



ESDU 87026

Issued November 1987

With Amendment A

November 1994

Fatigue strength of anodised aluminium alloy

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FATIGUE STRENGTH OF ANODISED ALUMINIUM ALLOY

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FATIGUE STRENGTH OF ANODISED ALUMINIUM ALLOY

1. INTRODUCTION

Anodising aluminium alloys in a suitable dilute acid converts the surface layer into a hard, corrosion resistant material. Since fatigue damage is usually initiated at the surface of a component, the properties of the anodised surface layer control fatigue crack initiation and the early stages of crack propagation. In addition to the anodising process itself, the fatigue properties of the surface are influenced by the various treatments carried out both in preparation for, and after, anodising. There are many permutations of the available treatments and data are only available for some of them. This Data Item therefore provides guidance on the influence on the fatigue strength of the major variables of the anodising process that can be determined from the available data.

It should be noted that in some circumstances large reductions in fatigue strength can occur as a consequence of the type of anodising process or from pre- or post-anodising treatments. It is therefore necessary to ensure that the complete process does not degrade the fatigue strength of a component below an acceptable level and also to ensure that the process is controlled adequately so as always to produce a satisfactory and consistent surface.

2. NOTATION

Both SI and British units are quoted.

f_p	proof stress of base material	N/m ²	lbf/in ²
f_t	tensile strength of base material	N/m ²	lbf/in ²
K_t	elastic stress concentration factor based on net area		
m	parameter characterising shape of semi-range/mean stress diagram (see Equation (4.1))		
N	endurance		
R	S_{min}/S_{max}		
S_a	alternating stress based upon net area	N/m ²	lbf/in ²
S_{a0}	value of S_a at zero mean stress	N/m ²	lbf/in ²
S_m	mean stress based upon net area	N/m ²	lbf/in ²
S_{max}	maximum stress based upon net area	N/m ²	lbf/in ²
S_{min}	minimum stress based upon net area	N/m ²	lbf/in ²
S_{1g}	nominal stress in 1g level flight based upon net area	N/m ²	lbf/in ²

Issued November 1987
With Amendment A, November 1994

3. THE ANODISING PROCESS

A thin layer of oxide will immediately form on an aluminium surface newly exposed to air. The oxide layer is relatively hard and inhibits further oxidation. By means of anodising the thickness of the oxide film can be relatively quickly increased to form a more protective layer. In the process the aluminium component is made an anode in a suitable dilute acidic solution. The passage of an electric current results in the generation of atomic oxygen from the solution at the aluminium surface and this reacts with the aluminium to produce the desired oxide layer. The oxide is slightly larger in volume than aluminium and, although hard, is honeycombed with microscopic pores. The depth of the layer of oxide produced depends upon the type of electrolyte (acid) used and its temperature, the voltage and the duration. For any given combination of these the depth of the surface layer grows at an ever decreasing rate and slowly stifles the process. It is usual to maintain a chosen concentration of acid and to vary the voltage and duration to achieve the desired layer thickness.

The commonly used anodising treatments for aluminium and its alloys can be conveniently described under three headings, chromic acid anodising, sulphuric acid anodising and hard anodising. Table 6.1 describes these three processes and indicates their primary advantages and disadvantages. The fatigue strength of sulphuric acid anodised aluminium alloys is usually below that of the untreated alloy. This is primarily the result of the honeycomb structure of the oxide and the small tensile stress that its increased bulk generates in the parent material at its interface with the oxide. Post-anodising processes are often employed to seal the honeycomb structure. The most common process is immersion in boiling water which hydrates the oxide, causing it to expand and fill the pores, so improving the structure of the surface layer. Other processes which are more effective in that they improve the fatigue strength are also available (see Section 4).

4. PRESENTATION OF DATA

An index to all the data provided is given in Table 6.2. The data are ordered according to alloy type and anodising process. For each set of data a table is provided giving the available details of the alloy, the anodising process and the fatigue tests conducted. Each table is identified by a number and is followed by one or two figures which give the fatigue test results.

From an analysis of Tables 6.3 to 6.17 and Figures 1 to 15 some major trends have been identified and these are described in Sections 4.1 and 4.2. Section 4.3 draws attention to other factors that affect fatigue strength that are shown by the tables and figures. Section 4.4 deals with the variable amplitude data of Tables 6.18 to 6.20 and Figures 16 to 18.

4.1 Sulphuric Acid Anodising and Hard Anodising

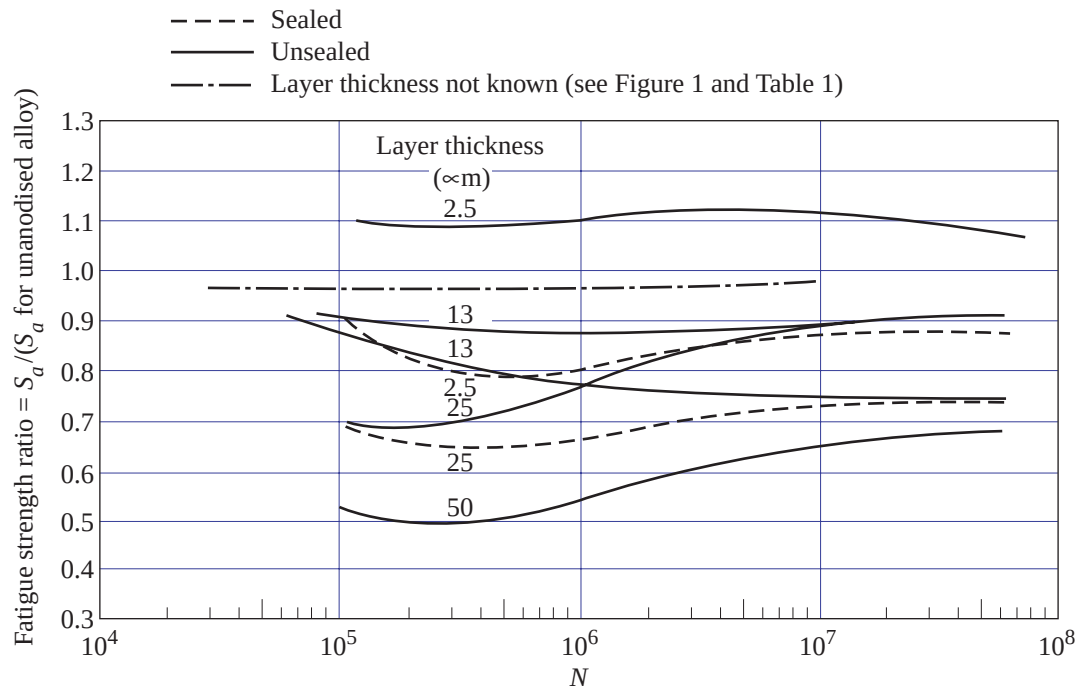
Constant amplitude fatigue data for various alloys that have been sulphuric acid anodised or hard anodised are given in Tables 6.3 to 6.13 and Figures 1 to 11.

