

K-Solution Approximation Option for Through Cracks Subject to Out-of-Plane Bending

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For

LexTech, Inc.

AFGROW Workshop

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Background

We have been receiving requests to add the solution for a corner cracked plate under out-of-plane bending.

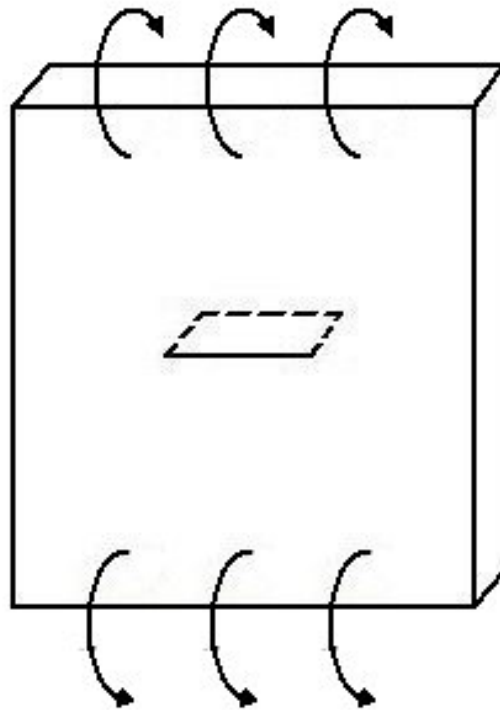
While this solution exists, we have no solution to continue crack growth predictions if the crack transitions to become a through-the-thickness crack (e.g. cases with combined axial & bending loading)

We have included an estimated solution for a single, straight through crack at a hole using a conservative approximation that it is equivalent to $2/3$ of the axial load case.

This conservative solution has also come into question as being far too conservative, and there is some interest in allowing users to specify the fraction of the axial solution to be used for the straight through crack.

As a result of a discussion at our recent European Workshop, I have taken the action item to compare the Fawaz/Andersson tabular solution for an oblique crack at a hole under out-of-plane loading to a straight through crack with various axial load fractions

There are no general closed-form K-solutions available for a through-the-thickness crack under out-of-plane loading



Idealized Case

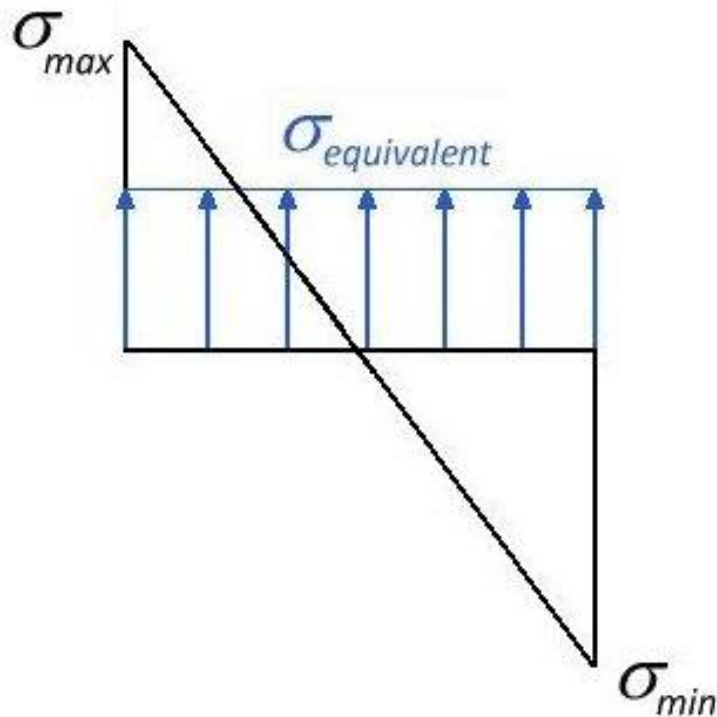


Reality



The assumption of a straight crack front is poorly suited for the out-of-plane loading case

How to Approximate the Out-of-Plane Bending Effect for a Straight Through-the-Thickness Crack?



Is there an “equivalent” Axial Stress?

What are the important considerations?

