

FATIGUE CRACK PROPAGATION RATES AND THRESHOLD STRESS INTENSITY FACTOR RANGES FOR ALUMINIUM ALLOY PLATE, EXTRUDED BAR AND FORGINGS

1. NOTATION

a	crack length or crack half-length as defined in Sketch 7.1	m	in
C	coefficient for linear interpolation of crack growth rate curve defined by $da/dN = C(\Delta K)^n$	$m\left(\frac{m}{N}\right)^n$	$in\left(\frac{in}{lbf}\right)^n$
f_p	0.2 per cent proof stress of material	N/m ²	lbf/in ²
f_t	tensile strength of material	N/m ²	lbf/in ²
K	stress intensity factor defined by $S(\pi a)^{1/2}\alpha$	N/m ^{3/2}	lbf/in ^{3/2}
K_{Ic}	plane strain critical stress intensity factor obtained from test pieces that conformed to BSI or ASTM recommended standards (see Section 2.4)	N/m ^{3/2}	lbf/in ^{3/2}
K_Q	critical stress intensity factor obtained from test pieces that did not conform to BSI or ASTM recommended standards (see Section 2.4)	N/m ^{3/2}	lbf/in ^{3/2}
ΔK	stress intensity factor range	N/m ^{3/2}	lbf/in ^{3/2}
ΔK_{TH}	threshold value of ΔK below which fatigue cracks do not exhibit significant growth, typically $< 10^{-11}$ m/cycle	N/m ^{3/2}	lbf/in ^{3/2}
N	number of load cycles		
n	characteristic of slope of crack growth rate curve		
R	S_{min}/S_{max}		
r_p	radius of plastic zone	m	in
S	stress based upon gross cross-sectional area of component	N/m ²	lbf/in ²
α	geometrical factor in stress intensity factor		

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1.1 Additional Notation for Test Pieces (Sketch 7.1)

B	thickness of test piece	m	in
b	half-width of test pieces type 1 and 2	m	in
H	half-depth of test pieces type 3 and 4	m	in
L	length of test pieces type 1 and 2	m	in
P	applied direct load for test pieces type 3 and 4	N	lbf
W	distance from applied load P to back face of test pieces type 3 and 4	m	in

The crack orientation of the test pieces relative to the grain flow is indicated by the two-letter code system described in Appendix A.

Suffixes

max, min indicate the maximum and minimum values respectively of stress or stress intensity factor in loading cycle.

1.2 Conversion Factors

Both SI and British units are shown in the notation. The data are presented in terms of SI units and the following conversion factor for British units applies.

$$1 \text{ MN/m}^{3/2} = 1 \text{ MPa m}^{1/2} = 910.047 \text{ lbf/in}^{3/2}.$$

Note also that

$$1 \text{ MN/m}^{3/2} = 31.623 \text{ N/mm}^{3/2}.$$

2. NOTES

2.1 General

This Data Item presents fatigue crack propagation rate data (da/dN in the range 5×10^{-12} to 10^{-3} m/cycle) and threshold stress intensity factor ranges, ΔK_{TH} , for aluminium alloy plate, extruded bar and forgings. The chemical composition, mechanical properties and heat treatment of the materials are given in Table 7.1. The data analysed in the fatigue threshold region have been obtained from tests that provide low crack propagation rates (in the range 10^{-8} to 5×10^{-12} m/cycle). Data giving values of ΔK_{TH} only were not considered.

2.2 Test Conditions and Limitations

The data are derived from constant amplitude fatigue tests conducted in air at room temperature with, in most cases, uncontrolled humidity. The loading frequencies of the fatigue machines were in the range of 0.1 to 200 Hz. Generally measurements of crack length were made using either optical methods or potential

drop techniques.

Tests were conducted on test pieces of the types shown in Sketch 7.1; the thicknesses ranged from 5 mm to 26 mm. The crack orientation of the test pieces relative to the grain flow was not always given but where known it has been stated in Table 7.1, and on the figures, using the identification system described in Appendix A.