4.1.1 7075-T6 Alloy

Sketch 4.1 shows that for this alloy the fatigue strength is strongly influenced by the thickness of the oxide layer. Data are available for layers that are 2.5, 13, 25 and 50 μm thick (0.1×10^{-3} , 0.5×10^{-3} , 1.0×10^{-3} and 2×10^{-3} in) tested at $R = -1.0$ and $K_t = 1.0$. Sketch 4.1 shows a small improvement in fatigue strength ratio (about 10 per cent) for 2.5 μm thick layers and a reduction to a fatigue strength ratio of about 0.5 for 50 μm thick layers. Note that two sets of data are available for 13 μm thick layers (from Table 6.5 and Figure 3) and that one set gives a curve that extends below the 25 μm thick layer at the high endurance end.

Sketch 4.1 also shows that sealing this alloy using boiling water or dichromate can considerably reduce the

fatigue strength ratio, particularly when the layer is thin; compare the sealed and unsealed curves for the 2.5 μm thick layers. The effect of sealing can be beneficial. Several substances, other than water and dichromates, have been examined and those with polar organic long chain molecules have been found to be beneficial, see Table 6.3. Sealing using palmitic acid is particularly beneficial and Sketch 4.2 compares the effect of sealing in palmitic acid with sealing in water. The large improvements in fatigue endurance shown on Sketch 4.2 are attributed by Derivation 4 to “the reaction between the metal and the organic molecules forming metal soap which inhibits the formation of an oxide film on the surface of the advancing fatigue crack”.



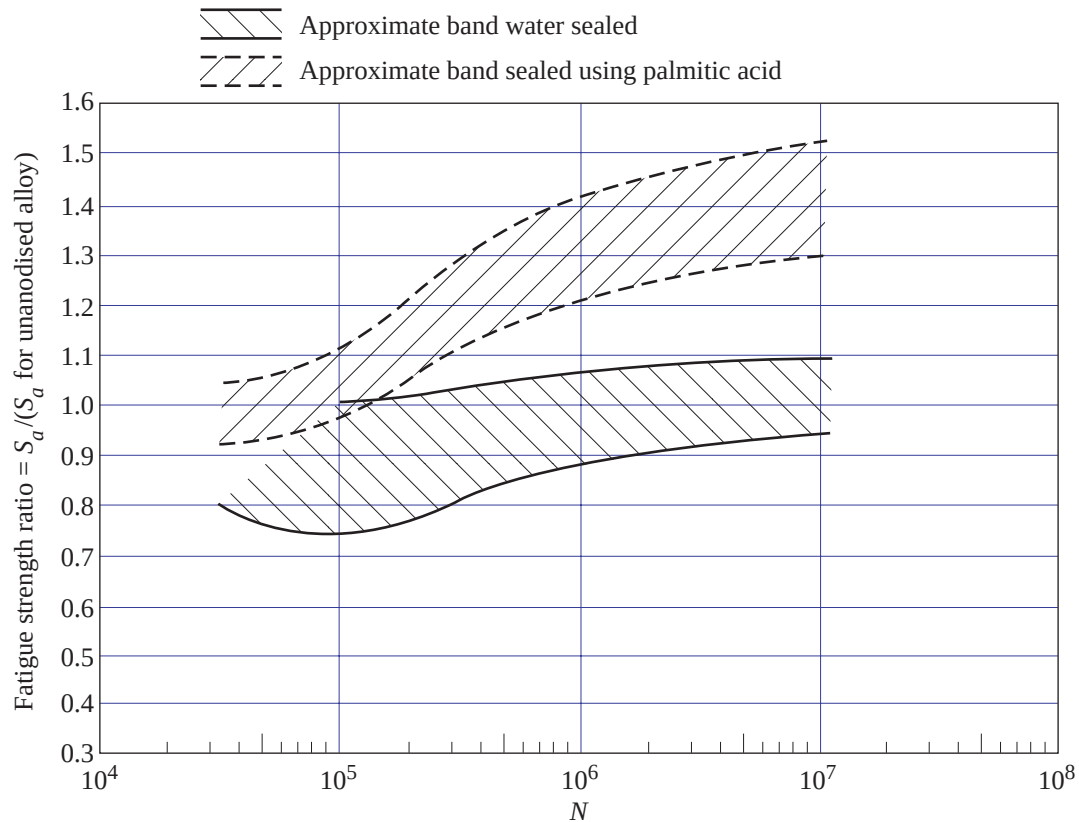
Sketch 4.1 7075-T6 sulphuric acid anodised, $R = -1.0$, $K_t = 1.0$

Sketch 4.2 is derived from Table 6.7 and Figure 5 which relate to $K_t = 1.0$ and loading with $R = 0$. A curve for unanodised 7075-T6 tested at $R = 0$ is not available on Figure 5. A curve for this condition has been derived from Curve 1A of Figure 1, which is for this alloy loaded with $R = -1.0$, using the following equation to correct for mean stress.

$$(S_a / S_{a0}) = 1 - (S_m / f_t)^m \quad (4.1)$$

In accordance with Data Item No. E.07.03* the index m has been assumed to be in the range 1.0 to 1.4. Also, f_t for 7075-T6 sheet has been taken to be between 475 and 525 MN/m^2 (68 900 and 76 100 lbf/in^2). For $R = 0$ the stresses $|S_a| = S_m$ and endurance taken from Figure 1 associated with S_{a0} , resulting from solution of Equation (4.1), were accorded to S_a at $R = 0$. By this means limiting bands for 7075-T6 with $R = 0$ were drawn up. From these approximate bands the curves of Sketch 4.2 were derived. The lower band for specimens sealed using boiling water is consistent with the data of Sketch 4.1.

