65 L. Bairstow, "The Elastic Limits of Iron and Steel Under Cyclical Variation of Stress," *Phil. Trans. Roy. Soc.*, series A, vol. 210, 1911, p. 35.

66 W. T. Chodorowski, "Fatigue Strength in Shear of an Alloy Steel," *Proc. Int. Conf. Fatigue of Metals*, London-New York, 1956, pp. 122–131.

67 M. Kawamoto and K. Nishioka, "Safe Stress Range for Deformation Due to Fatigue," TRANS. ASME, vol. 77, July, 1955, pp. 631–634.

68 P. G. Forrest, "Influence of Plastic Deformation on Notch Sensitivity in Fatigue," *Proc. Int. Conf. Fatigue of Metals*, London-New York, 1956, pp. 171–183.

69 R. W. Smith, M. H. Hirschberg, and S. S. Manson, "Fatigue Behavior of Materials Under Strain Cycling in Low and Intermediate Life Range," NASA Tech. Note D-1574, April, 1963.

70 F. Vitovec and B. J. Laazan, "Axial Stress Fatigue, Creep, and Rupture Properties of Unnotched and Notched Specimens of Heat-Resistant Alloys," *ASTM Spec. Tech. Pub. No. 196*, 1957, pp. 45–62.

71 F. H. Vitovec, "Effect of Relaxation on the Behavior of Materials Under Combined Alternating and Static Stress," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, vol. 28, 1960, pp. 441–445.

72 F. H. Vitovec, "Combined Stress Effect at Elevated Temperatures on Super Alloys," *SAE* Preprint No. 495C, January, 1962.

73 A. S. Ross and J. Morrow, "Cycle-Dependent Stress Relaxation of A-286 Alloy," JOURNAL OF BASIC ENGINEERING, TRANS. ASME, Series D, vol. 82, 1960, pp. 654–660.

74 D. Rosenthal and G. Sines, "Effect of Residual Stress on the Fatigue Strength of Notched Specimens," *Proc. ASTM*, vol. 51, 1951, pp. 593–610.

75 H. O. Fuchs, "Forecasting Fatigue Life of Peened Parts," *Metal Progress*, May, 1963, p. 75.

76 R. L. Templin, "Fatigue of Aluminum," *Proc. ASTM*, vol. 54, 1954, pp. 641 and 663.

77 E. H. Spaulding, "Lightweight Springs for Limited Life," *SAE* Preprint No. T30, October, 1955.

DISCUSSION

J. A. Bennett[3]

Professor Fuchs has made an important contribution in this paper which emphasizes the fact that a single criterion cannot be adequate for explaining fatigue behavior. I believe that a great deal of time has been wasted in the past by investigators who have ignored this fact.

In order to increase the usefulness of these concepts, it would be desirable to extend the criterion for crack nucleation into the finite life range. This will introduce several difficulties and another parameter, the number of cycles of stress. To obtain a basis for the criterion it will be necessary to have data on the fatigue strength at a given number of cycles, and these strengths must be based on crack nucleation rather than fracture. This distinction was not necessary in developing the criterion for long life fatigue because the fatigue limit of a smooth specimen is the same whether one considers crack initiation or fracture, but this is far from true in the finite life range. (See, for example, reference [57] of the paper.) Unfortunately, fatigue data in terms of crack nucleation are quite scarce because of the difficulty of determining when a crack starts.

The evolution of gas which occurs during the propagation of fatigue cracks in certain metals[4] provides a convenient means for detecting small cracks. Under the proper conditions this gas can be trapped under transparent pressure-sensitive tape so that it forms bubbles which are readily visible. By taking time-lapse photographs of the specimen it is possible to determine accurately the number of cycles when the first bubble appeared; we have found that with age-hardening aluminum alloys this occurs very shortly after the crack is formed. Thus I believe that this technique can be useful in providing data of a type that will be increasingly needed as a result of Professor Fuchs' paper.

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[4] W. L. Holshouser and J. A. Bennett, "Gas Evolution From Metal Surfaces During Fatigue Stressing," *Proceedings ASTM*, vol. 62, 1962, p. 683.

R. E. Peterson[5]

This paper represents a much-needed effort to clarify combined steady and alternating stress conditions in the presence of notches.