In general the thicknesses of the test pieces were such that

$$B > 2.5 (K_{Ic}/f_p)^2, \quad (2.1)$$

which is a condition generally accepted for ensuring conditions of plane strain for all values of $K_{max} \leq K_{Ic}$. The exceptions to this were the L64 extruded bar, the 7075 forging, the 2024-T3, 7010, 7050, 7475 and DTD 5090 plates and also some of the 7050 and 7075-T73511 extruded bars and the 7075-T7351 and DTD 5120 plates. The thicknesses of the 7050-T73511 and 7075-T7351 test pieces were only marginally less than that required to satisfy Equation (2.1).

All the tests were stated to be conducted within the framework of linear elastic fracture mechanics and thus throughout the tests the stresses across the uncracked sections of the test pieces did not exceed the yield strengths of the materials except at the crack tips. The plastic zones were small compared to the crack length (see Section 1 of Data Item No. 80036*).

2.2.1 Applicability of data to short cracks

The data presented in this Data Item have been obtained from fatigue tests on test pieces that contained machined slots or notches. The minimum length of these machined slots or notches was 2.5 mm. In general the test pieces were fatigue loaded so that small starter cracks, of unstated length, grew from the machined slots or notches before the crack propagation tests began. Therefore all the data presented in this Data Item have been obtained from test pieces with cracks $a > 2.5$ mm in length.

For components containing cracks of lengths < 1 mm the assumption that the material acts as a homogeneous continuum in the neighbourhood of the crack tip no longer applies. Also, inaccurate measurements of the lengths of small cracks, because of crack front curvature, lead to wide discrepancies in the estimations of the value of ΔK . Another important parameter to consider when dealing with short cracks is the ratio of the radius of the plastic zone to the crack length, r_p/a . This ratio can be critical if a component is subjected to high stresses such that gross yielding occurs across the net uncracked section and in consequence linear elastic fracture mechanics procedures do not apply.

For components containing short cracks the values of ΔK_{TH} may be much lower than those shown on the figures presented in this Data Item and the fatigue crack propagation rates may be much higher, for a given stress intensity factor range, ΔK . Therefore, if the data are applied to components containing short cracks, unsafe estimates may be obtained for values of ΔK_{TH} and for fatigue crack growth life under given loading conditions (References 39, 43, 44 and 45 show some of these effects). As the crack propagation rate increases, however, the long crack data may overestimate fatigue crack growth rate because components containing short cracks generally have higher values of apparent fracture toughness than components containing long cracks. Another paper that discusses the significance of ΔK_{TH} and short cracks in aircraft structures is Reference 47.

* Data Item No. 80036 "Use of linear elastic fracture mechanics in estimating fatigue crack growth rates and residual strength of components".

2.3 Determination of Fatigue Threshold (ΔK_{TH})

There was no clear and consistent convention used in the Derivations for determining the threshold value of the stress intensity factor range, ΔK_{TH} (that is, the value of ΔK below which fatigue cracks will not exhibit significant growth). In the majority of the Derivations fatigue crack propagation rates of less than 10^{-10} m/cycle were obtained from the tests. For this Data Item, where tests were terminated in the region of $da/dN = 10^{-10}$ m/cycle, the crack growth curves have been extrapolated by eye so that values of ΔK_{TH} may be obtained. The values of ΔK_{TH} are considered to be valid if the crack propagation curves are vertical or very nearly vertical. For most of the materials for which data are presented this condition is taken to be at a da/dN value of 10^{-11} m/cycle.

In most tests the crack was grown, at any one cyclic load level, until the increment of growth was several times larger than the plastic zone size corresponding to K_{max} , before crack measurements were taken. This procedure eliminated the effects of stress history. The plastic zone size in conditions of plane strain may be calculated using a modified form of Equation (3.13) of Data Item No. 80036, so that

$$r_p = \frac{1}{6\pi} \left(\frac{K_{max}}{f_p} \right)^2. \quad (2.2)$$

Not all the Derivations stated clearly how the testing was conducted at low crack propagation rates, but near the threshold condition load reduction (or load shedding) was the most popular method. Generally testing was terminated, and a value of ΔK_{TH} considered to have been obtained, if there was not measurable crack growth after the application of about 10^7 cycles for a given applied load.