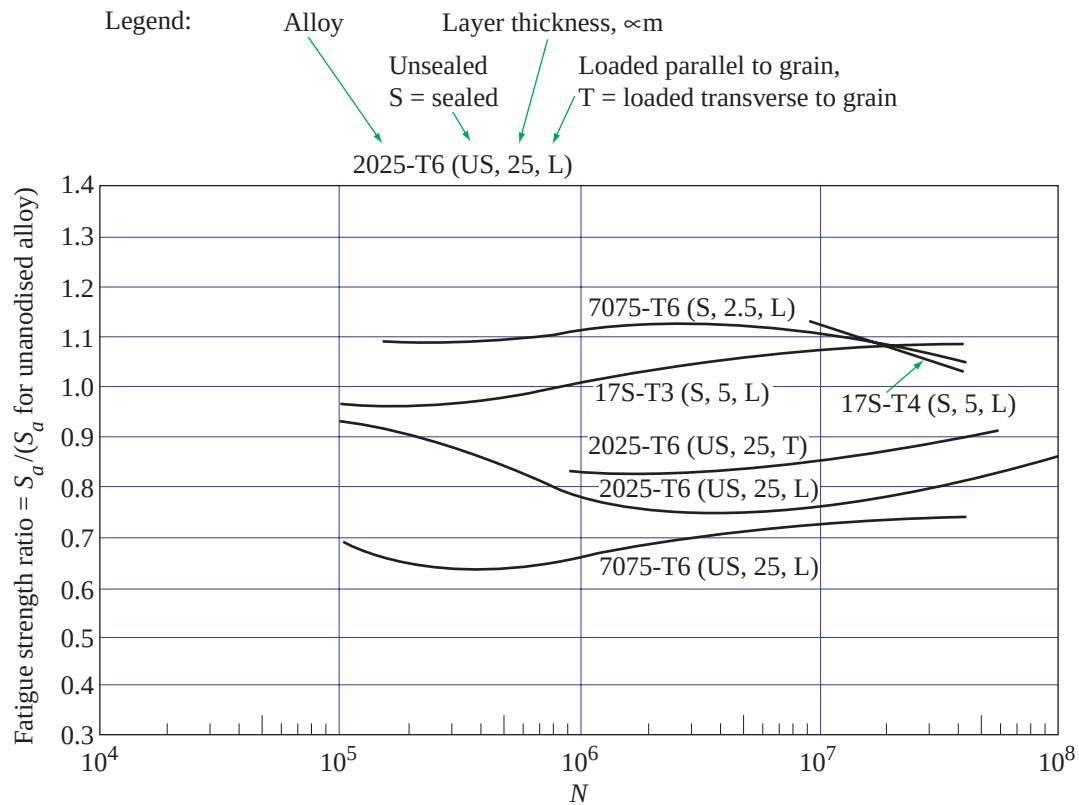
* Data Item No. E.07.03 “The effect of mean stress on the endurance of aluminium alloys”.



Sketch 4.2 7075-T6 sulphuric acid anodised, $R = 0$, $K_t = 1.0$ or 2.37

4.1.2 Various alloys tested at $R = -1.0$, $K_t = 1.0$

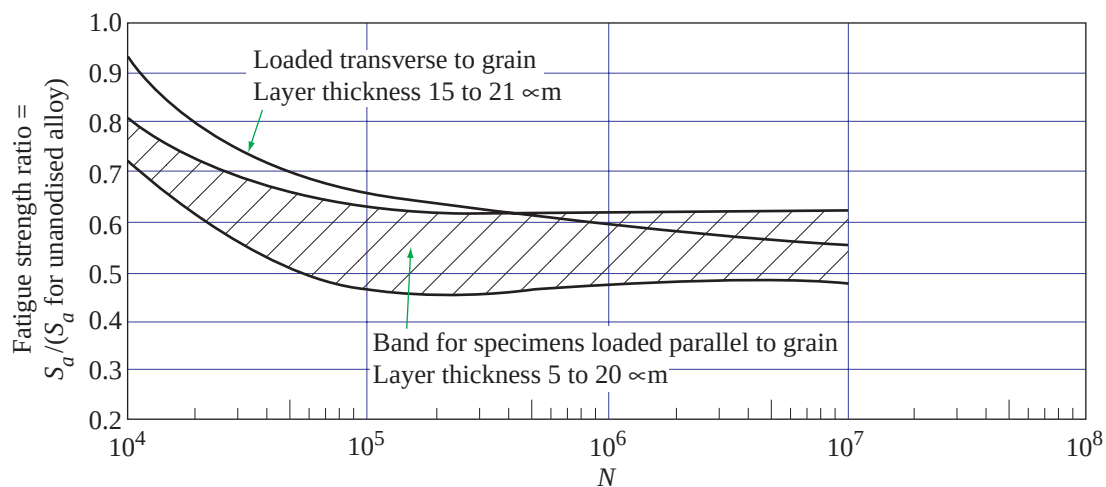
Sketch 4.3 compares the variations of fatigue strength ratio with N for 7075-T6, 2025-T6, 17S-T3 and 17S-T4. The sketch shows that the reduction in fatigue strength ratio with increasing oxide layer thickness shown in Sketch 4.1 also occurs in other alloys.



Sketch 4.3 Comparison of alloys anodised in sulphuric acid, $R = -1.0$, $K_t = 1.0$

