CRACK-LIKE NOTCHES AND NOTCH-LIKE CRACKS

D.Taylor*

The author attempts to define the transition point at which a blunt notch becomes equivalent to a sharp crack, for the purposes of fatigue behaviour. Various pieces of work from the author's laboratory, and elsewhere, are examined. Upper and lower bounds are defined for a critical root radius, below which a notch becomes crack-like. This critical value depends on material strength level and on the applied stress level, but is only mildy dependant on notch length. Critical values for a typical alloy steel at its fatigue limit are estimated. The effects of very short notches, such as surface roughness, are discussed.

INTRODUCTION

A continuing problem in design is the assessment of fatigue behaviour for a notch, whether this notch is a design feature or a defect. Typical design rules are based on K_t and K_f assessment. These tend to be least accurate for situations involving small notches, high stress concentration factors and low-strength materials. A fracture mechanics approach, in which the notch is assumed to be a sharp crack, is attractive because it simplifies calculations and tends to be conservative. However, the use of a crack assumption for a very blunt notch leads to very great conservatism. Designers require some simple rules enabling them to decide whether a particular notch can be assessed as a crack, and quantifying the degree of conservatism involved. To this end, we consider here the definition of a parameter ρ_{crit}, where ρ is the root radius of the notch, and when $\rho < \rho_{crit}$ then the notch can be assumed to behave like a sharp crack. The value of ρ_{crit} will depend on material, notch geometry and also on the applied stress level, with a tendancy to be larger at higher stresses. The present discussion will be limited to low

* Mechanical Engineering Dept., Trinity College, Dublin, Ireland.

stress levels and especially to the definition of a fatigue limit. The approach will be to define generalised rules for the calculation of an upper bound and lower bound for ρ_{crit}, based on experimental evidence and simple theory. It is hoped that the approach can be extended through the use of more sophisticated modelling.

BLUNTED CRACKS - A Lower Bound for ρ_{crit} ?

One approach for the definition of ρ_{crit} is to study the behaviour of notches produced by blunting sharp cracks. In a study of A533B steel (1), fatigue cracks were grown and blunted by application of high monotonic loads, before being fully stress-relieved. These were then fatigued at constant ΔK (assuming them to be cracks). Fig.1 shows some results. As would be expected, the relatively blunt notches showed some slow initial growth which was transient. Sharper notches showed no transient behaviour, establishing initial growth at the expected da/dN value. Very sharp notches showed a fast transient which is believed to be due to closure effects; this will not be considered specifically here, though it is accepted that closure effects will play a role in the notch/crack transition.

A possible definition for ρ_{crit} is the transition value between the slow-transient and no-transient behaviour. This value can be predicted by a simple theory based on comparison of plastic zone sizes (1); transition occurs in practice when the notch plastic zone size is approximately equal to 2ρ. However, provided the slow-transient growth is only transient in nature, it could be argued that the notch is still basically crack-like, from the point of view of definition of a fatigue limit, for instance. Thus the above approach yields only a lower bound value for ρ_{crit} .

THE EFFECT OF K_t - Definition of an Upper Bound

Much work is available in the literature on the effect of K_t on fatigue limit for machined notches; ref.(2) is typical. Fig.2 shows schematically the effect of K_t for a fixed notch length, a, K_t being varied by varying ρ . At low K_t, fatigue limit falls in proportion to K_t; this is clearly the region of notch-like behaviour. At very high K_t, where ρ falls below the lower bound for ρ_{crit} defined above, crack-like behaviour occurs, requiring a horizontal line on the plot. A simple approach for the intermediate region is to extend the "crack" region to the point at which it intersects the "notch" prediction. This approach has the advantage of being conservative at low K_t, and predictions agree reasonably well with some experimental data (e.g (2,3)). However, in practice we expect some notch-like behaviour, indicated schematically by the dashed line on fig.2, thus the point of intersection will in fact be an upper bound value for ρ_{crit} .

It is interesting to predict how this upper bound will vary with notch geometry and material properties. Fig.3 shows crack and notch predictions for a typical alloy steel, assuming elliptical notches of various a and ρ values. Fig.4, using the same values as fig.3, defines regions of notch and crack behaviour for various a and ρ values; this amounts to a kind of mechanism map, since it allows us to see which kind of modelling should be used for given notch geometry.