2.4 Presentation of Data

Figures 1 to 19 provide crack propagation rate curves, da/dN , plotted against stress intensity factor range, ΔK , for various values of R . Each figure relates to a particular type of alloy or group of alloys of similar composition. Figures 3a, 4a, 5a, 6a, 7a, 8a, 10 and 18 provide curves for low crack propagation rates, that is $da/dN \leq 10^{-8}$ m/cycle down to ΔK_{TH} ($da/dN = 10^{-11}$ m/cycle). For many of the alloys considered there are insufficient data available to provide more than one curve, but where sufficient data are available a mean curve, shown solid, and the upper limit of either all or 95 per cent of the data, shown dashed, are presented.

It can be seen from the curves that the data do not always allow smooth curves to be drawn between crack propagation rates above and below 10^{-8} m/cycle so that on Figures 4a, 7a and 8a there are discontinuities between the curves for high and low values of da/dN . These discontinuities may have been influenced by the different test procedures used and by the test pieces having different crack orientations relative to the grain flow, see Appendix A. Also different procedures for load shedding in the near threshold region may have been used which may have influenced the discontinuities. A further influence may have been that the data were obtained from completely different populations which were unrelated except by alloy type. For example, when analysing the RR58/2618-T651 data (presented on Figures 5 and 5a) it was found that some test pieces were cut in the S-L orientation and these data tended to have steeper crack propagation rate curves and higher values of ΔK_{TH} than the majority of the data analysed. It was possible, however, to draw smooth curves through the data obtained from tests on this alloy because the differences in crack propagation rates were small and were lost in the overall scatter of the data.

The data presented on Figures 6 and 6a for the alloys 2219-T87 and -T851 came from the same population and it was possible to draw smooth curves through them.

Figures 20, 21 and 21a provide summary curves so that the crack propagation rates of the different alloys

considered can be compared. Figure 22 summarises and compares the forging data with some of the plate data for similar values of R .

Figure 23 shows how the value of the fatigue threshold stress intensity factor, ΔK_{TH} , varies with the stress ratio, R , for various alloys.

The thickness and, where available, crack orientations relative to the grain flow of the test pieces are quoted on the figures. The values of fracture toughness obtained from tests for each material grade, as given in the Derivations, are quoted in Table 7.1 and are also indicated on the figures. The values of fracture toughness have been designated K_{Ic} where they were obtained from tests that conformed to the British Standards Institution (BSI) or the American Society for Testing and Materials (ASTM) criteria (see References 42, 50 and 51). Where the results did not meet the validity criteria or the tests did not conform to these recommendations they have been designated K_Q .

3. DISCUSSION OF DATA

3.1 Method of Analysis of Test Data

Where the basic crack growth data (a , N) were available the crack propagation rate has been determined by differentiating the basic crack growth curve obtained using the curve fitting technique described in Reference 36. Basic a , N data were available only for some of the test pieces of type 1 in Sketch 7.1. In the cases where the basic growth data were not available, quoted values of da/dN and ΔK have been taken directly from the Derivations. In these cases the authors had drawn smooth curves through the a , N data using appropriate curve fitting methods and these smoothed curves had been differentiated to obtain the crack propagation rate, da/dN , for a given value of stress intensity factor range, ΔK . Equation (4.2) of Data Item No. 80036 defines ΔK as

$$\Delta K = (S_{max} - S_{min})(\pi a)^{1/2} \alpha \quad (3.1)$$

The values of α used in Equation (3.1) have been taken either directly from the Derivations, (where values appropriate to the loading conditions and geometry of the test pieces were given) or, in the cases where the basic a , N data have been analysed as described by Reference 36, from Equation (3.2) below.

3.1.1 Central crack in a plate loaded in tension (type 1, Sketch 7.1)

The expression obtained from Reference 37 and used in Data Items Nos 83007*, 84001* and 89051* has been used, namely,

$$\alpha = \left[1 - 0.5 \frac{a}{b} + 0.326 \left(\frac{a}{b} \right)^2 \right] \left(1 - \frac{a}{b} \right)^{-1/2} \quad (3.2)$$

The expression is valid for all values of a/b .

