



ESDU 84025

Issued October 1984

With Amendment A

July 1985

Supersedes ESDU E.05.04

Endurance of aluminium alloy lugs with steel interference-fit pins or bushes

Endorsed by
The Royal Aeronautical Society
The Institution of Mechanical Engineers

AVA Documents
Document Sharing Hub

ESDU DATA ITEMS

Data Items provide validated information in engineering design and analysis for use by, or under the supervision of, professionally qualified engineers. The data are founded on an evaluation of all the relevant information, both published and unpublished, and are invariably supported by original work of ESDU staff engineers or consultants. The whole process is subject to independent review for which crucial support is provided by industrial companies, government research laboratories, universities and others from around the world through the participation of some of their leading experts on ESDU Technical Committees. This process ensures that the results of much valuable work (theoretical, experimental and operational), which may not be widely available or in a readily usable form, can be communicated concisely and accurately to the engineering community.

We are constantly striving to develop new work and review data already issued. Any comments arising out of your use of our data, or any suggestions for new topics or information that might lead to improvements, will help us to provide a better service.

THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item, which supersedes ESDU E.05.04, was monitored and guided by the Fatigue Committee which first met in 1955 and now has the following constitution:

Chairman	
Mr A.D. Hall	— Westland Helicopters Ltd
Vice-Chairman	
Mr J.A.B. Lambert	— British Aerospace, Aircraft Group, Hatfield
Members	
Mr K.E. Cheverton	— Rolls-Royce Ltd, Bristol Engine Division, Filton
Mr H.L. Cox	— Independent
Dr M.S.G. Cullimore	— University of Bristol
Dr P.R. Edwards	— Royal Aircraft Establishment, Farnborough
Mr J.Y. Mann*	— Aeronautical Research Laboratories, Melbourne, Australia
Mr N.H. Mason	— Consulting Engineer
Mr L.F. Nicholls	— British Aerospace, Aircraft Group, Bristol
Mr C.J. Robinson	— British Aerospace, Aircraft Group, Brough
Mr T. Swift*	— Federal Aviation Administration, USA
Mr R.J. Wanhill*	— National Aerospace Laboratory, NLR, The Netherlands
Dr R.N. Wilson	— Royal Aircraft Establishment, Farnborough
Mr H. Wood*	— Wright-Patterson Air Force Base, Ohio, USA.

* Corresponding Member

The construction and subsequent development of the Item were undertaken by

Mr C.R. Hookham — Senior Engineer.

The person with overall responsibility for the work in this subject area is Mr M.E. Grayley, Head of Strength Analysis Group.

ENDURANCE OF ALUMINIUM ALLOY LUGS WITH STEEL INTERFERENCE-FIT PINS OR BUSHES

CONTENTS

	Page
1. NOTATION	1
2. NOTES	2
3. PRESENTATION OF DATA	3
3.1 Calculation of Stress Concentration Factor, K_t	4
4. DISCUSSION OF RESULTS	4
4.1 Solution Treated and Artificially Aged Alloys ($0.84 \leq f_p/f_t \leq 0.91$)	4
4.2 Solution Treated and Naturally Aged Alloys ($0.72 \leq f_p/f_t \leq 0.75$)	5
4.3 Solution Treated and Cold Worked Alloys (2024-T3) ($0.66 \leq f_p/f_t \leq 0.8$)	5
5. DERIVATION AND REFERENCE	5
5.1 Derivation	5
5.2 Reference	6
6. TABLES	7
APPENDIX A ESTIMATION OF INTERFACE STRESSES AROUND BOUNDARY OF HOLE (UNBUSHED SPECIMEN)	27
A1. ADDITIONAL NOTATION	27
A2. NOTES	27
APPENDIX B STRESS DISTRIBUTION IN A LUG LOADED VIA AN INTERFERENCE-FIT PIN OR BUSH	29
B1. INTRODUCTION	29
B2. LUGS WITH PUSH-FIT PINS	29
B3. LUGS WITH INTERFERENCE-FIT PINS	29

ENDURANCE OF ALUMINIUM ALLOY LUGS WITH STEEL INTERFERENCE-FIT PINS OR BUSHES

1. NOTATION

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

a	distance from centre of hole to end of lug (see Sketch 2.1)	m	in
d	pin or bush external diameter	m	in
d_i	internal diameter of bush	m	in
d_l	diameter of hole in lug	m	in
f	maximum tensile stress acting around boundary of hole, caused by interference alone	N/m ²	lbf/in ²
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 of lug with pin-fit < 0.1 per cent clearance, based on net area (see Section 3.1)		
N	endurance		
P	applied tensile load	N	lbf
R	S_{min}/S_{max}		
S	nominal stress acting on net cross-sectional area of lug (excluding bush) = $P/(W - d)t$	N/m ²	lbf/in ²
t	thickness of lug	m	in
W	width of lug	m	in