4.1.3 Notched AZ74 alloy tested at $R = 0$, $K_t = 1.5$

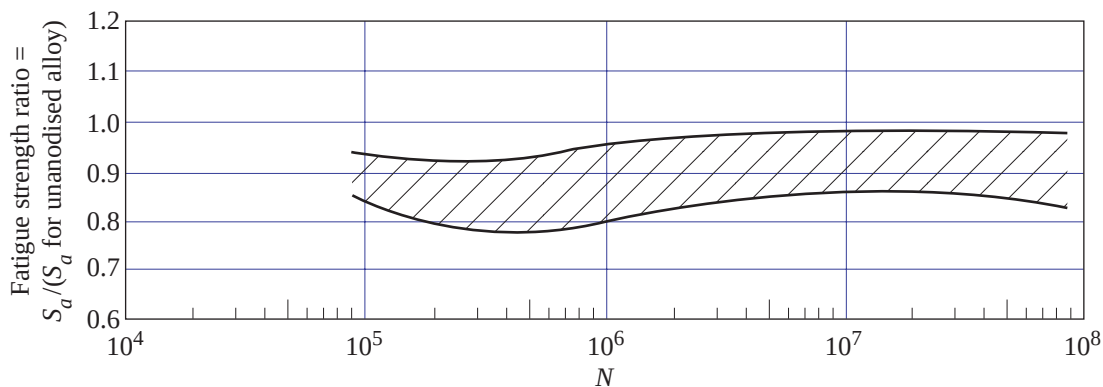
Sketch 4.4 shows fatigue strength ratios in the region of 0.4 to 0.8. These low strength ratios are probably a consequence of the fact that the specimens were notched and were tested at $R = 0$. The sketch shows that over most of the endurance range, the results for specimens loaded transverse to the grain direction of the material are within the band for specimens loaded parallel to the grain direction.



Sketch 4.4 AZ 74 sulphuric acid anodised and sealed, $R = 0$, $K_t = 1.5$

4.1.4 Clad sheet tested at $R = -1.0$, $K_t = 1.0$ (7075-T6, 2024-T3, 7178-T6)

Sketch 4.5 shows fatigue strength ratios lying between 0.8 and 1.0 which encompass all the data for these alloys, all of which were sealed in boiling water after anodising. The relatively narrow band width derives from the fact that the alloys were all clad with commercially pure aluminium which provided the surfaces that were anodised. The initiation and initial stages of crack growth were therefore similar irrespective of the base alloy composition.



Sketch 4.5 Clad sheet, 7075-T6, 2024-T3, 7178-T6 sulphuric acid anodised and sealed, $R = -1.0$, $K_t = 1.0$

4.2 Chromic Acid Anodising

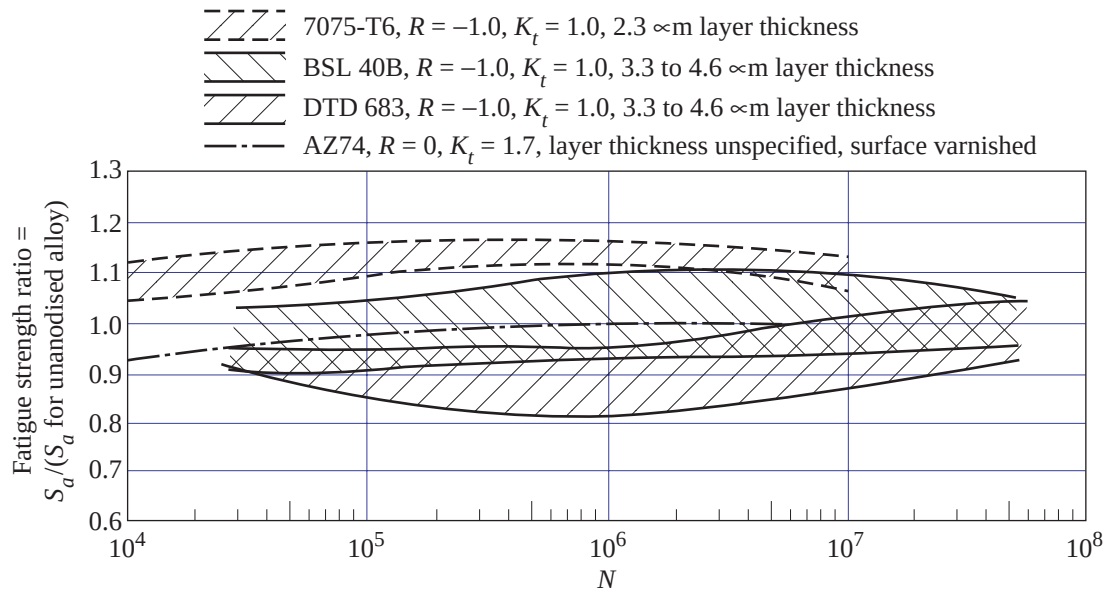
Sketch 4.6 shows fatigue strength ratios for 7075-T6, BS 2L40B, DTD 683 and AZ74. The fatigue strength ratios all lay between 0.8 and 1.2. With the exception of the AZ74 alloy, all the curves relate to specimens with $K_t = 1.0$ and $R = -1.0$ having similar thickness oxide layers. The AZ74 data are for $K_t = 1.7$ and $R = 0$ and show fatigue strength ratios in the region of 0.95 to 1.0. This may be compared with the fatigue strength ratios for sulphuric acid anodised AZ74, shown on Sketch 4.4, which average about 0.55.

4.3 Notes on Tables 1 to 15 and Figures 1 to 15

Table 6.3, and Figure 1, show that sealing using the various inert substances listed in Table 6.3 does not significantly affect the fatigue strength but that sealing using the polar organic molecule substances significantly improves the fatigue strength.

Tables 6.6, 6.8 and 6.10 and Figures 4, 6 and 8 are a set of identical tests on three different aluminium alloy sheets all of which were clad with commercially pure aluminium.

The tests on 7075-T6 (Table 6.5), 2025-T6 (Table 6.9), 17S-T3 (Table 6.11) and 17S-T4 (Table 6.12) were conducted at 3500 or 10 000 cycles per minute. The latter, high, loading rate was used to obtain the higher endurance, up to $N = 10^8$ cycles.



Sketch 4.6 Chromic acid anodising of four alloys (unsealed)

Tables 6.14 and 6.15 and Figures 12 and 13 show BS 2L40B and DTD 683 subjected to a similar range of treatments. Figure 12a shows no influence of anodising on the BS 2L40B whereas Figure 13a shows a significant reduction in the fatigue strength of DTD 683. Thus, the influence of anodising is clearly base material dependent to a small degree. Figures 12b and 13b show that pre-treatments also influence the fatigue strength. For both alloys the orthophosphoric acid – hydrofluoric acid pickle and the sulphuric acid – sodium fluoride pickle show the lowest fatigue strengths.