* Data Item No. 83007 "Fatigue crack propagation rates and threshold stress intensity factor ranges for aluminium alloy sheets".
Data Item No. 84001 "Growth of cracks under constant amplitude fatigue loading: example calculations".
Data Item No. 89051 "Fatigue crack propagation rates of titanium alloy sheets".

3.2 Effect of Stress Ratio, R

3.2.1 Effect of stress ratio on growth rate

The crack propagation data presented in this Data Item cover values of R in the range 0 to 0.92. In general, the larger the value of R the higher the crack growth rate, da/dN , for a given value of applied ΔK . Many models are available that describe the effect of R upon crack growth rate. Several such models are reviewed in Reference 49.

The influence of R on da/dN is largely explained by crack tip shielding phenomena (often referred to as crack closure). These are discussed fully in Data Item No. 80036. The effect of R on da/dN is smallest for the naturally aged alloys and largest for the artificially aged alloys. Of the artificially aged alloys the Al-Zn group exhibits the largest changes in fatigue crack growth rate with variation in R for the ranges of R investigated.

3.2.2 Effect of stress ratio on threshold

The stress ratio has a strong influence on ΔK_{TH} which, again, can largely be explained by crack tip shielding. If R is high enough to keep the crack open throughout the fatigue cycle then the level of ΔK_{TH} is unaffected by R . However, reducing the value of R such that crack tip shielding occurs will result in an increase in ΔK_{TH} .

The influence of R value on ΔK_{TH} is illustrated in Figure 23. The limited data indicate that a linear relationship may exist between ΔK_{TH} and R up to some, limiting, value of R . For example, the dashed line on Figure 23 indicates that such a limit for 2219 may occur at approximately $R = 0.5$. Hence in Figure 23 three straight lines of best fit have been drawn: the upper line passes through values for 2024-T3 and -T351 alloys, the middle line is for RR58/2618-T651 alloy and the lower line is for the remaining alloy types.

3.3 Effect of Test Piece Thickness

For the range of thicknesses covered in this Data Item (5 mm to 26 mm) there is no significant variation in crack propagation rate with thickness. Nevertheless, in comparison with the sheet data given in Data Item No. 83007 the data show higher crack propagation rates at high values of ΔK . This latter effect appears to be dependent upon the value of R and the difference in crack propagation rates is greater at high values of R . At low value of ΔK , however, the difference between the plate data and the sheet data for a given value of ΔK is small.

3.4 Effect of Crack Orientation of Test Piece Relative to Grain Flow

Where possible, the orientation of the crack and direction of crack growth relative to the grain flow are indicated in Table 7.1 and on the figures. The two-letter code system used to identify the crack orientation of the test pieces relative to the grain flow is described fully in Appendix A. The direction of grain flow in the test pieces does not appear to influence the crack propagation rates, but in most cases only data from test pieces with cracks oriented in the L-T or T-L directions have been analysed. As mentioned in Section 2.4, there is some evidence that test pieces manufactured with cracks in the S-L orientation may have steeper da/dN curves and higher values of ΔK_{TH} than test pieces that contained cracks in the L-T or T-L orientations.

3.5 Effect of Environment

All the test data analysed were obtained from tests conducted in air at room temperature, with uncontrolled

humidity. No effects of changes in humidity, and no other environmental factors such as atmosphere, temperature *et cetera*, have been considered in this Data Item. See Section 3.1 of Data Item No. 88007* for a discussion of environmental effects on crack propagation rate.

3.6 Comparison of Alloys

Figures 20, 21 and 22 have been included so that crack propagation rates of the various alloys may be compared. The curves for $R = 0$ to 0.1 from Figures 1 to 19, for the plate alloys, have been superimposed in Figure 20. Similarly, the curves for $R = 0.5$ from Figures 1 to 19 have been superimposed in Figure 21. Figure 22 compares data for test pieces cut from plate with data for those cut from forged material for similar groups of alloys.

