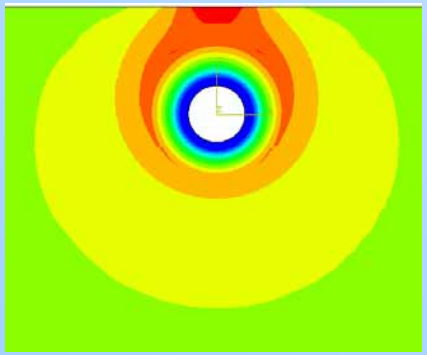
ENGINEERING DIVISION
Commercial Aircraft Group
ISRAEL AEROSPACE INDUSTRIES LTD

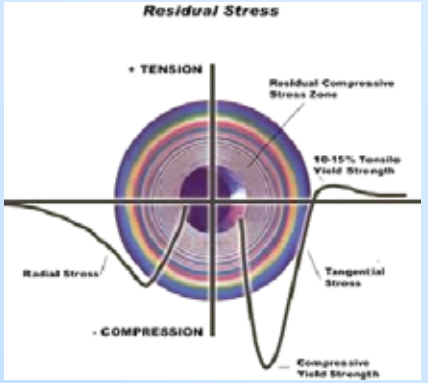
The Effects of Residual Tensile Stresses Induced by Cold-Working a Fastener Hole



A. Brot and C. Matias

Engineering Division

Israel Aerospace Industries

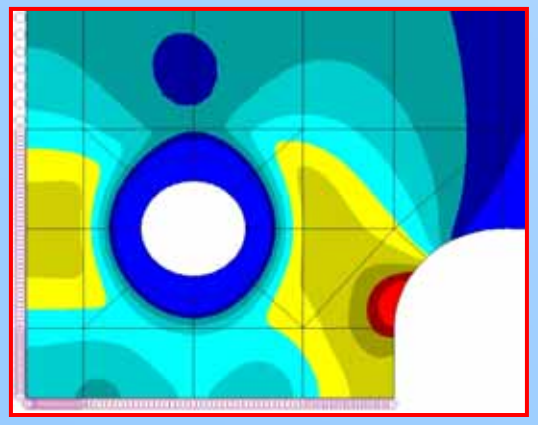


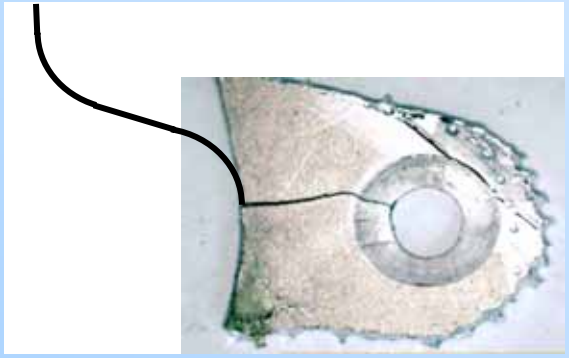
Presented to the:

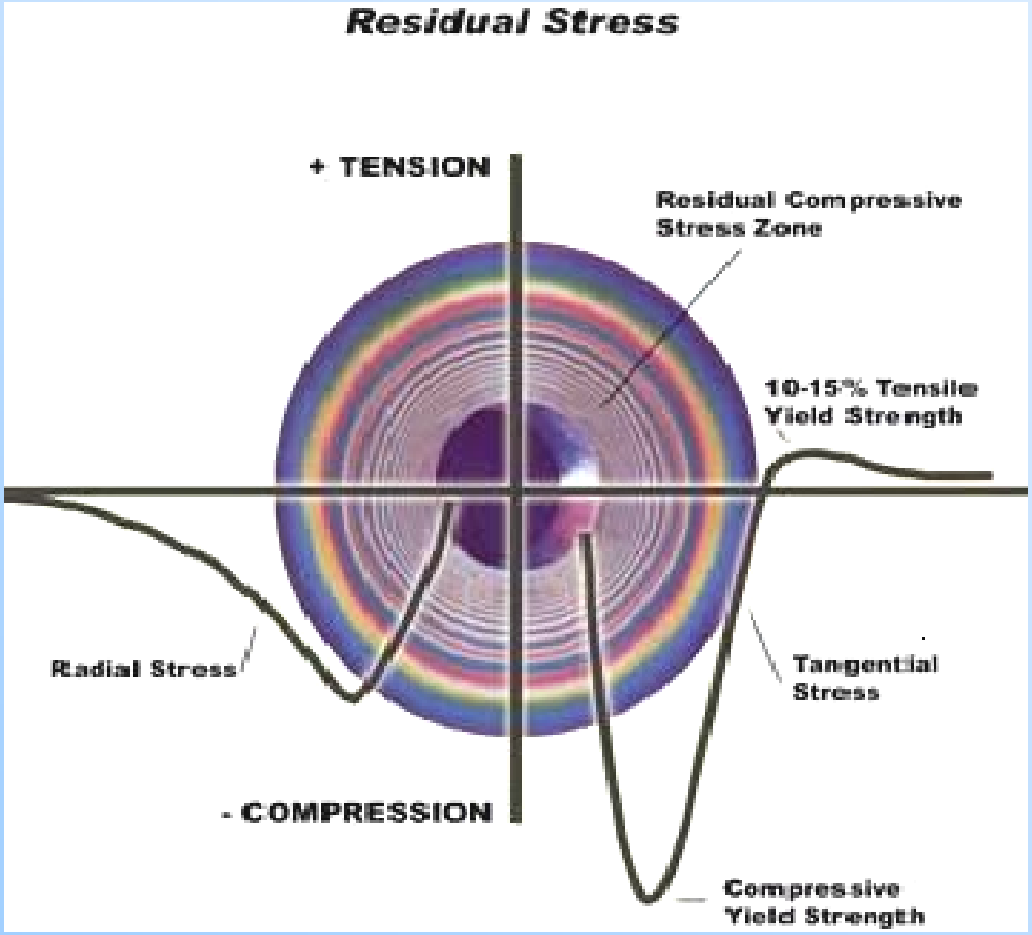
USAF Aircraft Structural Integrity Program (ASIP) Conference