- Maximum Stress?
- Thickness?
- Initial Crack Length?
-?

Using the Fawaz/Andersson Tabular Solution for Oblique Through Cracks at Holes

Model Geometry and Dimensions

Geometry | Dimension | Load

Model dimensions are initialized to default values at start-up or when a new model configuration is selected.

Enter specimen dimensions

Width (W): 6

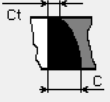
Thickness (T): 0.25

Hole Diameter (D): 0.25

Offset Hole

Hole Offset (B): 1

Enter crack dimensions



Crack Length -'C' Direction: 0.25

Crack Length -'Ct' Direction: 0.2

Oblique through crack

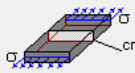
OK Cancel Apply Help

Model Geometry and Dimensions

Geometry | Dimension | Load

For some models AFGROW allows to combine multiple load case solutions. The ratio of the axial, bending or bearing stress to the reference stress must be input for each load case.

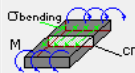
Axial



Filled Unloaded Hole

Stress Fraction: 0


Bending



$\sigma_{bending} = \frac{Mt}{2I}$

Stress Fraction: 1

Bearing



$\sigma_{bearing} = \sigma \cdot \frac{W}{D}$

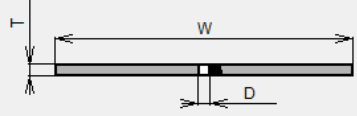
Equivalent width: 6

Stress Fraction: 0

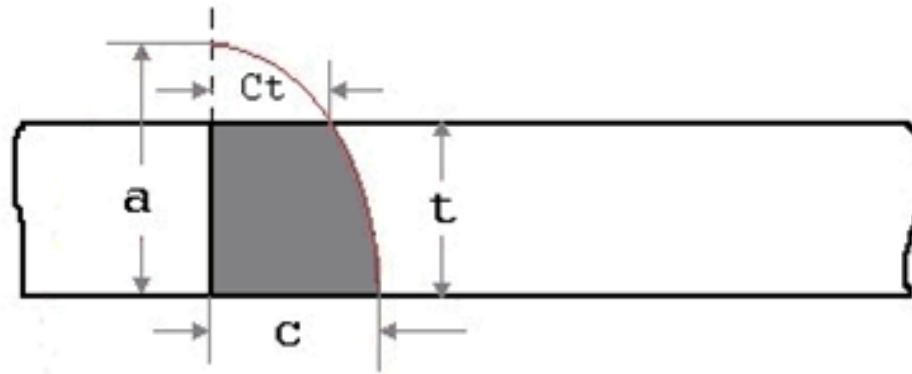
Filter Compression

Calculator Calculate Bearing Stress Fraction

OK Cancel Apply Help



Oblique Solution Limitations

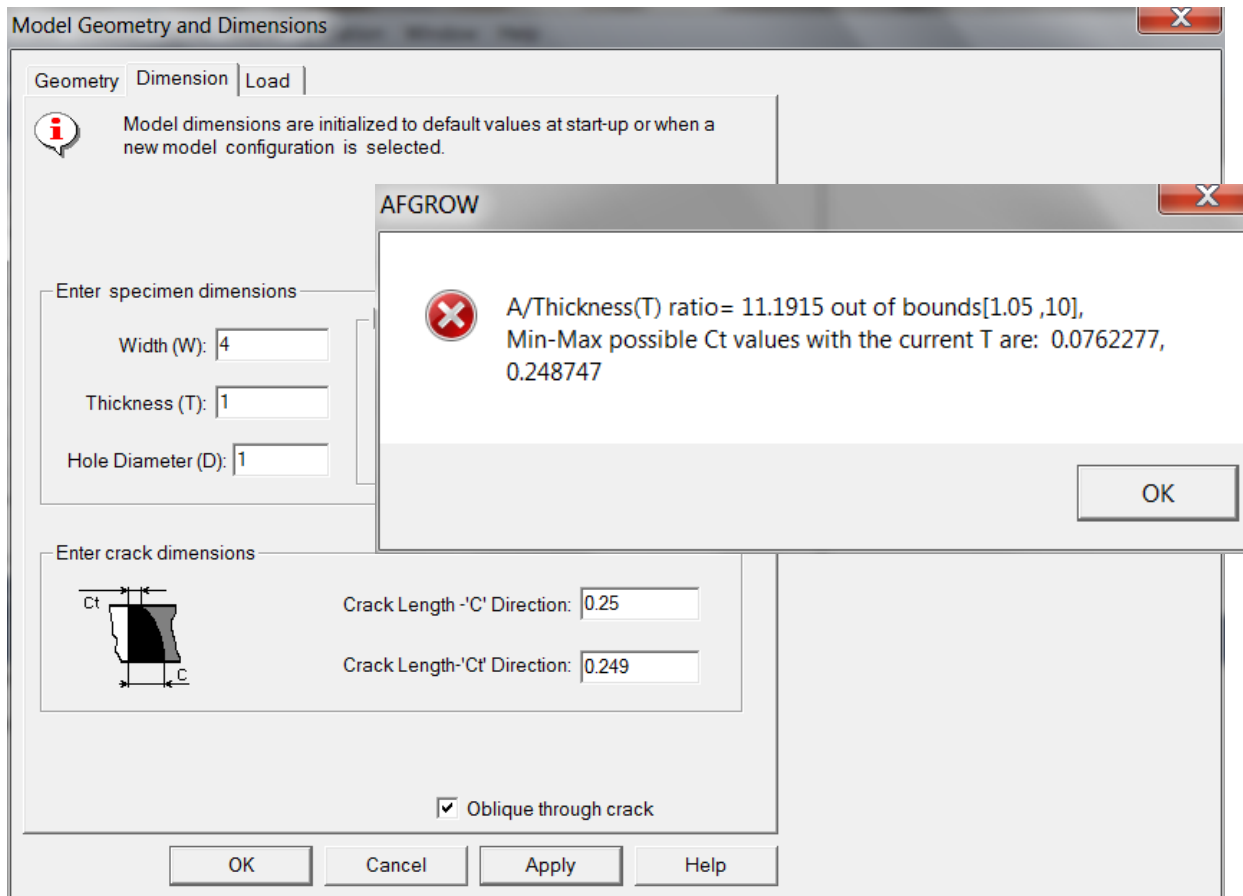


$a/c = 0.2, 0.3, 0.4, 0.6, 1.0, 2.0, 5.0, \text{ and } 10.0$

$a/t = 1.05, 1.07, 1.09, 1.13, 1.17, 1.21, 2.0, 5.0, \text{ and } 10.0$

$R/t = 0.5, 1.0, \text{ and } 2.0$ - where R is the hole radius

Initial Crack Length Limitations



For all oblique crack cases:

$$(C - Ct) < 3\% \text{ of } C$$

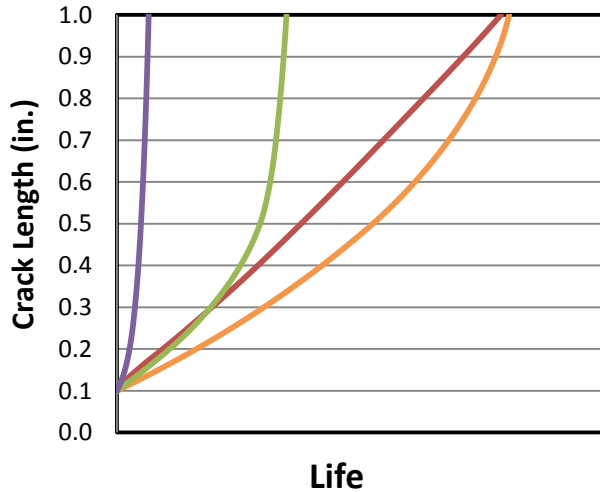
Comparison Results Assuming 100% Out of Plane Loading

