Effect of Thickness Variations upon the Plane Stress Fracture Resistance Parameter K_c

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Fracture resistance can be defined as the resistance of a material to rapid or catastrophic failure at nominally elastic stress levels when flaws or cracks are present. Since all materials and structures will contain cracks or crack-like defects, a key step toward fail-safe design is the incorporation of some measurement of fracture resistance in material specifications. Particularly suitable in this regard are the parameters of linear-elastic fracture mechanics (LEFM) which specify the magnitude of stress and length of crack required to cause catastrophic failure.

For thin sheet materials this LEFM parameter, designated as K_c, has been found sensitive to geometric variables caused by the physical restrictions of laboratory specimens. Specimen width and crack length-to-width ratio dependencies have been extensively studied. The schematic three-dimensional diagram of Fig. 1 illustrates this dependency, the surface representing a K_c value of 110 $MN/M^{3/2}$ (100 ksi$\sqrt{in.}$). Assuming a yield stress value of 414 MN/M^2 (60 ksi) for this hypothetical alloy, the hatched plane area parallel to the base plane separates the region in which yielding has occurred (above) from that in which yield has not occurred so that valid K_c data may be obtained. The assessment of these recognized geometric dependencies is required to provide correction factors and guideline information for developing standard test procedures. Up to the present, however, no standards have been adopted, though all research is being directed to this desirable end.

The influence of sheet thickness upon the measured K_c value has received less attention than other specimen dimensions although it is recognized as an important variable. This study examines the effect of sheet thickness upon the K_c value for sheet steels of differing yield strength and compares results with analagous studies on sheet specimens of aluminum and titanium alloys.

The fracture resistance of three steels representing four yield stress levels has been investigated: RSM 250 maraging, 4130, and D6A. These are compared with four titanium alloys: 6Al-4V, 4Al-3Mo-1V, 16V-2.5Al, 13V-11Cr-3Al; and five aluminums: 7178-T6, 7075-T6, 7079-T6, 2014-T6, and 2024-T3. All alloys were tested so that the path of fracture was parallel to the rolling direction (WR) since, if anisotropy is present, this will be the direction less resistant to fracture.

The specimen employed is the center-cracked tensile (CCT) sheet. Not only is a natural structural prototype precursor but the stress analyses of this specimen is well documented. The width of all specimens was 30 cm (12 in.). Central slits were produced by an electric discharge method (Elox) to give a .16 cm wide slit with the slit tip extended by a finer electrode to give tip radii of .0025 cm.

The postulated dependency of K_c upon specimen thickness is illustrated in Fig. 2. How closely this behavior is achieved in real materials is seen in Fig. 3a,b, and c. The data indicates that few of the alloys manifest the type of dependency anticipated by Fig. 2.

Models have been proposed wherein flat fracture is considered as a surface phenomenon and slant fracture a volume sensitive one. It is further postulated that once the slant fracture (shear lip) is fully developed, the total lip width no longer increases. However, for all alloys studied, although the percent of slant fracture decreased with thickness, total lip width increased. Further, when the upper portions of Fig. 3a,b, and c are examined, it is readily seen that in many instances percent slant fracture decreases although K_c appears constant.

Since the relationships here discussed have been established for shelf stock only, it becomes important to consider other variables such as chemistry, rolling practice, etc. Investigation of thickness variables on identical materials is required to help clarify the inconsistencies noted and develop a more precise model for the effect of thickness upon K_c.

Finally, to illustrate the importance of the K_c parameter, the crack length causing failure is calculated at various levels of operating to yield stress ratio and plotted in Fig. 4; where applicable an average K_c value is employed for this calculation. The practicality of inspection techniques to insure against the presence of cracks of critical lengths in any structures should be a factor in material selection.

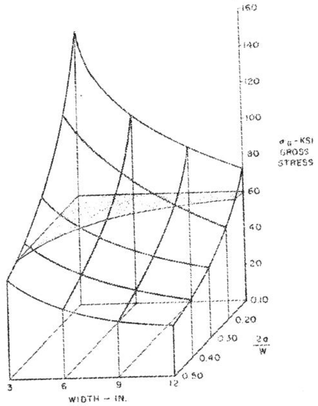
FIGURE CAPTIONS

Fig. 1 - Width and crack length effect on instability stress, schematic: surface $K_c = 100$; parallel plane $\sigma = \sigma_{ys}$

Fig. 2 - K_c vs thickness, B; schematic

Fig. 3 - K_c and % slant fracture vs thickness, B
a. steels; b. titanium alloys; c. aluminum alloys

Fig. 4 - Critical crack lengths, 2a, various ratios of operating to yield stress, σ_{ap}/σ_{ys}



Kc = 100 KSI √IN.
FIG. 1

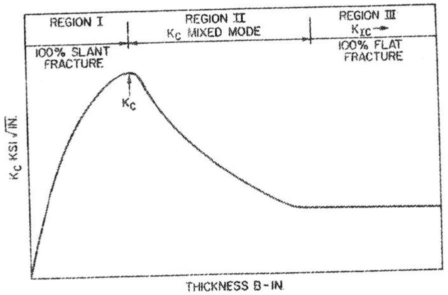


FIG. 2

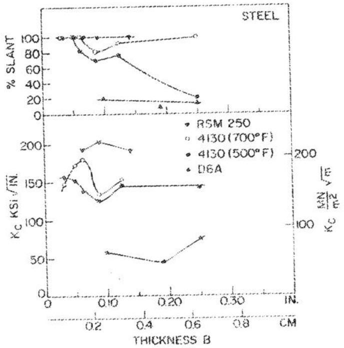


FIG. 3a

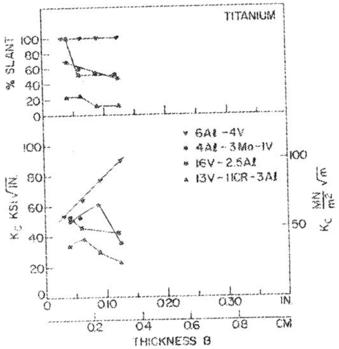


FIG. 3b

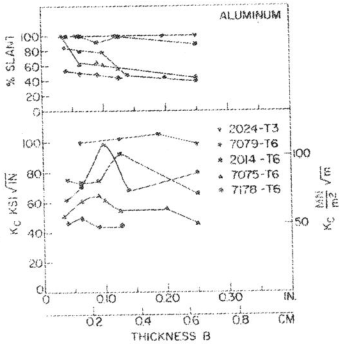


FIG 3c

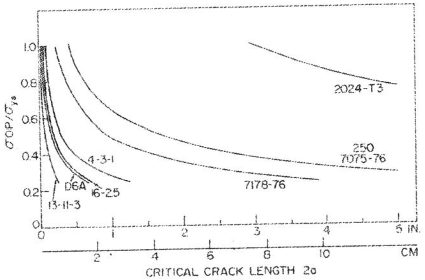


FIG. 4