4.4 Variable Amplitude Loading

4.4.1 2024-T3 and 7475-T761 (clad and bare) notched sheet and joints, chromic acid anodised and subjected to miniTWIST gust spectrum

Tables 6.18 and 6.19 and Figures 16 and 17 present data for two types of notched specimens, $K_t = 1.5$ and 2.34, and for a riveted lap joint subject to S_{1g} values which yield endurance in the region of 10^5 flights. The anodised specimens were all sealed using bonding primer subjected to a temperature–pressure cycle.

The figures show that for both the clad and bare 2024-T3 and 7475-T761 notched specimens there is only a relatively small reduction in the number of flights associated with anodising. In all but one case the scatter of the anodised specimens is within that of the untreated specimens. For both alloys, whether clad or bare, the anodised lap joint specimens showed an improvement in numbers of flights over the untreated lap joints by a factor of between 1.5 and 2.0. This was attributed to the improved resistance of the anodised surfaces to fretting. (Note that improvements based on numbers of flights should not be compared with the constant amplitude strength reduction factors of Sketches 4.1 to 4.6.)

4.4.2 AZ74 notched bar, chromic acid anodised and subjected to a military aircraft loading spectrum

Table 6.20 and Figure 18 present data plotted on the basis of a reference one ‘g’ level flight stress, S_{1g} , versus number of flights to failure. The notched specimens, $K_t = 1.7$, were subjected to a variety of peening processes (identical to those of Table 6.16 and Figure 14) and were then anodised and varnished. Reference curves and data are provided for unanodised and vacuum blasted specimens only.

The scatter shown on Figure 18 for each set of tests is considerably greater than that of the similar constant amplitude tests shown on Figure 14. The scatter and numbers of results is such that few firm conclusions can be drawn. Peening with glass beads appears to give the longest life (as on Figure 14); however, there are no data for unanodised AZ74 peened by glass beads to compare this with. It is only possible to note that, for this particular variable amplitude spectrum and specimen type, the behaviour is similar to that found for constant amplitude loading.

5. DERIVATION AND REFERENCES

5.1 Derivation

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

1. STICKLEY, G.W.
HOWELL, F.M. Effects of anodic coatings on the fatigue strength of aluminum alloys. *Proceedings of American Society for Testing and Materials*, 50, pp. 735-742, 1950.
2. FINNEY, J.M. The effect of pickling and anodizing on the fatigue properties of 2L40 and D.T.D. 683 aluminium alloys. *Metallurgica*, pp. 93-101, September 1959.
3. STICKLEY, G.W. Additional studies of effects of anodic coatings on the fatigue strength of aluminum alloys. *Proc. American Society for Testing and Materials*, 60, pp. 577-588, 1960.
4. KRAMER, I.R. Improvement of metal fatigue life by a chemical surface treatment. In: *Fatigue an interdisciplinary approach*. Edited by Burke *et al.*, Syracuse University Press, NY, pp. 245-257, 1964.
5. LARSSON, N.
JARFALL, L. Fatigue tests with turned, notched specimens of forged aluminum 3633-4 of various surface treatments. Technical Note FFA HU-1729, October 1977.
6. LARSSON, N. The influence on the fatigue properties of aluminum AZ74 from process variants in sulphuric acid anodizing. Technical Note FFA HU-1943, January 1979.
7. WANHILL, R.J.H. Effects of cladding and anodising on flight simulation fatigue of 2024-T3 and 7475-T761 aluminum alloys. International Conference on fatigue prediction and design, Amsterdam, April 1986.

5.2 References

The references given are recommended sources of information supplementary to that in this Item.

8. MoA Anodic oxidation of aluminium and aluminium alloys. Ministry of Aviation, process specification, No. DTD 910C, September 1951.
9. HARRIS, W.J. Metallic fatigue. pp. 60-64, Pergamon Press, London, 1961.
10. WERNICK, S.
PINNER, R. The surface treatment and finishing of aluminium and its alloys. Published by Robert Draper, Teddington, UK, 1972.

11. BSI Hard anodic oxide coatings on aluminium for engineering purposes. British Standards Institution BS 5599:1978.
12. AMS Anodic treatment – aluminum alloys, chromic acid process. Aerospace materials specification, AMS 2470H, January 1984.
13. AMS Anodic treatment – aluminum alloys, sulphuric acid process, undyed coating. Aerospace materials specification, AMS 2471D, January 1984.
14. AMS Anodic treatment – aluminum alloys, sulphuric acid process, dyed coating. Aerospace materials specification, AMS 2472C, January 1984.
15. MoD Hard anodizing of aluminium and aluminium alloys. UK MoD, Defence Standard 03–26 Issue 1, September, 1984.
16. MoD Sulphuric acid anodizing of aluminium and aluminium alloys. UK MoD, Defence Standard 03–25, Issue 1, September, 1984.
17. MoD Chromic acid anodizing of aluminium and aluminium alloys. UK MoD, Defence Standard 03–24 Issue 1, September 1984.

6. TABLES AND FIGURES

TABLE 6.1 TYPICAL ANODISING PROCESSES AND DESCRIPTION OF THE RESULTING SURFACES[†]

Chromic Acid Anodising	
The process	(i) Degrease (usually an alkaline cleaner). (ii) Wash in cold water. (iii) Anodise in dilute CrO_3 (usually between 30 and 50 g/l of CrO_3) at about 40°C (105°F) using 40 to 50 V for 20 to 40 min. (iv) Wash in water.
Properties	Thin layer of oxide produced, 3 to 5 μm (0.12×10^{-3} to 0.2×10^{-3} in) thick, offering corrosion resistance but little resistance to wear.
Sulphuric Acid Anodising	
The process	(i) Degrease (usually an alkaline cleaner). (ii) Wash in cold water. (iii) Anodise in dilute H_2SO_4 (usually between 165 and 230 g/l of H_2SO_4 of specific density of 1.84) at about 20°C (68°F) using 14 to 17 V for 30 to 50 min. (iv) Wash in water. (v) Seal in demineralised water at 90°C to 96°C (195 to 205°F) for between 10 and 30 min.
Properties	Layer of oxide produced in the region 10 to 25 μm (0.4×10^{-3} to 1.0×10^{-3} in) thick. Surface offers good corrosion resistance but is more brittle than chromic acid anodised surfaces. Wear resistance is improved over chromic acid anodising but the layer is too thin for use where wear is a major problem.
Hard Anodising	
The Process	(i) Degrease (usually an alkaline cleaner). (ii) Wash in cold water. (iii) Acid pickle in H_2SO_4 or CrO_3 or HNO_3 . (iv) Wash in cold water. (v) Anodise in dilute sulphuric acid (H_2SO_4) and oxalic acid ($\text{HOOC-COOH} \cdot 2\text{H}_2\text{O}$) constitution between 10 and 18 per cent by volume at -5 to +5°C (2 to 41°F) using 40 to 260 A/m ² raising the voltage as necessary until the required thickness of oxide is obtained (usually longer than 10 min). (vi) Wash in cold water. (vii) Seal in potassium dichromate at about 96°C (205°F). (viii) Wash in hot water.
Properties	Oxide layers in the thickness range 25 to 150 μm (1.0×10^{-3} to 6.0×10^{-3} in) obtained with excellent corrosion and wear resistance properties.

