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C.W. Smith, K.T. Gloss, D.M. Constantinescu (Virginia Polytechnic Institute & State University); C.T. Liu (AFRL/PRSM), "Stress Intensity Factors for Cracks Within and Near to Bondlines in Soft Incompressible Materials"

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LESLIE. S. PERKINS, Ph.D (Date)
Staff Scientist
Propulsion Directorate

STRESS INTENSITY FACTORS FOR CRACKS WITHIN AND NEAR TO BONDLINES IN SOFT INCOMPRESSIBLE MATERIALS

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ABSTRACT

Using a polyurethane photoelastic material, thick test specimens of several configurations with bonded end tabs are examined for measuring stress intensity factors (SIFs) for cracks within and near to bondlines in bonded photoelastic models. Effects of specimen height, glued end tabs, bondline and crack size and location are studied and analyzed using a two parameter model for extracting the SIFs and results are compared with cracked, homogeneous model results.

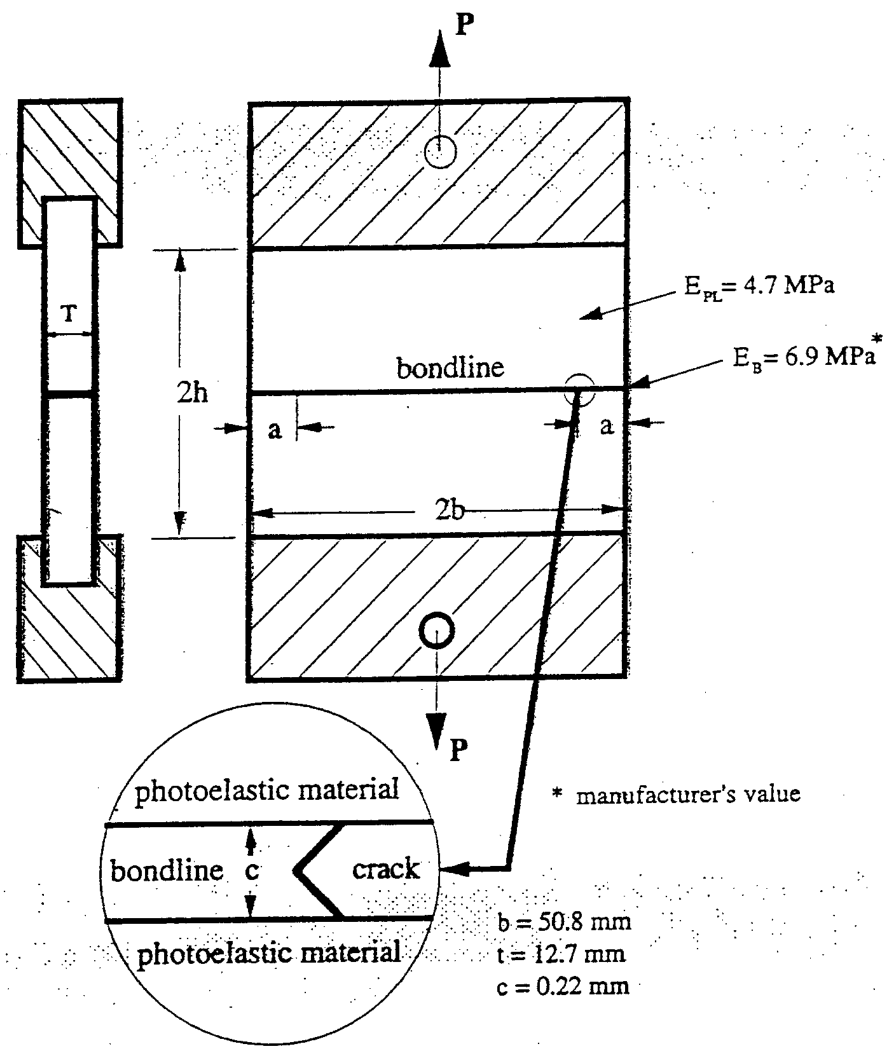

Figure 1 Test Setup for Bonded Specimens Containing Double Edge Bondline Cracks.

