

ENDURANCE OF TITANIUM ALLOY LUGS (Ti-6Al-4V, Annealed and Ti-4Al-4Mo-2Sn-0.5Si)

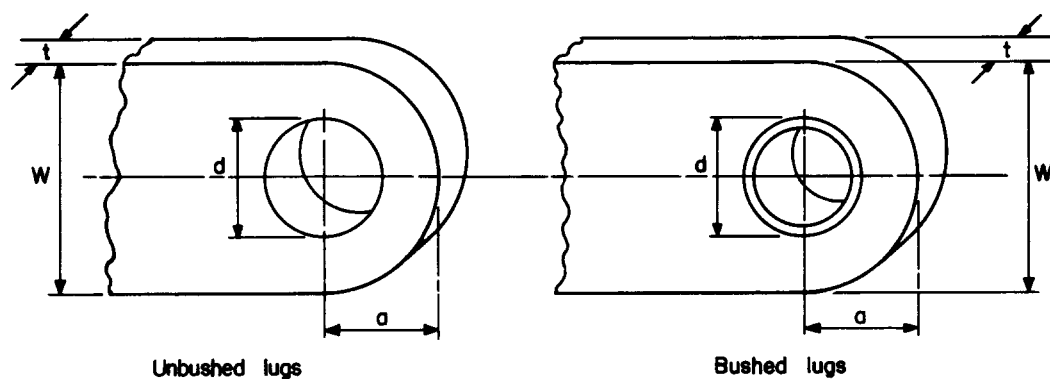
1. NOTATION

a	distance between centre of hole and end of lug	m	in
d	nominal diameter of pin or outside of bush (see Sketch 1.1)	m	in
f_p	0.2 per cent proof stress of lug material	N/m ²	lbf/in ²
f_t	tensile strength of lug 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
S'_m	mean stress at side of hole in lug, $K_t S_m$ or $f_p - K_t S_a$ if $K_t S_{max} > f_p$	N/m ²	lbf/in ²
S_{max}	applied peak stress in load cycle ($S_m + S_a$)	N/m ²	lbf/in ²
t	thickness of lug	m	in
W	width of lug	m	in

Both SI and British units are quoted in the Notation but throughout the Item only SI units are used. For convenience the following conversion factors are provided.

$$1 \text{ MN/m}^2 = 145.038 \text{ lbf/in}^2$$

$$1 \text{ m} = 39.37 \text{ in.}$$



Sketch 1.1

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2. NOTES

Constant amplitude fatigue test data obtained on lugs manufactured from the titanium alloys Ti-6Al-4V and Ti-4Al-4Mo-2Sn-0.5Si have been analysed. The Ti-6Al-4V titanium alloy lugs were manufactured from sheet or bar forged in the (alpha + beta) phase condition and subsequently annealed, see Item No. 77027*. For this material the data are presented for unbushed lugs with clearance-fit pins, either with or without the material around the hole having been cold worked, and for lugs with close-fit bushes and having clearance-fit pins in the bushes. The bushes were made of steel and the lugs were loaded axially through steel pins. The Ti-4Al-4Mo-2Sn-0.5Si lugs were manufactured from forged bar solution treated and aged below the transus temperature of 975°C, producing a structure in the (alpha + beta) phase. The data for this material are presented for lugs with close-fit bushes only. The bushes used were manufactured from either bronze (to DTD 197) or annealed copper beryllium† and the lugs were loaded axially through steel pins.

Lugs of various shapes and geometries were tested. The geometric stress concentration factors, K_t , of the lugs were in the range 2.1 to 4.4 and were obtained from Items Nos 71011‡ and 81006**. Table 5.1 gives the overall dimensions and mechanical properties of the materials for all the lugs tested. The fit between the hole and pin was not always stated but generally holes without bushes had some degree of clearance between the pin and lug. The bushed lugs had some degree of interference between the bush and lug with clearance-fits between the bush and pin. In the majority of tests loading on the lugs was tensile, that is, $S_m > |S_a|$. In the few cases where $|S_a| > S_m$ the stress range was taken to be 0 to S_{max} . The lugs were not subjected to out-of-plane bending loads and, since none of the lugs was clamped, there was no transfer of load by friction.