[†] For further information on wear resistant surfaces the following Data Item in the ESDU Tribology Sub-series should be consulted. Data Item No. 86040 "Selection of surface treatments and coatings for combating wear of load-bearing surfaces".

TABLE 6.2 INDEX TO TABLES AND FIGURES

Alloy	Temper and form	Anodising electrolyte	Fatigue test details			Table and Fig. Nos	Section Numbers	Relevant material specifications								
			Loading [†]	R	K _t [‡]			BS	DTD	AMS	UNS	AECMA	QQ	Other		
ALUMINIUM ZINC ALLOYS																
7178 6.8Zn –2.0Cu –2.7Mg –0.3Cr	T6 Clad sheet	H ₂ SO ₄	CA	–1.0	1.0	8	4.1.4	–	–	4051	A 97178	–	–	–		
6.0Zn –2.5Mg –0.9Cu –0.3Ag	Forged bar	CrO ₃	CA	0	1.7	14	4.2	–	–	–	–	–	–	AZ74 ^{††}		
			Military spectrum	–	1.7	18	4.4.2	–	–	–	–	–	AZ74 ^{††}			
	Die forged	H ₂ SO ₄	CA	0	1.5	11	4.1.3	–	–	–	–	–	–	AZ74 ^{††}		
5.7Zn –2.6Mg –0.9Cu –0.3Mn	T6 Bar extruded	CrO ₃	CA	–1.0	1.0	13	4.2 4.3	–	683 ^{‡‡}	–	–	–	–	–		
7475 5.7Zn –2.2Mg –1.6Cu –0.22Cr	T761 Clad sheet	CrO ₃	MiniTWIST	–	1.5 2.34	17	4.4.1	–	–	4100	A 97475	–	–	–		
7075 5.6Zn –2.5Mg –1.6Cu –0.23Cr	T6 sheet	H ₂ SO ₄	CA	–1.0	1.0	1	4.1.1 4.1.2	–	–	4045	A 97075	–	A250 /12	–		
	T6 Rolled and drawn					2, 3	4.1.4	–	–	4122		–	A225 /9	–		
	T6 Extrusion					3		–	5124	4154		–	–	–		
	T6 Clad sheet					4		L88	–	4049 4197		prEN 2092	A250 /13	–		
	T6 Plate						0	1.0 2.37	5			L95	–	4045	–	A250 /12
	T6 Extrusion	CrO ₃					–1.0	1.0	15	4.2		–	5124	4154		–
ALUMINIUM COPPER ALLOYS																
2024 4.5Cu –1.5Mg –0.6Mn	T3 Clad sheet	H ₂ SO ₄	CA	–1.0	1.0	6	4.1.4	L109	–	4041	A 97024	prEN 2090	A250 /5	–		
		CrO ₃	MiniTWIST	–	1.5 2.34 RJ	16	4.4.1									
2025 4.5Cu –0.8Si –0.8Mn	T6 Forged slab	H ₂ SO ₄	CA	–1.0	1.0	7	4.1.2	–	–	4130	A 92025	–	–	–		
17S 4.0Cu –0.5Mn –0.5Mg	T3 Sheet	H ₂ SO ₄	CA	–1.0	1.0	9	4.1.2	–	–	–	–	–	–	–		
	T4 Rolled and drawn slab					10	4.3	–	150A	–	–	–	–	–		
2.8Cu –0.9Mg –0.9Fe	T6 Bar extruded	CrO ₃	CA	–1.0	1.0	12	4.2 4.3	2L40B (L168)	–	–	–	–	–	–		

[†] CA = Constant amplitude.

[‡] RJ = Riveted joint.

^{††} AZ74 is a Swedish specification.

^{‡‡} Superseded in part by DTD 5024.

ALLOY TYPE	7075-T6
ANODISING PROCESS	Sulphuric acid
FATIGUE LOADING	Reversed bending

FIGURE No.	1
TABLE No.	6.3

TABLE 6.3

BASE MATERIAL		
Nominal composition		5.6Zn–2.5Mg–1.6Cu–0.23Cr
Form		Sheet.
Specification		Not given. Relevant current specifications are: AMS 4045, UNS A97075, QQ-A-250/12 Temp. T6.
Heat treatment		T6 – Solution treated and artificially aged.
f_t		–
f_p		–
ANODISING PROCESS		Degreased and cleaned in hot soap solution, 10 min. Placed in proprietary deoxidiser bath, 5 min. Sulphuric acid anodised, H ₂ SO ₄ , (15 per cent acid) at 22 to 24°C (71° to 75°F) using 160 A/m ² for 40 min. Sealed at 130°C (266°F) as detailed in test results below.
FATIGUE TEST DETAILS		
Specimen type		Test section 50.8 mm by 4.06 mm (2.0 in by 0.16 in). Specimens polished using 600 mesh abrasive paper.
K_t		1.0
Loading		Reversed bending $R = -1.0$.
Special features		None.
FATIGUE TEST RESULTS		
Symbol	Curve	
× △ }	1A Endurances are plotted on Figure 1	UNANODISED SPECIMENS See Figure 1. Treated as follows. Tested at $S_a = 172 \text{ MN/m}^2$ (24 950 lbf/in²) Etched in dilute hydrofluoric acid (5 per cent), $N = 0.34 \times 10^6$ Etched in dilute hydrofluoric acid (5 per cent) and coated with palmitic acid C₁₆H₃₂O₂ (130°C for 20 mins), $N = 0.36 \times 10^6$ Etched in dilute sodium hydroxide NaOH (20 per cent), $N = 0.31 \times 10^6$ Etched in dilute NaOH coated with C₁₆H₃₂O₂ , $N = 0.20 \times 10^6$ Chemical bright dip, $N = 0.22 \times 10^6$ Chemical bright dip plus C₁₆H₃₂O₂ coating, $N = 0.26 \times 10^6$
○ * ▲ ▼ }	1B Endurances are plotted on Figure 1	ANODISED AND SEALED USING INERT SUBSTANCES Water sealed (temperature and duration unspecified) Sealed with following, tested at $S_a = 172 \text{ MN/m}^2$ (24 950 lbf/in²) Water (temperature and duration unspecified) $N = 0.14 \times 10^6$ Sodium stearate $N = 0.16 \times 10^6$ Sealed with following, tested at $S_a = 179 \text{ MN/m}^2$ (25 950 lbf/in²) Water (temperature and duration unspecified) $N = 0.12 \times 10^6$ Zinc stearate $N = 0.16 \times 10^6$ Acetyl acetone $N = 0.24 \times 10^6$ Paraffin wax $N = 0.22 \times 10^6$ Paraffin oil $N = 0.67 \times 10^6$