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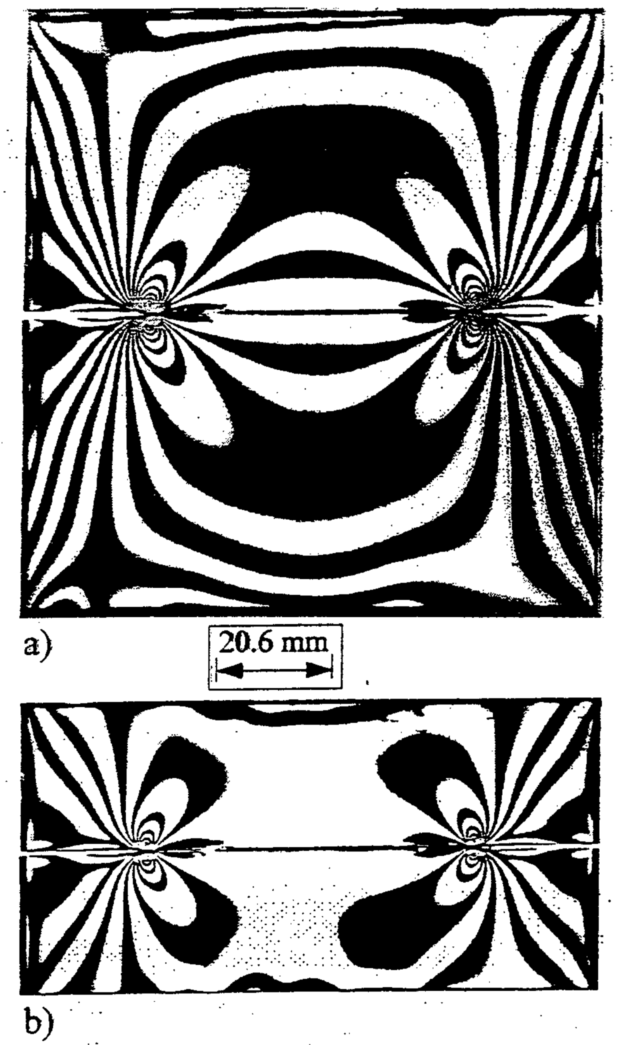

Figure 2 Global Stress Fringe Patterns for Bondline Cracks in a) Square and b) Half Height Specimens. Note effects of imperfections in glued joints on top and bottom and slight dissymmetry in local fringe patterns (Integral Fringes White).