Figures 20 and 21 show that the value of R does not affect comparative performance since trends are similar in both figures. The figures show that generally the Al-Zn alloys in the T6 condition have the highest crack propagation rates although on both figures the RR58/2618-T651 alloys have the highest crack propagation rates for the region $da/dN > 10^{-6}$ m/cycle. Figure 20 also shows that the alloys in the T73 condition have the lowest crack propagation rates for given values of ΔK , suggesting that alloys tempered to improve their resistance to stress corrosion cracking have improved resistance to fatigue crack propagation in the region $da/dN > 10^{-8}$ m/cycle. The differences between the Al-Cu alloys are small, especially at low values of ΔK .

Similarly Figure 21 summarises the low crack propagation rates ($\leq 10^{-8}$ m/cycle down to ΔK_{TH}) for seven of the alloys and for two ranges of R . The data show that, at $R = 0.1$, the 2024-T3/T351 alloy has the highest value of ΔK_{TH} , that is, $4.0 \text{ MN/m}^{3/2}$. Five of the alloys have values of ΔK_{TH} ranging from 2.5 to $3.0 \text{ MN/m}^{3/2}$ at $R = 0$ to 0.1. At high values of R ($R = 0.68$ to 0.7) the RR58/2618-T651 alloys have the highest value of ΔK_{TH} , that is, $1.35 \text{ MN/m}^{3/2}$, although the differences in ΔK_{TH} for all the alloys are very small, ΔK_{TH} being in the range 1 to $1.35 \text{ MN/m}^{3/2}$. The effect of R on ΔK_{TH} is also illustrated on Figure 23. Figure 21 also shows that as the crack propagation rate increases the RR58/2618-T651 curves tend to cross over the other crack propagation curves and at high values of da/dN they have the highest crack propagation rates for given values of ΔK . The BS 2L 93 alloys have the lowest values of da/dN for given values of ΔK at $da/dN > 10^{-9}$ m/cycle.

Analysis of aluminium alloys tested in high humidity air (Reference 39), has shown that the microstructure of the alloy can significantly affect crack propagation rates and the transition to the fatigue threshold. It is shown in Figure 22 that the fatigue threshold ΔK_{TH} is highest for Al-Zn alloys in the T651 condition. However, the data presented in Figures 20 and 21 for the Al-Zn alloys in the T73 condition show that they have the greater resistance to crack propagation for $da/dN > 10^{-8}$ m/cycle which implies a cross over of the T651 and T7351 crack propagation rate curves.

Figure 22 shows that generally the forged materials have lower crack propagation rates than the plate materials and the Al-Cu alloy forgings have the lowest crack propagation rates for given values of ΔK .

* Data Item No. 88007 "Effect of environment on fatigue crack propagation in aluminium alloy sheet and plate".

4. CALCULATION OF CRACK GROWTH LIFE

4.1 Use of Curves

The complete curves available from the data are presented in Figures 1 to 19. The curves are suitable for use in computer programs that predict crack growth life, as described in Section 4.2 of Item No. 80036. Alternatively, simple integration over selected portions of one of the curves will also lead to an estimate of the total crack growth and the associated number of cycles (see Data Item No. 84001). One method described in Data Item No. 84001 assumes that the crack propagation rate curves are straight lines over discrete ranges of da/dN and may be described by Equation (4.1) (Reference 34).

$$\frac{da}{dN} = C(\Delta K)^n \quad (4.1)$$

Suggested values of n and C for given values of R are shown in the tables on the figures. Equation (4.1) cannot be used to describe the full range of crack growth (that is, from fatigue threshold to failure). For values of $da/dN < 10^{-10}$ m/cycle the crack propagation rate curves become nearly vertical and the value of $n \rightarrow \infty$ so that Equation (4.1) is unusable. If Equation (4.1) is used in the region $da/dN = 10^{-10}$ to 10^{-9} m/cycle it should only be used over small ranges of da/dN .

