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This Week's Citation Classic

Johnson H H & Paris P C. Sub-critical flaw growth.
Eng. Fracture Mech. 1:3-45, 1968.
[Dept. Materials Science and Engineering, Cornell Univ., Ithaca, NY and Dept. Mechanics, Lehigh Univ., Bethlehem, PA]

The major evidence bearing upon subcritical flaw growth in structural materials is interpreted in a fracture mechanics framework. Attention is focused upon the growth of preexisting flaws at operating stresses less than the net section yield strength, from both the separate and combined effects of fatigue and aggressive environments. Engineering applications are discussed. [The *SCI*® indicates that this paper has been cited in over 110 publications since 1968, making it the most-cited paper published in this journal to date.]

Herbert H. Johnson
Department of Materials Science and Engineering
Cornell University
Ithaca, NY 14853
and
Paul C. Paris
School of Engineering
Washington University
St. Louis, MO 63130

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"The decade of the 1960s witnessed a strong surge of interest and accomplishment in the practical understanding and control of fracture. The increased use of high strength alloys in advanced technology systems—aircraft, space vehicles, ships, nuclear power plants, etc.—had emphasized the need for quantitative and reliable methods to test for and predict fracture. In the 1950s, George Irwin,[1] then of the US Naval Research Laboratory, and others had laid the foundation for modern engineering fracture mechanics. The stress intensity factor, a measure of the local stress at a flaw or crack tip, had been identified as the driving force for crack growth, and the concept of a critical flaw size for fracture was established.

"Paul Paris (now at Washington University), with a background in mechanics, had been a leading participant at Boeing and Lehigh University in the development of the new fracture mechanics concepts, and especially in the application of fracture mechanics to fatigue crack growth, a problem of obvious importance to the aircraft industry. He had shown how the stress intensity factor, a function of specimen and flaw geometry and load magnitude and geometry, could be used to correlate fatigue crack growth rate data obtained under a broad range of conditions. He had further demonstrated a power law relation between the stress intensity range in cyclic loading and the fatigue crack growth rate.[2]

"During the same period, Herbert Johnson, at Cornell University, with a metallurgy perspective, was investigating the effect of environment on fracture in high strength steels.[3] In particular, the influences of water, water vapor, hydrogen, and oxygen on crack initiation and growth from preexisting flaws were studied intensively. Fracture mechanics concepts, again in particular the stress intensity, were found to be most useful in correlating and interpreting data. The study of subcritical flaw growth as a consequence of cyclic loading and environment subsequently became a very active and well-populated research area, and remains so today.

"In 1967, however, this was still quite new, so Paul suggested that we should combine efforts and produce a comprehensive review of those two important aspects of fracture, fatigue, and environment, as investigated and interpreted from a fracture mechanics viewpoint. We were, between the two of us, in touch and familiar with the work of every active group—there weren't many then—in those newly emerging fields. Paul further suggested that the review could appear in the first issue of the new journal, *Engineering Fracture Mechanics*, of which he was a coeditor.

"The first draft was put together at Lehigh in a marathon—all day and night—session; Paul wrote the fatigue part and Herbert did the environment section. We both wrote largely from memory, with only an occasional look at the available literature. The final revisions were made some weeks later at a session in Ithaca, with final touches added while watching a Little League ball game at a field on the shore of Lake Cayuga.

"The review has been cited often because it was the first comprehensive summary of some scattered but quite important results. It showed very clearly the synthetic power of the fracture mechanics approach in the correlation and interpretation of subcritical crack growth rate data. Many subsequent investigators used the review as a springboard for their own experimental programs. For a report of recent work in the field, see reference 4."

1. **Irwin G R.** Fracture. (Flügge S, ed.) *Handbuch der physik*. Berlin: Springer-Verlag, 1958. Vol. VI. p. 551-90.
[The *SCI* indicates that this paper has been cited in over 300 publications since 1961.]
2. **Paris P C.** The fracture mechanics approach to fatigue. (Burke J J, Reed N L & Weiss V, eds.) *Fatigue—an interdisciplinary approach*. Syracuse, NY: Syracuse University Press, 1964. p. 107-32.
[The *SCI* indicates that this paper has been cited in over 200 publications since 1964.]
3. **Johnson H H & Willner A M.** Moisture and stable crack growth in a high strength steel. *Appl. Mater. Res.* 4:34-40, 1965.
4. **Roberts R,** ed. *Fracture mechanics*. Philadelphia: American Society for Testing and Materials, 1981. 649 p.