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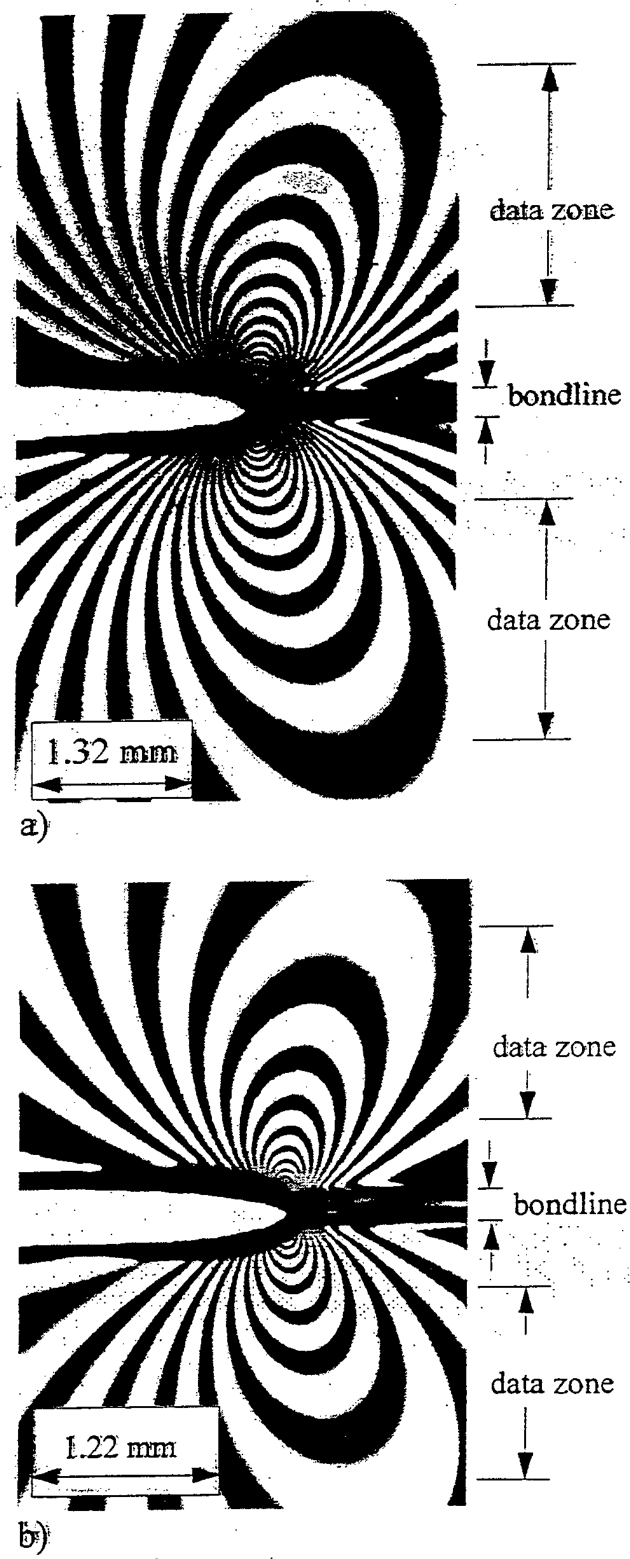


Figure 3 Local Stress Fringe Patterns for Bondline Cracks in both a) Square and b) Half Height Specimens. Absence of rotation of fringe patterns confirms pure Mode I loading (Integral Fringes White).

Mode I Algorithm for Homogeneous Case for Converting Optical Data into Stress Intensity Factor (SIF) Values.

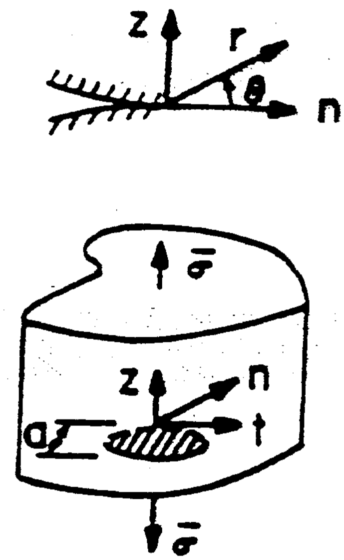


Figure A-1: Mode I Near-Tip Notation

Beginning with the Giffith-Irwin Equations, we may write, for Mode I, for the homogeneous case

$$\sigma_{ij} = \frac{K_I}{(2\pi r)^{1/2}} f_{ij}(\theta) + \sigma^{\circ}_{ij} \quad (i, j = n, z) \qquad (1)$$

where: σ_{ij} are components of stress, K_I is SIF, r, θ are measured from crack tip (Fig. A-1), σ°_{ij} are non-singular stress components.

Then, along $\theta = \pi/2$, after truncating σ_{ij}

$$(\tau_{nz})_{max} = \frac{K_I}{(8\pi r)^{1/2}} + \tau^{\circ} = \frac{K_{AP}}{(8\pi r)^{1/2}} \qquad (2)$$

where $\tau^{\circ} = f(\sigma^{\circ}_{ij})$ and is constant over the data range, K_{AP} = apparent SIF, $(\tau_{nz})_{max}$ = maximum shear stress in nz plane

$$\therefore \frac{K_{AP}}{\bar{\sigma}(\pi a)^{1/2}} = \frac{K_I}{\bar{\sigma}(\pi a)^{1/2}} + \frac{\sqrt{8}\,\tau^{\circ}}{\bar{\sigma}}\left(\frac{r}{a}\right)^{1/2} \qquad (3)$$

where (Fig. A-1) a = crack length, and $\bar{\sigma}$ = remote normal stress i.e.