4.2 Practical Solutions

Simple practical examples using Equation (4.1) are given in Data Items Nos 84001 and 84003* for crack propagation rates $< 10^{-8}$ m/cycle. Section 6 of this Item gives an example of the use of ΔK_{TH} in a practical situation.

Methods of obtaining values of α for cracks in structural components of more complex geometries are outlined in Data Items Nos 80036 and 78036† and may also be obtained directly from sources such as Reference 40.

* Data Item No. 84003 "Fatigue crack propagation rates and threshold stress intensity factors in high alloy and corrosion resistant (stainless) steel".

† Data Item No. 78036 "The compounding method of estimating stress intensity factors for cracks in complex configurations using solutions from simple configurations".

5. DERIVATION AND REFERENCES

5.1 Derivation

This section lists selected sources that have been of assistance in the preparation of this Data Item.

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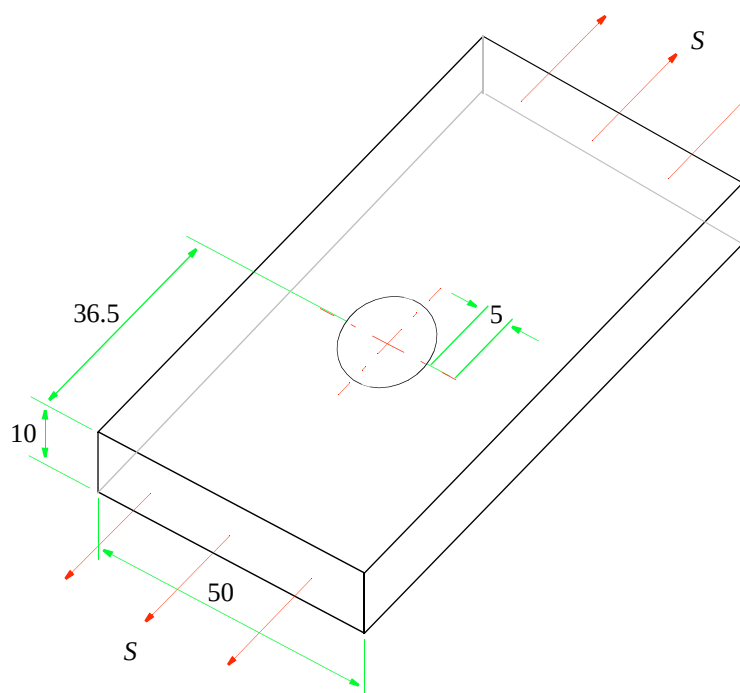
5.2 References

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6. EXAMPLE

A 5 mm crack has been found in a 50 mm wide reinforcing plate at an aircraft bulkhead joint. The plate is manufactured from an Al-Cu alloy to British Standard L 93 and is 10 mm thick. The crack originated at one side of the end fastener hole in the plate and the plane of propagation is normal to the direction of loading. It is required to know if the crack will propagate further under a reduced fluctuating tensile stress of 0 – 35 MN/m².



Sketch 6.1 Example Calculation

Equation (3.1) gives the stress intensity factor range for the cracked component as

$$\Delta K = (S_{max} - S_{min})(\pi a)^{1/2} \alpha \quad (6.1)$$

The value of α is required for the crack component geometry. Since the crack has developed at the end fastener hole the plate and hole may be considered to be a lug. The value of α can therefore be obtained using Data Item No. 81029* which provides values of α for various lug geometries.

The dimensions required to obtain a value of α are, in the notation of Data Item No. 81029,

diameter of fastener hole	$d = 13 \text{ mm},$
width of plate	$W = 50 \text{ mm},$
distance from hole to the end of plate (lug)	$c = 30 \text{ mm},$
crack length	$a = 5 \text{ mm},$
width of net section on one side of plate (lug)	$b = (W - d)/2 = 18.5 \text{ mm},$

so that $d/W = 0.26$, $c/W = 0.6$ and $a/b = 0.27$.

* Data Item No. 81029 "Stress intensity factors in lugs (through-thickness cracks)".

For a single crack for $c/W = 0.6$, Figure 6 of Data Item No. 81029 is appropriate and gives $\alpha = 2.3$.