All comparisons are for wide plates to minimize finite width effects

Nominal Hole Diameter and Thickness Under Low Maximum Stress

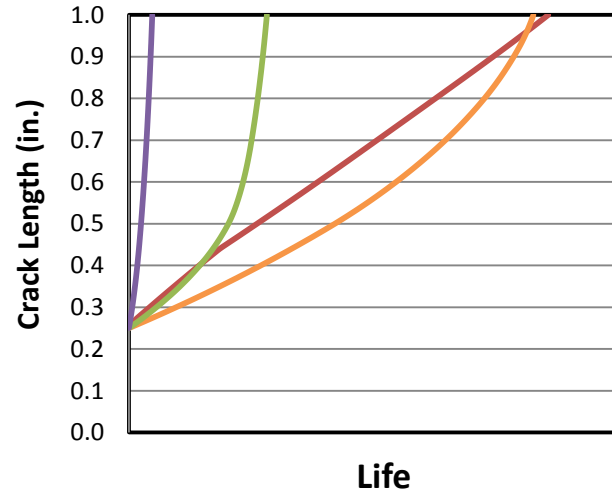
Single Through Crack at a Hole

Initial Crack Length = 0.1 in.



Single Through Crack at a Hole

Initial Crack Length = 0.25 in.



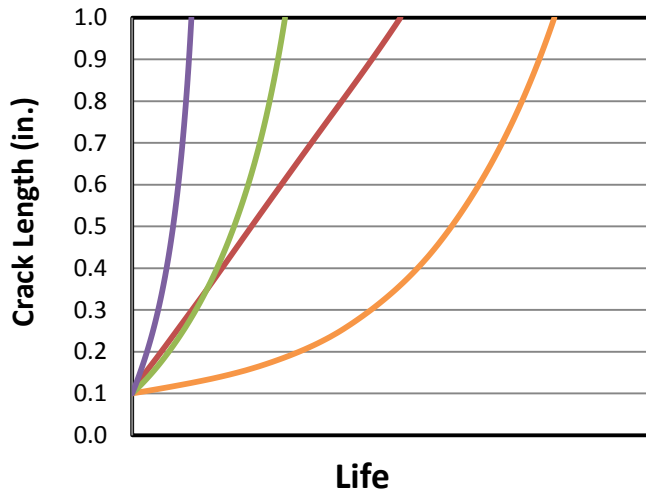
- Oblique Crack Solution
- Axial Fraction = 0.4
- Axial Fraction = 0.5
- Axial Fraction = 0.667

Hole Diameter = 0.25 in.
Plate Thickness = 0.25 in.
Plate Width = 25 in.
Maximum Bending Stress = 15 ksi

Nominal Hole Diameter and Thickness Under Moderate Maximum Stress

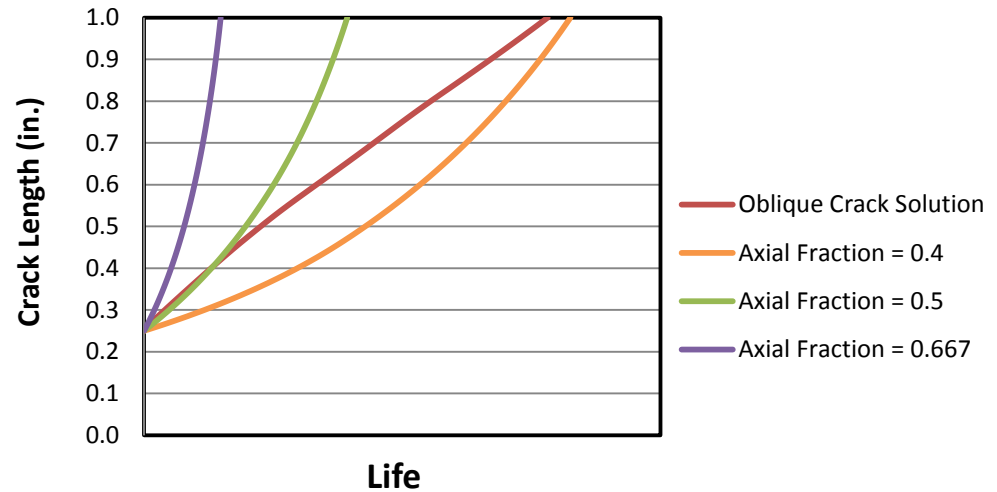
Single Through Crack at a Hole

Initial Crack Length = 0.1 in.



