

FRACTURE TOUGHNESS (K_{Ic}) VALUES OF SOME ALUMINIUM ALLOYS

1. NOTATION

K	crack-tip stress-field-intensity factor	$\text{N/m}^{3/2}$	$\text{lbf/in}^{3/2}$
K_c	plane stress fracture toughness (critical value of stress intensity in plane stress)	$\text{N/m}^{3/2}$	$\text{lbf/in}^{3/2}$
K_{Ic}	plane strain fracture toughness in Mode I (critical value of stress intensity in plane strain)*	$\text{N/m}^{3/2}$	$\text{lbf/in}^{3/2}$
k_1, k_2, k_3	statistical factors incorporating coefficients of variation of samples, see Section 4, Equations (4.1) and (4.4)		
n	number of values in a sample		
v	coefficient of variation, see Section 4		
X	statistical factor, see Section 4.2, Equation (4.3)		
Z_c	confidence level coefficient, see Section 4.2		
Z_p	probability of survival coefficient, see Section 4.2		
σ_p	0.2 per cent proof stress	N/m^2	lbf/in^2

* See Data Item No. 80036, "Introduction to the use of linear elastic fracture mechanics in estimating fatigue crack growth rates and residual strength of components".

See Appendix A for definition of crack orientation with respect to grain flow.

Both SI and British units are quoted.

Suffixes

mean The suffix *mean*, applied to K_{Ic} , refers to the arithmetic mean fracture toughness values in the tables of Section 8.

1.1 K_{Ic} Conversion Factors

$$1 \text{ MN/m}^{3/2} = 0.910\,047 \times 10^3 \text{ lbf/in}^{3/2} = 0.910\,047 \text{ ksi} \sqrt{\text{in}}.$$

Note also that,

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

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2. NOTES

2.1 General Notes

This Item presents plane strain fracture toughness (K_{Ic}) values for a variety of aluminium alloys along with notes on fracture toughness and other related topics in linear elastic fracture mechanics (LEFM). Further topics relating to fracture mechanics are discussed in Data Item No. 80036.

Fracture toughness values are used, within LEFM, to determine the static strength of components containing fatigue cracks or defects. Such flawed components will fail under a slowly increasing applied load when the stress intensity factor, K , reaches a critical value. In relatively thick sections, the crack may propagate rapidly and unstably through the component, causing sudden, complete failure. The critical value in this case is called the “plane strain fracture toughness”, designated K_{Ic} , which is a material property for a specified test environment.

In thin sections or the more ductile materials, the point of instability is less well-defined and depends on crack tip plasticity, thickness and other geometrical aspects (see also Section 5.1 of Data Item No. 80036). The results of tests on thinner sections are described simply as “fracture toughness” values (without the qualification “plane strain”) and are designated K_c . The plane strain K_{Ic} value for a given material is always* less than the corresponding K_c value and therefore represents a conservative choice for the designer. A worked example illustrating a use of fracture toughness data is given in Section 6.

2.2 Test Conditions

The data have been taken from tests performed in non-corrosive environments at temperatures between -253°C and 149°C (-423°F and 300°F) on specimens cut from plate, bar, forgings, *et cetera*, manufactured from U.S. standard specification materials. The tests have been carried out in accordance with the British Standards Institution's or American Society for Testing and Materials' standards (see References 20 and 21). Briefly, these tests involve applying a steadily increasing load to fracture a specimen containing a machined notch which has been lengthened and sharpened by fatigue cracking. Further information on testing is given in Data Item No. 80036. The standards place tight controls over various aspects of toughness testing, one of which is a minimum specimen thickness requirement† to ensure plane strain conditions.

2.3 Presentation of Data

The results of the fracture toughness tests evaluated are tabulated in Section 8. Details quoted include test temperature, crack orientation relative to grain flow, chemical analysis, heat treatment and proof stress. Where two values of thickness, separated by a comma, appear in the column headed “Form and thickness” the first value refers to the thickness of the test specimen while the second value refers to the thickness of the product, plate, forging, *et cetera*, from which the test specimen was taken. In a small number of cases, ranges are given for the thicknesses of the specimen and the product from which the specimen was taken. For these cases a similar interpretation applies; the first range, given as two numbers separated by a hyphen, refers to the thickness of the specimen while the second range, presented in the same way, refers to the thickness of the product.

The data in the tables in Section 8 are presented in two systems of units, the British system and the SI system. In many of the tables there are apparent inconsistencies in the conversion of the data between the two systems of units. There are two reasons for this inconsistency. The first is rounding and the second is

* Note that for very thin sheet or foil, oblique fracture may dominate giving an apparently lower toughness value.

† References 20 and 21 specify a minimum specimen thickness of $2.5 (K_{Ic}/\sigma_p)^2$ for the achievement of a valid K_{Ic} value. The thickness requirement is also discussed in Section 5.1.2 of Data Item No. 80036.

the fact that the conversions between the two systems were made before the data were rounded. See Section 8.6 for more details.

In order to assist in the interpolation of K_{Ic} and σ_p values in the tables, selected data are represented graphically in Section 7 where the typical dependencies of K_{Ic} , σ_p and K_{Ic}/σ_p on temperature are illustrated. The graphs have been drawn by eye through plots based on mean K_{Ic} and σ_p values, using, in some cases, relatively few points. Typical mean values have been chosen to construct the graphs because the wide variety of chemical analyses, heat treatments, *et cetera*, of the materials leads to a fairly wide scatter.

For the statistical confidence with which the K_{Ic} data may be applied, see Section 4.

3. FACTORS AFFECTING FRACTURE TOUGHNESS

The following sections explain the effect on toughness of the most important factors that are often varied during a test programme to reflect service conditions.

3.1 Crack Orientation

The notation for crack orientation relative to material grain flow is defined in Appendix A and the test specimen orientation, if known, is quoted in the tables of Section 8. Fracture toughness is reduced by the presence of inclusions. These inclusions are the main cause of the disparity in fracture toughness values for different crack orientations, since after heavy mechanical working, the shape of the inclusions is changed. For example, it can be seen in the tables of Section 8 that, in general, the results of tests on specimens of L–T orientation are approximately 20 per cent greater than those on specimens of T–L orientation.

3.2 Temperature

In order to aid interpolation of the data, the relationships between K_{Ic} , σ_p and K_{Ic}/σ_p and temperature are shown in Sketches 7.1 and 7.2 for different aluminium alloys. It can be seen that the variation of fracture toughness of aluminium alloys with temperature is far less pronounced than it is for steels, with only slight variations over the temperature range considered in this Item. Plane strain fracture toughness values for a variety of steels can be found in Data Item No. 83023*. This is mainly due to the fact that, over this range, there is no temperature transition for aluminium alloys as there is for ferritic steels.

3.3 Environment

The data in this Item refer to tests carried out in normal atmospheric conditions or in normally used coolants. In service, materials exposed to corrosive agents or nuclear irradiation will have reduced fracture toughness. In a corrosive environment cracks may propagate under sustained load due to stress corrosion cracking. The fracture toughness may also be lowered by the corrosive environment leading to failure at a lower level of crack tip stress intensity than would normally cause fracture in air.

3.4 Rate of Loading

The data in this Item were obtained at rates of loading implied by the range for the rate of increase of stress intensity specified in the standard test procedures, that is $0.5 - 3 \text{ MN}/(\text{m}^{3/2}\text{s})$ ($455 - 2730 \text{ lbf}/(\text{in}^{3/2}\text{s})$).