$$\frac{K_{AP}}{\bar{\sigma}(\pi a)^{1/2}} \text{ vs. } \sqrt{\frac{r}{a}} \text{ is linear.}$$

Since from the Stress-Optic Law $(\tau_{nz})_{max} = nf/2t$ where, n = stress fringe order, f = material fringe value, t = specimen thickness, then from Eq. 2,

$$K_{AP} = (8\pi r)^{1/2} (\tau_{nz})_{max} = (8\pi r)^{1/2}\, nf/2t$$

A typical plot of normalized K_{AP} vs. $\sqrt{r/a}$ for a homogeneous specimen is shown in Fig. A-2.

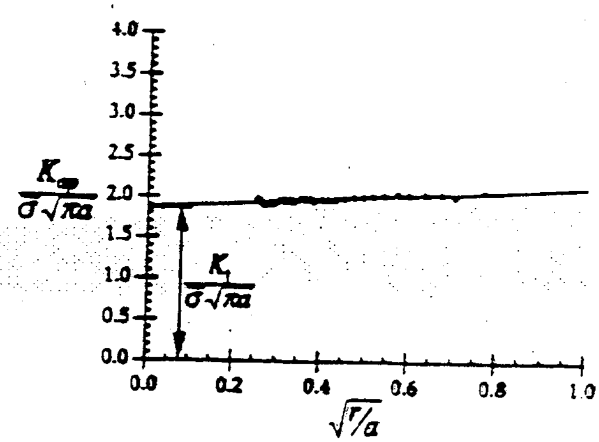


Figure A-2 - Estimating Normalized SIF from Test Data

Table 1 - Data and Results for Cracks Within Bondline

test#	a(mm)	h(mm)	a/b	P (N)	exp K/Ko	exp. corr. ($\nu = 0.5$) K/Ko	Bowie* ($\nu = 0.3$) K/Ko
DS2	7.94	50.8	0.16	74.95	1.14	1.05	1.06
DS3	12.7	50.8	0.25	74.95	1.09	1.00	1.04
DS4	17.4	50.8	0.34	74.95	1.15	1.06	1.04
DS5	20.6	50.8	0.41	74.95	1.23	1.13	1.06
DS6	25.4	50.8	0.50	74.95	1.38	1.27	1.10
DS7	27.9	50.8	0.55	74.95	1.37	1.26	1.12
DS8	7.94	25.4	0.16	74.95	0.93	0.86	—
DS9	12.7	25.4	0.25	74.95	0.94	0.87	—
DS10	17.4	25.4	0.34	52.68	0.98	0.90	—
DS11	20.6	25.4	0.41	50.72	1.00	0.93	—
DS12	25.4	25.4	0.50	50.72	1.18	1.09	—
DS13	27.9	25.4	0.55	51.01	1.22	1.12	—

* plane stress, no bondline $K_0 = \bar{\sigma}\sqrt{\pi a}$

$P_1 + P_2 = 110.55$ N
$T = 12.70$ mm
$t = 0.23$ mm
$w = 101.6$ mm
$h = 50.8$ mm or 25.4 mm
a = crack length
d = offset distance

