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ABSTRACT

The experimental stress intensity factors for various chevron notched four point bend specimens are presented. The experimental compliance is verified using the analytical solution for a straight through crack four point bend specimen and the boundary integral equation method for one chevron geometry. Excellent agreement is obtained between the experimental and analytical results. In this report, stress intensity factors, loading displacements and crack mouth opening displacements are reported for different crack lengths and different chevron geometries, under four point bend loading condition.

INTRODUCTION

The usefulness of the chevron notched specimens for testing the fracture toughness of brittle material is well established

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(Ref. [1]-[4]). However, the chevron notch bend specimen has not been analyzed as rigorously as the chevron notched short rod and bar specimens, ([5]-[12]). Munz et al. [13] used Bluhm's slice model [9] to obtain the stress intensity factors (SIF) for the four point bend specimen while Wu [14] used the same method to obtain the SIF for the three point bend loading condition. Shih [15] attempted to match a valid fracture toughness K_{Ic} value of a specific material with the maximum load to failure of a three point bend chevron notched specimen. To the author's knowledge, the only rigorous analysis for the three point bend specimen has been conducted using the boundary integral method [16] and the finite element method [17]. Furthermore the only experimental compliance calibration of the bend specimen has been the original work of Bluhm [9], [18] and Oucherlony [19] for the three point bend round bar. The continued interest in the chevron notched four point bend specimen especially for elevated temperature testing has prompted the current derivation of the stress intensity factor from experimental compliances for various chevron notched four point bend specimens.

COMPLIANCE MEASUREMENTS

Experimental Procedure

The four point bend loading fixture is shown in Fig. 1. This fixture allows the bottom support rollers and the top loading rollers to roll freely to eliminate errors due to any sliding friction. The load is transmitted through a conical pad on the top fixture to minimize any misalignment in the rollers and/or non-parallelism in the specimen. The upper fixture is lifted off and lowered onto the specimen through a spring system that is detached when the compliance measurements are taken, Fig. 1. The load displacement is taken as the relative vertical displacement between small pins located along the centerline of the specimen directly above the support rollers and below the loading rollers, Fig. 2-a. The motion is measured with an LVDT by attaching the core of the LVDT to a "T" shaped hanger that rests on the pins below the loading rollers, while the LVDT body is secured to a saddle arrangement resting on the pins above the support rollers. The support span (S_1) is fixed at 8" while a loading span (S_2) of either 2" or 4" is used. The roller diameters are changed to match the specimen according to ASTM E399 recommendations [21] for three point bend tests. The specimens are machined from a two inch thick plate of 7075-T651 aluminum in the L-T orientation (ASTM Coding) to a thickness B, of 1", a width W of 1" or 2", and a length of 8.25".

The chevron notches have a relative notch length at the surface ($a_1/W=\alpha_1$) of 1.0, and a relative notch length to the chevron tip ($a_0/W=\alpha_0$) of 0.0, 0.2, and 0.5 (see Fig. 2-b). The width of the chevron notch is 0.035" with a semicircular bottom. The notch is incrementally extended from α_0 to an α ($\alpha=a/W$) of 0.95 by sawing a 0.022" notch on a thin blade band saw. Load-deflection traces are made after each incremental extension of the notch. The load is progressively decreased as the notch depth is increased to keep the applied stress intensity factor below 10ksi$\sqrt{in}$.

Analytical Procedure

To support the experimental compliance method, a three dimensional elastic analysis is performed on one chevron notched geometry using the boundary integral equation method (BEM). This method uses only boundary surface elements. The BEST3D computer code [22], which employs a quadratic variation of the boundary traction and displacement over triangular and rectangular elements, is used. Due to the symmetries in the loading and the geometry, only a quarter of the specimen was modelled. The quarter of the beam is also divided into three subregions that are interconnected by interface elements since the aspect ratio of the beam length over the beam width is large, Fig. 2-c. Making use of the half symmetry option in the BEST3D code, surface elements were not required in the YZ plane at x=0, as seen in Fig. 2(c). The shaded area along the XY plane represents the un-cracked ligament of the chevron notch for α=a/W=0.5. The finite width slot N cut into the specimens to form the chevron is not modelled. The load line displacements are calculated for one chevron geometry (with $\alpha_1=a_1/W=1.$, $\alpha_0=a_0/W=0.2$ and B/W=0.5) and different crack length a/W ranging from 0.25 to 0.75 for two span length ratios (S_1/S_2=2. and 4.). Crack mouth opening displacement is calculated for different crack increments and compared to the experimental results. The analytical calibration of the stress intensity factor K simulated the experimental calculations in determining the change in the external work as the crack advances:

$$K = \sqrt{E\,G} = \sqrt{\frac{1}{2}\,P\,\frac{\delta}{\delta A}D} \qquad (1)$$

Where G is the energy release rate

E is the elastic modulus

P is the total applied load

D is the load line deflection

A is the cracked area

Before performing the experimental calibration on the chevron notched four point bend specimens, the accuracy of the experimental set up is tested by calibrating a straight through four point bend specimen and comparing it with published results.

RESULTS

Straight Through Notch Specimens

The experimental load line compliance for the straight through notched four-point bend specimen is normalized in the following manner, to cancel the effects of various span lengths:

$$D_N = \left(\frac{E\,D\,B}{P} - C_0\right)\left(\frac{W}{S_1 - S_2}\right)^2 \qquad (2)$$

where B is the beam thickness, W is the beam height, and C_0 is the un-notched non-dimensional beam compliance obtained from Bluhm [9]:

$$C_0 = \left(\frac{S_1 - S_2}{W}\right)^2 \quad \left[\frac{S_1 + 2\,S_2}{4\,W} + \frac{W\,(1 + \upsilon)}{2\,(S_1 - S_2)}\right] \tag{3}$$

where υ is the Poisson's ratio.

