

THE CUMULATIVE DAMAGE OF ALUMINIUM ALLOY SPECIMENS UNDER VARIABLE AMPLITUDE FATIGUE LOADING

1. NOTATION

f_p	proof stress of material	N/m ²	lbf/in ²
K	elastic stress concentration factor based on net area		
N	constant amplitude endurance at a given stress level		
n	number of cycles applied at a given stress level		
S_{max}	nominal tensile stress associated with highest peak load in spectrum	N/m ²	lbf/in ²

Both SI and British units are quoted but any coherent system of units may be used.

2. NOTES

This Item gives the results of fatigue tests on aluminium alloy specimens in which the applied loads were selected to simulate aircraft gust and manoeuvre conditions. The data analysed do not include those of tests that involved ground-to-air load cycles. It is intended to consider such data in a subsequent Item.

Figures 1 to 4 give data in terms of the fatigue damage $\Sigma(n/N)$ at failure and KS_{max}/f_p . Each point represents the log mean of a number of tests conducted under nominally identical conditions. In Figures 1 and 2, scatter bands indicate the extreme observations in each investigation. Where these overlap, only the highest and lowest values recorded in all the investigations at a constant value of KS_{max}/f_p are shown. In Figures 3 and 4, bands relate data from a series of tests involving the variation of a single factor.

On each figure a horizontal line is drawn through $\Sigma(n/N) = 1.0$. This line corresponds to the life estimate according to the Palmgren-Miner Hypothesis (Derivation 1).

The specimens tested comprised complete wings and riveted sections having a range of K from 3.0 to 4.0 and notched bars and plates with a range of K from 1.0 to 7.0. No allowance has been made, however, for the reduction in K brought about by the clamping effect of bolts and rivets. The application of loads to complete structures was such that normal flight conditions were represented. Simple coupon specimen data were all obtained under axial loading.

Loads were ordered in either periods of programmed or random block sequences or in random half cycles about a fixed datum. In the latter case load cycles determining fatigue damage were based on the combination of the maximum peak and the maximum trough proceeding through combinations of successively smaller peaks and troughs to the minimum values of each. A more complete description of this method is given in Derivation 13.

Endurances N required in the damage calculation were derived from stress – endurance curves obtained from constant stress amplitude tests on nominally identical specimens with the appropriate mean or datum stress.

In cases where, as a result of the influence of fretting, failure occurred slightly away from a point at which the stress concentration could be determined (for example, failure under the head of a rivet) values of KS_{max}/f_p relate to the stresses at the adjacent raiser. The stresses at the actual point of failure in such cases would have been rather less. Values of K for joints fabricated with countersunk rivets have been taken as the stress concentration factor of a plain hole of diameter equal to that of the rivet stem. No allowance has been made for the reduction in the effective value of K arising from bolt or rivet clamping pressure.

Values of f_p relate to either 0.1 or 0.2 per cent strain.

Failure in a structural specimen was assumed to have occurred when the first crack had been observed.

3. INTERPRETATION OF FIGURES 1 TO 4

Figures 1 and 2 give $\Sigma(n/N)$ for values of KS_{max}/f_p for gust and manoeuvre load tests respectively. Typical examples of load spectra used in the tests are illustrated on the relevant figures.

Figure 1 shows that when KS_{max}/f_p is increased beyond 1.0, values of $\Sigma(n/N)$ are generally greater than 1.0. This can be attributed to tensile loads high enough to cause local plastic deformation inducing compressive residual stresses which reduce the damage of subsequent loads. However, as KS_{max} is increased still further, values of $\Sigma(n/N)$ decrease again. This may be due to the troughs in the loading waveform which, as they approach zero or go into compression, may cause local plastic compressive deformation which will tend to offset the beneficial effects of the peak loads.

Figure 2 shows that this reduction in $\Sigma(n/N)$ with increasing KS_{max}/f_p is less marked in manoeuvre test data, possibly owing to the reduction in severity and frequency of troughs in the loading spectra under which these data were obtained.

Figure 3 shows the effect of load sequence on the value of $\Sigma(n/N)$. In the figure each band compares log mean values of $\Sigma(n/N)$ from tests in which load sequence was the only variable. The implication is that this effect can be considerable, particularly at high values of KS_{max}/f_p . The data are insufficient for positive conclusions to be drawn. However, the evidence suggests that the best approximation to a random sequence is afforded by the low-high-low sequence.

Figure 4 shows the effect of including loads corresponding to endurances exceeding 10^8 in tests under otherwise identical conditions. Each pair of data compares log mean values of $\Sigma(n/N)$ derived from tests with and without low-amplitude loads applied. It is evident that in general the inclusion of these loads reduces the value of $\Sigma(n/N)$ obtained. This may be due to loads that do not contribute to $\Sigma(n/N)$ in the damage calculation ($n/N \rightarrow 0$ as $N \rightarrow \infty$) increasing the damage initiated under some prior load.

4. DERIVATION

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