Single Through Crack at a Hole

Initial Crack Length = 0.25 in.



Hole Diameter = 0.25 in.

Plate Thickness = 0.25 in.

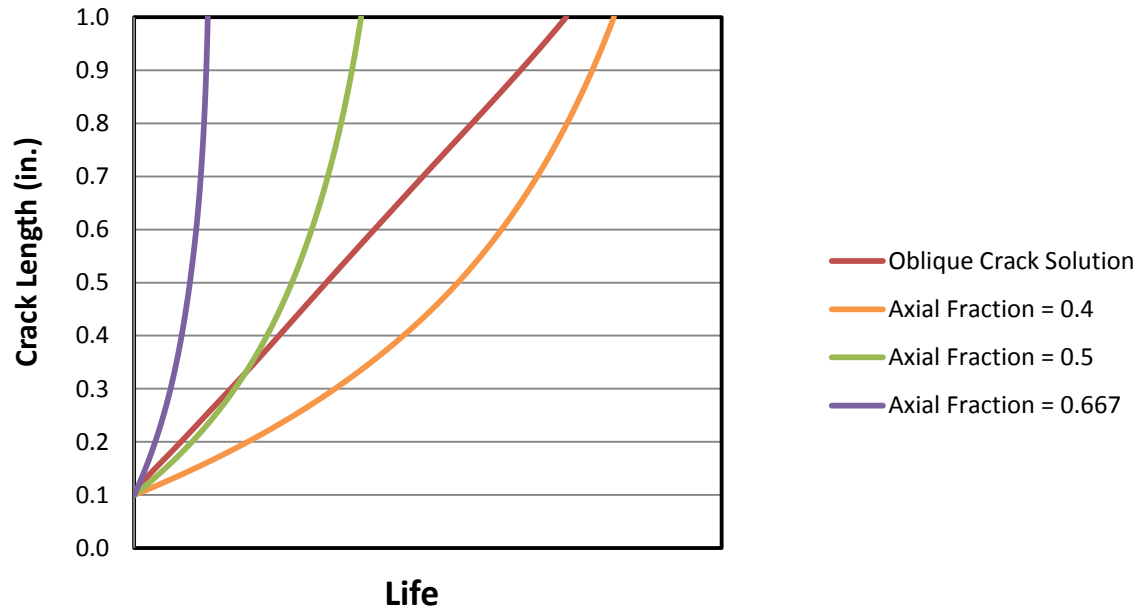
Plate Width = 25 in.

Maximum Bending Stress = 25 ksi

Nominal Hole Diameter and Thickness Under High Maximum Stress

Single Through Crack at a Hole

Out-of-Plane Bending ($\sigma_{\max} = 35 \text{ Ksi}$)



Hole Diameter = 0.25 in.

Plate Thickness = 0.25 in.

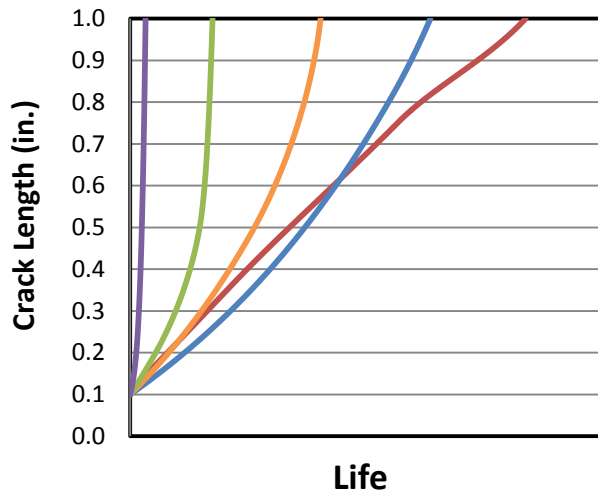
Plate Width = 25 in.