The normalized load line compliance D_N is plotted as a function of the normalized crack length α in Fig. 3 for different span ratios and specimen geometries. The normalized compliance D_N is fitted using the least squares method to give:

$$D_N = \frac{9.30551\alpha + 4.30643\alpha^2 - 4.55453\alpha^3 - 1.02783\alpha^4 + 2.04204\alpha^5}{(1 - \alpha)^2} \tag{4}$$

The experimental data as well as the values from Eq. 4 are shown in Table 1. A good fit is observed over the full range of α= 0 to 0.95, independent of span lengths and beam heights, as seen in Fig. 3.

The normalized stress intensity factor Y is determined based on Eq. 1 as the change in specimen compliance with increased crack length:

$$Y = \left[\frac{K\,B\,W^{3/2}}{P\,(\,S_1 - S_2\,)}\right] = \left[\frac{1}{2}\frac{\delta}{\delta\alpha}D_N\right]^{1/2} \tag{5}$$

The calculated normalized stress intensity factors Y are listed in Table 1 with those from the Srawley-Gross relationship for pure bending [23] given here for completeness:

$$Y = \frac{3}{2}\sqrt{\frac{\alpha}{(1-\alpha)^3}}$$

$$\left[1.9887 - 1.326\alpha - \frac{(3.49 - 0.68\alpha + 1.35\alpha^2)\ \alpha\ (1-\alpha)}{(1+\alpha)^2}\right] \qquad (6)$$

The agreement between the experimentally derived normalized stress intensity factor Y and the analytical solution is quite good over the full range from α=0 to 0.95 as shown in Fig. 4. As Eq. 6 indicates, the normalized stress intensity factor is independent of the specimen geometry and the span ratios.

Chevron Notch Specimen

The normalized load line compliances D_N for the chevron notched four-point bend specimens are also calculated using eq. 2 which was shown to render the D_N values independent on the span lengths and the beam height used. The un-notched dimensionless compliance is again computed from Eq. 3. The normalized load line displacements are shown in Fig. 5 along with the analytic solution from the BEM for a chevron notch specimen with an α=0.2 and α_1=1.0. The values from the analytical solution are somewhat lower than the experimental values. This is due in part to the difference in the value used for the un-notched compliance and also since the analytic solution is based on a sharp crack while the actual specimens had a finite width slot. The method of least squares was used to fit an expression to the normalized load line compliance for each notch geometry. These expressions had the same form as Eq. 2:

$$D_N = \left[\frac{EDB}{P} - C_0 \right] \left(\frac{W}{S_1 - S_2} \right)^2 = \frac{f_0 + f_1\alpha + f_2\alpha^2 + f_3\alpha^3 + f_4\alpha^4 + f_5\alpha^5}{(1-\alpha)^2} \tag{7}$$

where the least square coefficients f_i are listed in Table 2 for different crack geometries.

The normalized stress intensity factor Y^* for a chevron notch is obtained from the following relation given by Munz [13]:

$$Y^* = \left[\frac{K\,B\,W^{3/2}}{P\,(S_1 - S_2)} \right] = \left[\frac{1}{2} \; \frac{\alpha_1 - \alpha_0}{\alpha - \alpha_0} \; \frac{\delta}{\delta\alpha} D_N \right]^2 \tag{8}$$

The values of Y^* are plotted in Fig. 6 along with values from the analytical solution for α_0=0.2, α_1=1.0. Good agreement between the values derived from the data and the BEM results is observed.

Crack Mouth Opening Displacement

In addition to the load line deflections, the crack mouth opening displacement V is determined with an ASTM E399 type clip gage. The crack mouth opening displacement (CMOD) measurements are simpler and more direct then the load line displacement, thus they lend themselves very well to automated cyclic crack growth and "R" curve studies. The normalized form of the crack opening displacement is formulated in the following manner:

$$V_N = \left(\frac{EVB}{P} \right) \frac{W}{S_1 - S_2} \tag{9}$$

where V_N is now normalized with respect to the moment $P(S_1-S_2)$ and modulus, E.

The experimental normalized CMOD data as well as the analytical values is plotted in Fig. 7. The values from the analytical solution are somewhat lower. This is due in part to the difference in the notch geometry. In the analytical solution the notch width is zero while the test specimens have a notch width of 0.035". The method of least squares is also used to fit an expression of the same form as Eq. 3 to the normalized CMOD data:

$$V_N = \left[\frac{EVB}{P} - V_0 \right] \left(\frac{W}{S_1 - S_2} \right) = \frac{f_0 + f_1 \alpha + f_2 \alpha^2 + f_3 \alpha^3 + f_4 \alpha^4 + f_5 \alpha^5}{(1-\alpha)^2} \tag{10}$$

where the least square coefficients f_i are given in Table 2.

In crack growth and R curve studies, determining the crack length from the crack opening displacement is more convenient. Therefore, inverse expressions were obtained following the form used by Haggag and Underwood [24], to estimate the crack length given the CMOD value:

$$\alpha = f_0 + f_1 U + f_2 U^2 + f_3 U^3 + f_4 U^4 + f_5 U^5 \tag{11}$$

where

$$U = \frac{1}{\sqrt{V_N} + 1}$$

The least square coefficients f_i for different crack geometries are also given in Table 2.

CONCLUSIONS

1. The excellent agreement between the Srawley-Gross analytical results and the experimentally derived stress intensity factors for a straight through crack in a four point bend specimen substantiates the method used in obtaining the experimental load line displacements.