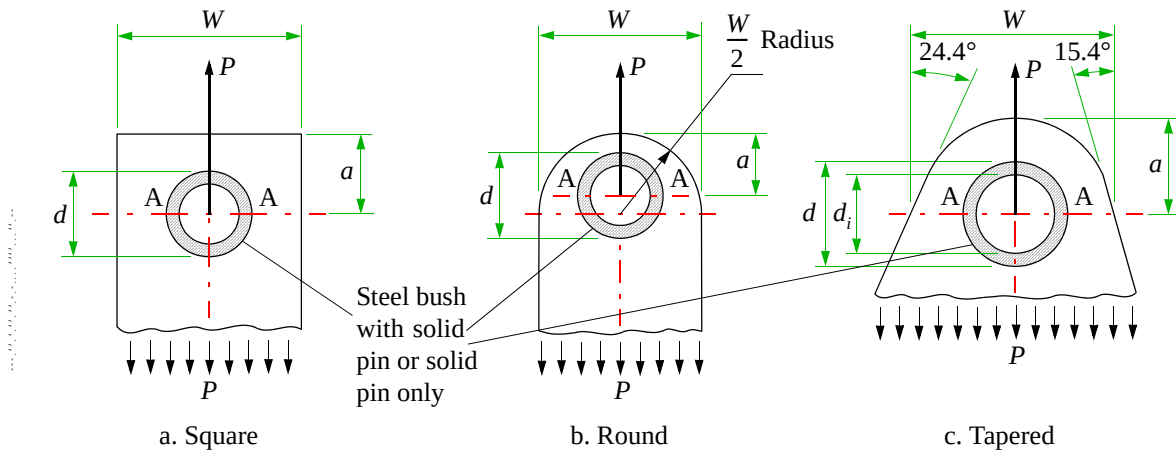
Suffixes

a	indicates nominal alternating values in loading cycle
m	indicates nominal mean value in loading cycle
max, min	indicate maximum and minimum values in loading cycle respectively

Issued October 1984
With Amendment A, July 1985

2. NOTES

The results of about 800 constant amplitude fatigue tests on aluminium alloy lugs have been analysed. These lugs were either loaded by steel interference-fit pins, or contained steel interference-fit bushes that were loaded by steel clearance-fit pins. The test data and endurance curves are presented in terms of the parameters $K_t S_a / f_t$ against N for various values of $K_t S_m / f_t$. This form of presentation for the fatigue endurance curves has been used so that a direct comparison of endurance data can be made with those obtained from fatigue tests on aluminium alloy lugs containing push-fit pins and presented in ESDU 80007*.



Sketch 2.1 Lug geometries for which data are available

All the tests were conducted at room temperature. The types of lug tested and descriptions of their end shapes are illustrated in Sketch 2.1. The lugs were loaded axially and, since there was no clamping, all the loading was transferred through the pin. The lugs were not subjected to bending loads but, where they had a t/d ratio greater than 0.5, an estimate of the effect of pin bending was included in the calculation of K_t (see Section 3.1). The lugs tested were manufactured from either Al-Cu-Mg or Al-Zn-Mg alloys. For the purposes of this Data Item materials have been grouped according to their ratios of 0.2 per cent proof stress to tensile strength, f_p/f_t . The ranges of f_p/f_t covered are as follows.

Solution treated and artificially aged alloys	$0.84 \leq f_p/f_t \leq 0.91$
Solution treated and cold worked alloys (2024-T3)	$0.66 \leq f_p/f_t \leq 0.80$
Solution treated and naturally aged alloys (other than 2024-T3)	$0.72 \leq f_p/f_t \leq 0.75$

To indicate size effect the data have been sub-divided into three convenient groups based upon either pin or bush external diameter d . The effect of size on the fatigue strength of lugs is influenced by other parameters, but d is the most sensitive dimension. The data have been grouped as shown in Table 2.1. (Note that there are no data available for small specimens containing bushes.)

* ESDU 80007 "Endurance of aluminium alloy lugs with nominally push-fit pins (tensile mean stress)".