Palm Springs, CA

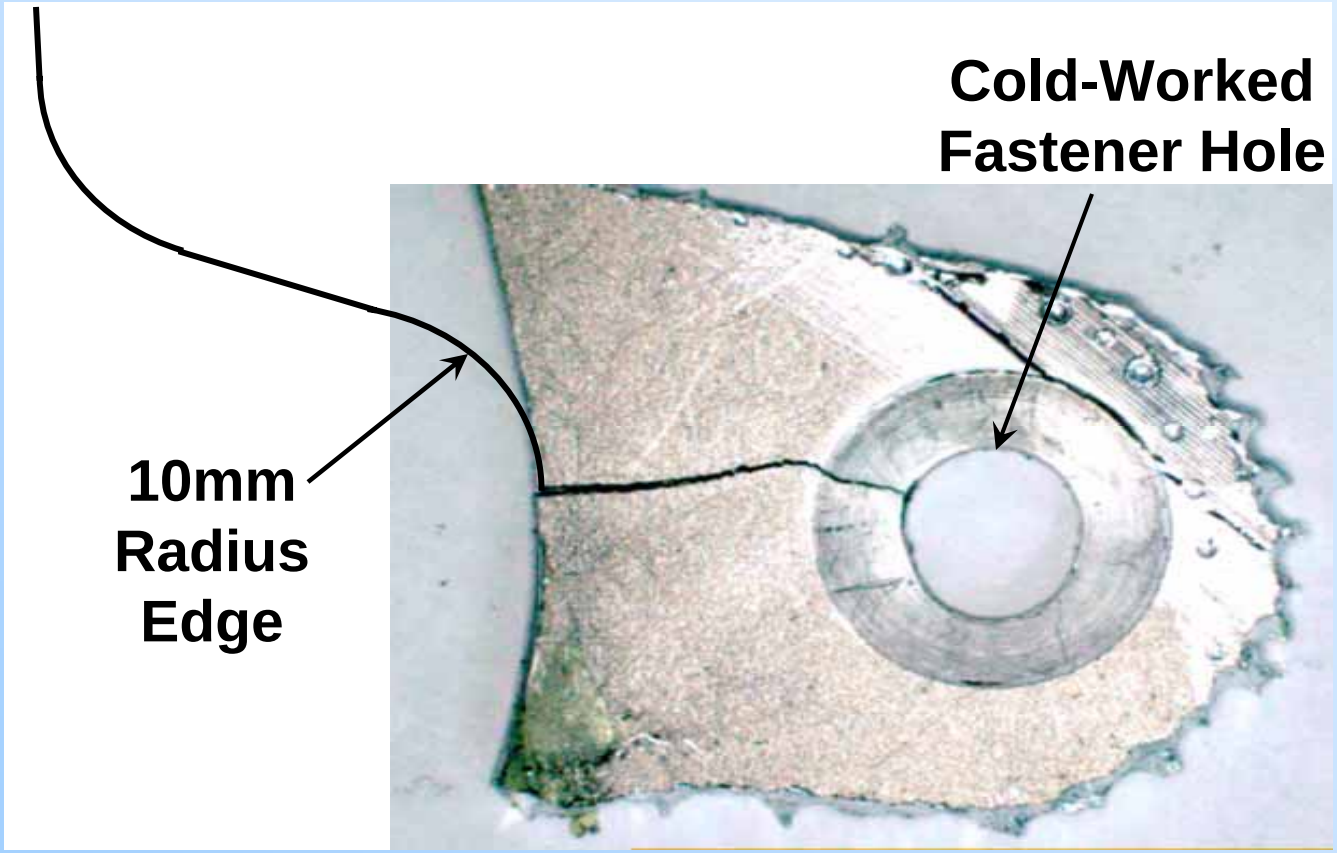
4 December 2007



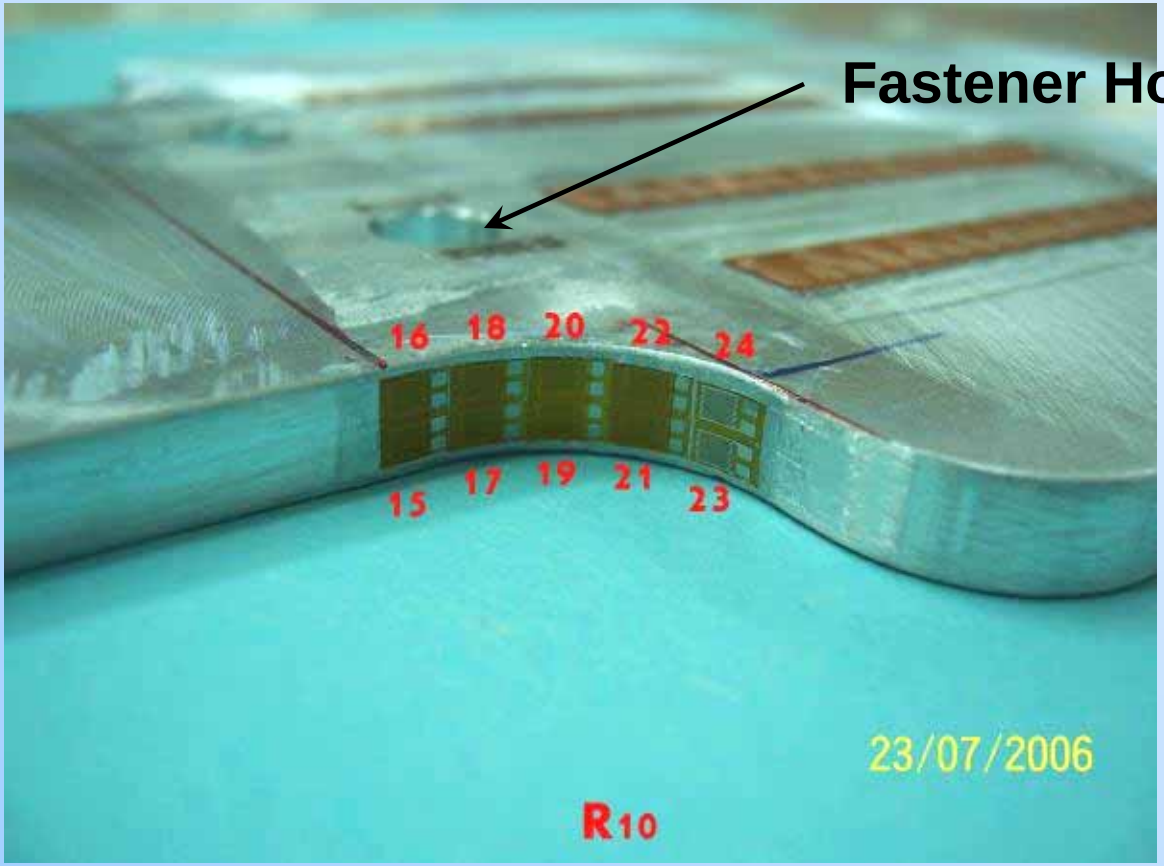




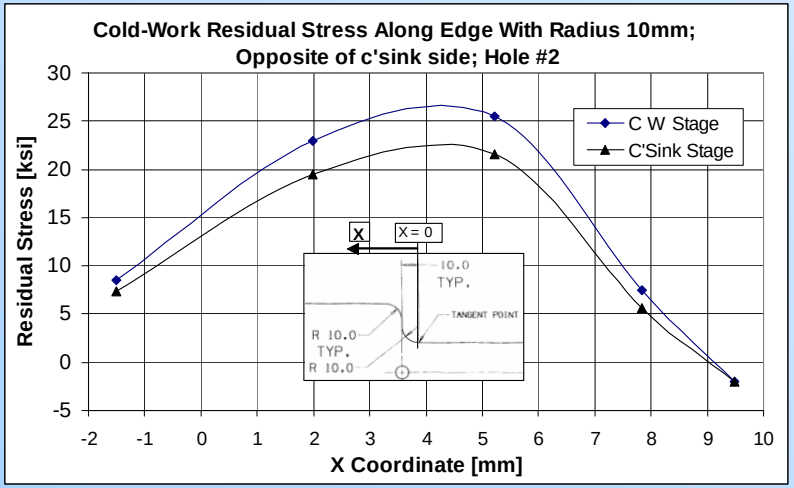
Photoelastic Measurements of the Stress Field at a Cold-Worked Hole *(provided by Fatigue Technology Inc.)*

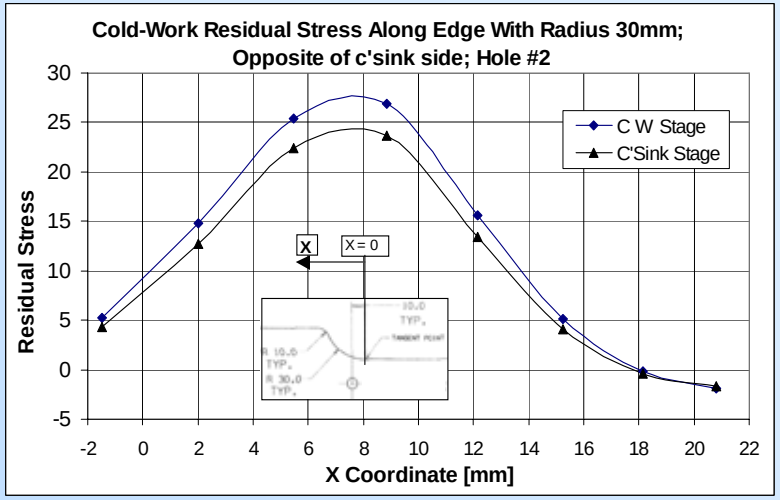


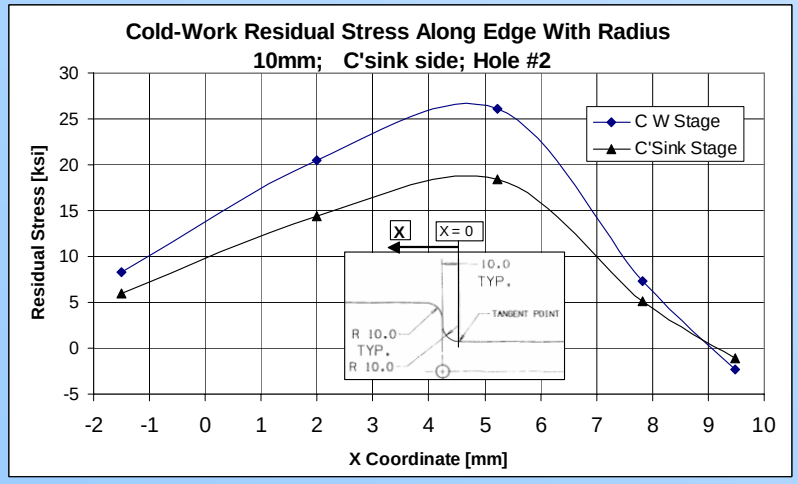
Crack Growth from a Notched Edge towards a Cold-Worked Fastener Hole for 7475-T7351 Aluminum Alloy
(detail was cut-away from a component test specimen)

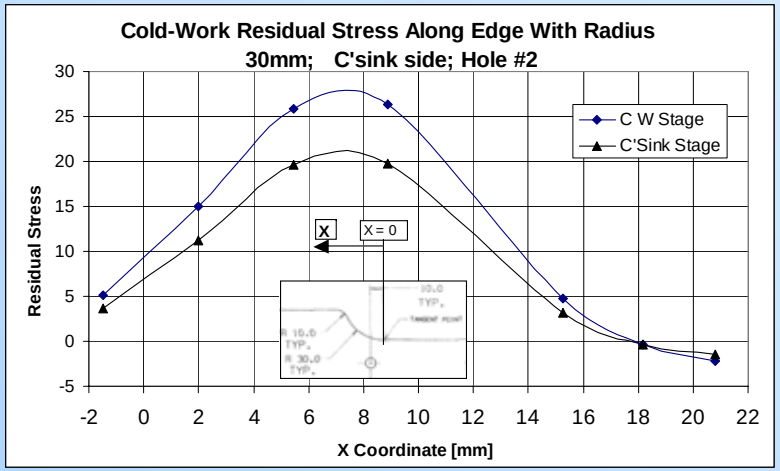


Test Specimen Used to Measure Residual Stresses Induced by Cold-Working (10mm notch radius)

