Fracture Toughness (K_{INu}) for Aluminum Sheets

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Abstract

Aluminum strips of 150mm x 50mm x 0.3mm with single edge notch depth (a) in the range of 5mm to 25mm, center crack length($2a$) in range of 5m to 25mm and double edge notch specimens with individual notch depth(a) in the range of 5mm to 20mm were prepared. These strips were tested under tensile loading at a strain rate of 0.2mm/minute and 1mm/minute. The stress intensity factor (SIF) for varying notch depth was calculated using finite element simulations using global energy release rate method and domain integral (J-integral) method. These tests were followed by preparation of strips of 150mm x 50mm x 0.3mm with inclined center crack length($2a$) varying in range of 10 mm to 50mm. The angle of inclinations were 30^o, 45^o and 60^o. These strips were tested under tensile loading at a strain rate of 0.2mm/minute. The stress intensity factor(SIF) was calculated numerically using domain integral method for the inclined crack geometries. The apparent fracture toughness(K_{INu}) values were calculated using the peak loads obtained from the experimental data and the numerically calculated SIF's.

Key words: *Aluminium; Apparent Fracture Toughness; Stress Intensity Factors; Strain Energy Release; J-Integral; Plane Stress*

Experimental Determination of Apparent Fracture Toughness of Thin Aluminium Sheets

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Aim

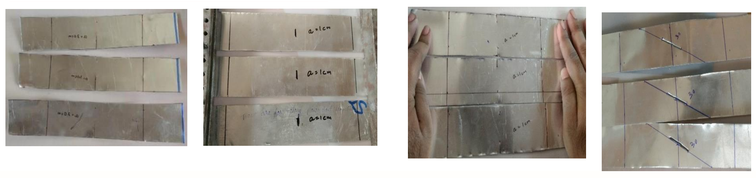
To conduct experiments to determine Mode-I critical stress intensity factor (K_{1C},K_{1Nu}) of aluminium sheets of 0.3 mm thickness for varying strain rates and crack lengths for different specimen geometries.

$$K_{1C} = \sigma_C \sqrt{\pi (a_0 + \Delta a_{ec})}\, f\left(\frac{a_0 + \Delta a_{ec}}{w}\right)$$

Eqn.1: Critical Stress Intensity Factor (Plane Stress)

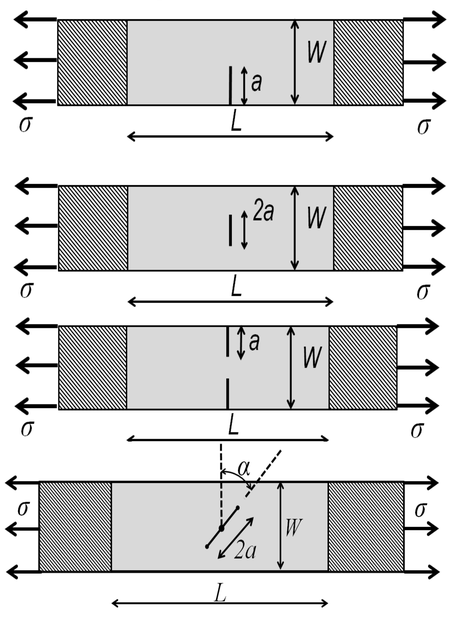
$$K_{1Nu} = \sigma_C \sqrt{\pi a_0}\, f\left(\frac{a_0}{w}\right)$$

Eqn.2: Apparent Fracture Toughness



Experimental Description

Test Samples: Tensile Loading



Single Edge Notch (**SEN**)

Center Crack Specimen (**CCS**)

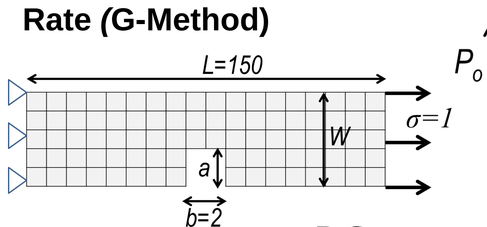
Double Edge Notch (**DEN**)