TABLE 2.1

Specimen size group		<i>d</i>				<i>d/W</i>		<i>t/d</i>		Approximate number of specimens
		<i>min</i>		<i>max</i>		<i>min</i>	<i>max</i>	<i>min</i>	<i>max</i>	
		mm	in	mm	in					
Large pin	} unbushed	19.05	0.75	31.75	1.25	0.33	0.56	0.25	1.0	160
Medium pin		9.53	0.375	15.88	0.625	0.19	0.5	0.25	1.71	240
Small pin		4.78	0.188	7.94	0.313	0.25	0.5	0.5	1.0	180
Large pin	} bushed	19.05	0.75	32.0	1.26	0.34	0.5	0.16	1.27	180
Medium pin		10.0	0.39	15.0	0.59	0.33	0.45	0.5	0.6	40

The interference -fit* between pin and lug ranged from 0.25 to 0.8 per cent and between bush and lug ranged from 0.08 to 1.0 per cent. Tables 6.1 to 6.5 give a comprehensive listing of all the lug specimens considered. Throughout the text, and on the figures of this Item, the lugs with interference-fit pins are described as 'unbushed specimens' and the lugs containing bushes are described as 'bushed specimens'.

The effects of antifretting compounds on fatigue endurance were not considered but in many of the tests the pins or bushes were lightly greased prior to assembly. Some of the test specimens contained bushes and pins that were cadmium plated, particularly those made from corrosion resistant (stainless) steels. In two of the derivations tapered bushes were inserted in the specimens, see Table 6.4 for details.

3. PRESENTATION OF DATA

The fatigue test data are presented on Figures 1 to 14 in terms of the type of alloy, specimen size, whether bushed or unbushed and degree of interference-fit. Endurance curves are drawn through the data in terms of $K_t S_a / f_t$ and, where possible, the mean stress parameter $K_t S_m / f_t$. On some figures it was not possible to draw curves for constant values of $K_t S_m / f_t$ but it was possible to draw a curve for a constant value of R (in all such cases $R = 0$).

On each figure the non-dimensional interference-fit stress parameter f/f_t for the range of interference-fits considered is given. The value of f was calculated using either the method given in Appendix A of this Item, for unbushed specimens, or from ESDU 71011†, for bushed specimens. For the types of specimens and materials available the values of the ratio f/f_t are proportional to the degree of interference fit. For the unbushed specimens f/f_t is approximately equal to the percentage fit and for the bushed specimens (which are relatively thin) f/f_t is approximately equal to half the percentage fit. The circumferential tensile stress caused by the pin or bush interference around the boundary of the hole increases the local tensile mean stress but more importantly reduces the fatigue alternating stress‡ at the point of maximum stress on the transverse diameter of the hole, point A on Sketch 2.1. This reduction in alternating stress together with the reduction of fretting damage between the pin or bush and the lug produces an increase in fatigue endurance compared with data obtained for lugs with push-fit pins. Where possible each figure shows the corresponding range of endurance curves for lugs with push-fit pins (shown dashed and obtained from ESDU 80007) so that a comparison of fatigue endurance may be made between lugs with interference-fit pins and lugs with push-fit pins.

* The percentage interference is defined by the expression $[1 - d_l/d] \times 100$.

† ESDU 71011 "Stresses due to interference-fit pins and bushes in plates, strips or lugs".

‡ See Appendix B for explanation.

On most figures the interference-fit pin lugs have longer endurance than the corresponding push-fit pin lugs. It should be noted, however, that this increase in endurance may not be so large if the lugs are subjected to variable amplitude loading.

Note that the values for the various ranges of mean stress are denoted by different symbols on the figures. These symbols identify the source (derivation) from which the data have been obtained. The data are presented in this way because of the very large amount of scatter in the test results compared with the corresponding push-fit pin data given in ESDU 80007.

3.1 Calculation of Stress Concentration Factor, K_t

Solutions for the stress concentration factor at the edge of a loaded hole in a lug with interference-fit pins or bushes are not known. Therefore, in this Item, the elastic stress concentration factors given in ESDU 81006* have been used to give a value of K_t that corrects for geometry rather than stress, but enables a direct comparison with the fatigue endurance for lugs with push-fit pins to be made. The values of K_t quoted are calculated for a pin-clearance of less than 0.1 per cent. For the square-ended lugs values of K_t may be obtained directly from the figures and for round-ended lugs values of K_t may be obtained using the formula and method presented in ESDU 81006. An additional multiplying factor (which takes into account the effect of pin bending) is also obtained from ESDU 81006 and is applied to the nominal stress concentration factor if the t/d ratio of the component is greater than 0.5.