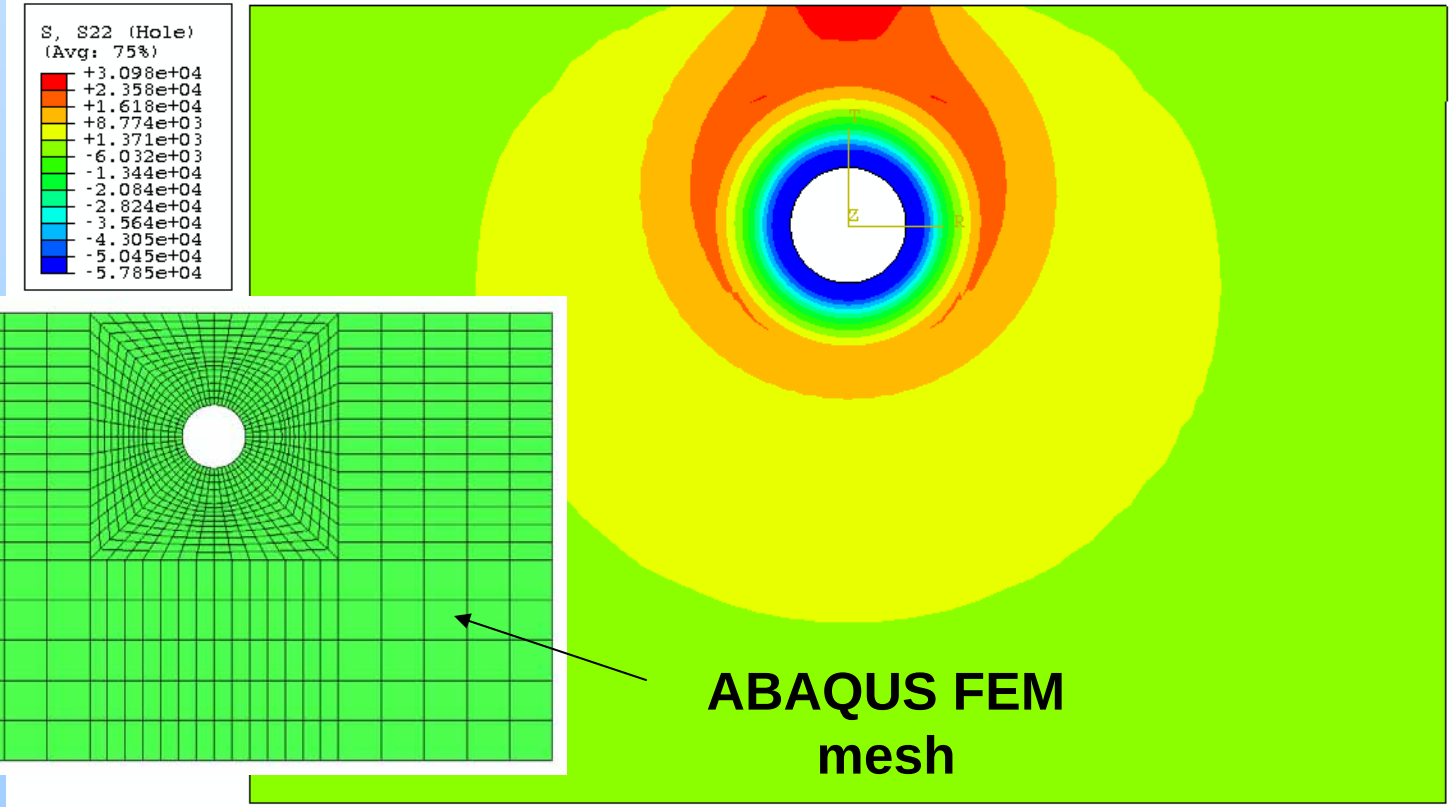








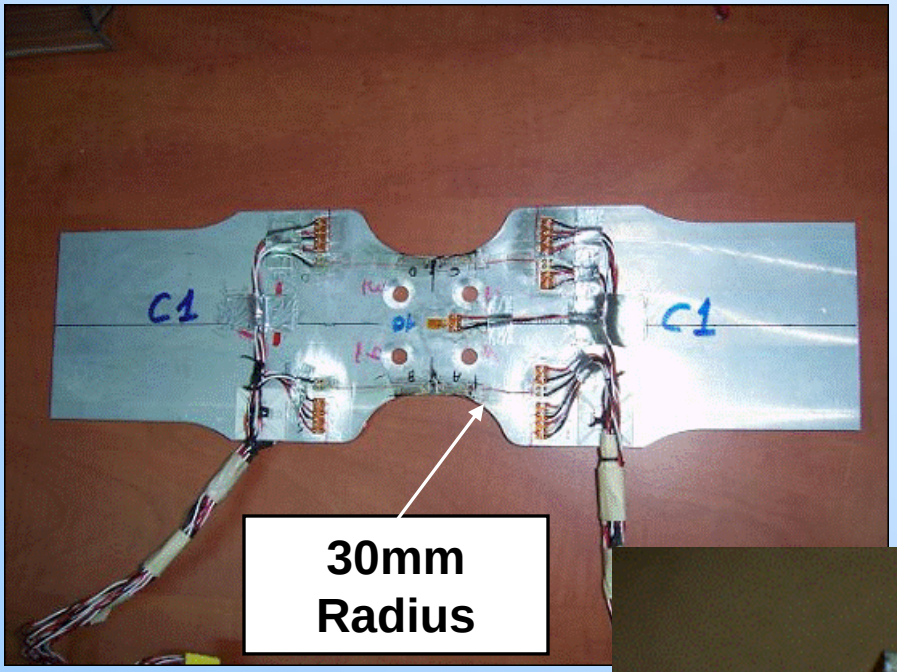
Measured Stress Distribution along Edge of Notch

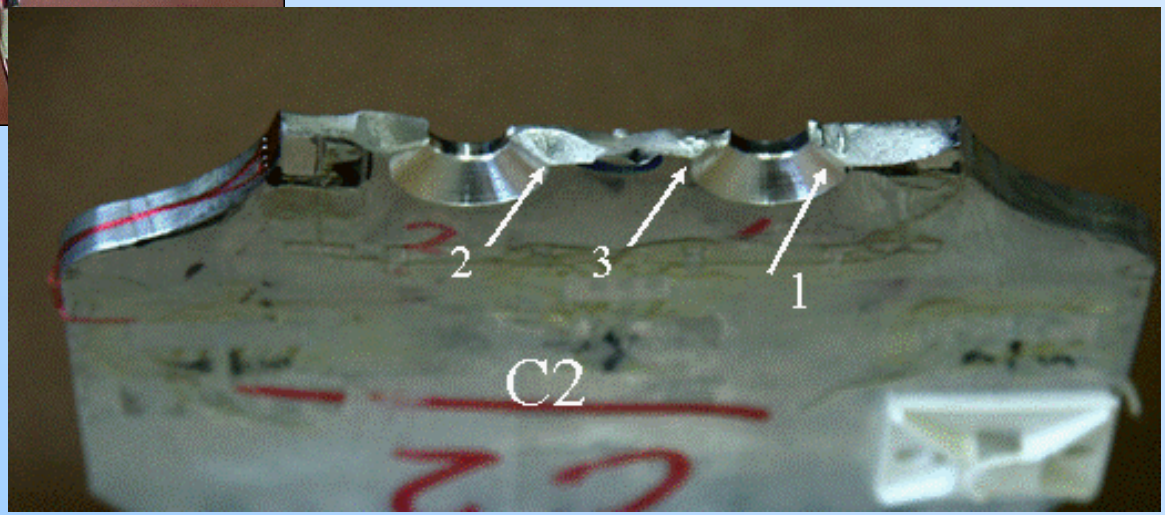


Stress Field around a Cold-Worked Hole near an Edge (e/D = 1.95) showing a residual stress of about 31 ksi.

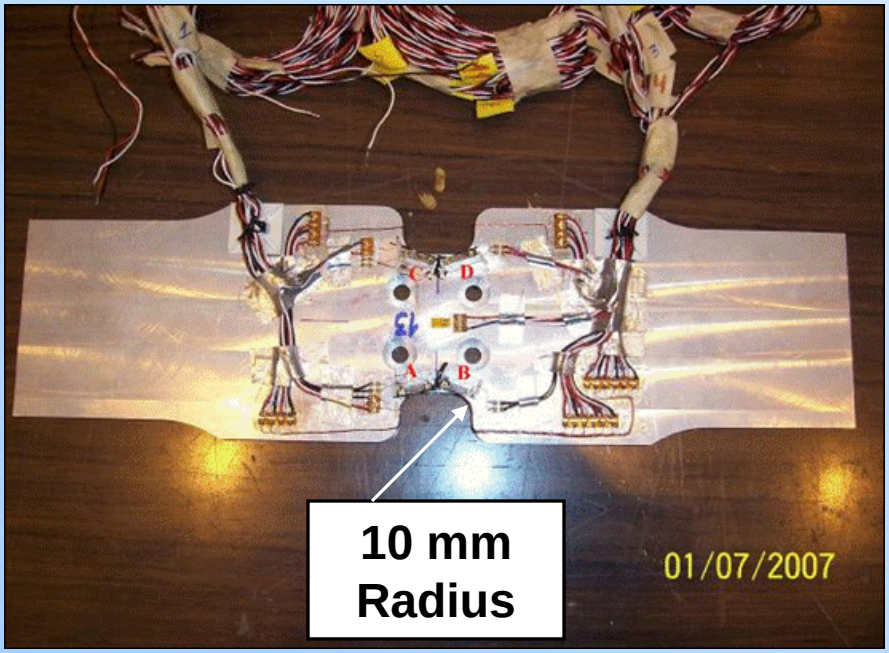
Elastic-plastic (ABAQUS) FEM, using quadratic reduced integration, courtesy of Fatigue Technology Inc.