* Data Item No. 83023, "Fracture toughness (K_{Ic}) values of some steels".

Strictly, the data should not be applied to rates of loading that fall significantly outside this range. However, fracture toughness values for aluminium alloys are far less rate sensitive than those for steels and can therefore, with due care, be used in situations that are not within the above range.

4. STATISTICAL ANALYSIS OF DATA

4.1 Introduction

Before the K_{Ic} values can be applied with any confidence, an allowable value for the design in hand should be determined. Owing to the cost and complexity of fracture toughness testing, the number of tests performed on a specific material at a given temperature, orientation, *et cetera*, is more often than not too small to constitute a statistically significant sample. This section explains two basic procedures for obtaining a K_{Ic} value for use in design. The procedure selected depends upon the number of K_{Ic} values available for a particular material under specific test conditions.

With 30 or more values a rigorous statistical analysis can be conducted, the results of which would enable a suitable design value to be obtained. Various rigorous statistical analyses and methods that are applicable to these cases, such as those used in Section 4.2, may be found in Data Item No. 91041^{*}; they rely solely upon the data from the sample and assume only a Normal distribution for the *population*. However, if it is assumed that the *sample* is of Normal distribution, Equations (4.1) to (4.3), which use the sample size and coefficient of variation, may be used directly to find the allowable K_{Ic} . The statistical details of the samples in this Item for which this can be done are given in Table 4.1. The coefficient of variation, v , of a sample is the standard deviation of the sample divided by the sample mean. For some engineering quantities the coefficient of variation tends to a consistent value and it seems reasonable, on the evidence of Table 4.1, to suppose that for the fracture toughness of aluminium alloys this value is in the region of 0.08. This is reinforced by the results in Section 4.3 where the analysis of a combined sample of 828 values gave 0.077 as an estimate of the population coefficient of variation.

With a sample size less than 30, a rigorous value for allowable K_{Ic} is unobtainable; however, an approximate value can be found using Equation (4.4) and Figures 1 and 2. Figure 1 was derived from the typical scatter of K_{Ic} in the population and Figure 2 gives a factor that makes an allowance for the uncertainty about where the mean of the sample lies in relation to the population mean.

For the purposes of this Data Item, one sample is equivalent to a single line of data in the tables of Section 8.

4.2 Large Samples

The results of an analysis of a sample of 30 or more values are generally considered to be statistically significant in that they enable both the fit of the sample to a Normal distribution to be assessed and a useful estimate of the population coefficient of variation to be made. In this Item there are 8 samples of 30 or more values obtained from tests for which the conditions were identical.

These samples were tested for normality using ESDUpac A9141[†] which also gives the mean, the standard deviation and the coefficient of variation of the sample being tested. The significance level of the test for normality is the percentage of samples from Normal populations for which the hypothesis of normality would be rejected by the test. The results of the analyses of the samples are presented in Table 4.1.

^{*} Data Item No. 91041, "The statistical analysis of data from Normal distributions, with particular reference to small samples".

[†] ESDUpac No. A9141, "The statistical analysis of data from Normal distributions, with particular reference to small samples".

TABLE 4.1 Results of Statistical Analyses of Large Samples

Alloy designation and orientation	Table	Sample mean (K_{Ic}) _{mean} MN/m ^{3/2} (10 ³ lbf/in ^{3/2})	Sample standard deviation MN/m ^{3/2} (10 ³ lbf/in ^{3/2})	Sample coefficient of variation v	Number of values n	Hypothesis of normality accepted at significance level of 5 per cent	Highest significance level at which hypothesis of normality would be accepted, per cent*
2124 L-T	8.5	32 (29)	2.5 (2.3)	0.08	42	No	0.2
2124 T-L	8.5	26 (24)	2.3 (2.1)	0.09	41	No	0.8
2124 L-T	8.5	34 (31)	2.6 (2.3)	0.08	30	Yes	33.6
2124 T-L	8.5	27 (24)	2.0 (1.8)	0.07	30	Yes	12.9
2124 S-L	8.5	24 (22)	2.3 (2.1)	0.09	81	Yes	7.2
2124 S-L	8.5	25 (23)	1.5 (1.4)	0.06	30	Yes	19.2
7475 T-L	8.23	38 (34)	2.6 (2.3)	0.07	42	Yes	51.6
7475 T-L	8.23	38 (35)	4.1 (3.7)	0.11	40	Yes	18.1

* A larger figure in this column indicates that the distribution of the sample values closely resembles the distribution of a sample taken from a Normal population. A smaller figure indicates that the distribution of the sample deviates significantly from the distribution of a sample taken from a Normal population.

An allowable value of K_{Ic} may be obtained by using Equations (4.1) to (4.3) in conjunction with Table 4.2. The factor k_1 relates to a chosen probability of survival and a chosen confidence level and (K_{Ic})_{mean} is the sample mean. For an explanation of the term confidence level, see Data Item No. 91041, Section 6.

$$K_{Ic} = k_1 (K_{Ic})_{mean}, \quad (4.1)$$

where

$$k_1 = 1 - (Xv), \quad (4.2)$$

v is the coefficient of variation and

$$X = \frac{Z_p + Z_c \sqrt{\frac{1}{n} \left(1 - \frac{Z_c^2}{2(n-1)} \right) + \frac{Z_p^2}{2(n-1)}}}{1 - \frac{Z_c^2}{2(n-1)}}. \quad (4.3)$$

Z_c and Z_p are statistical coefficients which may be obtained from Table 4.2 below.

TABLE 4.2 Confidence Level and Probability of Survival Coefficient

<i>Chosen confidence level or probability of survival (per cent)</i>	<i>Confidence level coefficient, Z_c, or probability of survival coefficient, Z_p</i>
80	0.842
90	1.282
95	1.645
98	2.054
99	2.324
99.5	2.576
99.8	2.878
99.9	3.09

The following brief example uses the results for the third sample of Table 4.1 ($(K_{Ic})_{mean} = 34 \text{ MN/m}^{3/2}$, $v = 0.08 \text{ MN/m}^{3/2}$ and $n = 30$).

To ensure that K_{Ic} will not be less than the design value 99 times out of a hundred with 95 per cent confidence, values of Z_c equal to 1.645 and Z_p equal to 2.324 are read from Table 4.2.

Using Equation (4.3), a value of X equal to 3.05 is obtained. Inserting this result into Equation (4.2) produces a value of k_1 equal to 0.76. Equation (4.1) then gives the allowable value as

$$K_{Ic} = 0.76 \times 34 = 25.8 \text{ MN/m}^{3/2} \text{ (or } 23.5 \times 10^3 \text{ lbf/in}^{3/2}\text{)}.$$

Note that using combinations of low percentage probabilities of exceeding the allowable value and low percentage confidence levels may lead to cases where the value of K_{Ic} obtained is greater than the minimum value of the sample given in the tables. In such cases it is suggested that further consideration is given to selecting a value to be used for the design in hand.

4.3 Small Samples

Samples of between 8 and 30 values are considered statistically significant only in that it is possible to assess the fit of the sample to a Normal distribution. A range for the population coefficient of variation can be obtained, but it is more often than not too broad to be of practical use. Also, as the sample size decreases there is increasing uncertainty about where the mean of the sample lies in relation to the population mean. In order to make an allowance for this uncertainty, which would otherwise be carried through to the final allowable value, an empirically obtained factor has been incorporated into the small sample analysis. The following method, consisting of two parts, was therefore adopted to analyse the data.

