DISCUSSION

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The authors have stated that the crack propagation life provides a margin of safety for the ASME Code designs. Although much of the information used in constructing the original Code design fatigue curves came from Lehigh cantilever specimens for which failure was defined as the development of a crack of a particular length, not all data were so based. In fact much of the more recent data given Code consideration came from tests in which failure was defined as separation of a specimen into two or more parts. Thus, for recent design fatigue curves, the crack propagation life is included in the curve and does not contribute to the margin of safety. Therefore, for some materials, the only factor of safety on complete rupture is that portion of the 2.0 (on stress) and 20.0 (on life) factors not displaced by scatter, surface finish effects, size effect, etc.

It should be pointed out that the use of strain-based stress amplitudes rather than strain amplitudes in the Code is not just for convenience. Langer [5][4] pointed out that the use of stress values derived from strains avoids the confusion which can result when dealing with combined thermal and mechanical loads. Additionally, failure criteria are developed in terms of stresses.

The writers disagree that the best fatigue data are obtained from bending specimens. Use of unnotched cantilever bending specimens does not permit direct observation of the nominal stress (load based) amplitude, mean stress, or crack propagation rates through the thickness direction. Further the net section maximum nominal strain amplitude in the cantilever specimen decreases as the crack grows which means that the cycling is not truely constant strain amplitude. A direct evaluation cannot be made of the cyclic stress-strain characteristics, mean stress effects, or life to complete separation for constant net section strain amplitude cycling. Conversely, carefully controlled constant strain amplitude, axial fatigue tests allow determination of the aforementioned. Since the stress is constant across the test section of axially loaded specimens, load measurements will directly yield a value of load-based stress amplitude and mean stress. Calculation of stress in bending tests is sufficiently complicated to preclude an accurate estimate of the surface stresses unless axial cycling test results are already available. The value of the unnotched cantilever specimen lies in its ability to verify the use of any given theory of failure for multiaxial stresses. The notched cantilever specimen has the same faults as the unnotched specimen. The authors correctly point out that crack propagation may occupy a significant portion of life for sharply notched geometries but since the notched bending (Lehigh) specimens do not maintain the initial value of the maximum nominal strain amplitude after crack initiation, the notched cantilever bending specimens are of little value. Axial notched geometries, however, can give significant results since they avoid the troubles noted previously for Lehigh specimens.

The authors state that the mean strain is significant and that the effect of mean strain has been verified by Ecole Polytechnique. It is the discussers view that the term "effect of mean strain" used by the authors is unfortunate since: (*a*) The mean strain effect is used in the analysis in place of the term mean stress; (*b*) the Ecole Polytechnique data seem to show no effect of mean strain variation without a concurrent variation in the load-based mean stress; and (*c*) the authors consider that mean strain reduces to zero at high loads which actually is an excellent description of the mean load-based stress but is not the description of mean strain. Due to the foregoing the writers assume that the term load-based mean stress was intended.

The authors state that the fatigue strength reduction factor is a function of, among other parameters, the strain level. The writers know of no published data which demonstrate that the strain level effects, directly, the fatigue strength reduction due to a notch when the requirements of Section III of the ASME Code are satisfied. It is possible that the high loadings can cause strain concentration in excess of the peak elastic value in load-controlled tests. It is expected, however, that the strength reduction factor (strain concentration) will be almost unaffected in deflection controlled cycling for design lives in excess of 10 cycles (which represent actual fatigue failures at 200 cycles). Thus the strain level effect on the fatigue strength reduction factor is not clear.

The authors state that the assumption of notch acuity (by the analyst) has a considerable effect on the calculated fatigue strength reduction factor. However, the choice of notch acuity for either of the notch fatigue analysis methods known to the writers is not a particularly important decision. Both the Del concept [6] and the Neuber concept [7] are not sensitive to the assumed notch acuity. In fact it is this correct representation of natural behavior that is a positive factor in their utility. Both methods consider a notch as just another stress intensification.

[2] Pittsburgh—Des Moines Steel Co., Pittsburgh, Pa. Mem. ASME.
[3] Sunstrand Aviation, Rockford, Ill. Mem. ASME.
[4] Numbers in brackets designate Additional References at end of discussion.

Additional References

5 Langer, B. F., "Design Values for Thermal Stress in Ductile Materials," Welding Research Supplement, Sept. 1958, pp. 411-S to 417-S.

6 O'Donnell, W. J., and Purdy, C. M., "The Fatigue Strength of Members Containing Cracks," Journal of Basic Engineering, Trans. ASME, Series B, Vol. 86, No. 2, May 1964, pp. 205–213.

7 Kuhn, P., Hardrath, H. F., "An Engineering Method for Estimating Notch-Size Effect in Fatigue Tests on Steel," NASA TN 2805, Oct. 1952.

Authors' Closure

There are two corrections which the authors would ask the readers to make in this paper. In Fig. 1 the legend should be corrected by shading the symbols for Weld Defect Specimens, A201 High Biaxial Tension, A212 Clad Biaxial Fatigue Model, and the Penn State Models. In Fig. 6 the Nomenclature for the ordinate should be "strain range, in. $\times 10^3$."

Messrs. Snow and Gibbons have been kind enough to review our paper and we wish to express our appreciation.

Certainly it is correct that it is mean stress which reduces to zero at geometric discontinuities and not mean strain. However, the use of the term *load-based* mean stress is confusing. The stresses at geometric discontinuities encountered in pressure vessels are not zero at zero load and do not vary linearly with load throughout the cycle if significant initial yielding has occurred. An example of the hysteresis that can be expected is shown in Fig. 3.

The authors contend that best fatigue data are obtained from cantilever beam tests for reasons stated in the paper. If one wishes to create a plastic zone in an axially loaded specimen adjacent to and controlled by material in the elastic range, then one must use a notched specimen. In this case it is difficult to measure strain as is possible with the unnotched cantilever beam specimen. It is the accurate determination of very high strains under conditions which simulate strain behavior at geometric discontinuities which permits use of the Lehigh data for analysis of crack initiation and propagation as outlined in this paper.

The authors do not understand the reviewers' argument with the effect of notch acuity on the Neuber method of calculating fatigue strength reduction factor [7] when notch flank angle and root radius are included in the formula for K_N. In the extensive tabulated data in reference [7], the ratio of stress in a smooth specimen to nominal stress in the net section of a notched specimen at the endurance limit, i.e., K_F at $N = 10^7$, is shown to vary significantly with root radius and flank angle with other parameters being equal.

If one observes that fatigue curves of notched and unnotched specimens of the same material remain reasonably parallel and have significant gradient below $N = 10^6$ [8, 9], then one must observe that K_F varies with stress (or strain level).

Additional References

8 Neuber, H., "Investigation of the Distribution of Tensile and Bending on Notched Flat Bars," Wright-Patterson AFB, Report No. ASD-TDR-63-515, July 1963.

9 Pickett, A. G., and Grigory, S. C., "Studies of Fatigue Strength of Pressure Vessels," Progress Report 17, U. S. Atomic Energy Commission Contract AT (11-1)-1228, Jan. 1, 1966.