- **Failure of a 30mm radius test coupon under 20 ksi (R = 0.05) loading.**
- ***Failure originated from the outer diameter of the countersunk holes.***
- **Mean life of *first failure* (3 coupons, 12 holes): 186,000 cycles.**

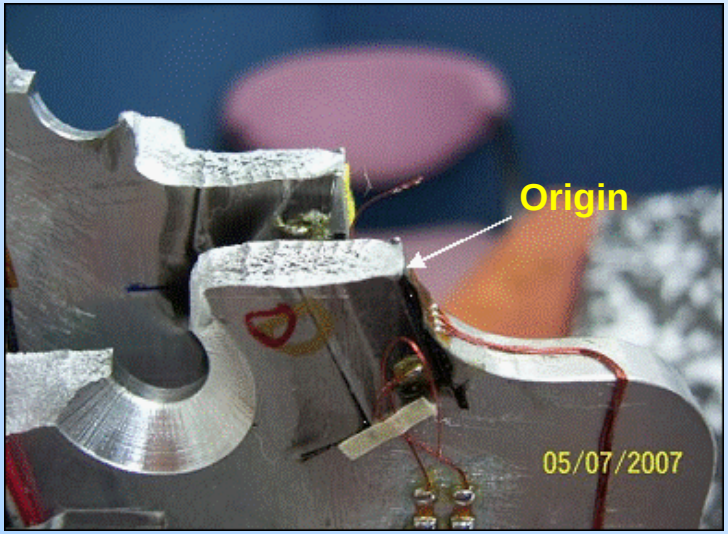




Test Results for the 30mm Radius Coupon with Cold-Worked and Countersunk Holes



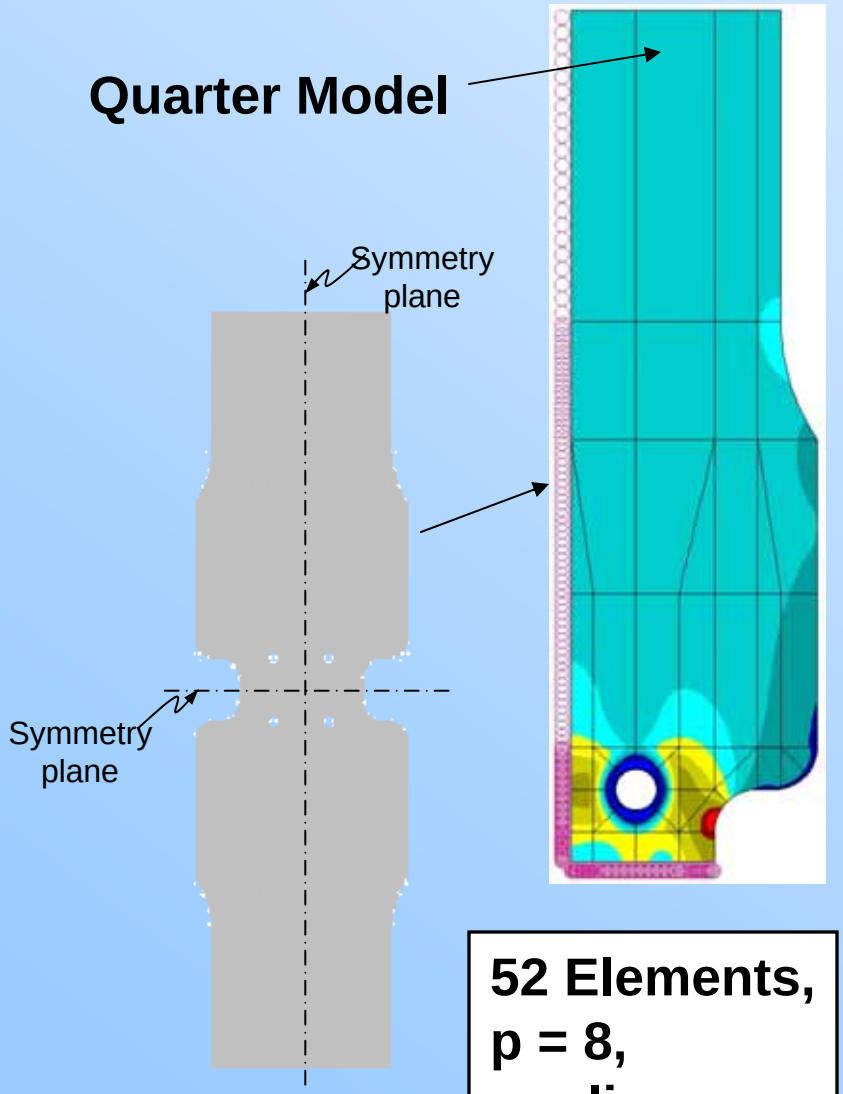
- Failure of a 10mm radius test coupon under 20 ksi (R = 0.05) loading.
- *Failure originated from the 10mm radius edge, adjacent to the cold-worked hole.*
- Minimum life (1 coupon, 4 holes): 57,000 cycles.



Test Results for the 10mm Radius Coupon with Cold-Worked and Countersunk Holes

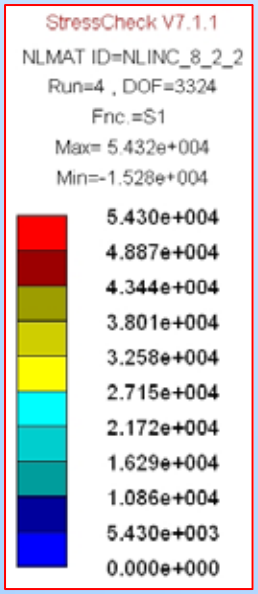
StressCheck (ver. 7.1) Analysis of Cold-Worked Specimen

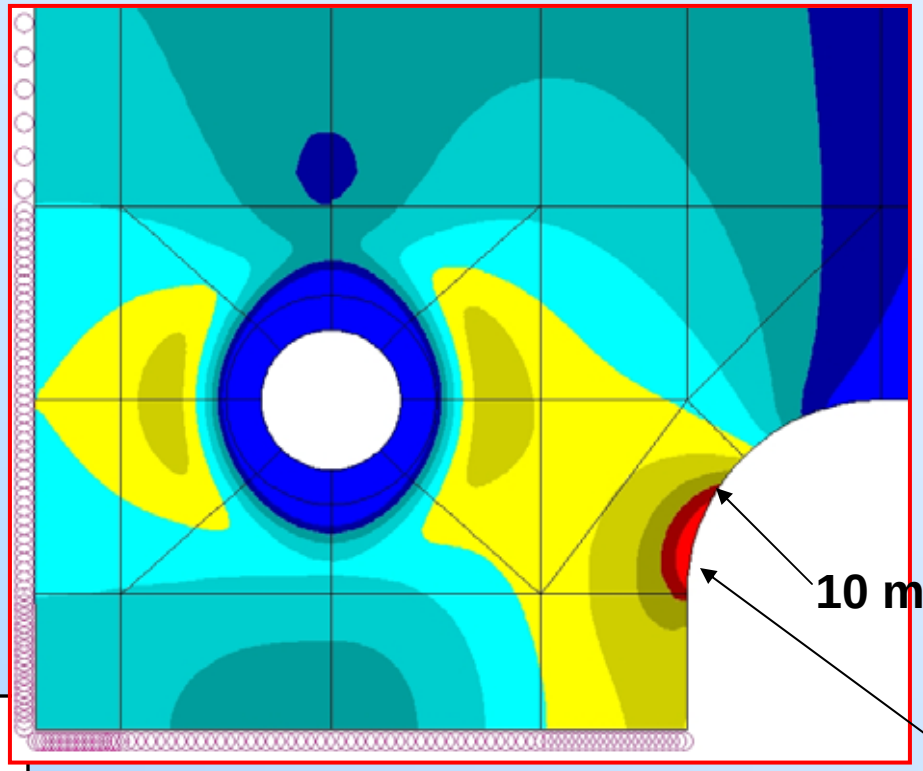
Quarter Model



52 Elements, p = 8, nonlinear solution

P-level	DOF	Total Potential Energy	Convergence Rate	% Error
1	119	1.230594E+03	0	31.35
2	342	1.131074E+03	1.11	9.72
3	579	1.125535E+03	0.7	6.71
4	920	1.121601E+03	1.63	3.15
5	1365	1.120756E+03	1.81	1.54
6	1914	1.120553E+03	2.11	0.76
7	2567	1.120506E+03	2.23	0.39
8	3324	1.120494E+03	2.23	0.22