2. The experimental data confirms that the normalized stress intensity factor Y is independent of span ratio and specimen geometry for the straight through crack four point bend specimen.

3. The experimental study performed in this study provides the necessary numerical results to determine the stress intensity factor for several four point bend chevron notched geometries.

REFERENCES

1. Nakayama, J.: Direct Measurement of Fracture Energies of Brittle Heterogeneous Materials. Jour. Am. Ceram. Soc. Vol. 48, No. 11, Nov. 1968.

2. Tattersol, H. G.; Tappin, G.: The Work of Fracture and Its Measurement in Metals, Ceramics and Other Materials. Jour. of Mat. Sci., 1966.

3. Pook, L. P.: An Approach to a Quality Control KIC Test Piece. Int. Jour. Of Fracture Mech. Vol. 8, 1972, pp. 103-108.

4. Barker, L. M.: A Simplified Method for Measuring Plane Strain Fracture Toughness. Eng. Frac. Mech. Vol. 9, 1977, pp. 361-369.

5. Munz, D.; Bubsey, R. T.; and Srawley, J.E.: Compliance and Stress Intensity Coefficients for Short Bar Specimens with Chevron Notches. Int. Jour. of Frac. Vol. 18, No. 2, Feb. 1982.

6. Bubsey, R. T.; Munz, D.; Pierce, W. S.; and Shannon, Jr., J. L.: Compliance Calibration of the Short Rod Chevron-Notch Specimen for Fracture Toughness Testing of Brittle Materials. Int. Jour. of Frac., Vol. 18, No. 2, Feb. 1982.

7. Barker, L. M.; and Guest, R. V.: Compliance Calibration of the Short Rod Fracture Toughness Specimen. Terra Tek Report 78-20, 1978.

8. Shannon, Jr., J. L.; Bubsey, R. T.; Pierce, W. S.; and Munz, D.: Extended Range Stress Intensity Factor Expressions for Chevron-Notched Short Bar and Short Rod Fracture Toughness Specimens. Int. Jour. of Frac Vol. 19, 1982, pp. R55 R58.

9. Bluhm, J. I.: Slice Synthesis of a Three-Dimensional "Work of Fracture" Specimen. Eng. Frac. Mech., Vol. 7, 1975, pp. 593-604.

10. Ingraffea, A. R.; Perucchio, R.; Han, T. Y.; Gerstle, W. H.; and Huang, Y. P.: Three Dimensional Finite and Boundary Element Calibration of the Short-Rod Specimen. ASTM, STP 855, April 1983.

11. Mendelson, A.; and Ghosn, L. J.: Three Dimensional Analysis of Short Bar Chevron-Notched Specimens by Boundary Integral Method. ASTM, STP 855, April 1 1983.

12. Raju, I. S.; Newman, J. C., Jr.: Three Dimensional Finite Element Analysis of the Chevron- Notched Fracture Specimens. ASTM, STP 855, April 1983.

13 . Munz, D.; Bubsey, R. T.; and Shannon, Jr., J. L.: Fracture Toughness Determination of A1203 Using Four-Point Bend Specimens with Straight Through and Chevron Notches. Jour. of the Amer. Ceram. Soc., Vol. 1 . 63, No. 5-6, 1980.

14. Wu, Shang-Zian: Fracture Toughness Determination of Bearing Steel Using Chevron-Notch Three Point Bend Specimen. Eng. Frac. Mech. Vol. 19, No. 2, pp. 221~223, 1984.

15. Shih, T. T.: An Evaluation of the Chevron V-Notched Bend Bar Fracture Toughness Specimen. Eng. Frac. Mech., Vol. 14, no. 4, pp. 821-832, 1981.

16. Gerstle, W. H.: Finite and Boundary Element Modelling of Crack Propagation in Two- and Three- Dimensions Using Interactive

Computer Graphics. PH. D. Thesis, Cornell University, 1986.

17. Jenkins, M.G., Kobayashi, A.S., White, K.W., and Bradt, R.C.: A 3-D Finite Element Analysis of a Chevron-Notched, three-Point Bend Fracture Specimen for Ceramic Materials. Int. Journal of Fracture, Vol. 34, 1987, pp. 281-295.

18. Bluhm, J. I.: Stability Considerations in the Generalized Three Dimensional "Work of Fracture" Specimen. Fracture, Vol. 3, D.M.R. Tappin, ed., Pergamon Press, New York (1978).

19. Oucherlony, F.: Compliance Calibration of a Round Fracture Toughness Bend Specimen with Chevron Edge Notch. Report OS 198418 Stiftelsen Svensk Detonikforskning, Box 32058, S-12611, Stockholm, Sweden, 1984.

20. Sakai, M.; Yamasaki, K.: Numerical Fracture Analysis of Chevron-Notched Specimens: I, Shear Correction Factor, k, Jour. of the American Ceram. Soc. Vol. 66, No. 5, pp. 371-375, 1983.

21. ASTM E399-90, 1992 Annual Book of ASTM Standards, Metals Test Methods and Analytical Procedures, vol. 03.01, ASTM Philadelphia, PA (1992), pp. 506-536.

22. Wilson, R. B.; and Banerjee, P. H.: 3-D Inelastic Analysis Methods for Hot Section Components, Third Annual, Vol. II, Advanced Special Functions Models, NASA Contractor Report 179517, August

1987.

23. Srawley, J. E.; and Gross, B: Side Cracked Plates Subject to Combined Direct and Bending Forces. Cracks and Fracture ASTM STP 601, 1976, pp. 559-579.