It is not clear why the S_{PC} values are presented as a constant for any given material. As stated by the author, Frost [78] has found that the critical stress is inversely proportional to the crack length. For geometrically similar notched specimens, this means that the critical propagation stress would be expected to decrease as the specimens are increased in size (see writer's Fig. 17 in reference [79]).

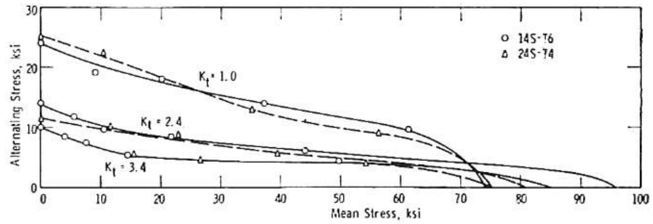

Fig. 9 Stress range diagrams for aluminum alloys (Lazan and Blatherwick)

In Fig. 9, combined stress curves are shown for notched and unnotched specimens of aluminum alloys [80]. Similar curves are also found in some other materials [81]. The writer has been puzzled as to why the higher K_t curves tend to become concave upward in the region near zero mean stress. It will be noticed that the author's Fig. 3 (dashed lines) shows a similar effect. This perhaps provides the answer to this unusual shape; apparently this is a condition (high stress gradient) where slightly lower stresses produce nonpropagating cracks.

As a minor comment, it is noted that the author uses octahedral shear stress and finally converts a 0.47 value to 1/2. Failure on the fixed octahedral shear plane is not a reality and for this and other reasons [82] it seems preferable to use the Mises Criterion; in this instance the final result as used by the author is obtained directly by use of the Mises Criterion or alternatively by use of "equivalent" or "effective" stress [83].

Additional References

78 N. E. Frost, "The Critical Alternating Propagation Stress and Crack Length for Mild Steel," *Proceedings Institute Mechanical Engineering*, vol. 173, 1959, p. 811.

79 R. E. Peterson, "The Role of Stress Distribution in Fatigue," *Proceedings SESA*, vol. 18, no. 1, 1961, p. 105.

80 B. J. Lazan and A. A. Blatherwick, "Strength Properties of Rolled Aluminum Alloys Under Various Combinations of Alternating and Mean Axial Fatigue Stresses," *Proceedings ASTM*, vol. 53, 1953, p. 856.

81 F. H. Vitovec and B. J. Lazan, "Fatigue, Creep, and Rupture Properties of Heat Resistant Materials," WADC TN 56-181, Wright Air Development Center, Ohio (1956).

82 R. E. Peterson, *Stress Concentration Design Factors*, John Wiley & Sons, New York, N. Y., 1953, p. 6.

83 Marks Mechanical Engineers Handbook, sixth edition, 1958, p. 5-5. See also J. E. Dorn, *Mechanical Behavior of Materials at Elevated Temperatures*, McGraw-Hill Book Company, Inc., New York, N. Y., 1961, p. 403.

Author's Closure

The author is grateful for the written discussions by Mr. Bennett and by Dr. Peterson, and for the remarks and suggestions offered by Dr. Carden and by Dr. Morrow.

The technique for the detection of cracks developed by Mr. Bennett and his associates is beautifully simple and shall be tried in experiments planned by the author.

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The question of finite life which Mr. Bennett raises is indeed important. The author believes that linear interpolation of the log-stress versus log-life data between a very long life (of the order of three million cycles) and a very short life (of the order of three thousand cycles) will be sufficient for design purposes. Techniques suggested in this paper are intended to permit forecasting a long life point under various conditions of stress. Techniques for forecasting a short life point were presented by several other investigators in this conference.

Dr. Peterson's Fig. 9 is an illustration of behavior which can be explained by the techniques presented in this paper. An extension of the data of Fig. 9 into the region of compressive mean stress would be very interesting and conclusive. The author was gratified to hear from Dr. Blatherwick that this paper is encouraging him to plan tests with notched specimens in the region of compressive mean stress.

The values for S_{PC} are presented as constants although the author knows and stated that strictly speaking they are not constant. This is done quite intentionally in order to emphasize that any reasonable value for S_{PC} will lead to results which are far more realistic than currently used criteria, and close enough for forecasts. Refinements by correction for crack length or for mean stress introduce second order corrections which the author believes to be unwarranted until the base values of S_{PC} are more firmly established. Fig. 4 of the paper was intended to illustrate this point.