TABLE 6.3 (Continued)

FATIGUE TEST RESULTS																																															
Symbol	Curve																																														
● { ▲ 1C Endurances are plotted on Figure 1[†]		ANODISED AND SEALED USING POLAR ORGANIC MOLECULE SUBSTANCES Sealed using palmitic acid (C₁₆H₃₂O₂) for 20 min. Sealed with following, tested at $S_a = 179 \text{ MN/m}^2$ (24 950 lbf/in²) <table> <tr> <td>Propionic acid,</td><td>C₃H₆O₂</td><td>$N = 2.8 \times 10^6$</td></tr> <tr> <td>Hexandeamine,</td><td></td><td>$N = 3.0 \times 10^6$</td></tr> <tr> <td>Docosanoic acid,</td><td>C₂₂H₄₄O₂ (= Behenic acid)</td><td>$N = 6.0 \times 10^6$</td></tr> <tr> <td>Octyl alcohol,</td><td>C₈H₁₈O</td><td>$N = 6.0 \times 10^6$</td></tr> <tr> <td>Dodecyl alcohol,</td><td>C₁₂H₂₆O</td><td>$N = 7.0 \times 10^6$</td></tr> <tr> <td>Decanoic acid,</td><td>C₁₀H₂₀O₂</td><td>$N = 7.5 \times 10^6$</td></tr> <tr> <td>Lauric acid,</td><td>C₁₂H₂₄O₂</td><td>$N = 8.6 \times 10^6$</td></tr> <tr> <td>Stearic acid,</td><td>C₁₈H₃₆O₂</td><td>$N = 8.7 \times 10^6$</td></tr> <tr> <td>Caproic acid,</td><td>C₆H₁₂O₂ (= Hexanoic acid)</td><td>$N = 9.2 \times 10^6$</td></tr> <tr> <td>Myristic acid,</td><td>C₁₄H₂₈O₂</td><td>$N = 11.6 \times 10^6$</td></tr> <tr> <td>Octanoic acid,</td><td>C₈H₁₆O₂</td><td>$N = 12.3 \times 10^6$</td></tr> <tr> <td>Sebacic acid,</td><td>C₁₀H₁₈O₄</td><td>$N = 13.7 \times 10^6$</td></tr> <tr> <td>Valeric acid,</td><td>C₅H₁₀O₂</td><td>$N = 15.0 \times 10^6$</td></tr> <tr> <td>Dodecylamine,</td><td>C₁₂H₂₇N</td><td>$N = 18.5 \times 10^6$</td></tr> <tr> <td>Palmitic acid,</td><td>C₁₆H₃₂O₂</td><td>$N = 30.0 \times 10^6$</td></tr> </table>	Propionic acid,	C ₃ H ₆ O ₂	$N = 2.8 \times 10^6$	Hexandeamine,		$N = 3.0 \times 10^6$	Docosanoic acid,	C ₂₂ H ₄₄ O ₂ (= Behenic acid)	$N = 6.0 \times 10^6$	Octyl alcohol,	C ₈ H ₁₈ O	$N = 6.0 \times 10^6$	Dodecyl alcohol,	C ₁₂ H ₂₆ O	$N = 7.0 \times 10^6$	Decanoic acid,	C ₁₀ H ₂₀ O ₂	$N = 7.5 \times 10^6$	Lauric acid,	C ₁₂ H ₂₄ O ₂	$N = 8.6 \times 10^6$	Stearic acid,	C ₁₈ H ₃₆ O ₂	$N = 8.7 \times 10^6$	Caproic acid,	C ₆ H ₁₂ O ₂ (= Hexanoic acid)	$N = 9.2 \times 10^6$	Myristic acid,	C ₁₄ H ₂₈ O ₂	$N = 11.6 \times 10^6$	Octanoic acid,	C ₈ H ₁₆ O ₂	$N = 12.3 \times 10^6$	Sebacic acid,	C ₁₀ H ₁₈ O ₄	$N = 13.7 \times 10^6$	Valeric acid,	C ₅ H ₁₀ O ₂	$N = 15.0 \times 10^6$	Dodecylamine,	C ₁₂ H ₂₇ N	$N = 18.5 \times 10^6$	Palmitic acid,	C ₁₆ H ₃₂ O ₂	$N = 30.0 \times 10^6$
Propionic acid,	C ₃ H ₆ O ₂	$N = 2.8 \times 10^6$																																													
Hexandeamine,		$N = 3.0 \times 10^6$																																													
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DERIVATION NUMBER		4																																													

[†] Each is average of at least 4 tests.