24. Haggag, F. M.; and Underwood, J. H.: Compliance of a Three-Point Bend Specimen at Load Line. Int. Jour. of Frac. 26, 1984, R63-R65.

Table 1- Normalized load line displacements and stress intensity factors for four point bend straight through cracks (E=10.5MSi, υ=0.3)

W,in	1.002			1.984					
B,in	1.001			1.001					
S_1,in	8.00			8.00					
S_2,in	2	4			4				
α	D_N			α	D_N		α	Y	
	DATA		EQ.4		DATA	EQ.4		EQ.5	REF[23]
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-
0.093	0.056	0.073	0.076	0.099	0.081	0.084	0.05	0.65	0.64
0.195	0.31	0.21	0.29	0.203	0.41	0.32	0.10	0.85	0.89
0.298	0.72	0.70	0.71	0.298	0.66	0.71	0.15	1.05	1.08
0.352	1.08	1.07	1.04	0.347	1.00	1.01	0.20	1.24	1.26
0.400	1.43	1.33	1.43	0.398	1.35	1.41	0.25	1.43	1.44
0.451	1.99	1.95	1.96	0.457	2.06	2.04	0.30	1.64	1.64
0.504	2.74	2.67	2.70	0.505	2.85	2.72	0.35	1.87	1.86
0.554	3.60	3.57	3.65	0.553	3.61	3.63	0.40	2.13	2.12
0.602	4.94	4.78	4.92	0.604	4.95	4.97	0.45	2.44	2.43
0.656	6.88	6.91	6.99	0.651	6.55	6.75	0.50	2.81	2.81
0.698	9.54	9.32	9.42	0.695	9.67	9.19	0.55	3.28	3.30
0.750	14.50	14.25	14.26	0.753	14.58	14.61	0.60	3.90	3.94
0.800	22.87	22.52	22.97	0.806	24.39	24.44	0.65	4.74	4.82
0.859	47.86	47.37	47.44	0.856	44.68	45.67	0.70	5.96	6.06
0.901	100.6	98.29	98.86	0.902	99.62	101.6	0.75	7.84	7.95
0.946	364.2	359.0	350.7	0.955	470.1	503.5	0.80	11.01	11.10
							0.85	17.09	17.06
							0.90	31.76	31.33
							0.95	91.15	88.69

Table 2- Least square fit for the experimental calibration of chevron notched four point bend specimens (E=10.5MSi, υ=0.3)

NORMALIZED LOAD LINE DISPLACEMENT

$$D_N=\left[\frac{EDB}{P}-C_0\right]\left(\frac{W}{S_1-S_2}\right)^2=\frac{f_0+f_1\alpha+f_2\alpha^2+f_3\alpha^3+f_4\alpha^4+f_5\alpha^5}{(1-\alpha)^2}$$

α_0	α_1	W/B	f_0	f_1	f_2	f_3	f_4	f_5
0	1	2	0.4157	-0.6514	6.2589	-7.9652	1.8503	1.1208
0.2	1	2	1.3099	-5.8070	19.923	-28.178	17.932	-4.1748
0.5	1	2	0.8610	35.001	-179.50	349.35	-302.48	97.894
0	1	1	0.554	-1.4107	8.8164	-14.661	10.412	-2.6803

NORMALIZED CRACK MOUTH OPENING DISPLACEMENT

$$V_N=\left[\frac{EVB}{P}\right]\left(\frac{W}{S_1-S_2}\right)=\frac{f_0+f_1\alpha+f_2\alpha^2+f_3\alpha^3+f_4\alpha^4+f_5\alpha^5}{(1-\alpha)^2}$$

α_0	α_1	W/B	f_0	f_1	f_2	f_3	f_4	f_5
0	1	2	1.6958	-0.2878	16.144	-33.834	29.0289	-8.7674
0.2	1	2	4.7670	-18.477	62.901	-96.074	71.914	-21.110
0.5	1	2	121.922	-754.42	1927.9	-2452.4	1546.83	-385.633
0	1	1	2.0193	-2.8288	26.5249	-55.0951	48.3189	-14.7658

NORMALIZED CRACK LENGTH AS A FUNCTION OF THE NORMALIZED CMOD

$$\alpha=f_0+f_1U+f_2U^2+f_3U^3+f_4U^4+f_5U^5$$

$$\text{where } U=\frac{1}{\sqrt{V_N}+1}$$

α_0	α_1	W/B	f_0	f_1	f_2	f_3	f_4	f_5
0	1	2	1.01069	-2.5953	9.38905	-69.880	198.741	-194.025
0.2	1	2	1.01269	-2.8250	15.6780	-140.298	512.360	-683.339
0.5	1	2	0.97845	-0.54499	-30.981	227.687	-576.58	-328.473
0	1	1	1.02438	-3.3387	21.2819	-147.101	417.057	-419.430

Table 3- Normalized load line displacements for chevron notched four point bend specimens (E=10.5MSi, υ=0.3)