Maximum Bending Stress = 35 ksi

Low Thickness and Maximum Stress at Two Thickness Values

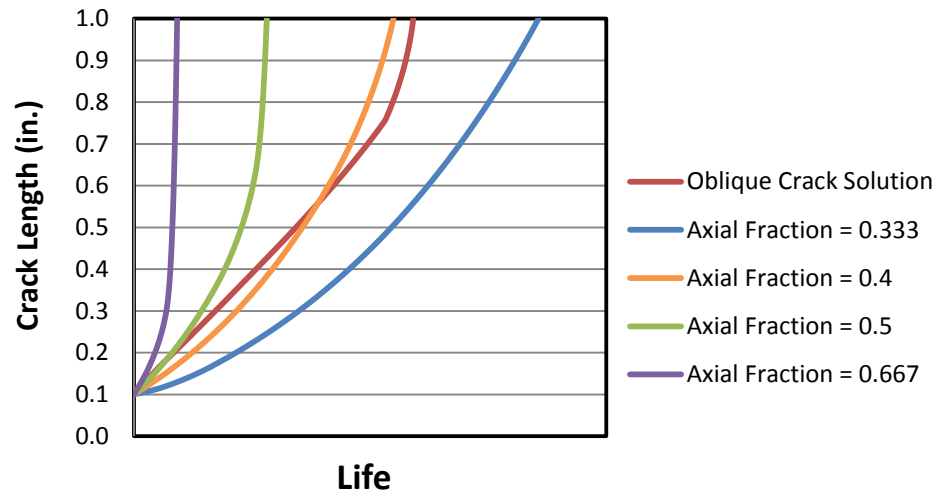
Single Through Crack at a Hole

Hole Diameter = 0.25 in.



Single Through Crack at a Hole

Hole Diameter = 0.125 in.

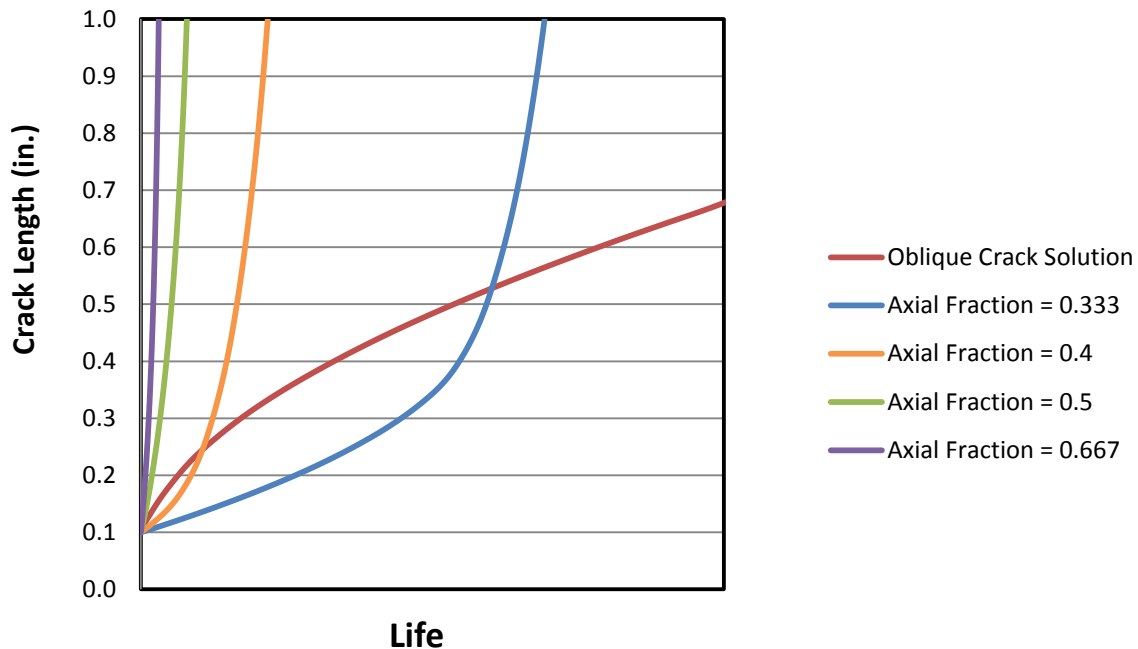


Initial Crack Length = 0.1 in.
Plate Thickness = 0.125 in.
Plate Width = 25 in.
Maximum Bending Stress = 15 ksi

Nominal Hole Diameter, Low Thickness Under Moderate Maximum Stress

Single Through Crack at a Hole

Out-of-Plane Bending ($\sigma_{\max} = 25$ Ksi)



Hole Diameter = 0.25 in.