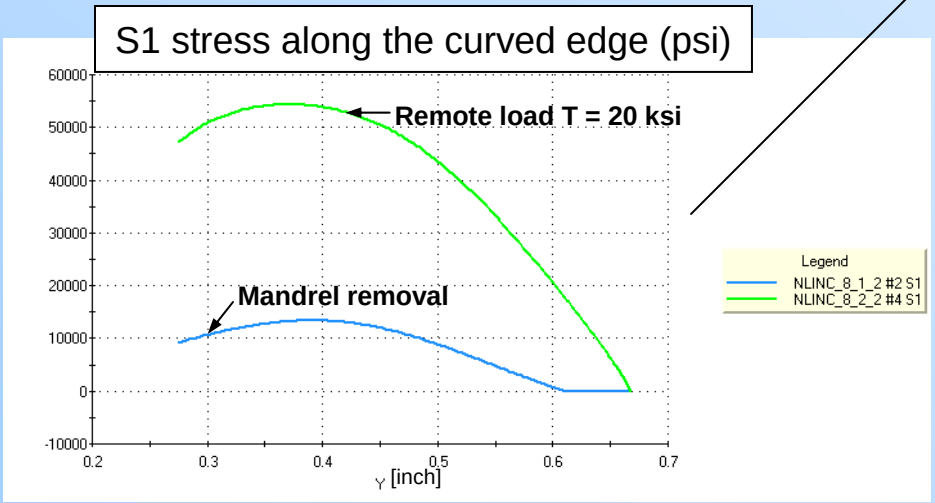


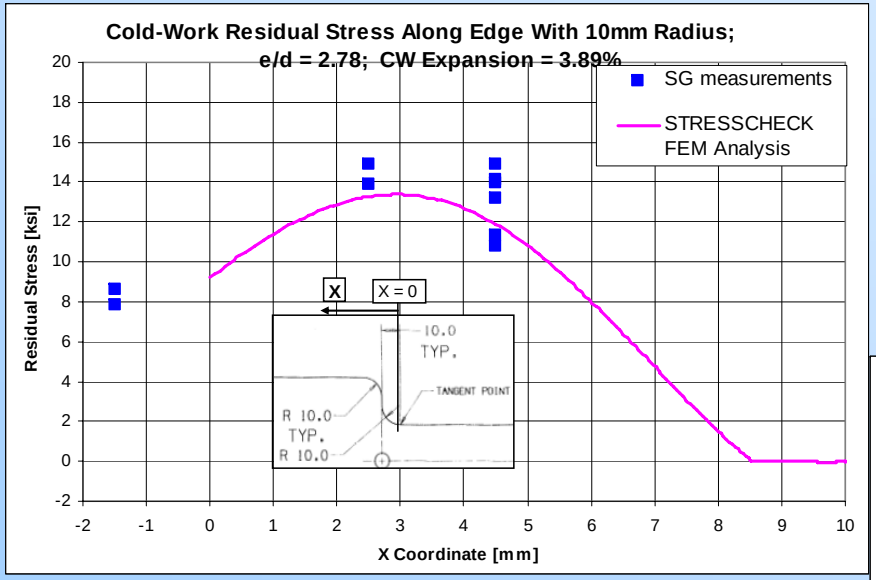


Residual Stress Distribution for e/D = 2.78

External stress = 20 ksi

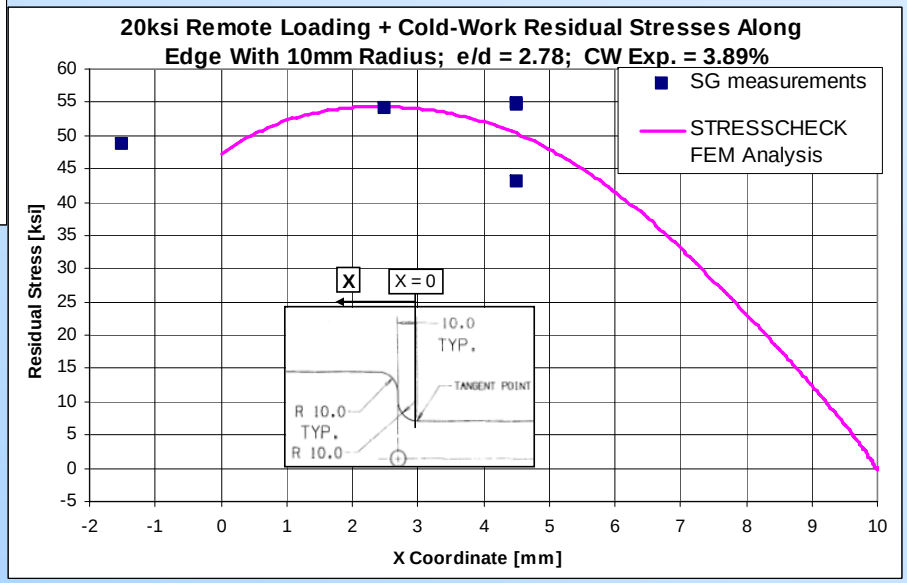
Produced by StressCheck ver 7.1, *(Courtesy of ESRD)*



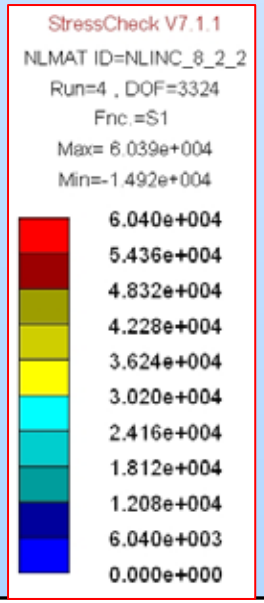


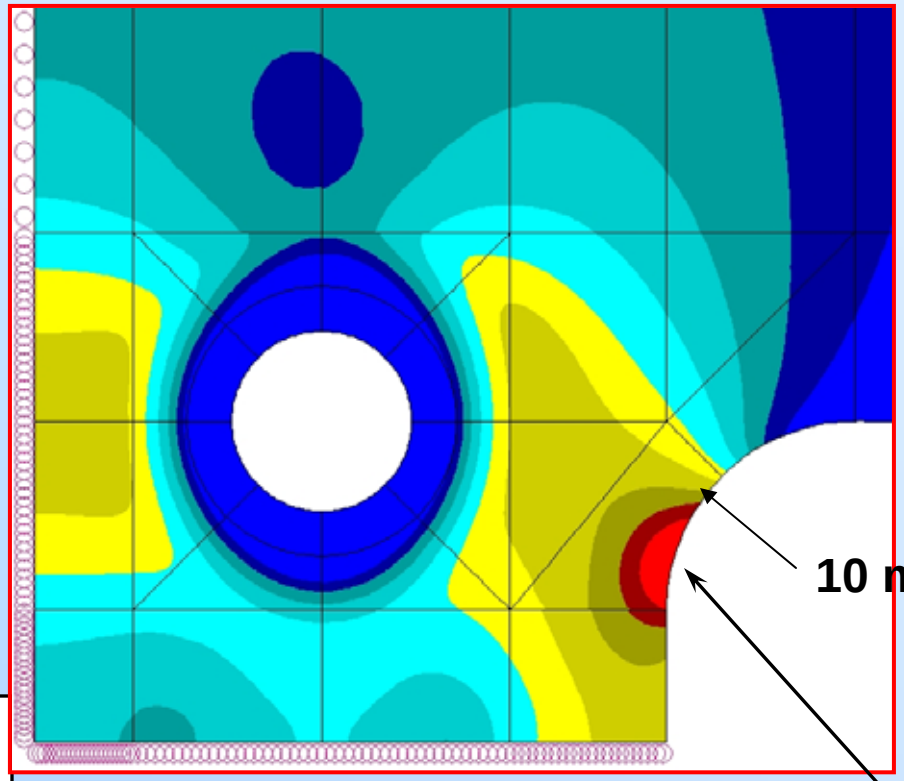
Notch stresses after cold-working (no external loading)

Notch stresses after application of 20 ksi stress



Comparison of Measured Stresses and those Calculated by the StressCheck (ver. 7.1) FEM