α_0	0.0			0.2							0.5				0.0			
α_1	1.0			1.0							1.0				1.0			
W, in	2.003			2.003							2.003				1.001			
B, in	1.002			1.003							1.003				1.001			
S_1, in	8			8							8				8			
S_2, in	2	4			2	4						2	4			2	4	
α	D_N			α	D_N			α	D_N		α	D_N			α	D_N		
	DATA		EQ.7		DATA		EQ.7		EQ.7	BEM		DATA		EQ.7		DATA		EQ.7
.009	0.43	0.41	0.42	.200	1.15	1.17	1.17	.20	1.17		.500	5.24	5.26	5.24	.0	0.55	0.56	0.56
.100	0.48	0.48	0.50	.253	1.30	1.29	1.31	.25	1.30	1.15	.546	5.76	5.77	5.79	.103	0.61	0.61	0.61
.200	0.76	0.78	0.74	.301	1.49	1.52	1.51	.30	1.50	1.37	.598	6.95	6.89	6.90	.223	0.87	0.91	0.90
.299	1.20	1.15	1.19	.350	1.79	1.81	1.79	.35	1.79	1.67	.649	8.90	8.66	8.76	.306	1.29	1.30	1.27
.401	1.95	2.04	1.97	.396	2.17	2.15	2.15	.40	2.19	2.05	.698	11.69	11.54	11.66	.352	1.53	1.59	1.57
.499	3.18	3.16	3.22	.454	2.77	2.77	2.77	.45	2.72	2.58	.749	16.79	16.68	16.70	.402	1.96	1.96	1.97
.550	4.20	4.16	4.20	.500	3.41	3.43	3.42	.50	3.42	3.27	.800	25.63	25.62	25.85	.452	2.50	2.49	2.50
.599	5.50	5.53	5.50	.552	4.43	4.38	4.42	.55	4.37	4.20	.850	45.53	45.55	44.92	.498	3.10	3.17	3.12
.653	7.60	7.62	7.56	.599	5.67	5.64	5.66	.60	5.69	5.51	.901	101.0	100.4	101.6	.548	4.04	4.03	4.03
.702	10.48	10.49	10.45	.650	7.57	7.56	7.60	.65	7.60	7.39	.953	466.8	460.6	462.9	.606	5.54	5.41	5.54
.748	14.89	14.92	14.78	.701	10.59	10.61	10.58	.70	10.51	10.13					.650	7.23	7.30	7.22
.798	22.66	23.35	23.21	.748	15.15	14.95	15.06	.75	15.31	14.66					.703	10.32	10.27	10.32
.852	43.88	44.07	43.65	.797	24.00	23.18	23.40								.749	14.65	15.10	14.75
.900	96.58	94.22	96.83	.849	42.94	42.34	42.60								.802	24.34	24.45	24.24
.957	539.9	543.3	538.1	.897	91.70	91.06	92.25								.846	40.15	40.12	40.77
				.955	490.1	429.2	489.4								.900	99.80	98.86	98.79
															.946	345.7	345.0	345.4

Table 4- Normalized stress intensity factor Y for chevron notched four point bend specimens (E=10.5MSi, υ=0.3)

α_0	0.0	0.2		0.5	0.0
α_1	1.0	1.0		1.0	1.0
W,in	2.0	2.0		2.0	1.0
B,in	1.0	1.0		1.0	1.0
α	Y^*				
	DATA	DATA	BEM	DATA	DATA
.05	3.18				2.18
.10	2.92				2.53
.15	2.91				2.67
.20	2.95				2.78
.25	3.04	5.14	5.37		2.89
.30	3.16	4.43	4.56		3.02
.35	3.31	4.26	4.26		3.17
.40	3.51	4.27	4.27		3.37
.45	3.76	4.41	4.42		3.63
.50	4.09	4.66	4.65		3.97
.55	4.53	5.04	5.06	9.09	4.42
.60	5.12	5.60	5.65	8.44	5.04
.65	5.96	6.41	6.41	8.82	5.91
.70	7.18	7.64	7.63	9.76	7.19
.75	9.08	9.55	8.88	11.41	9.15
.80	12.28	12.77		14.37	12.42
.85	18.41	18.92		20.33	18.64
.90	33.10	33.60		35.23	33.47
.95	92.03	92.19		96.51	92.67

Table 5- Normalized crack mouth opening displacement for chevron notched four point bend specimens (E=10.5MSi, υ=0.3)

α_0	0.0			0.2							0.5				0.0			
α_1	1.0			1.0							1.0				1.0			
W,in	2.003			2.003							2.003				1.001			
B,in	1.002			1.003							1.003				1.001			
S_1,in	8			8							8				8			
S_2,in	2	4			2	4						2	4			2	4	
α	V_N			α	V_N			α	V_N		α	V_N			α	V_N		
	DATA		EQ.10		DATA		EQ.10		EQ.10	BEM		DATA		EQ.10		DATA		EQ.10
.009	1.74	1.74	1.73	.200	4.61	4.56	4.57	.20	4.57		.500	19.04	19.04	19.03	.0	2.02	2.04	2.02
.100	2.19	2.14	2.22	.253	5.10	5.03	5.08	.25	5.05	4.61	.546	21.00	20.84	20.95	.103	2.41	2.45	2.43
.200	3.26	3.26	3.71	.301	5.79	5.72	5.78	.30	5.76	5.34	.598	25.29	25.06	25.22	.223	3.72	3.75	3.66
.299	4.87	4.82	4.80	.350	6.79	6.74	6.76	.35	6.76	6.31	.649	32.43	32.38	32.15	.306	5.10	5.09	5.07
.401	7.41	7.33	7.40	.396	8.04	7.97	7.98	.40	8.10	7.54	.698	42.48	42.41	42.71	.352	6.14	6.11	6.12
.499	11.44	11.35	11.54	.454	10.15	10.04	10.07	.45	9.90	9.21	.749	61.03	60.99	61.02	.402	7.48	7.45	7.54
.550	14.90	14.73	14.85	.500	12.41	12.27	12.32	.50	13.32	11.47	.800	95.14	95.04	95.30	.452	9.28	9.23	9.36
.599	19.38	19.29	19.31	.552	15.81	15.76	15.79	.55	15.63	14.52	.850	171.5	170.6	169.7	.498	11.48	11.60	11.52
.653	26.75	26.79	26.64	.599	20.23	20.07	20.21	.60	20.32	18.82	.901	393.6	394.5	396.2	.548	14.62	14.65	14.66
.702	37.29	37.13	37.16	.650	27.07	27.09	27.23	.65	27.23	25.16	.953	1832.	1806.	1817	.606	20.02	20.07	19.93
.748	53.88	53.53	53.34	.701	38.20	38.09	38.27	.70	38.00	34.59					.650	26.01	26.00	25.87
.798	83.79	87.23	85.48	.748	55.28	54.81	55.13	.75	56.07	50.50					.703	37.22	37.39	37.00
.852	164.7	164.6	164.6	.797	88.20	89.68	87.02								.749	52.67	53.90	53.28
.900	369.3	368.5	371.7	.849	160.5	159.8	161.3								.802	89.24	89.21	88.81
.957	2104.	2099.	2089.	.897	352.0	350.4	354.7								.846	149.7	150.4	151.9
				.955	1918	1910	1906								.900	380.9	380.7	377.7
															.946	1350.	1354.	1354.