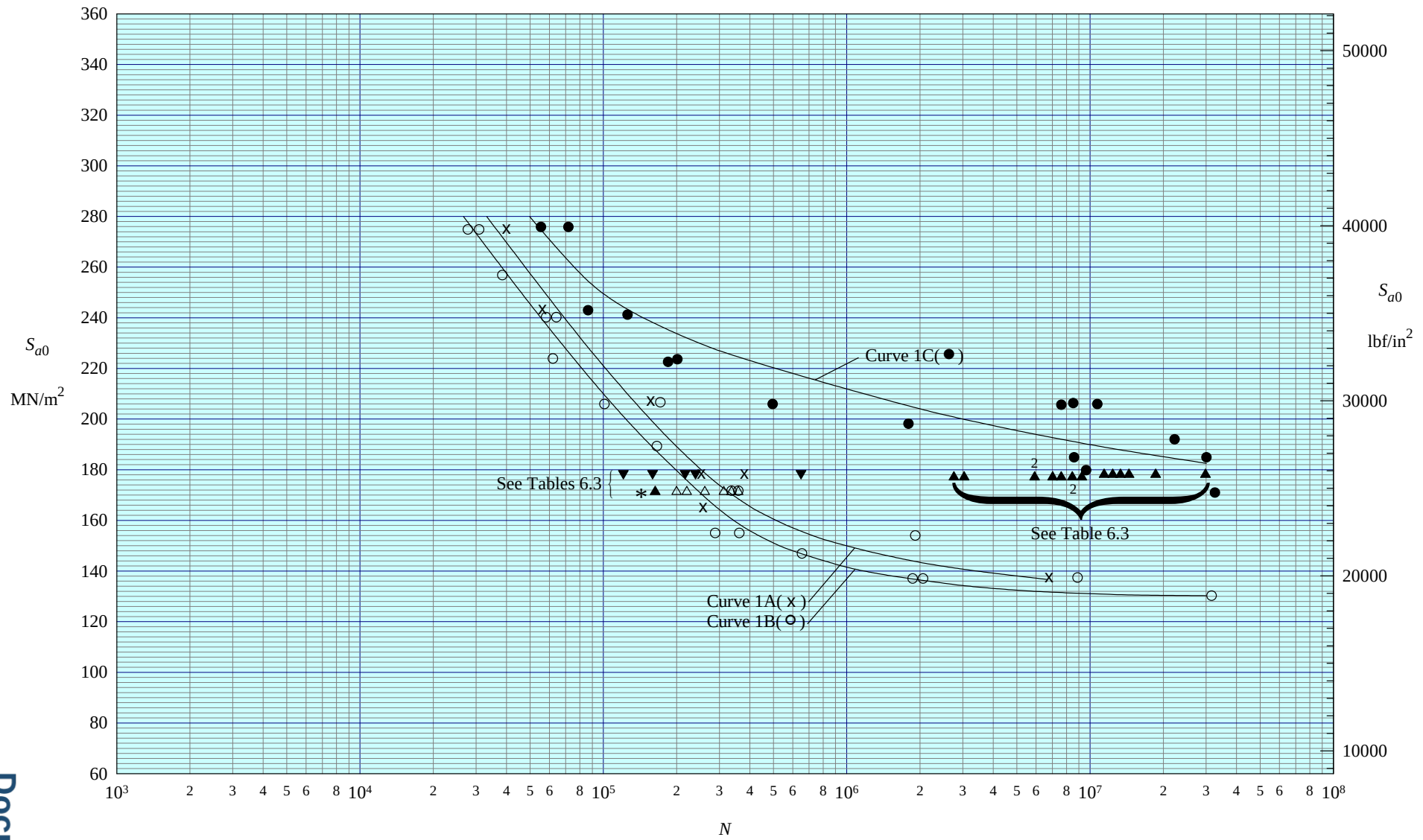


FIGURE 1 7075-T6 SHEET SUBJECT TO REVERSE BENDING. EFFECT OF VARIOUS SULPHURIC ACID ANODISING PROCESSES

ALLOY TYPE	7075-T6
ANODISING PROCESS	Sulphuric acid
FATIGUE LOADING	Rotating bending

FIGURE Nos	2a and 2b
TABLE No.	6.4

TABLE 6.4

BASE MATERIAL			
Nominal composition		5.6Zn–2.5Mg–1.6Cu–0.23Cr	
Form		Rolled and drawn or extruded rod 19.05 mm (0.75 in) diameter.	
Specification		Not given. Relevant current specifications are: AMS 4122, UNS A97075, QQ–A–225/9 Temp. T6.	
Heat treatment		T6 – Solution treated and artificially aged.	
		Rolled, longitudinal	Extruded, longitudinal
f_t		596 MN/m ² (86 400 lbf/in ²)	615 MN/m ² (89 200 lbf/in ²)
f_p		515 MN/m ² (74 700 lbf/in ²)	557 MN/m ² (80 800 lbf/in ²)
ANODISING PROCESS		Sulphuric acid anodised, H ₂ SO ₄ , 15 per cent acid at 21°C (70°F) using 129 A/m ² for the following durations.	
		Duration (min)	Resulting thickness of layer
		6	2.5 µm (0.1 × 10 ^{–3} in)
		30	12.0 µm (0.5 × 10 ^{–3} in)
		66	25.0 µm (1.0 × 10 ^{–3} in)
FATIGUE TEST DETAILS			
Specimen type		Test section 7.62 mm (0.3 in) dia, smooth polished.	
K_t		1.0	
Loading		Rotating bending, $R = -1.0$.	
Special features		None.	
FATIGUE TEST RESULTS			
Symbol	Curve		
Figure 2a			
×	2aA	Unanodised specimens.	
○	2aB	Anodised to give 2.5 µm (0.1 × 10 ^{–3} in) thick layer.	
◁	–	Etched in 5 per cent NaOH for 30 s at 65°C (150°F) then anodised as for symbol ○ above.	
◄	–	Brightening dip for 90 s at 88°C (190°F) then anodised as for symbol ○ above.	
●	2aC	Anodised to give 25.4 µm (1.0 × 10 ^{–3} in) thick layer.	
□	2aD	Anodised to give 50.8 µm (2.0 × 10 ^{–3} in) thick layer.	
◇	–	Etched in 5 per cent NaOH for 30 s at 65°C (150°F) then anodised as for symbol □ above.	
◆	–	Brightening dip for 90 s at 88°C (190°F) then anodised as for symbol □ above.	
Figure 2b			
○	2bA	Specimens anodised to give 2.5 µm (0.1 × 10 ^{–3} in) thick layer then sealed in boiling water.	
●	} 2bB	Specimens anodised to give 25.4 µm (1.0 × 10 ^{–3} in) thick layer then sealed in boiling water.	
►		As for ● above but sealed in dichromate.	
DERIVATION NUMBER		3	