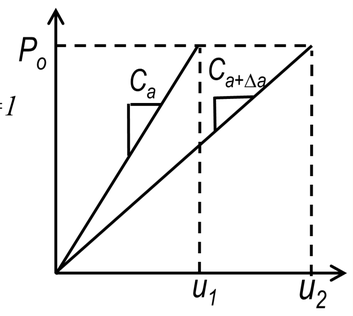
Inclined Center Crack
α= 30º, 45º, 60º

Specimen Type L=150, W=50, Grip Length = 2 x 25		Crack	Dimensions (mm)	Strain Rate in mm/minute
SEN		a	5, 10, 15, 20, 25	0.2
				1
Center Crack(CCS)		2a	5, 10, 15, 20, 25	0.2
				1
DEN		a	5, 10, 15, 20	0.2
				1
Inclined Center crack	α=30^O	2a	10, 20, 30, 40, 50	0.2
	α=45^O			
	α= 60^O			

Numerical Simulations for Determining K_I

Global Compliance and Strain Energy Release Rate (G-Method)



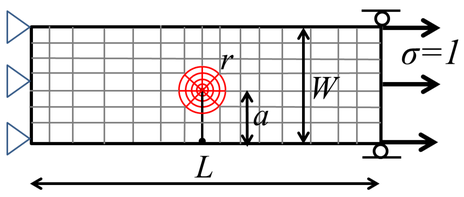


$$u_1 = P_0 C_a \qquad u_2 = P_0 C_{a+\Delta a}$$

$$a_m = \frac{a + (a + \Delta a)}{2}$$

$$G(a_m) = \frac{1}{2}\left(\frac{P_0 u_2 - P_0 u_1}{\Delta a}\right) \qquad K_I(a_m) = \sqrt{EG(a_m)}$$

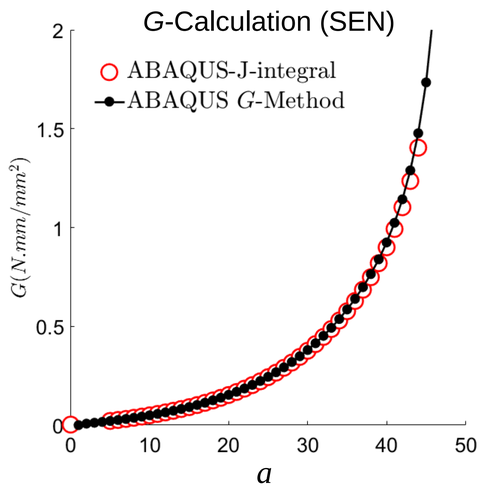
J-Integral Method

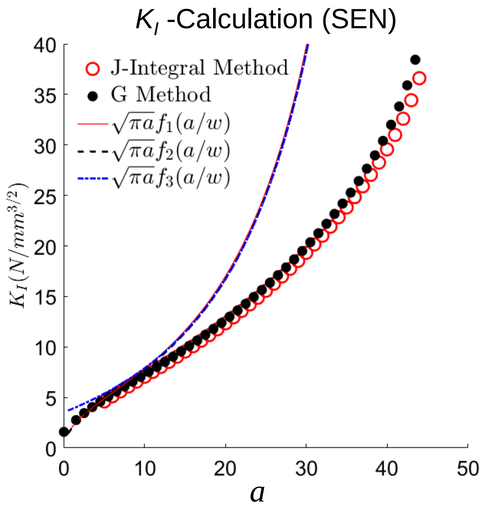


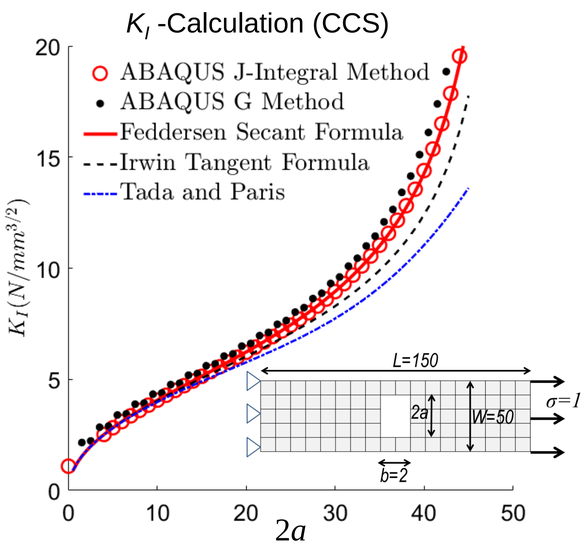
$$G = \int_\tau \left(Un_1 - T_i \frac{\partial u_i}{\partial x_1} \right) dS$$