4. DISCUSSION OF RESULTS

4.1 Solution Treated and Artificially Aged Alloys ($0.84 \leq f_p/f_t \leq 0.91$)

Endurance curves for solution treated and artificially aged materials are presented on Figures 1 to 5, for large and medium unbushed specimens, and on Figures 8 and 9 for small unbushed specimens, with pins having interference fits in the range 0.34 to 0.8 per cent. Endurance curves for bushed specimens are presented on Figures 11, 12 (large) and 14 (medium) with interference fits in the range 0.08 to 1.0 per cent. Where possible smooth curves have been drawn by eye through the logarithmic mean of the data for various ranges of the mean stress parameter $K_t S_m/f_t$. Where it was not possible to draw curves through values of $K_t S_m/f_t$ mean curves have been drawn through the $R = 0$ data, see Figures 2 and 14. It can be seen from the figures that the large and medium size specimens, made from Al-Cu-Mg alloys, with interference-fit pins have longer fatigue endurance, for given stress levels (at values of $K_t S_m/f_t < 1.0$), than the corresponding large and medium size specimens with push-fit pins. This increase in fatigue endurance between interference-fit pins and push-fit pins is not reflected, however, at values of $K_t S_m/f_t > 1.0$ and for the small specimen data, where in both instances there is very little difference in fatigue endurance for the two levels of pin fit. The trends of the data are that the higher the degree of interference fit the longer the fatigue endurance for any given stress level. On Figure 2 the data show that there is an optimum interference fit of about 0.7 per cent, because the specimens with 0.8 per cent interference-fit pins appear to have shorter fatigue endurance than those with 0.57 and 0.75 per cent interference ($R = 0$ curve). Note that the interference stress ratio f/f_t for the 0.8 per cent interference-fit pins is very high at 0.88.

Figures 11, 12 and 14 present endurance curves for bushed specimens where some of the bushes have been cadmium plated. On Figure 11 the specimens containing cadmium plated bushes have very much shorter fatigue endurance than specimens containing plain bushes. On Figure 14, however, the difference in endurance between specimens containing plain bushes and those containing cadmium plated bushes is much smaller although the trend is that specimens with cadmium plated bushes have shorter endurance. Similar trends are shown on Figure 12, although there are only eight test results for specimens that have cadmium plated bushes. Figure 15 compares the endurance curves for the artificially aged alloys for the three pin or

* ESDU 81006 "Stress concentration factors. Axially loaded lugs with clearance-fit pins".

bush sizes, at two values of $K_t S_m / f_t$. At $K_t S_m / f_t$ in the region of 0.6, the medium unbushed specimens have the longest endurance for given values of $K_t S_a / f_t$ and the Al-Zn-Mg alloy specimens with large pins have the shortest endurance. The scatter between the groups of specimens at this approximate value of $K_t S_m / f_t$ is very large. At higher values of $K_t S_m / f_t$, in the region of 1.4 to 1.5, the effect of pin size on fatigue endurance is less pronounced and in this instance small pin specimens have the longest endurance.

4.2 Solution Treated and Naturally Aged Alloys ($0.72 \leq f_p / f_t \leq 0.75$)

Figures 7 and 10 present data, at $R = 0$, for medium and small unbushed specimens for the naturally aged alloys for three values of interference fit. The data show that small specimens with 0.66 per cent interference-fit pins have longer endurance than those with 0.25 per cent interference-fit pins. The medium specimens with 0.4 per cent interference have an endurance curve that lies between the two small specimen endurance curves. Both figures show, that at endurance greater than 4×10^5 cycles, specimens with interference-fit pins have longer endurance than specimens with push-fit pins.

4.3 Solution Treated and Cold Worked Alloys (2024-T3) ($0.66 \leq f_p / f_t \leq 0.8$)

Figures 6 and 13 present data, at $R = 0$, for medium unbushed specimens and large bushed specimens for the 2024-T3 alloys. The large bushed specimens have shorter endurance than the medium unbushed specimens at endurance less than 10^7 cycles. As before, the interference-fit pin specimens have longer endurance than the specimens with push-fit pins.

5. DERIVATION AND REFERENCE

5.1 Derivation

This section lists selected sources that have assisted in the preparation of this Item.