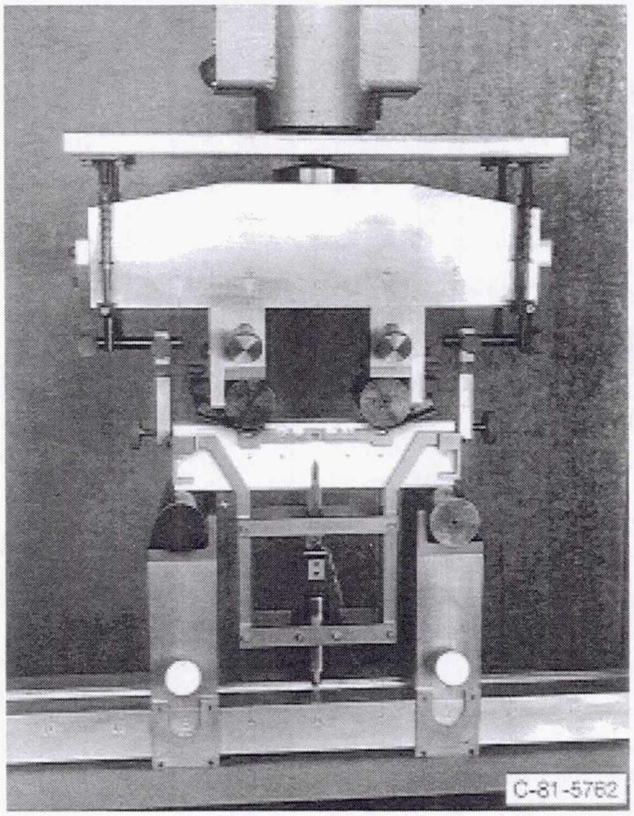
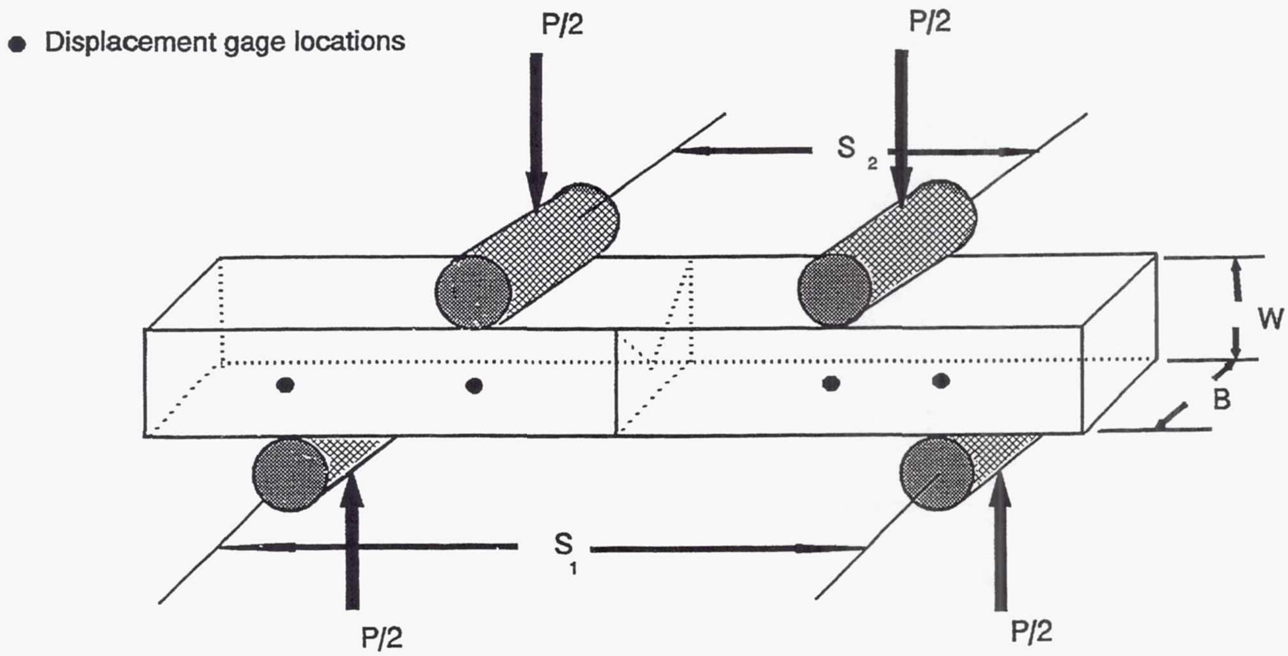
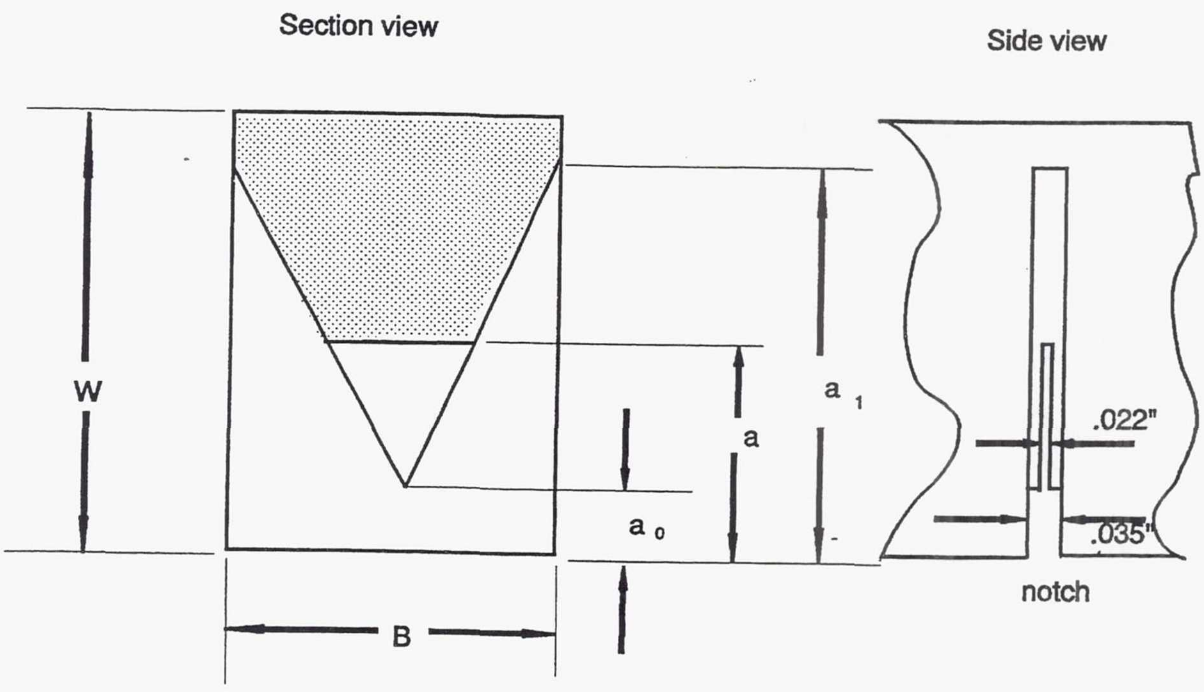


