

EFFECT OF AN AXIAL COMPRESSIVE MEAN STRESS ON THE FATIGUE STRENGTH OF ALUMINIUM ALLOY BAR (PLAIN AND NOTCHED)

1. NOTATION

f_p	tensile proof stress of bar material (see Table 5.1)	N/m ²	lbf/in ²
f_t	tensile strength of bar material	N/m ²	lbf/in ²
K_t	elastic stress concentration factor based upon net cross-sectional area		
N	endurance		
S_a	applied alternating stress, based upon net cross-sectional area	N/m ²	lbf/in ²
S_m	applied mean stress based upon net cross-sectional area	N/m ²	lbf/in ²

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

2. NOTES

The results of about 250 fatigue tests on notched and plain aluminium alloy bar subjected to an axial compressive mean load combined with a constant amplitude alternating load have been analysed. The data have been divided into two material groups as follows.

Solution treated and naturally aged alloys $0.71 \leq f_p/f_t \leq 0.73$.

Solution treated and artificially aged alloys $0.88 \leq f_p/f_t \leq 0.91$.

The specimens were manufactured from aluminium alloy bars to various specifications and were either circular or rectangular in cross-section. The fatigue tests were carried out carefully to try to ensure that the applied loading was truly axial and that no bending loads were transmitted to the specimens, although in some cases (particularly at high mean loads) this may not always have been achieved. In the tests four different criteria were used to define fatigue endurance. They were as follows:

- the initial detection of a crack,
- failure by shearing at 45° to the direction of the applied load,
- detection of change of stiffness of the specimen due to the presence of a crack, and
- the limiting condition where the fatigue machine could no longer maintain the desired load.

Table 5.1 describes the types of specimens tested and notes where possible the various descriptions of failure as given in the Derivations.

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The data are presented in Figures 1 to 5 as S-N curves using the non-dimensional term $K_t S_a/f_t$ plotted against endurance, N , and indicating the various values of $K_t S_m/f_t$. Mean curves have been drawn through the data points to show the effect of changes in the value of $K_t S_m/f_t$. In many cases the endurance of a specimen was recorded at the initial appearance of a crack and this endurance is shown on the figures by the letter c above the particular plotted result. A line linking this initial endurance to the final endurance is also drawn. The figures show that an increase in endurance is obtained when compressive mean stresses are applied. The effect of tensile mean stresses has not been included in Figures 1 to 5 as their influence follows the trends indicated in Data Items issued previously. (See Items Nos Fat A.00.01 and Fat E.07.03.)

From Figures 1 to 5 the compressive mean stress versus alternating stress diagrams of Figures 6, 7 and 8 have been constructed for the two alloy groups. These figures are presented in the non-dimensional form of $K_t S_a/f_t$ and $K_t S_m/f_t$ for various endurances, N , and also show the effect of tensile mean stresses for various endurance levels. The tensile mean stress sides of the diagrams have been derived from data taken from the same test programmes as for the compressive mean stress data. Figure 8 has been constructed because the data obtained for the alloy DTD 5014 show different characteristics from the other artificially aged alloys. The data obtained for this alloy indicate an improvement in endurance more in line with that shown by the naturally aged alloys. No reason for this is evident.

The proof stress limit lines are shown dotted on Figures 6, 7 and 8 for both the compressive and tensile regions of the figures. In the absence of specific information the values of compressive proof stress for the alloys are taken to be of the same magnitude as the tensile proof stresses. The curves drawn to the left of these lines, for compressive mean stresses, are above the proof stress limit, that is, yielding would be expected to have occurred; however, unlike the data for specimens tested with tensile mean stress (see Item No. Fat A.00.02) the data do not show any apparent influence of yielding.

3. DERIVATION

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GUNN, K.W.
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5. OSTERMANN, H.
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4. EXAMPLE ON THE USE OF FIGURES 6 AND 7

A notched ($K_t = 2.58$) aluminium alloy component manufactured from 2024-T4 is required to have an endurance of 10^7 cycles with a compressive mean stress of $-0.169 f_t$. At the notch root this stress will increase to $-0.435 f_t$. It is required to find the maximum allowable value of S_a at this endurance.

For 2024-T4 alloy f_t is 500 MN/m^2 .

From Figure 6 using the notched curve ($K_t = 2.58$) for $N = 10^7$, $K_t S_a / f_t$ at the notch root = 0.56; therefore

$$S_a = \frac{0.56 \times 500}{2.58} = 109 \text{ MN/m}^2.$$



5. MATERIALS AND SPECIMEN DETAILS

TABLE 5.1

Derivation	Material specification	f_t		f_p		f_p/f_t	K_t	Description of specimens and sizes	Description of failure	Figure Numbers
		MN/m ²	lbf/in ²	MN/m ²	lbf/in ²					
1	2024-T4 (Naturally aged alloy)	469*	68000*	331 [†]	48000 [†]	0.71	1.0	Round bar 15.88 mm (0.625 in) dia.	Initial detection of surface crack	1 and 6
2	2024-T4 (Naturally aged alloy)	530	76800	386 [‡]	55900 [‡]	0.73	1.0	Round bar 7.5 mm (0.295 in) dia.	Specimen completely sheared off at 45° direction, or when testing machine could no longer maintain the desired load	1 and 6
							and 2.58	Round bar 11.3 mm (0.445 in) dia. with transverse hole 3 mm (0.118 in) dia.		2 and 6
3	**BS 1476-HE 15W (Naturally aged alloy)	542	78600	387 [†]	56100 [†]	0.71	1.0	Round bar 8 mm (0.315 in) dia.	When specimen separated into two pieces or when the machine could not be operated	1 and 6
	**BS 1476-HE 15WP (Artificially aged alloy)	545	79000	493 [†]	71500 [†]	0.91				3 and 7
4	2L65 (Artificially aged alloy)	526	76370	482 [†]	69800 [†]	0.91	2.3 and 3.7	Rectangular bar 17.8 × 10.2 mm (0.7 × 0.4 in) with 6.4 mm (0.25 in) dia. hole	Test stopped when machine detected change in stiffness due to presence of crack	4, 7 and 8
	2024-T81 (Artificially aged alloy)	490	71120	434 [†]	62900 [†]	0.88				
	DTD 5014 (Artificially aged alloy)	420	60900	371 [†]	53800 [†]	0.88		Rectangular bar as above but with 6.4mm (0.25 in) central slot		5, 7 and 8
5	Hiduminium ^{††} RR 58 (Artificially aged alloy)	422	61200	383 [‡]	55500 [‡]	0.91	2.5	Rectangular bar 40 × 5 mm (1.57 × 0.197 in) with 8 mm (0.315 in) dia. hole	—	4 and 7
							and 3.6	Rectangular bar as above but with a 11.6 mm (0.456 in) central slot		5 and 7

* Minimum value from Aerospace Structural Materials Handbook

[†] 0.1 per cent tensile proof stress

[‡] 0.2 per cent tensile proof stress

** Current BS Spec. is BS 1474-HE 15TB and HE 15TF respectively

^{††} Manufacturer's specification

All static strengths quoted in the above table have been obtained from test values except where indicated thus *