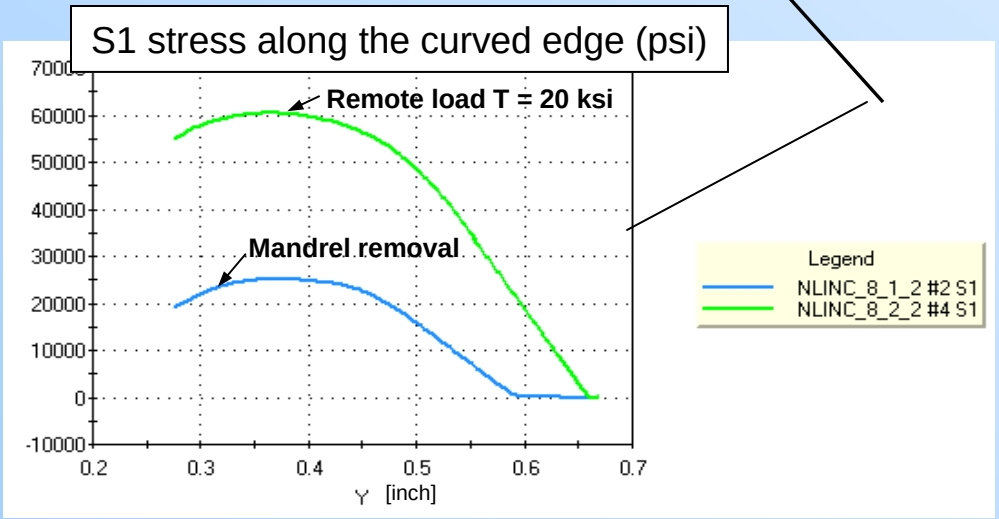


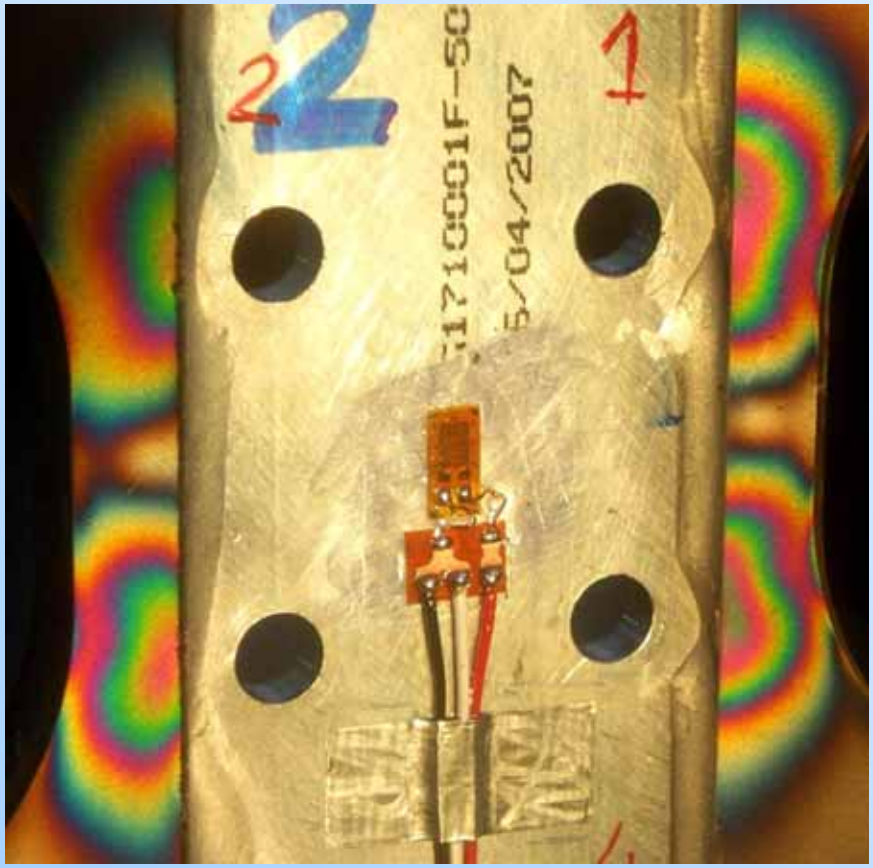


Residual Stress Distribution for e/D = 2.10

External Stress = 20 ksi

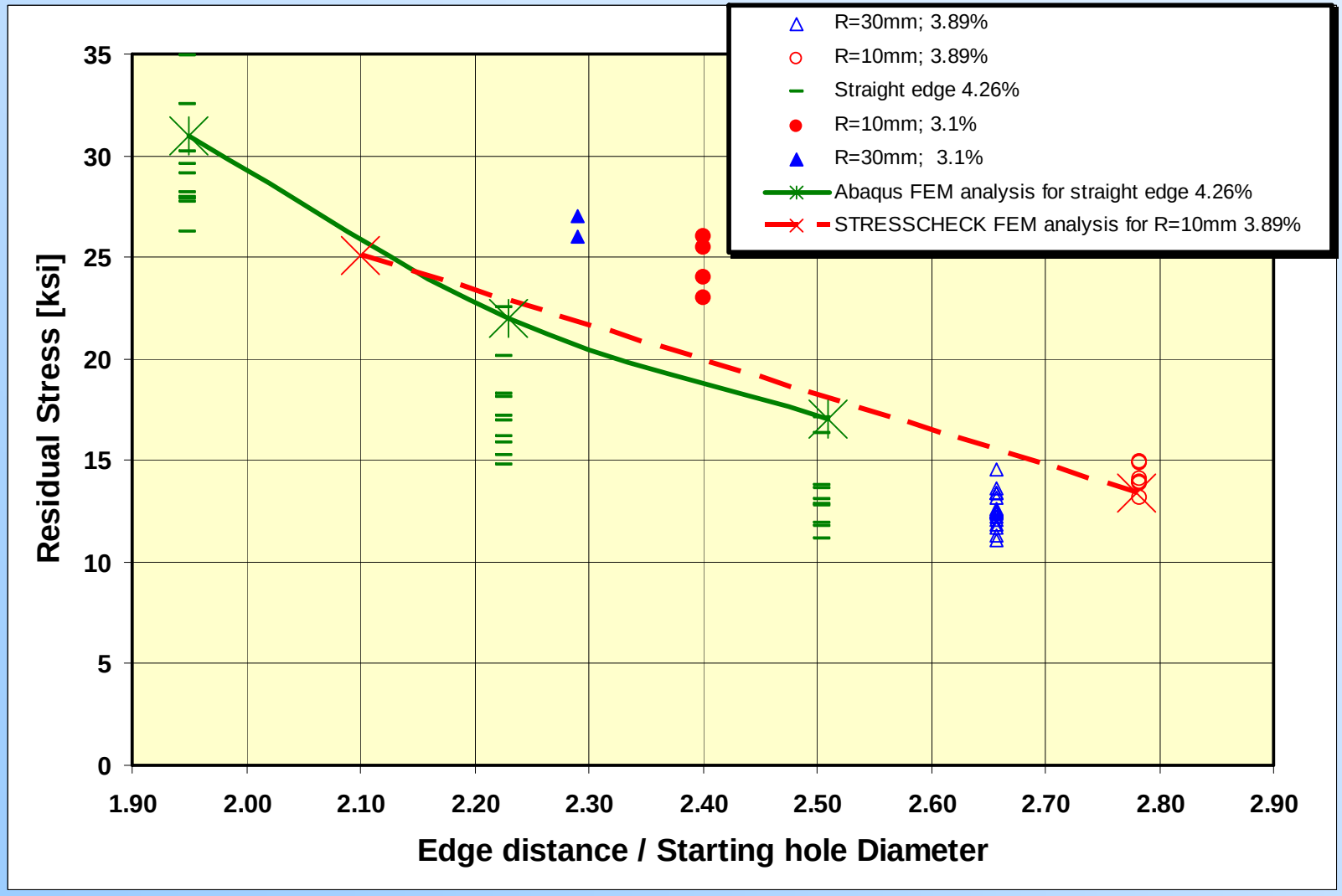
Produced by StressCheck ver 7.1, *(Courtesy of ESRD)*



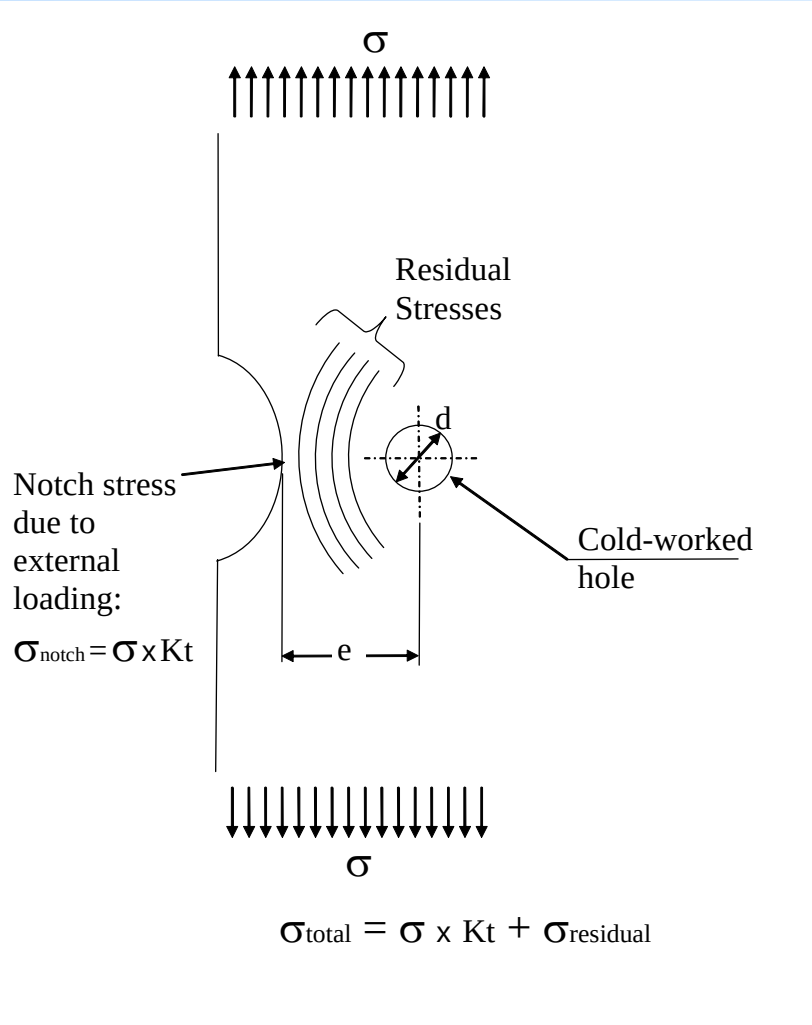


Photoelastic Measurements of Residual Stresses at the Edge Resulting From Cold-Working