Part 1 Combined analysis of small samples

- (i) The arithmetic mean, $(K_{Ic})_{mean}$, was determined for a group of 11 or more test results for which the chemical analysis, heat treatment, test temperature, *et cetera* were identical.
- (ii) Each individual test value was divided by the mean of the group to obtain a set of $K_{Ic}/(K_{Ic})_{mean}$ values which were then treated as the normalised sample values.
- (iii) Procedures (i) and (ii) were repeated for all other such samples.
- (iv) The samples were tested for normality using ESDUpac A9141.
- (v) The samples for which the hypotheses of normality were accepted, 48 in all, were compared to determine whether or not they could have originated from the same Normal population*. The hypothesis of a shared parent population was accepted for 43 of the samples. These 43 samples are marked with crosses in the columns headed "No. of tests" in the tables of Section 8.
- (vi) The 43 samples were combined and analysed as one sample of 828 test values.

The analysis of this sample rejected the hypothesis of normality and gave 0.077 as a point estimate of the population coefficient of variation.

Part 2 Determination of a factor to account for the uncertainty in the position of the sample mean in relation to the population mean

- (i) 2000 different samples each of size n were selected at random from one large sample of K_{Ic} data. The large sample used was a sample of 81 AA2124 values, details of which are given in Table 4.1.
- (ii) The arithmetic mean of each of these samples was calculated.
- (iii) The 2000 means obtained in Step (ii) were combined to form a sample of means.
- (iv) The coefficient of variation of the sample of means was calculated.
- (v) The process was repeated for all integer values of n from 3 to 30 inclusive.
- (vi) The appropriate value of n , the coefficients of variation and Equations (4.1) to (4.3) were used to calculate a statistical factor designed to take account of the uncertainty in the sample mean.

The factor is given in Figure 2 for various values of n , confidence levels and probabilities of the population mean exceeding the value given by the figure.

An allowable value of K_{Ic} may be obtained from the value of the sample mean, $(K_{Ic})_{mean}$, using Equation (4.4), in which the factors k_2 and k_3 relate to chosen probabilities of survival and chosen confidence levels.

$$K_{Ic} = k_2 k_3 (K_{Ic})_{mean}. \quad (4.4)$$

Figure 1, which was constructed using versions of Equations (4.2) and (4.3) and the results of the analysis of the combined sample of 828 values, gives the value of k_2 . The factor k_3 is read from Figure 2 which

* For details of the method used, see "Metallic Materials Data Handbook", Volume 1, Section 1, Appendix 5.

was constructed using the method outlined above.

For example, to ensure that K_{Ic} will not be less than the design value 99 times out of a hundred with 95 per cent confidence, a value of k_2 equal to 0.81 is read from Figure 1. If, in addition to this, $(K_{Ic})_{mean}$ has been calculated from a sample of, say, 4 values and the uncertainty in this value is to be taken account of using a 95 per cent confidence level and a 99 per cent probability of survival, a value of k_3 equal to 0.66 is read from Figure 2. Equation (4.4) then gives the design value as

$$K_{Ic} = 0.81 \times 0.66 (K_{Ic})_{mean},$$

where $(K_{Ic})_{mean}$ is obtained from the tables of Section 8.

The worked example illustrates the use of this section.

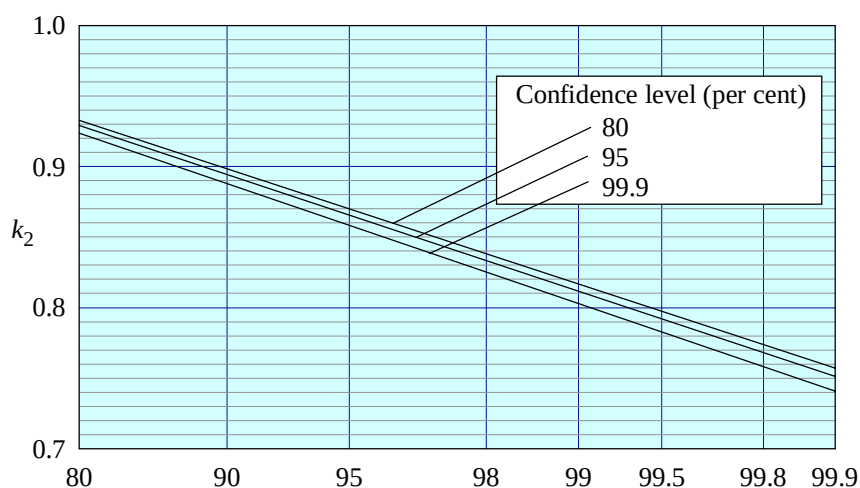


FIGURE 1 STATISTICAL FACTOR k_2 USED TO ESTIMATE ALLOWABLE VALUE OF K_{Ic} FOR SMALL SAMPLES

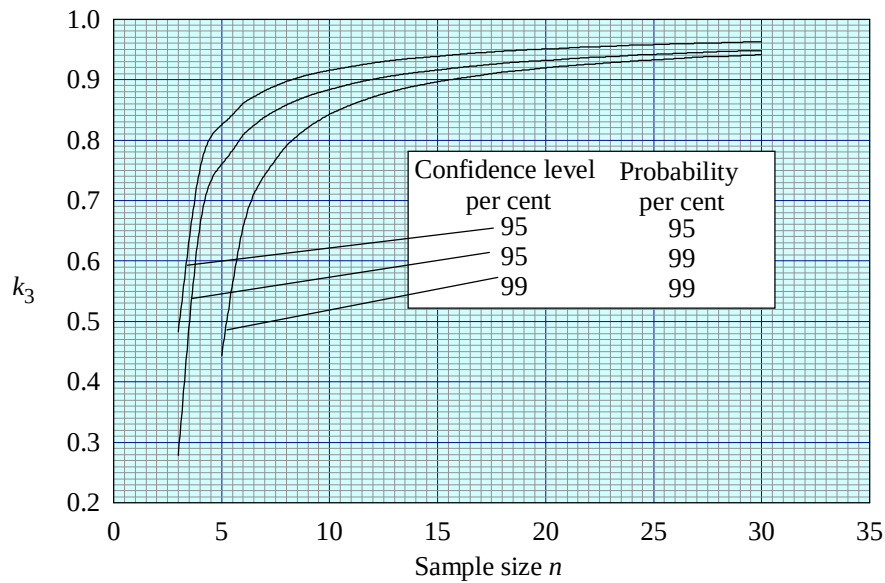


FIGURE 2 STATISTICAL FACTOR k_3 USED TO ALLOW FOR UNCERTAINTY IN SAMPLE MEAN

Note that using combinations of low percentage probabilities of exceeding the allowable value and low percentage confidence levels may lead to cases where the allowable value of K_{Ic} obtained is greater than the minimum value in the tables. In such cases it is suggested that further consideration is given to selecting a value to be used for the design in hand.