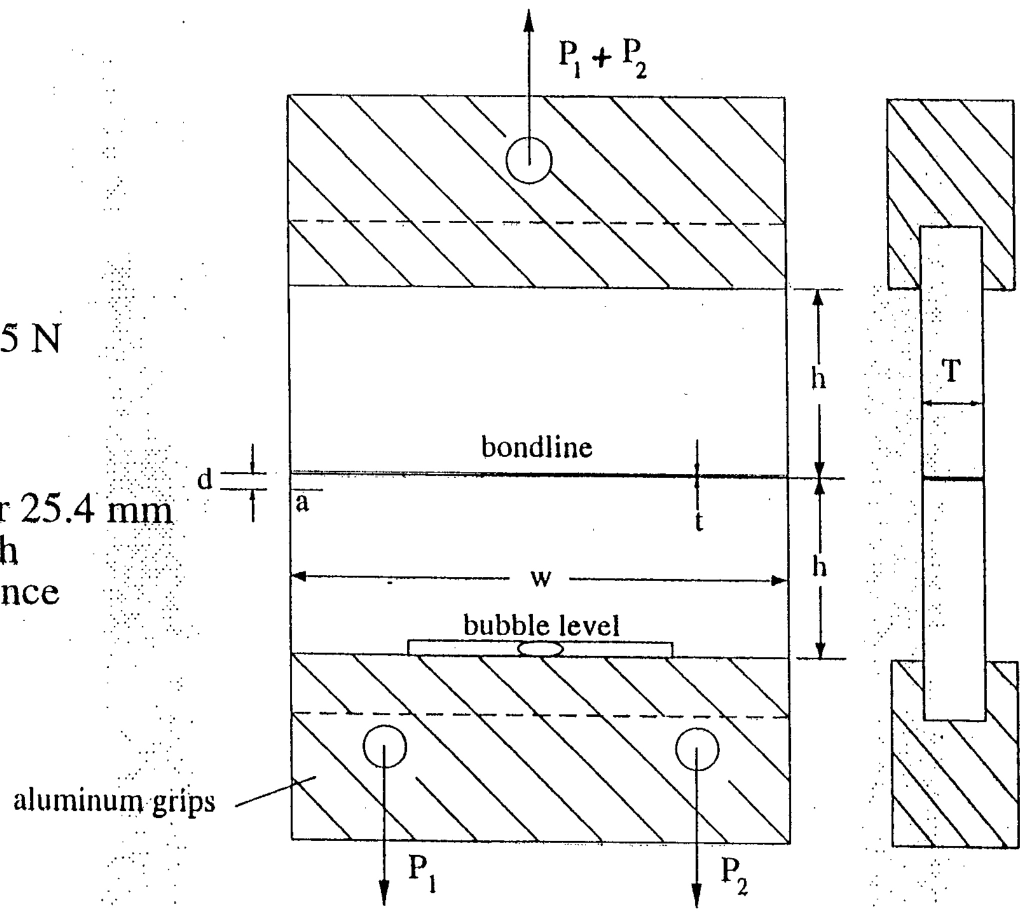
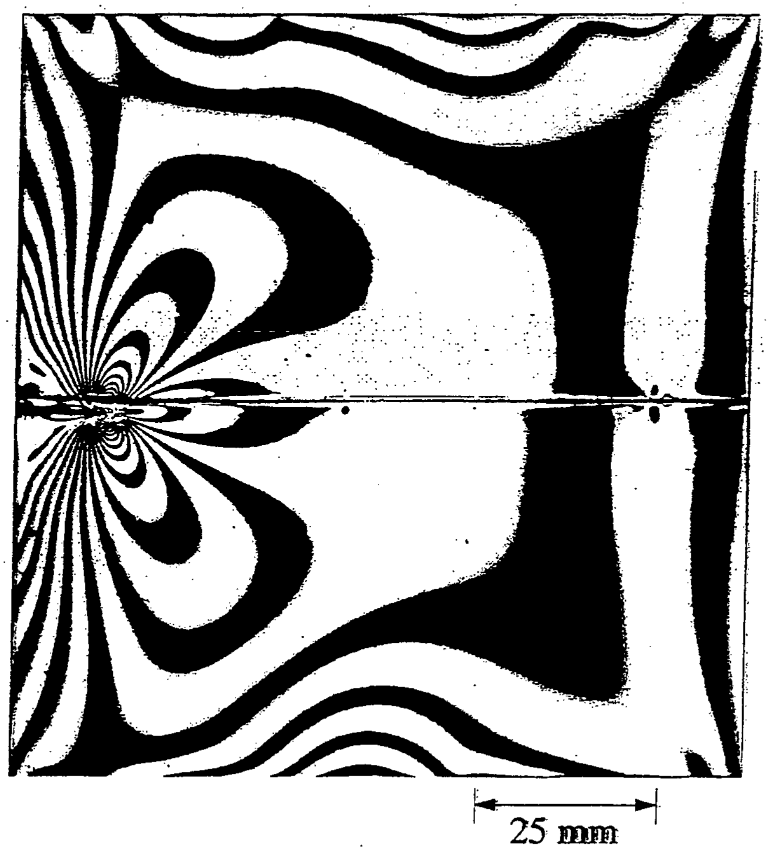


