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Fatigue Strength of Case Hardened Steel Specimens Containing Through-The-Case Cracks

Business machine components made from steel strip often require case hardened surfaces for adequate wear resistance and/or strength. Straightening operations, following the case-hardening heat treatment, may then be required to produce finished components which conform to flatness or straightness requirements. Subsequent magnetic particle examinations may reveal that the majority or all of the components in a particular order of parts contain cracks. This communication reports an investigation of case hardened specimens containing cracks under conditions of dynamic loading. The study was conducted in an attempt to better understand the behavior of cracked production parts.

Three series of test specimens, 4.00 × 1.00 × 0.06 in., with a 0.01 in. deep semicircular transverse slot providing a mild stress concentration[1] were fabricated. The Series 1 and 2 specimens were of AISI 8617 alloy steel, while those of Series 3 were of AISI C-1010 carbon steel. All the specimens were case carbonitrided to a depth of 0.003 to 0.005 in. and a peak case hardness equivalent to Rockwell "c" 60-62. The quenching temperature was controlled to produce a low core hardness in the first and third series (Rc 32-35 equivalent in Series 1 and Rb 75-77 equivalent in Series 3), and a high core hardness in Series 2 (equivalent to Rc 43-45).

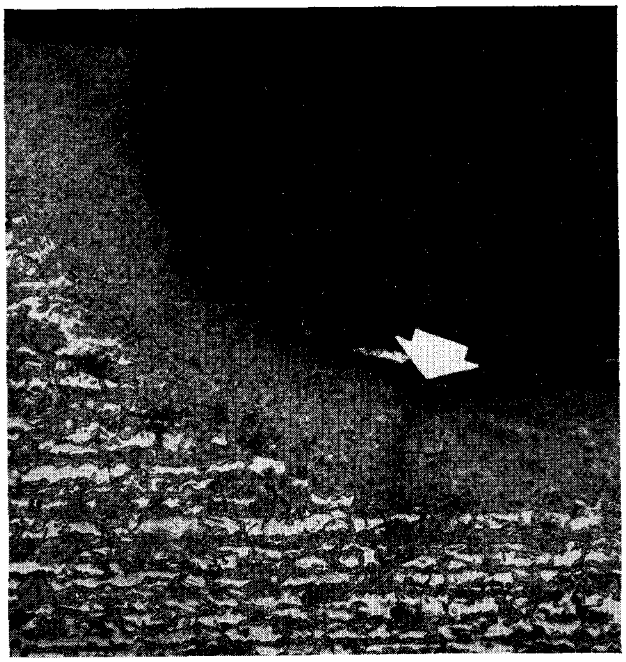
Cracks were formed in approximately half of the specimens of each series by the application of a static bending load. The presence of cracks, all of which started at the bottom of the transverse slot, was verified by magnetic particle and by metallographic examination of the surface of the slots. Metallographic examination of two cracked specimens of each series revealed that the cracks terminated near the end of the case (see Fig. 1). Fatigue tests (alternating bending with zero mean stress) were conducted on both cracked and uncracked specimens of each series. The maximum bending stress on a particular specimen was determined by the following equation:

$$S = 3PR/bh^2,$$

where S = maximum bending stress (psi)
P = applied load (lb)
R = bending lever (length/4 = 1 in.)
b = width (1 in.)
h = gross thickness under slot (0.05 in.)

Thus, $S = 1.2 \times 10^3 P$.

Figure 1 Cross section through cracked specimen of Series 1, AISI 8617 alloy steel. The crack is indicated by the arrow. Magnification: ×200. Etch: 2% nital.



Fatigue curves (conventional S/N diagrams) for the three series are shown in Figs. 2, 3, and 4. The data show that at 10^7 cycles (a value commonly taken as the endurance limit) the fatigue strength for both the cracked and uncracked specimens of Series 2 was about 105,000 psi, while the cracked specimens of Series 1 and Series 3 were approximately two-thirds as strong as the corresponding uncracked specimens at 10^7 cycles. For an equivalent number of cycles, the fatigue strength of the cracked specimens of Series 2 was greater than the fatigue strength of the uncracked specimens of Series 1 (approximately 15,000 psi greater at 10^7 cycles). Note that of the three series, the specimens of Series 2 were the least affected by the presence of existing through-the-case cracks.

The fatigue curves for the cracked specimens show the stress and number of life cycles required to propagate existing through-the-case cracks, while the fatigue curves for the uncracked specimens show the stress and number of life cycles required both to initiate and propagate cracks. Existing through-the-case cracks had the least effect on the specimens of Series 2. Since the specimens of Series 2 had the greatest core hardness (strength) of the three series, and also the greatest strength immediately beneath the case (or at the tip of an existing crack), it follows that they showed greater resistance to crack propagation. These specimens thus exhibited higher absolute fatigue strengths for equivalent lives than the specimens of the other two series.