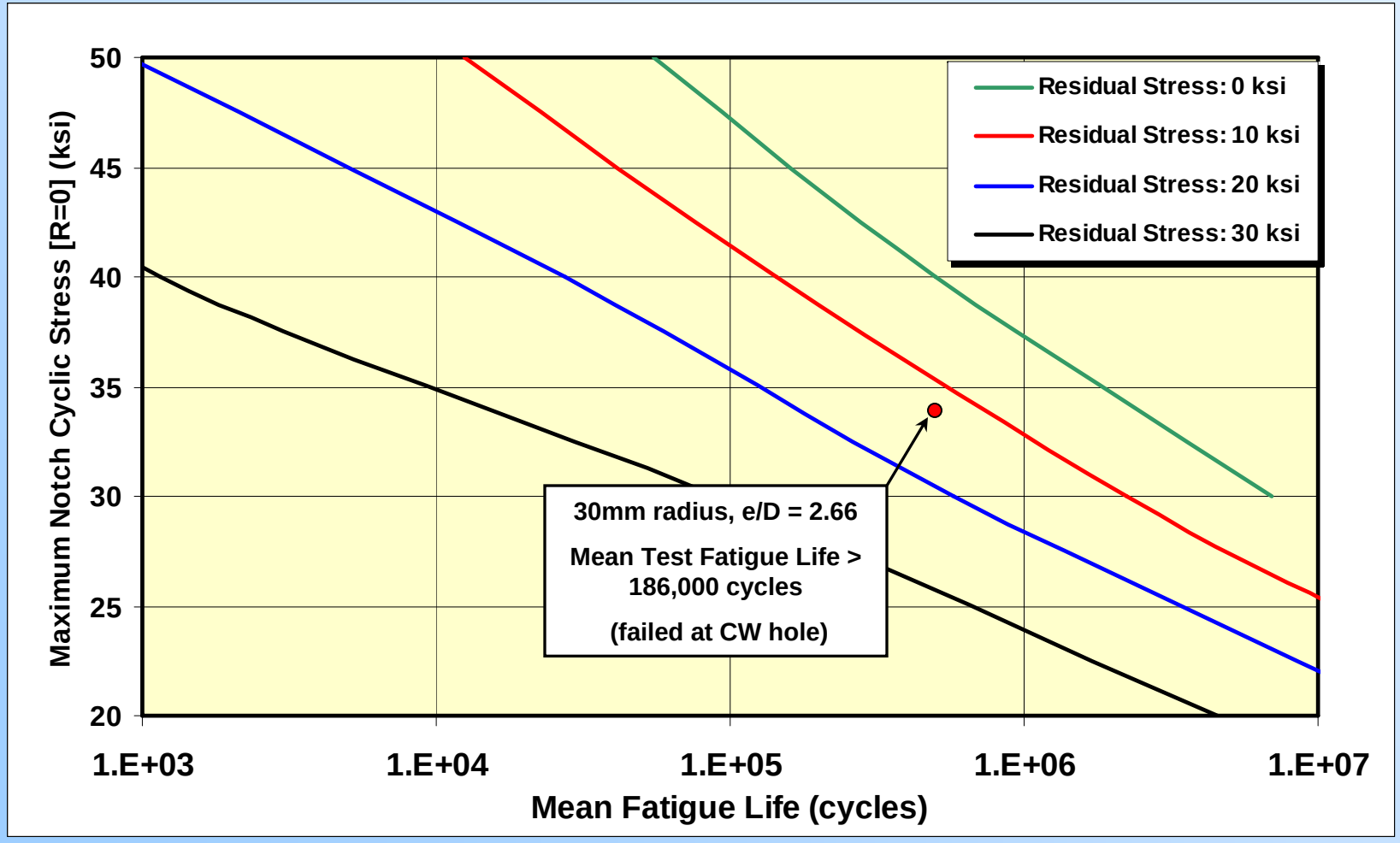
(performed by Vishay Israel Ltd.)



Measured and Calculated Residual Stresses at the Edge, Resulting From Cold-Working