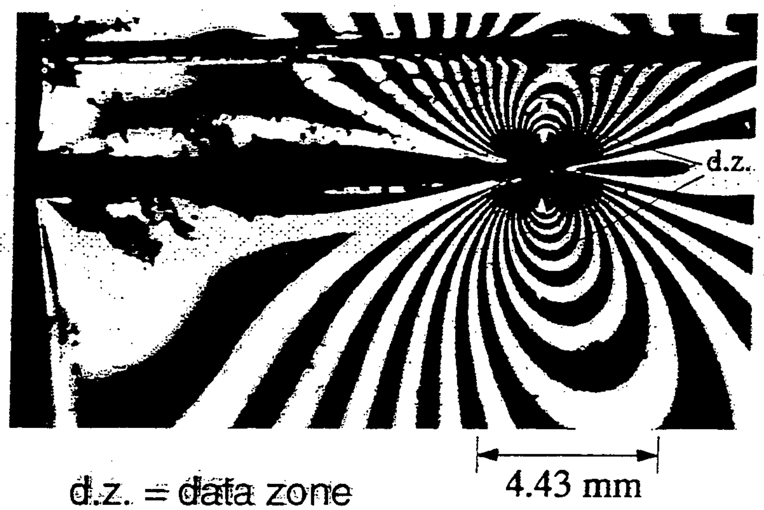
Figure 4 Test Setup for Bonded Specimens Containing Cracks Near to and Parallel to Bondline.

9

a)



b)



d.z. = data zone

Figure 5 a) Global and b) Local Stress fringe photos for a Square Specimen with Crack Parallel to Bondline. Note reduction in size of the linear zone above the crack. Lack of fringe loop rotation again confirms pure Mode I (Integral Fringes Dark).

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Table 2 - Data and Results for Cracks Parallel to Bondline

w = 101.6

Test #	a	d	h	a/w	K^*/K_0
SP6	2.78	2.58	50.80	0.027	0.976
SP7	2.98	1.19	50.80	0.029	0.885
SP8	8.33	2.58	50.80	0.082	1.139
SP9	7.95	1.19	50.80	0.078	1.017
SP10	13.09	1.19	50.80	0.129	1.173
SP11	12.70	2.58	50.80	0.125	1.365
SP12	2.58	2.78	25.4	0.025	0.806
SP13	7.54	2.78	25.4	0.074	0.876
SP14	12.70	2.78	25.4	0.125	1.028

Dimensions in mm, * Corrected for 3-D effects to a 2D solution.

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If not, suggest removing figure and table titles because it leads the reader to believe something is missing.