SMALL NOTCHES - Surface Roughness

Surface roughness is a well-known problem in fatigue life prediction, involving the two factors of notch effects and defect size effects. Work in the author's laboratory (4) has shown that individual roughness features can be described as cracks without undue conservatism in the growth-rate and fatigue limit predictions. This is surprising considering the very low K_t values of such features, but possibly less surprising when they are considered in terms of root radii. Considering a modified Kitagawa diagram (fig.5) in which crack length is replaced by an extreme-value roughness parameter such as Rmax, data can be compared to predictions based on both crack-like behaviour and notch-like behaviour, with allowance made for size effects. On this type of plot, the equivalent intersection point (as defined on fig.2) is the point at which the notch prediction falls below the crack prediction. The mechanism map (fig.4) can be modified to demonstrate the effect of short cracks and of short notches - for clarity the figure shows only the short-crack correction, which tends to make ρ_{crit} (upper bound) almost independent of notch length, a, until a becomes very small.

Data on the effect of surface roughness (5,6) for alloy steel En19 in a high-strength condition is shown on fig.5. In the short crack regime, predictions are very conservative both for cracks and notches, but comparison with sharp crack data (fig.5) suggests that a crack-like approach is relevant, at least for these small features. The larger roughness features could best be predicted by the notch model; in this regime the crack model is very conservative and inappropriate.

CONCLUSIONS

1) The critical root radius parameter, ρ_{crit} , is a useful basis for considering whether a notch can be modelled using fracture mechanics techniques.

2) Upper and lower bounds can be defined for ρ_{crit}; at present there is a large gap between these bounds. The lower bound is independent of notch geometry, and the upper bound is only sightly dependent on notch length except at very short lengths.

3) Procedures can be defined which ensure conservatism in the use of fracture mechanics for notches.

4) This approach can be extended to consider very small notches such as surface roughness, though in this regime our modelling accuracy depends on assumptions concerning the defect size effect.

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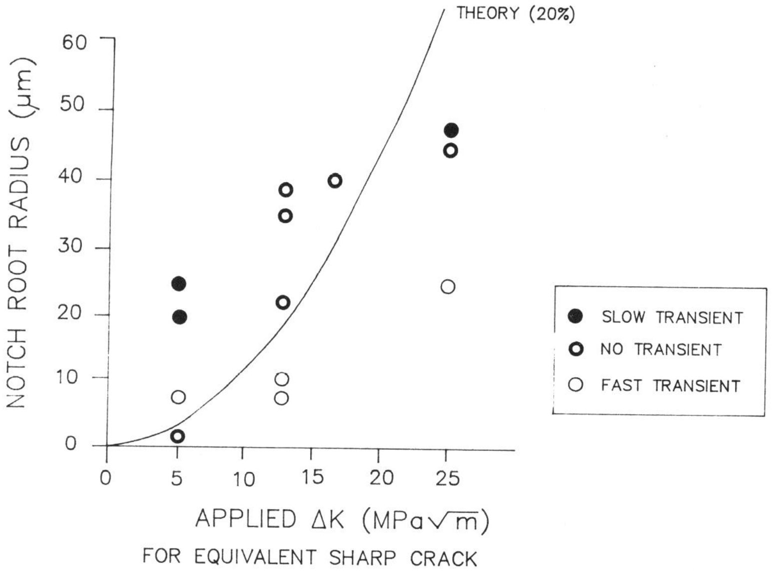

Fig.1 Data on fatigue from blunted cracks (1); the type of transient behaviour is defined for various a,