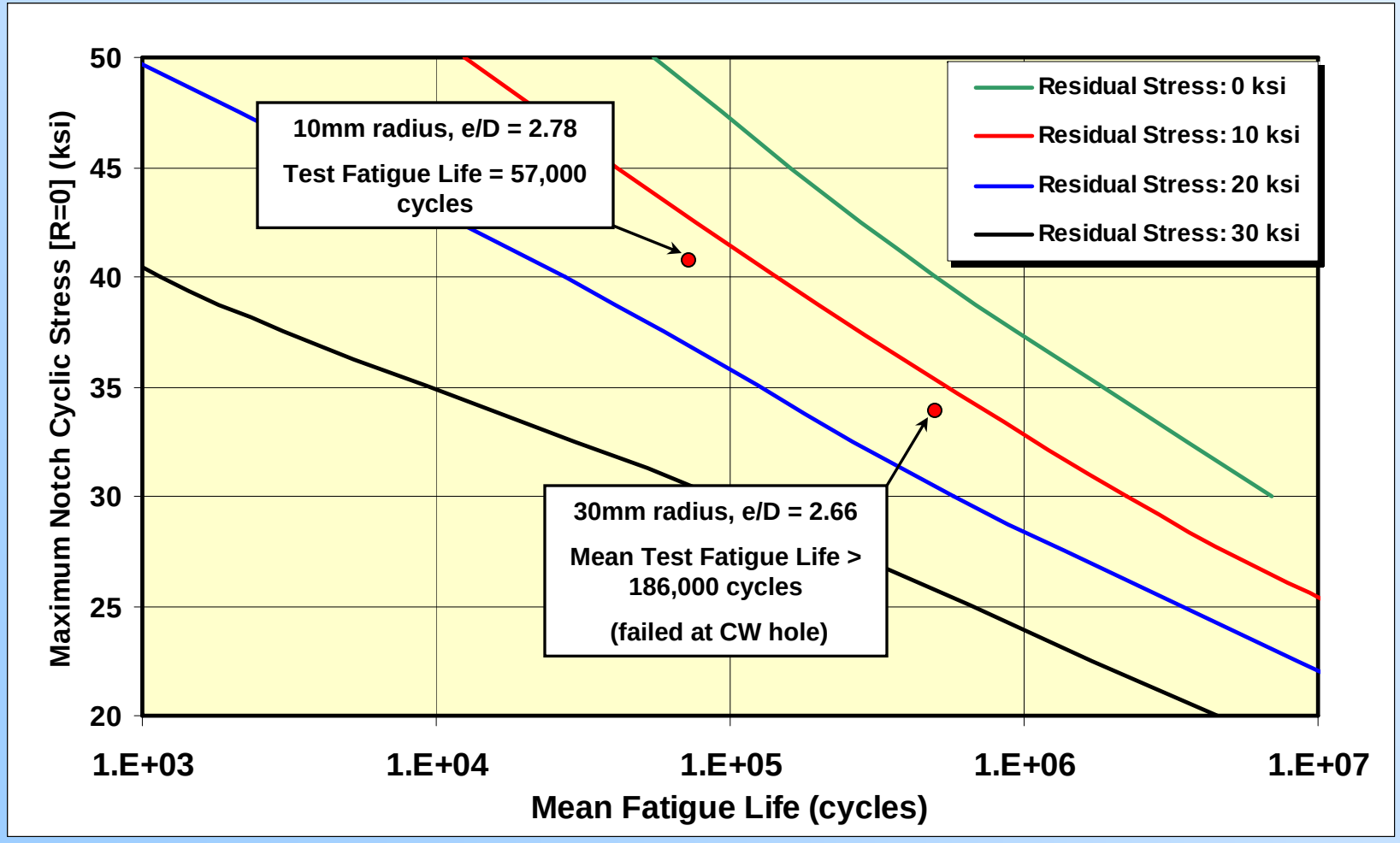


Superimposing of Notch Stresses with the Residual Stresses



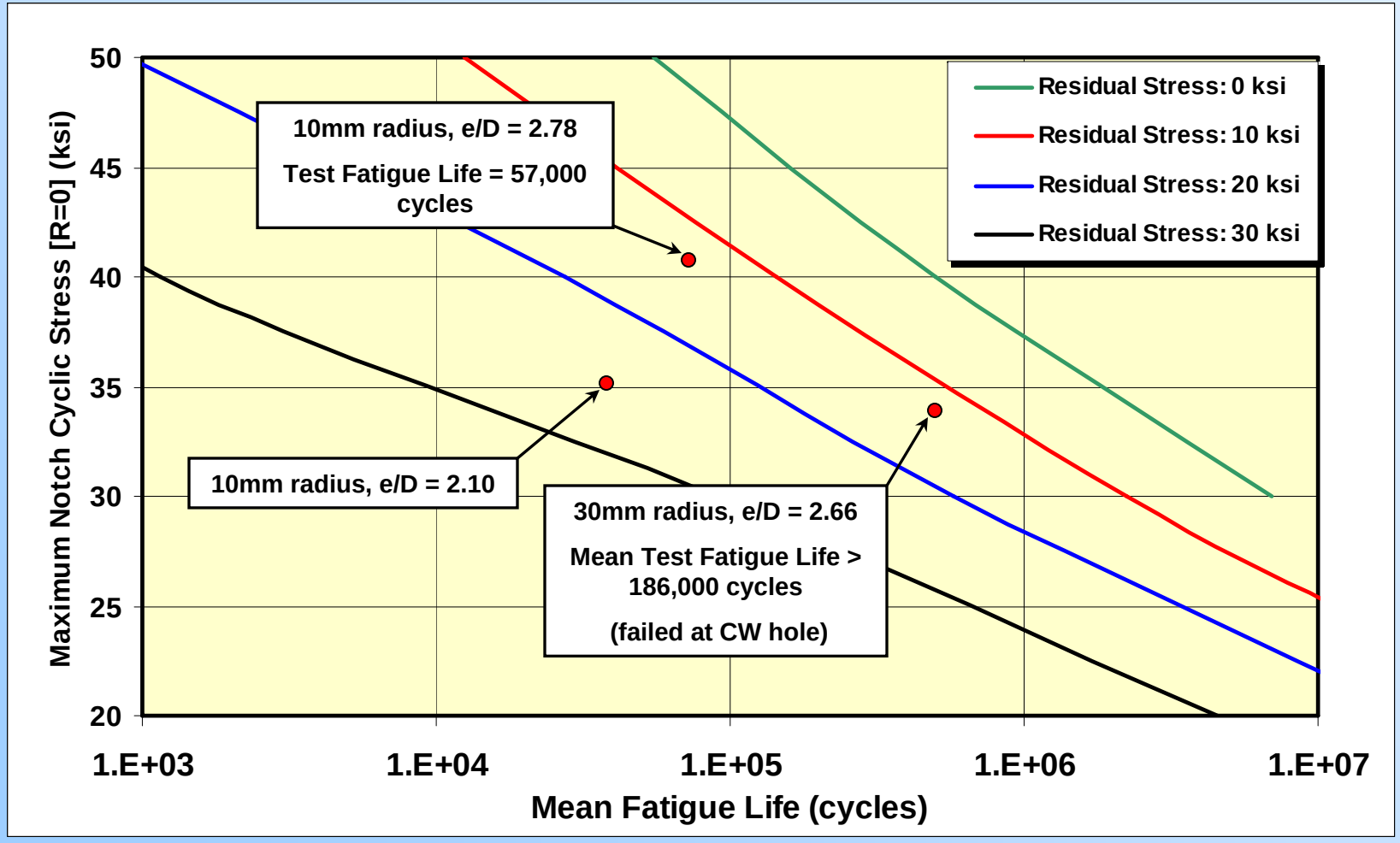
Fatigue Analysis Results for 7075-T7351 Aluminum alloy:

(superimposing notch stresses (R = 0) with residual stresses)



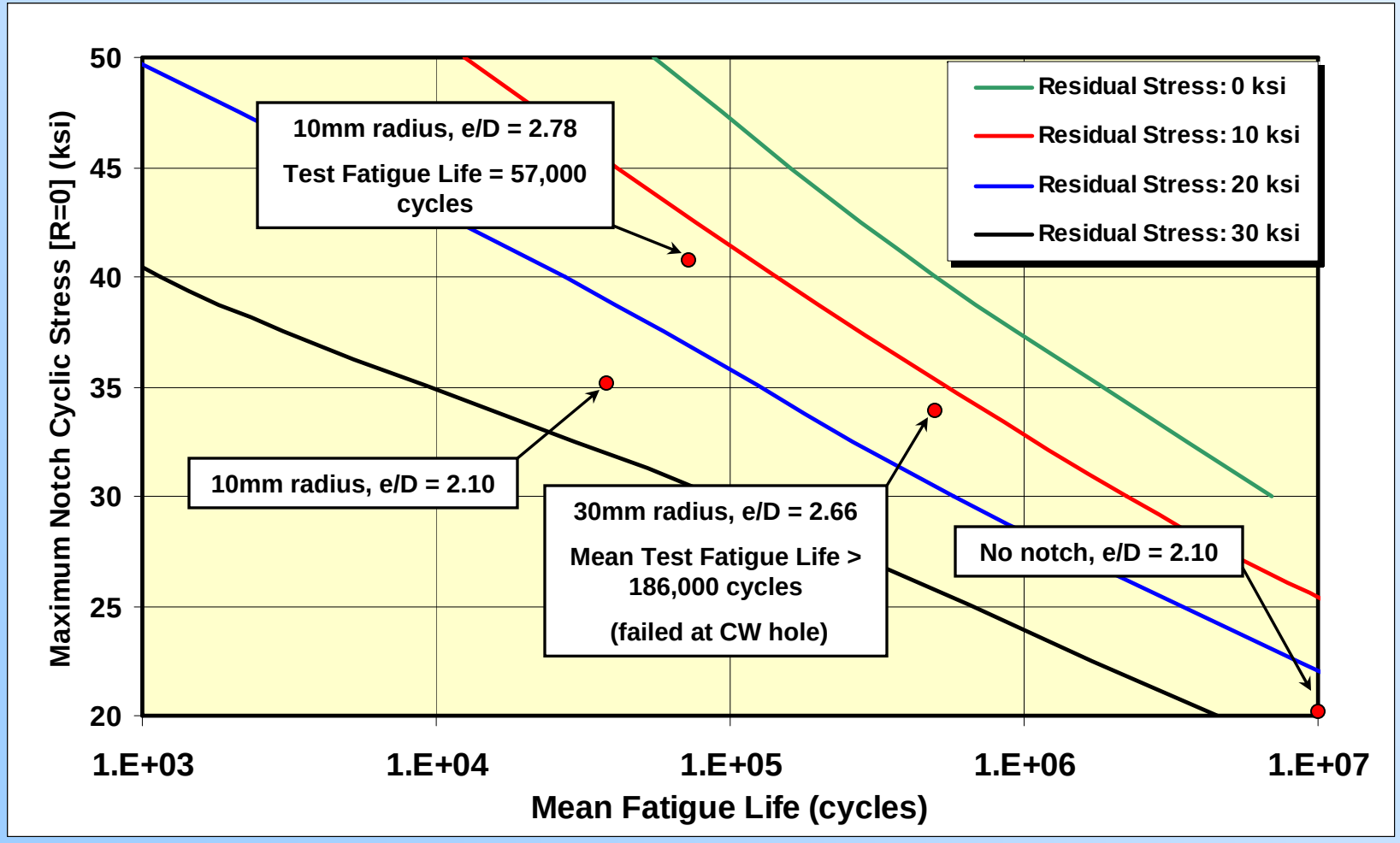
Fatigue Analysis Results for 7075-T7351 Aluminum alloy:

(superimposing notch stresses (R = 0) with residual stresses)



Fatigue Analysis Results for 7075-T7351 Aluminum alloy:

(superimposing notch stresses (R = 0) with residual stresses)



Fatigue Analysis Results for 7075-T7351 Aluminum alloy:

(superimposing notch stresses (R = 0) with residual stresses)

SUMMARY AND CONCLUSIONS

1. **Testing and analysis confirm that high tensile residual stresses can exist at an edge near a cold-worked hole.**
2. **These induced residual stresses are a function of:**
   a. **edge-distance to hole diameter ratio**
   b. **level of mandrel interference**
   c. **whether the fastener hole was final reamed and countersunk**
   d. **fit of the fastener that is installed in the hole**

SUMMARY AND CONCLUSIONS

3. **When these residual stresses are combined with high cyclic notch stresses that arise from external loading, the fatigue life at the edge can be drastically reduced. This should be accounted for in the design of details near a cold-worked hole.**
4. **Additional analysis and testing is needed to further quantify these effects.**

[To receive a copy of the written paper, please contact me at abrot@iai.co.il]

ACKNOWLEDGEMENT

- **The authors would like to thank *Len Reid*, Vice-President R&D at Fatigue Technology Inc., for his assistance and suggestions in studying this phenomenon and for *Tom Poast* for performing the elastic-plastic (ABAQUS) finite-element analyses.**

- **The authors would also like to thank *Dr. Ricardo Actis* and *Dr. Sebastian Nervi* of ESRD Inc., for performing the elastic-plastic (StressCheck ver 7.1) finite-element analyses.**