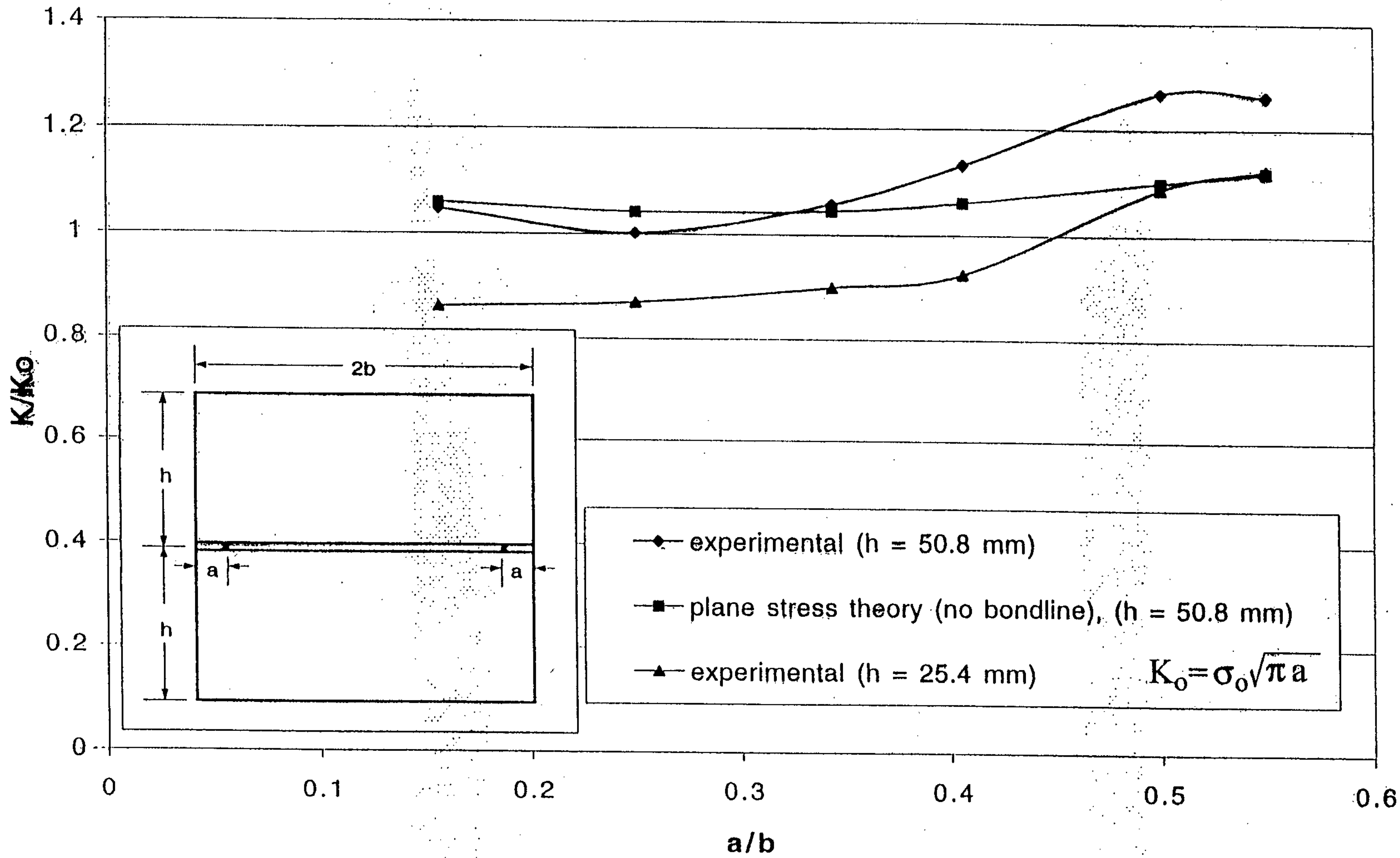

Figure 7 Effect of Crack Length on Stress Intensity Factor (SIF). Note reduction in SIF due to reduced specimen height and elevation of SIF with increasing crack length in contrast to results from unbonded specimen.