According to Cottrell,[2] as much as 90% of the fatigue life of homogeneous specimens may be required to grow existing cracks to a size where they can propagate rapidly to the extent that the remaining cross section is too small to support the applied load. Therefore, early through-the-case crack formation apparently accounted for the relative proximity of the two fatigue curves for the Series 2 specimens. While the case hardness (strength) of all the specimens was essentially the same, the core hardness (strength) of the specimens of Series 2 was greater than the core hardness of the other two series. These conditions plus generally higher applied stresses (105,000 to 165,000 psi) seemingly favored brittle through-the-case fracture early in the life of the specimens of Series 2. The specimens of Series 1 and 2 were relatively more sensitive to the presence of cracks as is evidenced by the greater separation of the cracked and uncracked fatigue curves for these series compared with those of Series 2 specimens.

Another possible explanation for the comparatively high fatigue strength of the cracked specimens of Series 2, which follows from the work of Frost,[3] might be that a more favorable distribution of residual compressive stress existed at the crack tips of these specimens. However, it is not the primary intent of this communication to discuss the theories of crack initiation and propagation but rather to present actual fatigue test data for a limited num-

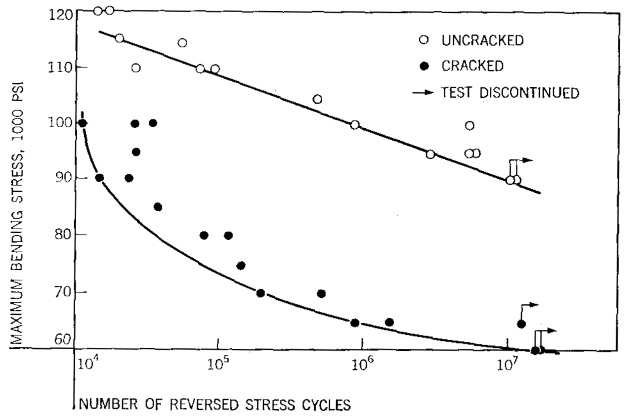


Figure 2 S/N curves for Series 1 specimens, AISI 8617 alloy steel.

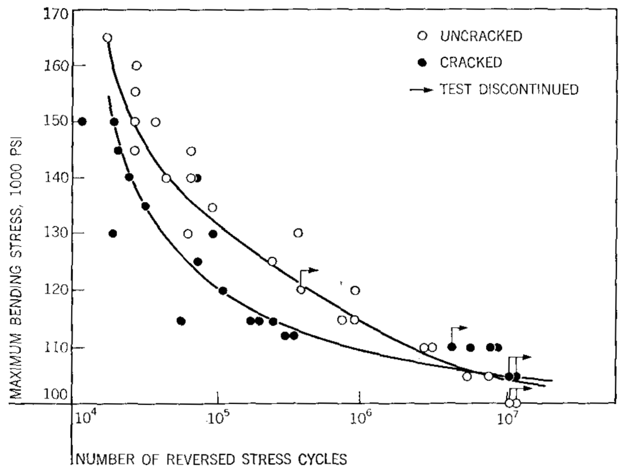
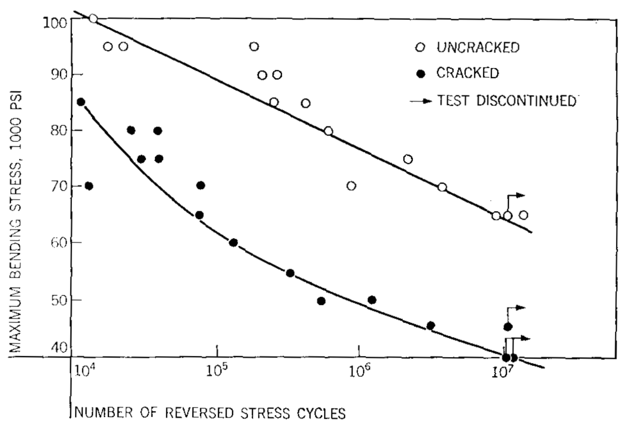


Figure 3 S/N curves for Series 2 specimens, AISI 8617 alloy steel.

Figure 4 S/N curves for Series 3 specimens, AISI C-1010 carbon steel.



ber of specimens containing through-the-case cracks.

These tests seem to confirm the importance of crack propagation as opposed to crack nucleation in this type of fatigue loading. The strength at the crack tip appears to be the controlling factor for the propagation mechanism. Considering these findings, a revision in the attitude toward the importance of surface cracks seems justified. Cracks and other defects in shallow cases may be deemphasized, while the quality of the core—its strength, hardness, and toughness—may be of much greater importance. It is possible for a seemingly sound, case hardened machine component to contain undetected straightening cracks, or for case cracks to develop very early during service, but the rate of propagation is the real determining factor for the fatigue life of such a component.

Acknowledgment

The author is indebted to Gabor Koves for his assistance in interpreting the test results.

References and footnote

1. The theoretical stress concentration factor K_t was equal to 2. See C. Lipson and R. C. Juvinall, *Handbook of Stress and Strength*, p. 264, Macmillan Company, New York, 1963.
2. A. H. Cottrell, *Proc. Roy. Soc. A*, **276**, 15 (1963).
3. N. E. Frost, *J. Mech. Phys. Solids* **9**, 149 (1961).

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