5. DERIVATION AND REFERENCES

5.1 Derivation

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

1. KAUFMAN, J.G.
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HOLT, M. Fracture toughness of aluminum alloy plate determined with centre-notch tension, single-edge-notch tension and notch-bend tests. *Engineering Fracture Mechanics*, Vol. 1, No. 2, pp. 259-274, 1968.
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5.2 References

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

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14. TADA, H.
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6. EXAMPLE

6.1 Notation

This notation is supplementary to that of Section 1.

a	crack length as defined in Sketch 6.1	m	in
K_I	nominal mode I stress intensity factor* at crack tip	N/m ^{3/2}	lbf/in ^{3/2}
P	load on lug	N	lbf
S	stress based on gross cross-sectional area such that $S = P/Wt$	N/m ²	lbf/in ²
b, c, d, W	dimensions of lug, see Sketch 6.1	m	in
t	thickness of lug	m	in
α	geometric factor*		

* See Data Item No. 80036 "Introduction to the use of linear elastic fracture mechanics in estimating fatigue crack growth rates and residual strength of components" for a definition of mode I cracks and notes on α .

6.2 Example

A proposed design consists of a round-ended lug loaded axially by a single clearance-fit pin. The overall width of the lug is 40 mm (1.6 in), it is 10 mm (0.4 in) thick and the diameter of the hole is 16 mm (0.6 in). In service the load, P , on the lug will be 24 000 N (5395 lbf) which equates to a gross section stress, S , of 60 MN/m² (8.7×10^3 lbf/in²). In service the temperature near the lug will not fall below room temperature 21°C (70°F). It is required to investigate the fracture toughness of AA2024 aluminium alloy plate to determine whether or not it might be a suitable material for the lug.

Linear elastic fracture mechanics will be used to determine the likelihood of the lug failing due to brittle fracture caused by the presence of a crack. In reality, several different crack positions and configurations would be examined but for the purposes of this example a single crack of uniform depth through the full thickness of the lug and on the transverse diameter will be investigated. The following analysis will determine the maximum size the crack can attain before the lug will fail due to brittle fracture; that is, when the calculated value of K_I reaches the appropriate value of K_{Ic} . The lug is shown in Sketch 6.1.

The general expression for stress intensity factor is

$$K_I = S(\pi a)^{1/2} \alpha \quad (6.1)$$

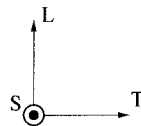
in which α accounts for the crack configuration and surrounding boundaries. Values of α for round-ended lugs of various geometries with through-thickness cracks are given in Data Item No. 81029*. Using the appropriate row of Table 5.2 in that Item, that is for $c/W = 0.5$ and $d/W = 0.4$, and taking the value of S

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

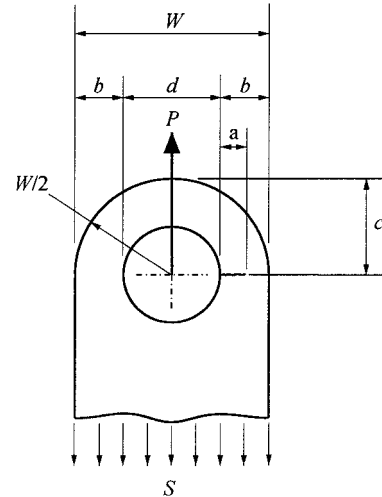
equal to 60 MN/m^2 , Sketch 6.2, which shows the variation of K_I with crack depth, may be constructed from Equation (6.1).

$$\begin{aligned} b &= 12 \text{ mm} \\ c &= 20 \text{ mm} \\ d &= 16 \text{ mm} \\ t &= 10 \text{ mm} \\ W &= 40 \text{ mm} \\ P &= 24\,000 \text{ N} \\ S &= P/Wt = 60 \text{ MN/m}^2 \end{aligned}$$

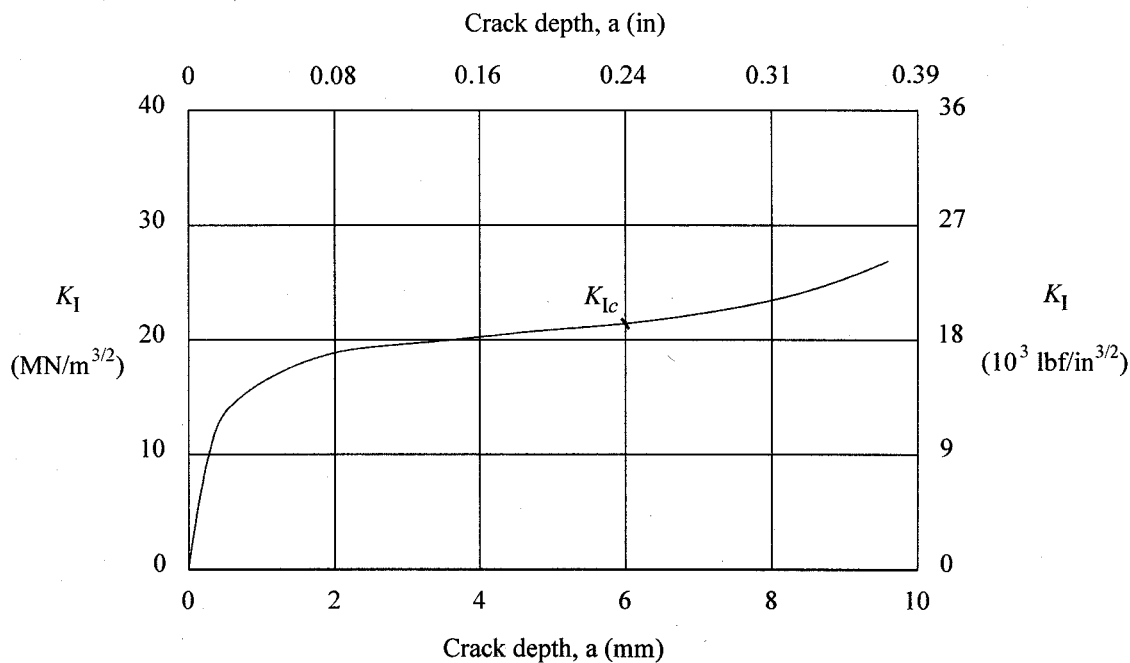
Grain flow orientation



Crack orientation is L - T



Sketch 6.1 View of lug and crack



Sketch 6.2 Variation of K_I with crack depth

The fracture toughness, K_{Ic} , of AA2048 aluminium alloy plate at room temperature may be determined using Table 8.4 where, at 21°C (70°F), a 25 mm (1 in) thick specimen with L-T crack orientation and a T851 heat treatment exhibits a mean value of fracture toughness, $(K_{Ic})_{mean}$, of $40 \text{ MN/m}^{3/2}$ ($36 \times 10^3 \text{ lbf/in}^{3/2}$) for a sample of four tests. The choice of orientation is, in many cases, a balance between