1. FISHER, W.A.P.
WINKWORTH, W.J. Improvements in the fatigue strength of joints by the use of interference fits. Royal Aircraft Establishment, Farnborough, UK, RAE Rep. Structures 127, May 1952.
2. HARTMAN, A.
JACOBS, F.A. The effect of various fits on the fatigue strength of pin-hole joints. National Aeronautical Research Institute, Amsterdam, The Netherlands, NLL Rep. M. 1946, April 1954.
3. HEYWOOD, R.B. The strength of lugs in fatigue. Royal Aircraft Establishment, Farnborough, UK, RAE tech. Note Structures 182, January 1956.
4. FISHER, W.A.P.
YEOMANS, H. Fatigue strength of aluminium alloy lugs (unbushed) with and without interference fit pins. Alloys DTD 364 and DTD 363. Royal Aircraft Establishment, Farnborough, UK, RAE tech. Note Structures 209, November 1956.
5. LOW, A.C. The fatigue strength of pin-jointed connections in aluminium alloy L65. Mech. Engng Res. Lab. (Mechanics and Materials Division), East Kilbride, Glasgow, UK, MERL PM 207, December 1956.
6. SCHIJVE, J.
BROEK, D.
JACOBS, F.A. Fatigue tests on aluminium alloy lugs with special reference to fretting. National Aero- and Astronautical Research Institute, Amsterdam, The Netherlands, NLR TN M. 2103, March 1962.

7. MORGAN, F.G. Static stress analysis and fatigue tests of interference-fit bushes. Royal Aircraft Establishment, Farnborough, UK, RAE tech. Note Structures 316, August 1962.
8. AUBREY, E.
McLEAN, J.L. The effect of clearance holes on the fatigue life of aluminum lugs. Can. Aeronaut. Space J., Vol. 10, No. 6, pp. 181-183, June 1964.
9. WÄLLGREN, G. Utmattningshållfastheten hos aluminiumöron med bussningar. FFA, Aero. Res. Instit., Sweden, tech. Note HU-1068, 1965.
10. ROWLAND, K. Lug fatigue tests. British Aircraft Corp., Weybridge, UK, BAC PRO. 223, August 1969.
11. BUCH, A. Fatigue properties of aircraft lugs with interference fit. In: Fatigue testing and design, Volume 2, Int. Conf. of Soc. Environ. Engrs - City Univ., London UK, April 1976.
12. BUCH, A. Estimation of fatigue properties of aircraft lugs with interference fits. Technion, Israel Instit. Tech., Haifa, Israel. TAE Rep. No. 290, June 1976.
13. MOON, J.E. Fatigue behaviour of BS 2L65 aluminium alloy pin-loaded lugs with interference-fit bushes. Royal Aircraft Establishment, Farnborough, UK RAE TR 77177, November 1977.
14. JARFALL, L. Review of some Swedish work on fatigue of aircraft structures during the period May 1975 to April 1977. FAA. Aero. Res. Instit., Sweden, tech. Note HE-1918, April 1977.
15. SANDIFER, R.H. Bolted joint fatigue programme. Vols 1 to IV, S and T-Memo-1-77. Defence Research Information Centre, Orpington, UK, May 1978.
16. BUCH, A. Comparison of fatigue behaviour of 2024-T3 and 7075-T6 Al-alloy lugs – Part I., Technion, Israel Instit. Tech., Haifa, Israel, TAE No. 365, May 1979.

5.2 Reference

This section gives a recommended source of information supplementary to that in this Item.

17. ROARK, R.J. Formulas for stress and strain. 3rd Edition, McGraw-Hill Book Co. Inc., 1954.

6. TABLES

Tables 6.1 to 6.5 give details of all the lug specimens used.

TABLE 6.1 Lug Parameters, Large Unbushed Specimens – 19.05 mm (0.75 in) $\leq d \leq$ 31.8 mm (1.25 in)

