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AN APPROACH TO A DUCTILITY CRITERION

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Ductility, or the capacity of a material for plastic deformation before fracture, serves an important lifesaving function. The plasticity of a material enables it to avert fracture by relieving stress peaks, a significant quality wherever stress concentrations are difficult to anticipate, arising as they may at (accidental) notches, points of stress transfer and flaws, or from shock or impact loads and local overheating. For description, ductility is as a rule sufficiently characterized in terms of elongation and reduction of area in the tensile test.

At this time no ductility criterion yet exists to assist in the dimensioning or life prediction of design items. The lack of a direct standard for load characteristics (such as stress would be relative to the strength of the material) makes it difficult to impose ductility requirements,and resort must necessarily be made to service experience with similar components. The present study is made in an attempt to provide a theorem or model to fill the gap.

Experience has shown that ductility with elongations of 10% to 15% will pose little risk to the normal life even of highly stressed components. It is only at values under 10% that a more detailed analysis will be advisable. For the purpose use of a criterion considering five different load characteristics is recommended.

The ductility requirement to be imposed rises with

1) The *utilization* of the material (where utilization is the ratio of load to strength).
2) The *uncertainty* of the load assumptions (low predictability, inaccurate stress analysis, etc.). For assessment, it will be well to tie the load assumption to utilization, for the more complete the utilization of the material, the more critical the uncertainties in the load assumption.
3) The *energy absorption* requirement (if perhaps an emergency margin is stipulated in the event of the failure of another part, or under impact or shock load).
4) The *configurational complexity* of the component (stress peaks not covered by normal stress analysis, say at notches or welds).
5) The *safety requirements* (consequences at failure: nuclear reactors and aircraft, e.g., necessitate much tighter requirements than will road vehicles).

By rating and weighting these five aspects as shown in Table 1, the ductility analysis yields a coefficient of ductility ($\mathcal{H}$) which with the aid of empirical data is then related to the ductility requirement.

Rated in Table 2 by way of illustration is a number of selected components of gas turbines (my special field of experience). Table 3 relates the

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resulting coefficient of ductility to elongation at rupture. Practical experience has already been gained in support of the lower limits of ductility (elongation) indicated in Table 3. Plotted in Figure 1 is the coefficient of ductility from Table 2 versus the minimum elongations from Table 3.

Using the available empirical data, a boundary indicating the ductility requirement to be imposed is drawn on the graph. From the definition of the characteristics this boundary is not sharply delineated but rather indicates a transition to a region of greater uncertainty for the life of the component. In the range of low ductility (say under 1% elongation) the scatter is considerable, however. In this range the model still needs perfecting.

Importantly, the ductility values generally specified today (see Table 3) are often greater than the lowest empirical figures. One reason for staying with the higher value is that elongation is used as a characteristic quantity for quality assurance purposes. Of significance also is the realisation that a reduction in ductility will still give considerable room for advances in many materials. Even highly stressed, vital components can well do with elongations of about 2% to 3%, provided their load spectrum can be adequately analysed.

The present attempt at a definition of a ductility criterion is admittedly still embarrassed by omissions and weaknesses. The assessment criteria being impossible to express in strictly physical terms, deviations may occur for specific limits. Also, when rating the load characteristics, estimation and with it, subjectivity and additional scatter are inescapable. Still, a ductility model cannot appropriately be expected to be simple, and a rough estimate is ultimately better than none. If nothing else, it brings present uncertainties into sharper focus.

It is hoped that this tentative scheme will prompt systematic analyses of the evidence obtained on low ductilities (under 10% elongation). In the course of time the model may ultimately be perfected iteratively until mature for adoption as a working theorem.