Figure 1.—Four point bend loading fixture.

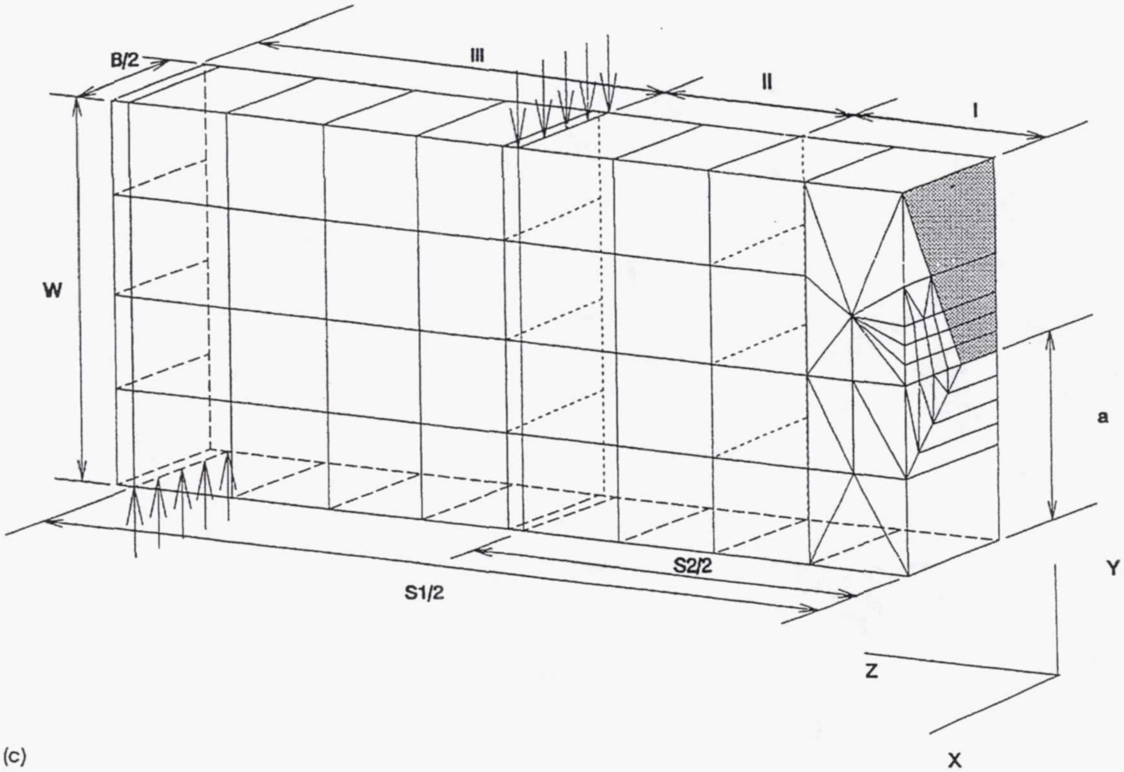


(a)



(b)

Figure 2.—(a) Schematic of a four point bend chevron notch specimen. (b) Detail view of the chevron notch geometry.