Figure Number	f_p / f_t	Material (a)	f_t		d		a		W		t		d/W	t/d	K_t	Percentage interference	f/f_t	Lug shape	Derivation
			MN/m ²	lbf/in ²	mm	in	mm	in	mm	in	mm	in							
1	0.91*	DTD 364	494	71700	19.05	0.75	38.1	1.5	57.15	2.25	19.05	0.75	0.33	1.0	3.61	0.35 to 0.46	0.35 to 0.46	Square	1
	0.91*	DTD 364	432	62720	19.05	0.75	44.45	1.75	49.53	1.95	8.89	0.35	0.38	0.47	2.85	0.39 to 0.43	0.39 to 0.43	Square	4
	0.91*	DTD 364	494	71680															
	0.91*	DTD 364	432	62720	19.05	0.75	38.1	1.5	57.15	2.25	19.05	0.75	0.33	1.0	3.61	0.40 to 0.47	0.40 to 0.47	Square	5
	0.91*	L65	519	75260	25.4	1.0	38.1	1.5	57.15	2.25	19.05	0.75	0.44	0.75	2.83	0.37 to 0.44	0.35 to 0.42		
1					19.05	0.75							0.38	0.33	2.77	0.40	0.41	Square	15
1 and 2	0.90	L71	478	69400			76.2	3.0	50.8	2.0	6.35	0.25				0.40	0.44		
					25.4	1.0							0.50	0.25	2.35	0.80	0.88		
2	0.91*	L65	519 521	75260 75600	19.05	0.75	38.1	1.5	57.15	2.25	19.05	0.75	0.33	1.0	3.63	0.60 to 0.80	0.55 to 0.74	Square	5
					22.23	0.875							0.39	0.86	3.13	0.57 to 0.75	0.53 to 0.70		
					25.4	1.0							0.44	0.75	2.83	0.66 to 0.72	0.64 to 0.69		
	0.91*	L65	519 521	75260 75600	25.4	1.0	38.1	1.5	57.15	2.25	19.05	0.75	0.44	0.75	2.83	0.57 to 0.64	0.55 to 0.61		
					28.58	1.125							0.50	0.67	2.60	0.62 to 0.68	0.61 to 0.67		
					31.75	1.25							0.56	0.60	2.40	0.57 to 0.67	0.57 to 0.67		
3	0.89*	DTD 363	541 587	78400 85120	19.05	0.75	44.45	1.75	49.53	1.95	8.89	0.35	0.38	0.47	2.85	0.36 to 0.43	0.31 to 0.36	Square	4

NOTES

(a) The following material specifications have been superseded:

DTD 364 is now BS L168

BS L65 is now BS L168

BS L71 is now BS L157

DTD 363 is now DTD 5064 and DTD 5124

Al-Cu-Mg alloys.

Al-Zn-Mg alloys.

* Values of f_p are minimum values obtained from standard specifications.

TABLE 6.2 Lug Parameters, Medium Unbushed Specimens – 9.5 mm (0.375 in) $\leq d \leq 15.9$ mm (0.6225 in)

Figure Number	f_p / f_t	Material (a)	f_t		d		a		W		t		d/W	t/d	K_t	Percentage interference	f/f_t	Lug shape	Derivation
			MN/m ²	lbf/in ²	mm	in	mm	in	mm	in	mm	in							
4	0.91	L65	519 521	75260 75600	11.12	0.438	38.1	1.5	57.15	2.25	19.05	0.75	0.19	1.71	6.76	0.34 to 0.59	0.30 to 0.53	Square	5
4 and 5	0.90	L71	478	69400	9.53	0.375	28.58	1.125	19.05	0.75	2.39	0.094	0.50	0.25	2.35	0.40 and 0.80	0.44 0.87	Square	15
					12.7	0.50	76.2	3.0	50.8	2.0	6.35	0.25	0.25	0.50	3.67		0.40 0.80		
					15.88	0.625	47.63	1.875	31.75	1.25	3.96	0.156	0.50	0.25	2.35		0.44 0.87		
6	0.66 ^{††}	2024–T3(b)	441 [*]	64000 [*]	10.0	0.394	11.3	0.445	24.6	0.969	5.6	0.22	0.41	0.56	3.37	0.21 to 0.31	0.24 [*] to 0.36	Tapered and round	11 and 12
					10.0	0.394	15.0	0.59	30.0	1.181	5.6	0.22	0.33	0.56	3.50	0.26 to 0.33	0.29 to 0.37	Round	
7	0.75	24ST	438	63530	10.0	0.394	20.0	0.787	30.0	1.181	3.0 6.0	0.118 0.236	0.33	0.30 0.60	3.35	0.40	0.45	Square	2
	0.74	2024–T4	593	86000	12.7	0.50	15.88	0.625	31.75	1.25	12.7	0.50	0.40	1.0	3.48	0.42	0.36	Round	8

NOTES

(a) Some of the material specifications have been superseded:

24ST is an early designation of the 2024 Al-Cu-Mg alloy. The mechanical properties quoted for this material suggest that the alloy was in the naturally aged condition (T4).

BS L65 is now BS L168	}	Al-Cu-Mg alloys.
BS L71 is now BS L157		

(b) Pin cadmium plated

^{*} Values of f_t are minimum values obtained from standard specifications.[†] Values of f_p are minimum values obtained from standard specifications.