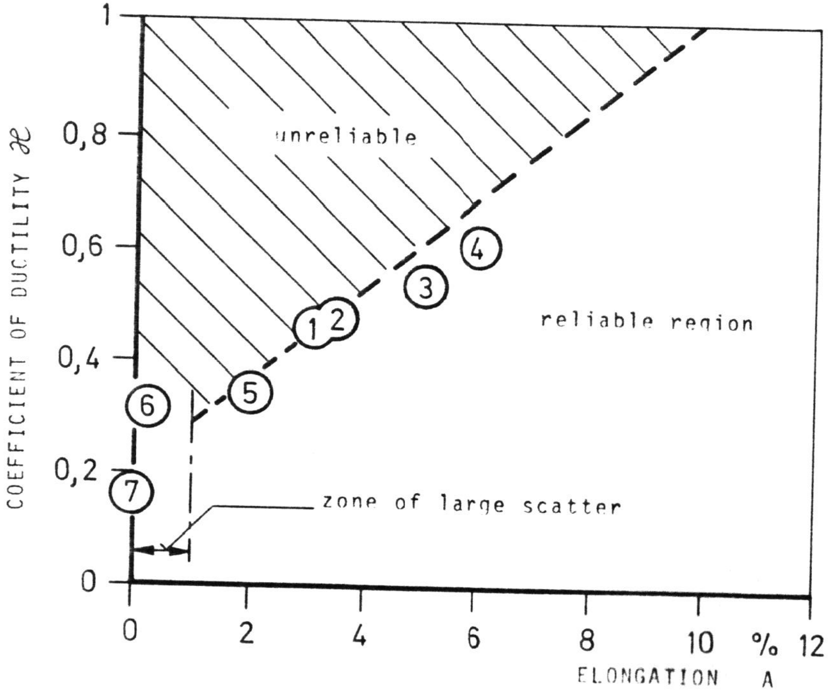

Figure 1 Ductility Chart: Ductility Coefficient versus Elongation (Data Taken From Tables 2 and 3)

Table 1 Evaluation Model for the Coefficient of Ductility

Assessment characteristic	Rated (w) (from 0 to 1)	Weighted (g)	Coefficient of ductility ($\mathscr{H}$)
1) Utilization	low to high 0 1	1	$\mathscr{H} = \frac{(wxg)}{3.7}$ (Sum of rating x weighting, normalized to 1 as highest possible value, gives a number between 0 and 1)
2) Load assumption	safe to unsafe 0 1	q = w (tied to utilization)	
3) Energy absorption	low to high 0 1	0.7	
4) Configuration	plain to complex 0 1	0.5	
5) Safety	low to high 0 1	0.5	

Table 2 Determination of Coefficient of Ductility Using Examples of Highly Stressed Gas Turbine Components (Pattern Taken from Table 1)

Examples / Assessment characteristics	1 Blade w	2 Disc w	3 Shaft w	4 Tie Bolt w	5 Gearbox Casing w	6 Roller Bearing w	7 Ceramic Comb Chamber w
1) Utilization	0,5	0,9	0,7	0,8	0,3	0,7	0,3
2) Load Assumption	0,4	0,2	0,2	0,2	0,6	0,1	0,3
3) Energy Absorption	0,6	0,1	0,8	0,7	0,2	0,1	0
4) Configuration	0,3	0,2	0,2	0,6	0,6	0,1	0,2
5) Safety	0,6	1	0,9	0,6	0,6	0,7	0,2
Coeff. of Ductility $\mathscr{H} = \frac{\Sigma(wxg)}{3,7}$	0,45	0,47	0,53	0,60	0,33	0,33	0,16

Table 3 Relating the Coefficient of Ductility to Elongation
(a) Lower Empirical Limit
(b) Generally Specified

Component (from Table 2)	1 Blade	2 Disc	3 Shaft	4 Tie Bolt	5 Gearbox Casing	6 Roller Bearing	7 Ceramic Comb Chamber
Coefficient of Ductility (per Table 2)	0.45	0.47	0.53	0.60	0.33	0.33	0.16
Minimum a) empirical elongation in percent	3	3 - 4	5	6	2	about 0.2	0.0...
Generally b) specified elongation in percent	3	3 (cast) 6 - 10 (wrought)	10	10	2 - 4	none	none