From the given data $S_{max} = 35 \text{ MN/m}^2$, $S_{min} = 0$ thus $S_{max} - S_{min} = 35 \text{ MN/m}^2$ and $R = 0$.

Substituting the appropriate values into Equation (6.1) gives

$$\Delta K = 35 \times \left(\frac{\pi \times 5}{1000} \right)^{1/2} \times 2.3 = 10.1 \text{ MN/m}^{3/2}.$$

The plate is manufactured from BS L 93 aluminium alloy and the threshold values of ΔK are provided on Figure 4a of this Item.

At $R = 0.08$, $\Delta K_{TH} = 2.8 \text{ MN/m}^{3/2}$ and this value will be used in the calculation.

Since $\Delta K > \Delta K_{TH}$ the crack will propagate under the reduced stress. The maximum stress in the load cycle will have to be reduced to at least

$$\frac{35 \times 2.8}{10.1} = 9.7 \text{ MN/m}^2$$

if the crack is to stop propagating.



7. TABLES

TABLE 7.1

Figure number	Derivation number	Material specification/designation	Chemical composition, per cent						f_t	f_p	K_Q^h	K_{Ic}^h	Freq. Hz	Specimen type	B mm	Crack ^k orientation	Heat treatment
			Cu	Mg	Mn	Zn	Si	Others	MN/m ²	MN/m ²	MN/m ^{3/2}	MN/m ^{3/2}					
1	2	BS L 64 ^a (Extruded bar)	4.4	0.7	0.6		0.7		517	363	i	i	0.3 25	2	12.7	L-S	Solution treated and naturally aged
2	5	2024-T852 (Forging)	4.6	1.7	0.7				451	399	–	20.2	–	1	19.05	T-L	Solution treated, cold worked, stress relieved by compression and artificially aged
	10 11 & 15	2124-T851 ^f (Plate)	3.8 4.9	1.2 1.8	0.3 0.9	0.03 0.25	0.07 0.2	Ti 0.15 Fe 0.11	481 483 414	443 428 379	–	35.8 30 25	25 30	3	6.3 19.05	L-T T-L S-T	Solution treated, cold worked, stress relieved by stretching and artificially aged
3 & 3a	3	DTD 5090 ^b (Plate)	4.4	1.5	0.6				484	376	40.7	–	0.3 25	2	12.7	L-T	Solution treated and naturally aged
	30	2024-T3 (Plate)	3.8 ⁿ 4.9	1.2 ⁿ 1.8	0.3 ⁿ 0.9	0.25 ⁿ	0.5 ⁿ	Cr 0.1 ⁿ	448	324 ⁿ	–	–	0.2 20	–	5 to 10	L-T	
	26	2024-T351 (Plate)	3.8 ⁿ 4.9	1.2 ⁿ 1.8	0.3 ⁿ 0.9	0.25 ⁿ	0.5 ⁿ	Cr 0.1 ⁿ	434 ⁿ	290 ⁿ	–	–	50	3	12.7	–	Solution treated, cold worked, stress relieved by stretching and naturally aged to a stable condition
4	2	DTD 5020 ^d (Plate)	4.4	0.7	0.6		0.7		476	442	26.4	–	0.3 25	2	12.7	L-T	Solution treated and precipitation treated ^p
	5	2014-T652 (Forging)	4.4	0.4	0.7		1.0		459	398	–	23.7	–	1	19.05	T-L	Solution treated, stress relieved by compression and artificially aged
4 & 4a	18	BS 2L 93 (Plate)	4.4	0.6	0.8	0.1	0.7	Fe 0.4	456	425	–	–	130 140	2	10	–	Solution treated, controlled stretched and precipitation treated ^p
5	2	RR58 ^c (Plate)	2.5	1.5			0.2	Ni 1.2 Fe 1.0	445	414	26.4	–	0.3 25	2	12.7	L-T	Solution treated and artificially aged
5 & 5a	13 & 14	RR58 ^c (Plate)	2.6	1.7		0.1	0.2	Ni 1.2 Fe 1.2	450	367 ^m	23.2	–	0.15	4	8	S-L	Solution treated and artificially aged
	19, 23 & 28	2618-T651 (Plate)	2.5	1.6	0.1		0.3	Ni 1.2 Fe 1.1	450	400	–	–	1 40	3	10	–	Solution treated, stress relieved by stretching and artificially aged
5a	24	2618-T651 (Plate)	2.6	1.6	0.1	0.1	0.2	Ni 1.1 Fe 1.2	447	402	–	20	0.5 130	3	20	L-T T-L	