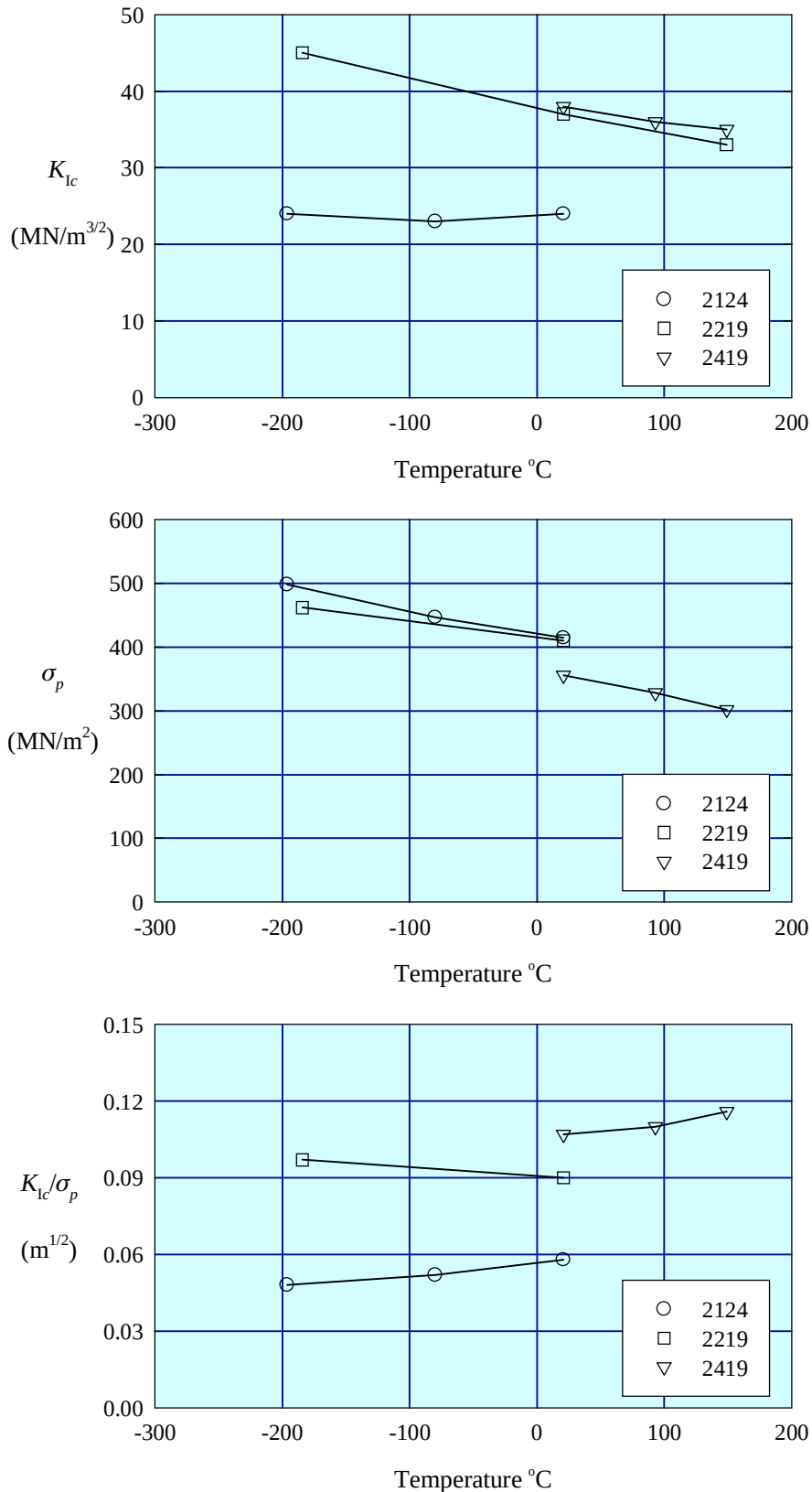
optimisation of the material properties with respect to the orientation and consideration of the requirements of the manufacturing process.

A suitable allowable value is obtained using Section 4.3. For a probability of 99 per cent that the actual value of K_{Ic} will exceed the allowable value calculated below, with a confidence level of 95 per cent, a value of k_2 equal to 0.81 is obtained from Figure 1. For the same probability of survival and confidence level and for a sample size of four, a value of k_3 equal to 0.66 is obtained from Figure 2. Substituting the values of $(K_{Ic})_{mean}$, k_2 and k_3 into Equation (4.4) gives

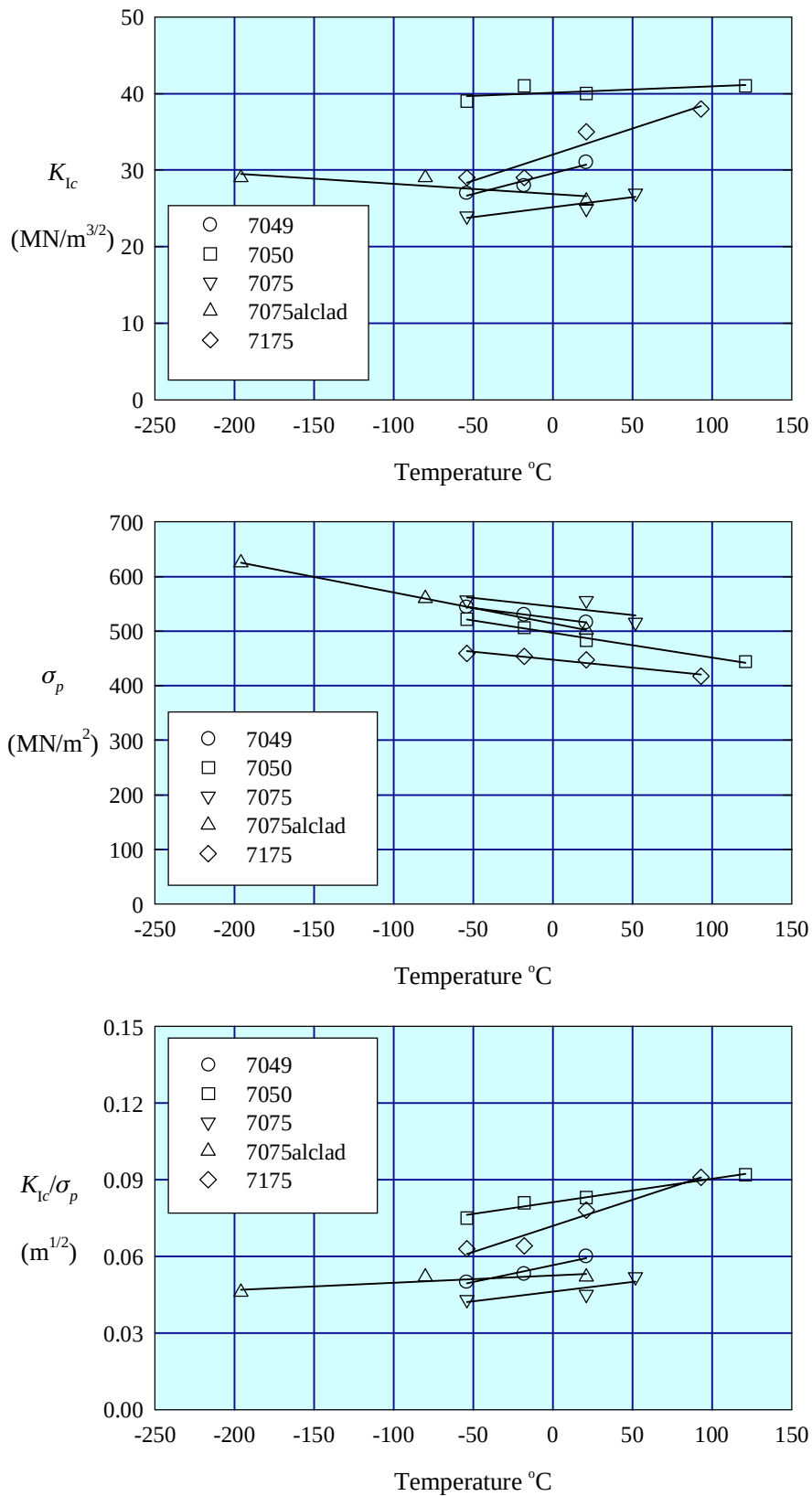
$$K_{Ic} = 0.81 \times 0.66 \times 40 = 21.4 \text{ MN/m}^{3/2} \text{ (or } 19.5 \times 10^3 \text{ lbf/in}^{3/2}\text{)}.$$

The allowable value of K_{Ic} is shown in Sketch 6.2. As may be seen the critical crack depth occurs at about 6 mm (0.24 in). Such a crack should be detected by routine non-destructive examination well before it reaches this depth. Thus, the material should be suitable for this purpose with regard to this particular crack configuration.