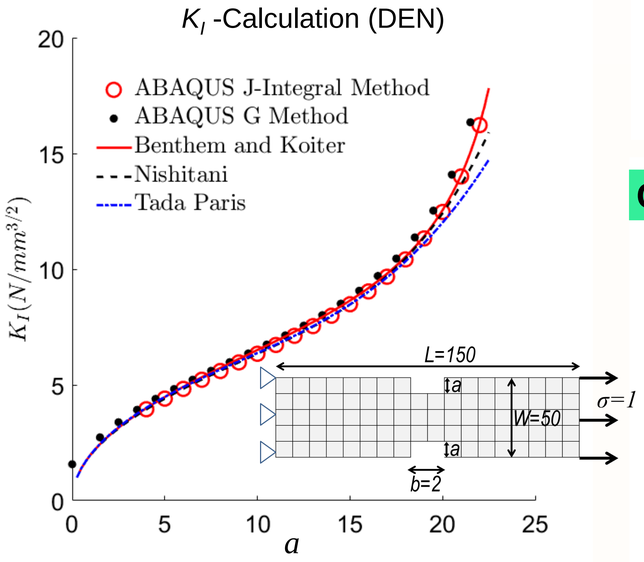
$$K = \sqrt{EG}$$

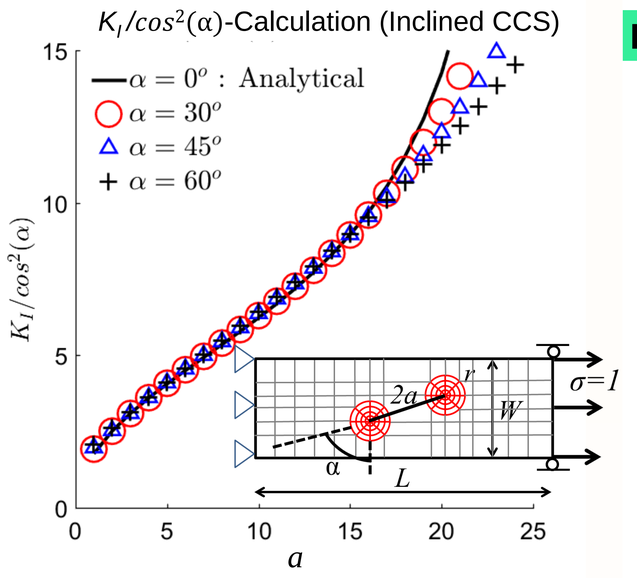
Numerical Results





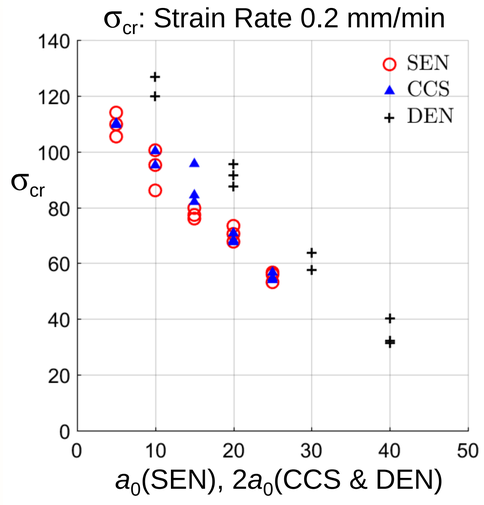


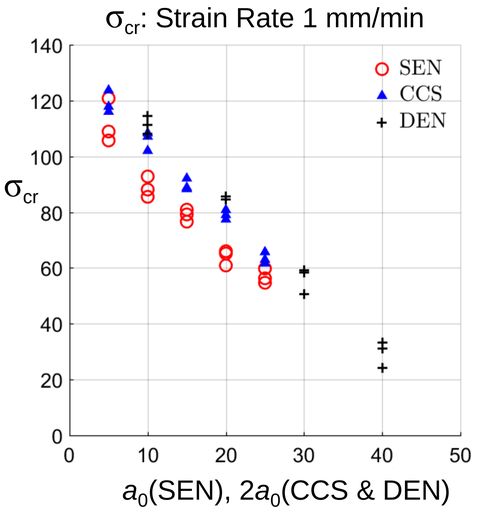




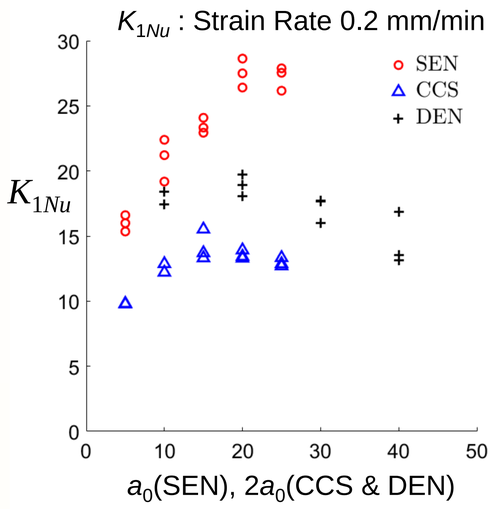
Experimental Results

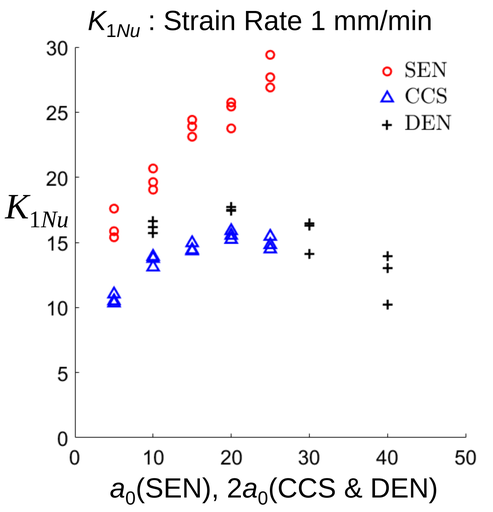
Peak Stress Values(MPa): SEN, CCS, DEN



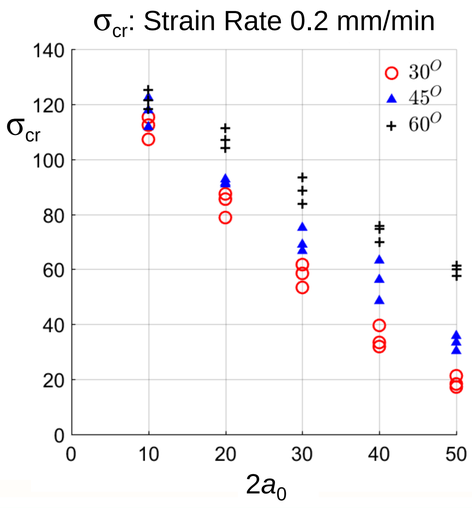


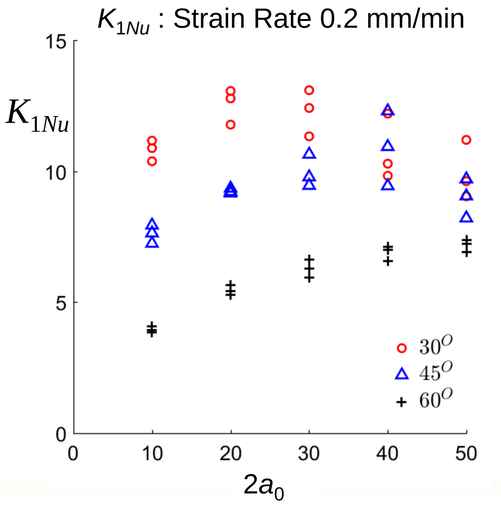
Apparent Fracture Toughness (K_{1Nu}) MPa$\sqrt{m}$: SEN, CCS, DEN





Inclined CCS: Peak Stress and Apparent Fracture Toughness





Conclusions

1. K_{1Nu} : Range of values 10-30 $MPa\sqrt{m}$.
2. K_{1Nu} : Negligible change with increase in strain rate from 0.2 mm/minute to 1mm/minute.
3. K_{1Nu}: Dependent on the crack length(flaw size) although the specimen size was constant.
4. For SEN specimens, the analytical expressions for K_I differ from numerical results obtained using both J-integral method and global energy release rate method. These analytical expressions need to be corrected.

Discussion

- The thin aluminium sheets are tested under plane stress conditions.
- The plastic zone size is large and the material behaves in a ductile manner.
- At peak load σ_C, $a_{actual} = a_o + \Delta a_{ec}$.
- Δa_{ec} is the sum of the physically visible crack growth size and crack-tip plastic zone size.

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