Letters refer to the Notes at the foot of the Table on Page 18

TABLE 7.1 (Continued)

Figure number	Derivation number	Material specification/ designation	Chemical composition, per cent						f_t	f_p	K_Q^h	K_{Ic}^h	Freq. Hz	Specimen type	B mm	Crack ^k orientation	Heat treatment
			Cu	Mg	Mn	Zn	Si	Others	MN/m ²	MN/m ²	MN/m ^{3/2}	MN/m ^{3/2}					
6 & 6a	27	2219-T87 (Plate)	6.3		0.3				472	386	—	—	30 50	3	6.3	—	Solution treated, 7 per cent cold worked and artificially aged
	17	2219-T851 (Plate)	6.3		0.3		0.1	Fe 0.3	455	359	—	—	0.1 5 200	1 and 3	6.3	L-T	Solution treated, cold worked, stress relieved by stretching and artificially aged
7	8	7075-T6 (Plate)	1.7	2.5		5.7		Cr 0.2	574	528	37.4	—	0.7	1	9.7	—	Solution treated and artificially aged
			1.7	2.7		5.6		Cr 0.2	598	551	28.2	—	30		12.7		
	1	7075-T651 (Plate)	1.6 ⁿ	2.5 ⁿ		5.5 ⁿ		Cr 0.3 ⁿ	588	531	33.8	—	—	1	19.05	L-T T-L	Solution treated, stress relieved by stretching and artificially aged. T6510 products receive no further straightening after stretching
	4	7075-T6510 (Extruded bar)	1.6	2.4		5.7		Cr 0.2	577	517	—	34.7	—	1	15.9 19.1	L-T	
7 & 7a	18	7075-T651 (Plate)	1.7	2.5	0.1	5.8	0.1	Cr 0.2	548	490	—	—	130 140	2	10	—	
	29		1.5	2.4		6.0		Cr 0.2 Fe 0.2	590	527	—	—	40	3	10	—	
8	1	7075-T7351 (Plate)	1.6 ⁿ	2.5 ⁿ		5.5 ⁿ		Cr 0.3 ⁿ	487	408	41.4	—	—	1	19.05	L-T	Solution treated and stabilised for good resistance to stress corrosion cracking. Stress relieved by stretching. T73510 products receive no further straightening after stretching
	6								494	421	—	—	10 25		25.4	T-L	
8 & 8a	18	7075-T7351 (Plate)	1.7	2.5	0.1	5.8	0.1	Cr 0.2 Fe 0.2	485	412	—	—	130 140	2	10	—	
	29		1.5	2.4		6.0		Cr 0.2 Fe 0.2	539	470	—	—	40	3	10	—	
8	4	7075-T73510 (Extruded bar)	1.6	2.5		5.8		Cr 0.2	508	440	—	37.1	—	1	19.1	L-T T-L	
	5	7075-T7352 (Forging)	1.4	2.6		5.7		Cr 0.2	441 434	365 345	—	37.4 28.5	—	1	19.05	L-T T-L	Solution treated and stabilised for good resistance to stress corrosion cracking. Stress relieved by compression
	22	7075-T73511 (Extruded bar)	1.4 1.6	2.3 2.4	0.01 0.02	5.5 6.1	0.03 0.17	Cr 0.2 Fe 0.0 to 0.3	536 484	473 420	—	47 24	30	3	15.9	L-T T-L	Solution treated and stabilised for good resistance to stress corrosion cracking. Stress relieved by stretching with minor straightening after stretching



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