7. GRAPHS OF TEMPERATURE DEPENDENCE OF K_{Ic} AND σ_p



Sketch 7.1 2000 series aluminium alloys. See Tables 8.5, 8.7 and 8.8



Sketch 7.2 7000 series aluminium alloys. See Tables 8.14 to 8.17 and 8.21

8. TABLES OF PLANE STRAIN FRACTURE TOUGHNESS VALUES

Aluminium alloys are classified by chemical composition in an internationally agreed system in which the first of the four digits indicates the alloy series according to the main alloying element. For the 2000 to 6000 series, the last two digits identify the different alloys in the series. The second digit indicates alloy modifications to achieve particular properties.

AA stands for Aluminum Association.

8.1 2000 Series Aluminium Alloys (Main alloying element is copper.)

AA 2014	8.1
AA 2020	8.2
AA 2024	8.3
AA 2048	8.4
AA 2124	8.5
AA 2214	8.6
AA 2219	8.7
AA 2419	8.8
AA 2618	8.9

8.2 6000 Series Aluminium Alloys (Main alloying elements are magnesium and silicon.)

AA 6061	8.10
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8.3 7000 Series Aluminium Alloys (Main alloying element is zinc.)

AA 7001	8.11
AA 7005	8.12
AA 7010	8.13
AA 7049	8.14
AA 7050	8.15
AA 7075	8.16
AA 7075 Alclad	8.17
AA 7079	8.18
AA 7080	8.19
AA 7149	8.20
AA 7175	8.21
AA 7178	8.22
AA 7475	8.23

8.4 Abbreviations Used in Tables

NA	Not available	SP	Super plastic
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8.5 Notes on Presentation of Data

Full details of the way in which the data are presented are given in Section 2.3. There are, however, four notable points regarding the presentation of the data and these are stated below.

1. Where two values of thickness, separated by a comma, appear in the column headed "Form and thickness" the first value refers to the thickness of the test specimen while the second value refers to the thickness of the product from which the test specimen was taken. In a small number of cases, ranges are given for the thicknesses of the specimen and the product from which the specimen was taken. For these cases a similar interpretation applies; the first range, given as two numbers separated by a hyphen, refers to the thickness of the specimen while the second range, presented in the same way, refers to the thickness of the product.
2. A cross in the columns headed "No. of tests" indicates data used in the statistical analysis of Section 4.3.
3. The data in the tables in this section are presented in two systems of units, the British system and the SI system. In many of the tables there are apparent inconsistencies in the conversion of the data between the two systems of units. There are two reasons for this inconsistency. The first is rounding and the second is the fact that the conversions between the two systems were made before the data were rounded.

For example, in Table 8.1, 29°C appears to correspond to both 84°F and 85°F. The reason for this is that the data were originally obtained in degrees Fahrenheit and were then converted to degrees Celsius and rounded to the nearest integer. In actual fact, 84°F is equivalent to 28.89°C and 85°F is equivalent to 29.44°C, both of which round to 29°C and it is thus that the apparent inconsistency arises.

Another example can be found in the column headed "Form and thickness" where 19 millimetres is given as equivalent to 0.8 inches. This is apparently wrong both ways, since 19 millimetres converts to 0.7 inches and 0.8 inches converts to 20 millimetres. The actual specimen thickness was 0.75 inches which converts to 19.1 millimetres. Rounding these figures gives those found in the table, 0.8 inches and 19 millimetres respectively.

4. In many of the tables in this section, sets of data from Derivation 13 for which the compositions are not available are separated by bold lines. The reason for this is that Derivation 13 contained data from a number of sources, copies of which were, in most cases, unattainable; sets of data taken from Derivation 13 but ultimately originating from different sources have therefore been separated by bold lines in the tables. This has been done to indicate that, although the data came ostensibly from the same source, the test specimens may have had slightly different compositions and were not necessarily tested in the same laboratory.

8.6 Heat Treatments

Listed below are details of the heat treatments that appear in the tables of fracture toughness values in this section.

T351 Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 2 per cent, but not less than 1.5 per cent nor more than 3 per cent. Product shall receive no further straightening after stretching.

T351 (417) NA

T3511	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 1 to 1.5 per cent, but not less than 1 per cent nor more than 3 per cent. Extrusions may receive minor straightening, after stretching, of an amount necessary to meet the tolerances.
T6	Solution and precipitation heat treated.
T61	Solution heat treated and precipitation heat treated. Quenching from the solution temperature shall be into water at 79.4 to 85.3°C (175 to 185.5°F).
T611	Solution and precipitation heat treated, low residual stresses. Material may, after quenching from the solution heat treatment temperature, receive minor straightening of an amount necessary to meet the tolerances specified on the drawing.
T6351	NA
T651	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 2 per cent, but not less than 1.5 per cent nor more than 3 per cent, and artificially aged. Product shall receive no further straightening after stretching.
T651 (417)	NA
T6510	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 1.5 per cent, but not less than 1 per cent nor more than 3 per cent, and artificially aged. Material shall receive no further straightening after stretching.
T6511	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 1.5 per cent, but not less than 1 per cent nor more than 3 per cent, and artificially aged. Material may receive minor straightening after stretching.
T652	Solution heat treated and stress relieved by compression to produce a permanent set of 1.5 to 5 per cent, and precipitation heat treated. During compression, primary focus shall be applied in the axial direction and on individual rings of approximately final dimensions.
T66	Solution and precipitation heat treated.
T7	Solution heat treated and averaged/stabilised.
T73	See T74
T7351	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 2 per cent, but not less than 1.5 per cent nor more than 3 per cent, and precipitation heat treated. Plate shall receive no further straightening after stretching.
T73510	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 1.5 per cent, but not less than 1 per cent nor more than 3 per cent, and precipitation heat treated. Material shall receive no further straightening after stretching.
T73511	NA
T7352	Solution heat treated and stress relieved by compression to produce a permanent set of 1 to 5 per cent, and precipitation heat treated. The method and direction of compression shall be as agreed upon by purchaser and vendor.

