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Effect of Size on Cracking of Materials

A new theory explains the effect of physical size of a specimen on crack propagation in any material. The brittle behavior of large mild steel

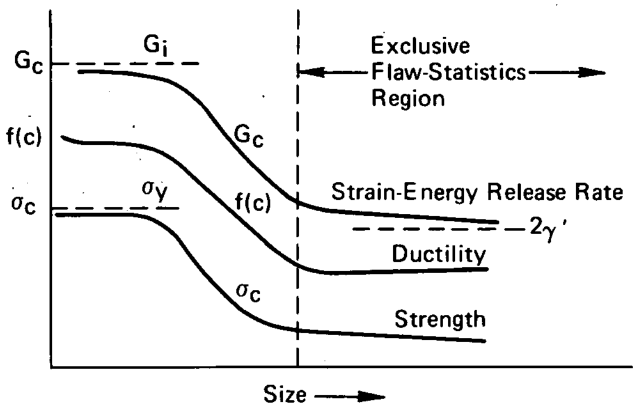

Figure 1. Size Dependence of Strength, Ductility, and Strain-Energy Release Rate of a Material (Schematic)

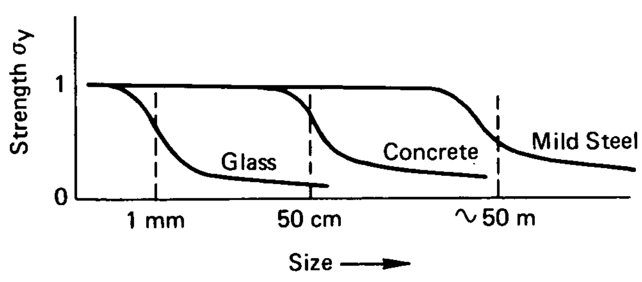

Figure 2. Transition Size for Some Typical Materials

elements, the plasticity recently shown to exist in glass, and the marked size sensitivity of fatigue specimens are all only little understood phenomena. These and other unexplained observations are actually manifestations of a single law, termed the Strain-Energy Size Effect.

The effect of a specimen's physical size on the initiation of cracking in any material occurs in accordance with the statistics of flaw distribution. However, the effect of size on complete fracture is also dependent on the stability or instability of crack propagation.

Cracks can stabilize because of energy dissipation, load relaxation, or crack orientation; the former results from the physical properties of the material. The energy dissipation stability is affected by the strain-energy content (and therefore by the size) such that the higher the energy, the earlier this stability transforms into instability. Consequently, the larger the specimen, the lower the breaking stress and ductility that accompany cracking. A possible explanation is presented in terms of dynamic effects caused by an excess in the energy released over the energy absorbed. These dynamic effects influence the stability of the propagating crack such that the size of the specimen plays a dominant part.

The conditions favoring instability are: (1) small capacity for dissipating potential energy; (2) inclusions and voids at all levels of aggregation and coarseness of grain; (3) extremely thin and short existing cracks; (4) small capacity for damping vibrations; and (5) large size relative to other conditions.

From the viewpoint of cracking behavior, materials can be classified into three broad groups: ductile (mainly soft metals), semiductile (materials such as concrete and gypsum), and brittle (glass and similar materials). The two material constants required for the complete description of the material's resistance to fracture are: (1) the surface tension, γ; and (2) a higher constant, which represents the ultimate resistance to fracture and is usually denoted as G_c for the less brittle materials.

(continued overleaf)

In cracking, a material goes through two critical phases. The initiation of the first crack is governed by a constant whose dimensions are equal to but whose value is much less than G_c. In glass, this initiation constant is γ. In metals, no experimental evidence exists to indicate what value this constant has in relation to γ. Therefore, a new value γ' is defined as the limiting value that (1/2) G_c will approach as the specimen size increases to infinity (under these conditions $G = 2\gamma$). For glass, $\gamma = \gamma'$. Similarly, the upper constant G_i is defined as the limiting value that G_c will approach as the specimen size decreases to zero.

Thus, γ' should be the true design criterion for very large scale members. For ordinary sized members, it is important because it determines the event of crack initiation. Similarly, G_i should be the true design criterion for small elements of glasslike materials.

All curves representing the size dependence of strength and semi-ductility (i.e., the ductility accompanying cracking) have the characteristic shape of a reversed sigmoid (see Figure 1). This figure also shows the effect of size on G_c, as well as the limiting values of G_i and γ'. The difference between the two plateaus in each of the three curves is equal to the strength, the ductility, and the G_c value that would be gained during the stable propagation of a crack in an extremely small specimen of the material.

In principle, all materials exhibit the behavior described. They vary, however, in both the magnitude of the transition and its position. Figure 2 illustrates this difference in approximate terms.

Note:

The following documentation may be obtained from:

Technology Utilization Officer
NASA Pasadena Office
4800 Oak Grove Drive
Pasadena, California 91103

Reference:
JPL Technical Report 32-1438, Strain-Energy Size Effect

Patent status:

No patent action is contemplated by NASA.

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