(c)

Figure 2.—Concluded. (c) Typical boundary integral mesh with quarter symmetry.

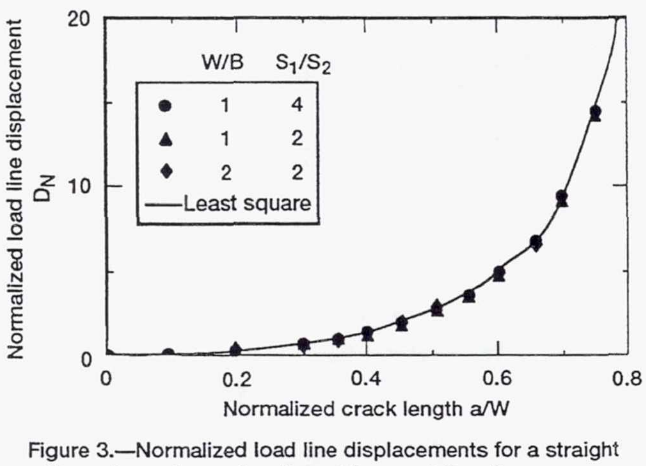


Figure 3.—Normalized load line displacements for a straight through crack as a function of the crack length.

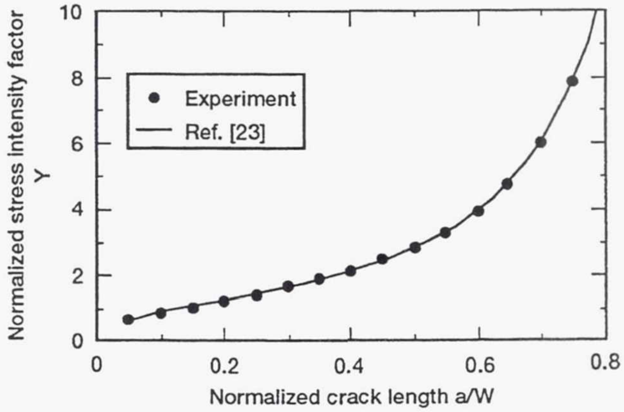


Figure 4.—Normalized stress intensity factors for a straight through crack as a function of the crack length.

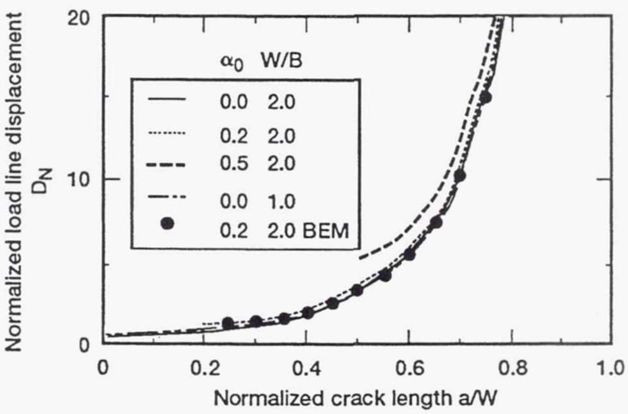


Figure 5.—Normalized load line displacements for various chevron notch geometries as a function of the crack length.

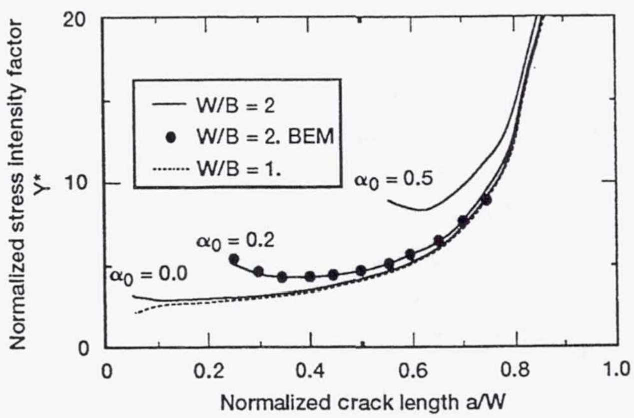


Figure 6.—Normalized stress intensity factors for various chevron notch geometries as a function of the crack length.

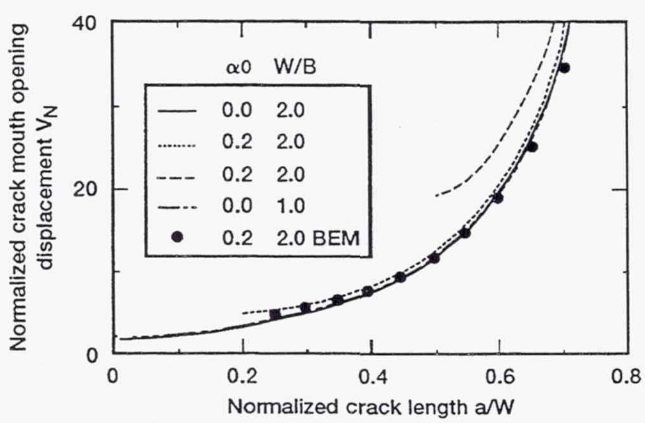


Figure 7.— Normalized crack mouth opening displacements for various chevron notch geometries as a function of the crack length.

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13. ABSTRACT *(Maximum 200 words)*

The experimental stress intensity factors for various chevron notched four point bend specimens are presented. The experimental compliance is verified using the analytical solution for a straight through crack four point bend specimen and the boundary integral equation method for one chevron geometry. Excellent agreement is obtained between the experimental and analytical results. In this report, stress intensity factors, loading displacements and crack mouth opening displacements are reported for different crack lengths and different chevron geometries, under four point bend loading condition.

14. SUBJECT TERMS

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