T736	See T74.
T73651	Solution heat treated and stress relieved by stretching to produce a nominal set of 2 per cent, but not less than 1.5 per cent nor more than 3 per cent, and precipitation heat treated.
T73652	Solution heat treated and stress relieved by compression to produce a permanent set of 1 to 5 per cent, and precipitation heat treated. The method and direction of compression shall be as agreed upon by purchaser and vendor.
T74	(Previously T73 or T736). Solution heat treated and artificially aged to resist stress corrosion cracking.
T75	NA
T76	Solution heat treated and artificially aged sufficiently to produce improved resistance to exfoliation.
T7651	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 2 per cent, but not less than 1.5 per cent nor more than 3 per cent, and artificially aged sufficiently to produce improved resistance to exfoliation and stress corrosion cracking. Plate shall receive no further straightening after stretching.
T7E56	NA
T851	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 2 per cent, but not less than 1.5 per cent nor more than 3 per cent, and artificially aged. Plate shall receive no further straightening after stretching.
T851 (417)	NA
T8510	NA
T8511	Solution heat treated and stress relieved by stretching to produce a nominal permanent set of 1.5 per cent, but not less than 1 per cent nor more than 3 per cent, and precipitation heat treated.
T852	Solution heat treated and stress relieved by compression to produce a permanent set of 1 to 5 per cent, and precipitation heat treated.
T87	NA
T87+	NA

TABLE 8.1 2014 Aluminium Alloy

Material composition (see below)	Heat treatment	Form and thickness, specimen, product mm (in)	Orientation	SI Units					British Units					No. of tests	Derivation No.
				Temperature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temperature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T6	Forging 18, 23 (0.7, 0.9)	L-T T-L	21 29	440 430	30 —	31 16	31 —	70 84	64 62	27 —	28 15	29 —	2 1	13
		Forging 6, 23 (0.3, 0.9)	T-L	21	432	17	19	20	70	63	16	17	18	4	
		Forged bar 19, 114 (0.8, 4.5)	L-T T-L	21 29 28	443 430 430	— 18 —	31 19 19	— 20 —	70 85 82	64 62 62	— 17 —	28 17 17	— 18 —	1 2 1	
		Forged bar 6, 114 (0.3, 4.5)	T-L	21	430	18	18	19	70	62	16	17	17	2	
NA		Forging 25, 203 (1, 8)	S-L S-T	21	421 421	17 21	18 21	18 21	70	61 61	16 19	16 19	16 19	4 4	4
NA		Forging 19, — (0.8, —)	NA	21	440 432	30 16	31 18	31 21	70	64 63	27 14	28 17	29 19	2 4	6
NA	T61	Forging 13, 50 (0.5, 2)	S-L	28	430	19	20	21	82	62	18	18	19	2	13
		Forging 13, 38 (0.5, 1.5)	S-T	21	390	22	22	22	70	57	20	20	20	2	
NA	T611	Forging 19, 25 (0.8, 1)	S-L	30 21	425 415	20 19	21 20	21 20	86 70	62 60	19 17	19 18	19 18	4 2	
NA	T651	Plate 25, 127 (1, 5)	L-T T-L	21	404 399	— —	25 21	— —	70	59 58	— —	22 19	— —	1 1	
		Plate 25, 64 (1, 2.5)	L-T	21	444	26	26	26	70	64	23	23	24	2	
HEAT TREATMENTS T6 T61 T611 T651															
Material composition	Chemical analysis of alloying elements by weight (per cent)														
	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Ti + Zn				Other: Each	Other: Total	
Specification	0 0.10	3.9 5.0	0 0.7	0.20 0.8	0.40 1.2	0.50 1.2	0 0.15	0 0.25	0 0.20				0 0.05	0 0.15	

TABLE 8.1 2014 Aluminium Alloy (continued)

Material composition (see below)	Heat treatment	Form and thickness, specimen, product mm (in)	Orientation	SI Units					British Units					No. of tests	Derivation No.
				Temperature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temperature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T651	Plate 25, 44 (1, 1.8)	L-T	21	472	24	24	25	70	68	22	22	22	3	13
			T-L		456	25	26	26		66	23	23	24	3	
		Plate 25, 25 (1, 1)	L-T	29	449	22	25	27	84	65	20	23	25	5	
			T-L	21	458	26	27	27	70	66	24	24	25	4	
				29	450	21	22	23	84	65	20	20	21	4	
				21	454	22	23	25	70	66	20	21	22	10	
				-196	517	-	29	-	-320	75	-	26	-	1	
		Plate 13, 127 (0.5, 5)	S-L	21	379	19	20	20	70	55	18	18	18	2	
		Plate 13, 38 (0.5, 1.5)	L-S	31	460	26	26	26	88	67	23	24	24	2	
			L-T		460	21	21	21		67	19	19	20	3	
			T-L		436	21	21	22		63	19	19	20	2	
			T-S		436	24	25	25		63	22	22	23	3	
NA	Plate 25, 25 (1, 1)	T-L	21	454	23	23	25	70	66	21	21	23	5	3	
NA	Plate 25, - (1, -)	L-T	21	428	-	27	-	70	62	-	25	-	1	13	
T-L		418	-	23	-		61	-	21	-	1				
i	T652	Forging 51, 152 (2, 6)	T-L	21	398	25	29	33	70	58	23	26	30	3	2
ii		Forging 38, 127 (1.5, 5)	L-T	21	419	31	32	33	70	61	28	29	30	3	
			T-L		395	20	22	23		57	18	20	21	3	
					387	18	20	22		56	17	18	20	3	
iii		Forging 38, 102 (1.5, 4)	L-T	21	431	36	38	39	70	63	33	34	35	3	
			T-L		408	25	25	26		59	23	23	24	3	
iv		Forging 25, 76 (1, 3)	L-T	21	456	29	29	30	70	66	26	27	27	3	
			T-L		449	21	22	22		65	20	20	20	2	
v		Forging 19, 51 (0.8, 2)	L-T	21	459	27	28	30	70	67	24	25	27	3	
	T-L			447	21	21	21		65	19	19	19	2		
HEAT TREATMENTS															
T651															
T652															
Material composition	Chemical analysis of alloying elements by weight (per cent)														
	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn	Ti + Zn			Other: Each	Other: Total		
Specification	0 0.10	3.9 5.0	0 0.7	0.20 0.8	0.40 1.2	0.50 1.2	0 0.15	0 0.25	0 0.20			0 0.05	0 0.15		
i	0.01	4.40	0.22	0.49	0.71	0.94	0.04	0.08	0.12						
ii	0.007	4.30	0.22	0.51	0.69	0.91	0.04	0.09	0.13						
iii	0.08	4.43	0.21	0.63	0.71	0.92	0.04	0.09	0.13						
iv	0.01	4.47	0.22	0.69	0.70	0.98	0.04	0.11	0.15						
v	0.01	4.41	0.24	0.50	0.73	0.97	0.04	0.14	0.18						

TABLE 8.2 2020 Aluminium Alloy

Material composition (see below)	Heat treatment	Form and thickness, specimen, product mm (in)	Orientation	SI Units					British Units					No. of tests	Derivation No.
				Temperature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temperature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T6	Plate 19, 20 (0.8, 0.8)	L-T	30	521	22	22	23	86	76	20	20	21	3	13
		Extrusion 17, 18 (0.7, 0.7)	L-T	21	521	—	25	—	70	76	—	22	—	1	
NA	T651	Plate 35, 35 (1.4, 1.4)	L-T	21	532	22	26	30	70	77	20	23	27	6	1
			T-L		534	18	19	19		77	17	17	17	2	
		Plate 25, 35 (1, 1.4)	L-T	29	526	22	23	25	84	76	20	21	23	3	
				21	534	23	24	25	70	78	21	22	23	2	
			T-L	29	534	19	19	20	84	77	17	17	18	3	
				21	541	19	19	19	70	78	17	17	18	2	
		Plate 13, 35 (0.5, 1.4)	S-L	31	513	17	17	17	88	74	15	15	16	2	
NA		Plate 25, 40 (1, 1.4)	L-T T-L	21	528 536	23 18	24 20	25 23	70	77 78	21 17	22 18	23 21	9 6	
HEAT TREATMENTS															
T6															
T651															
Material composition	Chemical analysis of alloying elements by weight (per cent)													Other : Each	Other : Total
	Cd	Cu	Fe	Li	Mg	Mn	Si	Ti	Zn						
Specification	0.10 0.35	4.0 5.0	0 0.40	0.9 1.7	0 0.03	0.30 0.8	0 0.40	0 0.10	0 0.25				0 0.05	0 0.15	