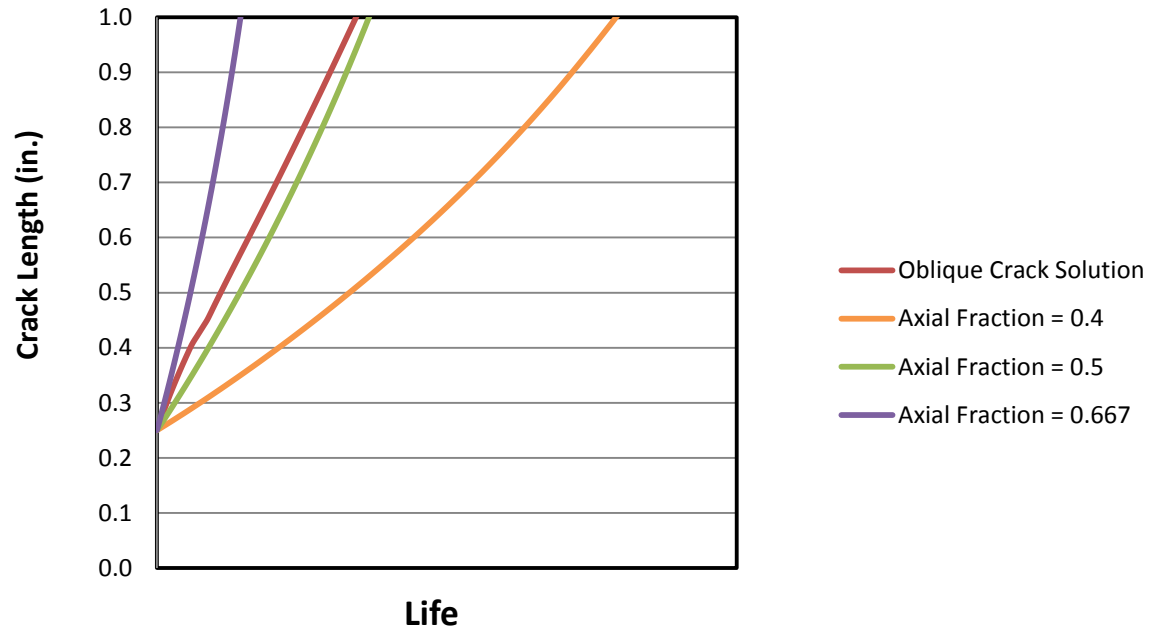
Plate Thickness = 0.125 in.

Plate Width = 25 in.

Maximum Bending Stress = 25 ksi

Large Hole Diameter and Thickness Under Low Maximum Stress

Single Through Crack at a Hole Out-of-Plane Bending ($\sigma_{\max} = 15$ Ksi)



Hole Diameter = 1.0 in.

Plate Thickness = 1.0 in.

Plate Width = 100 in.

Maximum Bending Stress = 15 ksi

Discussion

The straight through-the-thickness crack approximation using an axial load fraction is not ideal, but it appears that the $2/3$ fraction is too conservative for most practical cases

The result of this comparison for 100% out-of-plane bending for a through cracked hole indicate that axial stress fractions from 0.333 to 0.5+ may be appropriate for most practical problems.

The appropriate axial stress fraction appears to be a function of the plate thickness more than any other parameter. The fraction appears to increase with plate thickness.

Initial crack length and stress level don't seem to be significant parameters, but hole diameter does influence the results for the cracked hole case.

In the absence of an oblique crack solution, it may be a reasonable approach for the edge cracked plate geometry. However, the effect of combined loading is unknown.

Adding a capability for a user-defined axial stress fraction may also be a good idea. However, because of legacy issues, it may be a good idea to keep the $2/3$ fraction as the default value.

Comments?