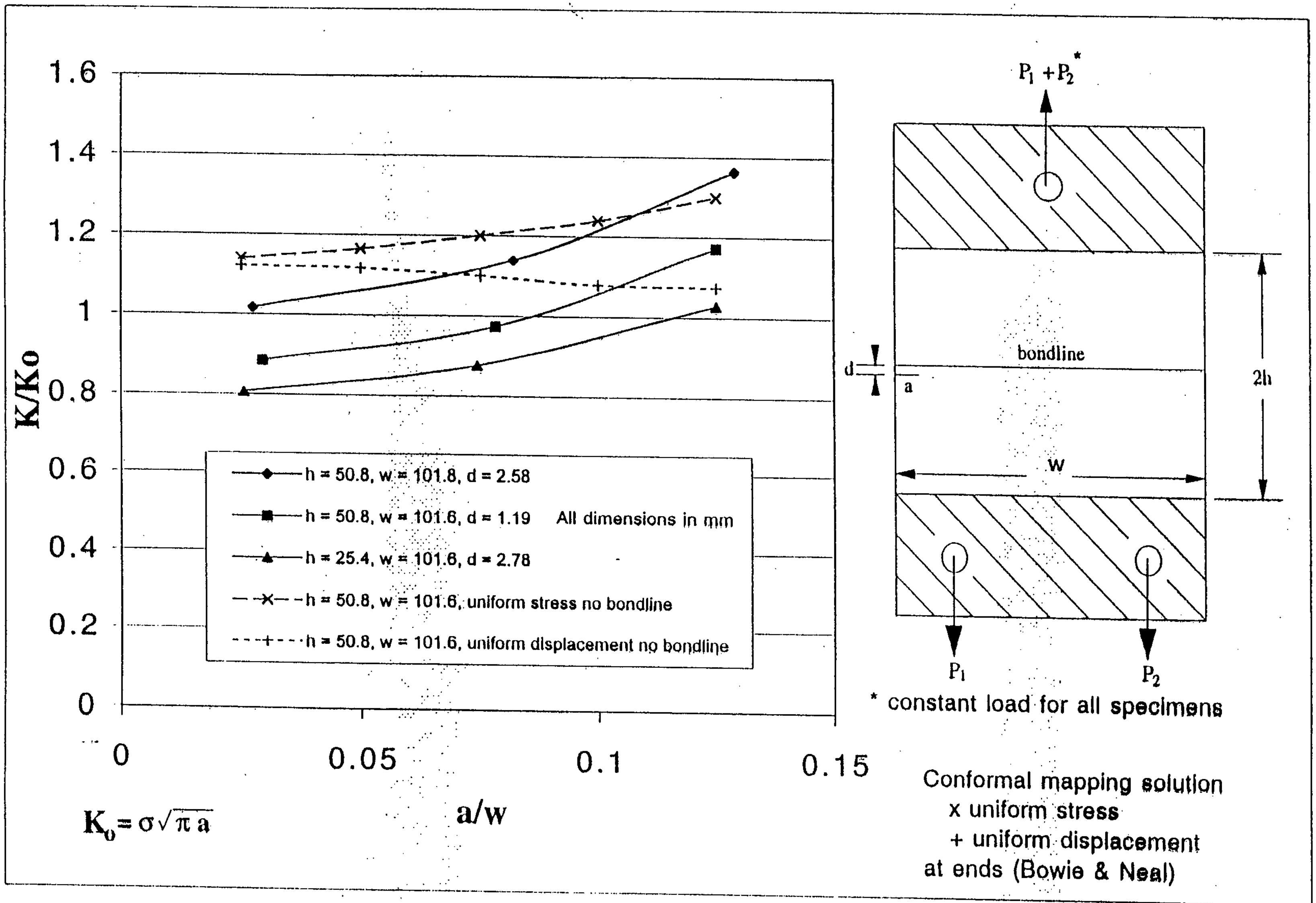

Figure 8 Effect of Crack Length and Specimen Height on SIF Compared with Analytical Results for Uniform Stress and Uniform Displacement in Homogeneous Models.

Summary

In summary, results show that:

1) Normalized SIFs increase with relative crack length for both square and half height bonded specimens more rapidly than indicated by solutions for unbonded specimens for both bondline cracks and cracks parallel to the bondline.

2) Reducing specimen height reduces normalized SIF's for all crack lengths in both bondline cracked specimens and those containing cracks parallel to the bondline. Since Torvik, (1979) indicated such an effect in unbonded edge cracked specimens, this reduction appears to be due to specimen shape rather than a bondline effect and may be conjectured to apply to the bondline cracked specimen results as well.

3) The experiments revealed

a) No shear mode effect

b) A shielding effect due to the bondline for short cracks and those with less separation from the bondline for the cracks parallel to the bondlines.

4) Imperfections in the glued tab arrangement were clearly shown.

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