3. PRESENTATION OF DATA

Figures 1 to 4 present the fatigue data in terms of the non-dimensional stress ratio $K_t S_a / f_t$ and the cycles to failure, N . The use of the stress ratio $K_t S_a / f_t$ takes into account the major effects of geometry and variations in material tensile strength of the specimens tested and hence generally reduces the scatter of the fatigue test results. Values of mean stress are indicated on each figure by different symbols for several values, or ranges of values, of the non-dimensional ratio for mean stress S'_m / f_t . The use of the parameter S'_m / f_t can in some cases help to show the effect of variations in values of mean stress, see Section 3.1. Note that in the cases where the value of $K_t S_{max} / f_t$ exceeds f_p / f_t , that is, when local plastic deformation occurs around the hole (see Item No. Fat. A.00.02††), corrections to the value of mean stress have been made such that $S'_m / f_t = (f_p - K_t S_a) / f_t$. In general on Figures 1 and 3 yielding has taken place on the specimens where $K_t S_a / f_t > 0.48$. On Figure 2 some specimens have yielded over the full range of $K_t S_a / f_t$. On Figure 4 only two specimens have yielded. Figures 1 to 3 present data for the Ti-6Al-4V alloy and Figure 4 presents data for the Ti-4Al-4Mo-2Sn-0.5Si alloy. It should be noted that the values of K_t used in the presentation of data for the interference-fit bushed lugs on Figures 3 and 4 are geometric values obtained from Item No. 71011 and therefore do not take into account any effects of redistribution of stress around the holes due to the interference.

* Data Item No. 77027 "Fatigue of wrought and cast Ti-6Al-4V titanium alloy. (In bending and under axial loading)".

† The constituent elements are 2 per cent beryllium and the rest is copper. The material is precipitation treated to the required tensile strength after machining.

‡ Data Item No. 71011 "Stresses due to interference-fit pins and bushes in plates, strips or lugs".

** Data Item No. 81006 "Stress concentration factors. Axially loaded lugs with clearance-fit pins".

†† Data Item Fat. A.00.02 "The effect of mean stress on fatigue strength (test piece with stress concentration)".

3.1 Ti-6Al-4V Alloy

Figure 1 presents data for lugs without bushes. On this figure it has been possible to distinguish the effect of variations in the value of mean stress and lines have been drawn by eye around the data for two ranges of values of S'_m/f_t for which data are available, that is, for $0.2 < S'_m/f_t \leq 0.47$ (continuous curves) and $S'_m/f_t \geq 0.54$ (dashed curves). The curves enclose about 92 per cent of the data for values of $S'_m/f_t \geq 0.54$ and about 96 per cent of the data for values of $S'_m/f_t \leq 0.47$. For guidance mean curves have been drawn by eye between the bounding curves for each range of S'_m/f_t .

Figure 2 presents data for lugs without bushes but where the material around the hole has been cold worked, either by a roll-a-finish process or by ballising*. The number of data points presented on Figure 2 is limited and the results are simply compared with the curves for the clearance-fit pins of Figure 1. The figure shows that cold working the material around the hole does give improved performance compared with that of the lugs that have not been cold worked. It is not clear from the data available which of the two cold working processes gives the better results in terms of fatigue endurance; it has been suggested, however, that in general the ballising process gives the longest endurances.

Figure 3 presents data obtained from tests on lugs containing close-fit steel bushes in which the fit between the bush and hole ranges from 0.25 per cent clearance to 0.5 per cent interference. On this figure there is a series of data points, indicated by the letter L, that have been obtained from fatigue tests on large specimens ($d = 101.6$ mm), see Table 5.1 for details. The fatigue endurances of these very large specimens tend to be lower than the bulk of the data for the close-fit bushed lugs. Curves have been drawn by eye enclosing about 99 per cent of the data, excluding the large specimen results, and a mean line between these curves has also been drawn. It is difficult to distinguish the effects of variations in mean stress levels for these lugs, because the bulk of the specimens have been tested at one level of S'_m/f_t . For guidance the curves of Figure 1, where $S'_m/f_t \leq 0.47$ (dashed-dot curves), have also been drawn on this figure. Comparing the data of Figures 1, 2 and 3, it can be seen that lugs without bushes but with the material around the hole cold worked tend to give the highest fatigue endurances for given values of $K_t S_a$. Although the lugs with bushes generally have some degree of interference-fit between the lug and bush they have only marginally better fatigue endurances than have the lugs without bushes.

3.2 Ti-4Al-4Mo-2Sn-0.5Si Alloy

Figure 4 presents data for lugs manufactured from this alloy and fitted with copper alloy bushes. Curves have been drawn by eye to enclose about 94 per cent of the data for values of $K_t S_a/f_t > 0.1$ and a mean curve between these bounding curves has also been drawn. Most of the tests were conducted at one mean stress level ($S'_m/f_t = 0.42$) and therefore there are not enough results to distinguish the effects of changes in the value of mean stress. For guidance the curves for Ti-6Al-4V alloy bushed lugs, from Figure 3, are also presented (dashed curves) and it can be seen that the endurances of the Ti-4Al-4Mo-2Sn-0.5Si alloy lugs are much lower than those of the Ti-6Al-4V lugs, particularly at low stress levels.

* The roll-a-finish process can produce hole diameters and surfaces to a fine tolerance and surface finish. The tool operates by the action of caged rollers rotating around and bearing on a central tapered mandrel. The interference between the rollers and the bore of the hole can be adjusted by varying the depth of engagement on the tapered mandrel. Ballising is a process where an oversize steel ball is forced through the hole.