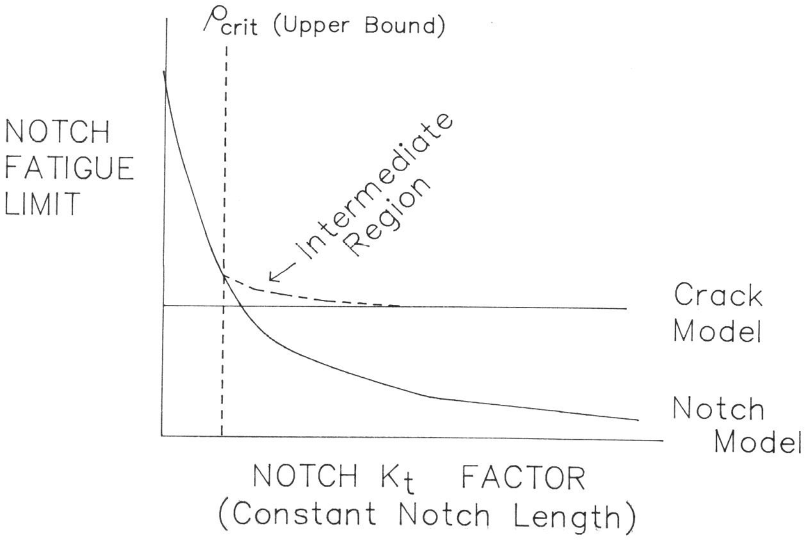

Fig.2 Schematic variation of fatigue limit with K_t, for notches of constant length, varying root radius.

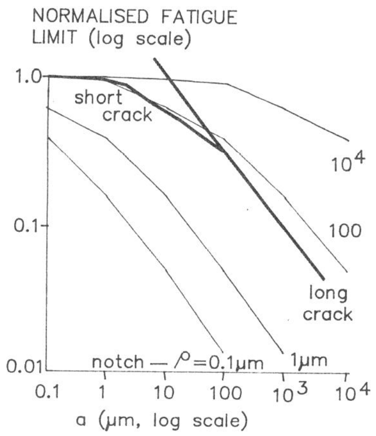

Fig.3 Notch and crack predictions for effect of fatigue limit on notch length, for various root radii. Short crack effects are included. Typical alloy steel.

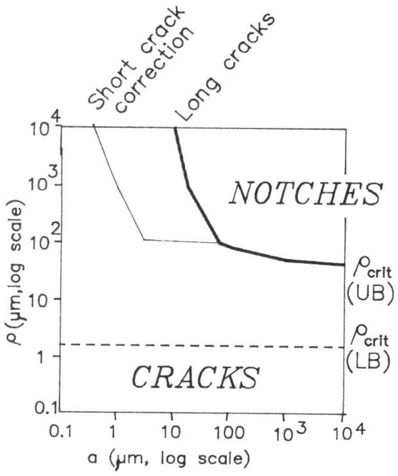

Fig.4 The data of fig.3 plotted to show regions of notch and crack-like behaviour, including the lower bound for

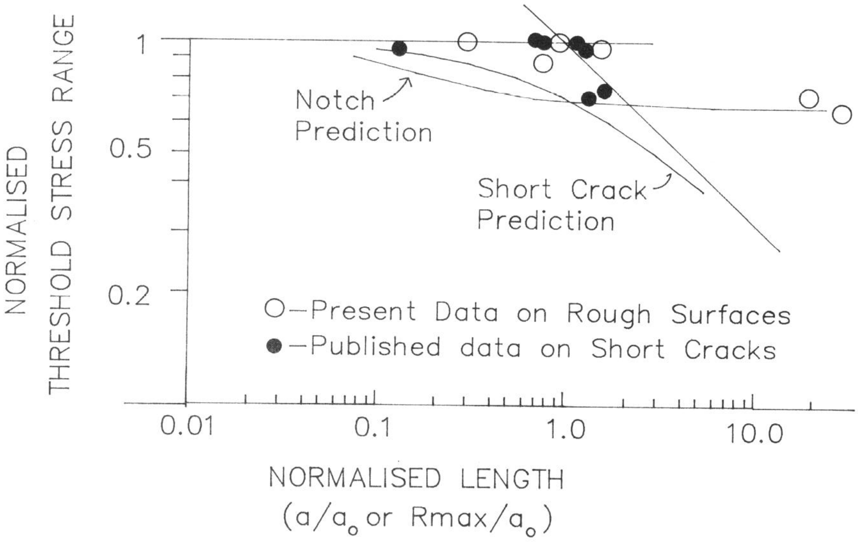

Fig.5 Predictions for notch and crack-like behaviour for surface roughness; data on roughness and on short cracks.