TABLE 8.3 2024 Aluminium Alloy

Mat- erial comp- osition (see below)	Heat treat- ment	Form and thickness, specimen, product mm (in)	Orien- tation	SI Units					British Units					No. of tests	Deri- vation No.
				Temp- erature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temp- erature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T351	Plate 25, 64 (1, 2.5)	L-T	29	385	30	30	31	85	56	27	28	28	2	13
			S-L	21	371	—	33	—	70	54	—	30	—	1	
				32	292	—	21	—	90	42	—	19	—	1	
				29	309	—	24	—	85	45	—	22	—	1	
		Plate 19, 25 (0.8, 1)	T-L	29	338	29	29	29	84	49	26	26	27	2	
		Extrusion 38, 127 (1.5, 5)	T-L	28 21	283 299	26 —	27 26	27 —	82 70	41 43	24 —	24 23	24 —	2 1	
		Extrusion 38, 76 (1.5, 3)	T-L	21	294	28	28	28	70	43	25	25	26	4	
		Extrusion 25, 76 (1, 3)	S-L	28	291	23	25	26	82	42	21	23	24	4	
		Forged bar 38, 127 (1.5, 5)	T-L	28	307	27	27	28	82	45	24	25	25	2	
Forged bar 38, 76 (1.5, 3)	T-L	28	315	25	26	26	82	46	23	24	24	2			
Forged bar 25, 89 (1, 3.5)	T-L	28	286	28	28	28	82	42	25	25	26	2			
Forged bar 25, 76 (1, 3)	S-L	28	290	25	25	25	82	42	23	23	23	2			
NA		Plate 32, 76 (1.3, 3)	S-T	21	441	23	23	24	70	64	21	21	22	3	
HEAT TREATMENTS															
T351															
Chemical analysis of alloying elements by weight (per cent)															
Material composition		Cr	Cu	Fe	Mg	Mn	Si	Zn					Other : Each	Other : Each	
Specification		0 0.10	3.8 4.9	0 0.50	1.2 1.8	0.30 0.9	0 0.50	0 0.25					0 0.05	0 0.15	

TABLE 8.3 2024 Aluminium Alloy (continued)

Material composition (see below)	Heat treatment	Form and thickness, specimen, product mm (in)	Orientation	SI Units					British Units					No. of tests	Derivation No.
				Temperature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temperature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T3511	Extrusion 30, - (1.2, -)	L-T	21	422	38	42	44	70	61	34	38	40	4	13
NA	T851	Plate 19, 76 (0.8, 3)	L-S	93	389	33	33	34	200	56	30	30	31	2	
				21	421	33	34	35	70	61	30	31	32	3	
				-18	436	35	35	35	0	63	31	32	32	2	
				-54	444	32	33	35	-65	64	29	30	31	3	
			L-T	149	379	29	30	30	300	55	27	27	27	3	
				93	404	28	29	31	200	59	26	27	28	3	
				21	437	30	30	30	70	63	27	27	27	2	
				-18	452	28	30	32	0	66	25	28	30	3	
			T-L	-54	461	27	29	30	-65	67	24	26	28	3	
				149	373	24	24	25	300	54	22	22	22	2	
				93	402	23	24	25	200	58	21	22	23	3	
				21	438	22	24	25	70	64	20	22	23	3	
				-18	452	23	24	25	0	66	21	22	23	2	
				-54	459	-	26	-	-65	67	-	23	-	1	
NA		Plate 35, 35 (1.4, 1.4)	L-T	21	454	24	25	28	70	66	22	23	25	6	11 ⁺
			T-L	21	447	20	23	28	70	65	18	21	25	2	
		Plate 25, 35 (1, 1.4)	L-T	21	452	25	25	25	70	66	23	23	23	2	
			T-L	21	453	24	25	26	70	66	22	23	24	2	
		Plate 25, 25 (1, 1)	L-T	21	453	-	23	-	70	66	-	21	-	1	
			T-L	21	456	-	24	-	70	66	-	22	-	1	
		Plate 19, 19 (0.8, 0.8)	L-T	21	450	-	21	-	70	65	-	19	-	1	
			T-L	21	459	21	21	22	70	67	19	20	20	2	
Plate 16, 16 (0.6, 0.6)	L-T	21	463	24	25	26	70	67	22	23	24	2			
	T-L	21	459	21	21	22	70	67	19	20	20	2			
Plate 13, 35 (0.5, 1.4)	L-S	21	456	24	25	25	70	66	22	22	23	2			
	T-S	21	451	-	25	-	70	65	-	23	-	1			
Plate 13, 13 (0.5, 0.5)	L-T	21	463	23	23	23	70	67	21	21	21	2			
	T-L	21	459	21	21	21	70	67	19	19	20	2			
HEAT TREATMENTS															
T3511															
T851															
Material composition	Chemical analysis of alloying elements by weight (per cent)												Other: Each	Other: Each	
	Cr	Cu	Fe	Mg	Mn	Si	Zn								
Specification	0 0.10	3.8 4.9	0 0.50	1.2 1.8	0.30 0.9	0 0.50	0 0.25						0 0.05	0 0.15	

TABLE 8.3 2024 Aluminium Alloy (continued)

Mat- erial comp- osition (see below)	Heat treat- ment	Form and thickness, specimen, product mm (in)	Orien- tation	SI Units					British Units					No. of tests	Deri- vation No.		
				Temp- erature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temp- erature °F	σ_p 10 ³ lb/in ²	K_{Ic} 10 ³ lb/in ^{3/2}						
						min.	mean	max.			min.	mean	max.				
NA	T851	Plate 35, 35 (1.4, 1.4)	L-T	21	453 450	23 22	25 22	28 22	70	66 65	21 20	23 20	25 20	6 2	13		
			T-L	28 21 28 21	452 452 445 449	25 — 22 20	25 25 22 21	26 — 23 22	82 70 82 70	66 66 65 65	22 — 20 18	23 23 20 19	23 — 21 20				
		Plate 25, 35 (1, 1.4)	L-T	29	475 466	23 21	23 21	23 21	84	69 68	21 19	21 19	21 19	3 3			
			T-L														
		Plate 13, 35 (0.5, 1.4)	L-S	31 30	456 454	25 22	25 23	26 24	88 86	66 66	22 20	23 21	23 22	2 3			
				S-L	31 31	442 452	17 22	18 23	19 23	88 88	64 66	16 20	16 21	17 21		3 3	
			T-S	30 31	451 442	— 17	25 17	— 17	86 88	65 64	— 16	23 16	— 16	1 3			
				S-T	31 30	442 443	17 17	17 18	17 19	88 86	64 64	16 16	16 16	16 17		3 3	
			Plate 32, 81 (1.3, 3.2)	L-T	21	409	20	20	21	70	59	19	19	19		2	
			Plate 32, 51 (1.3, 2)	L-T	21	440	24	26	28	70	64	22	24	26		4	
		NA		Plate 25, 102 (1, 4)	L-T T-L	21	444 435	22 20	25 21	27 22	70	64 63	20 18	23 19		25 20	4 4
				Plate 19, 19 (0.8, 0.8)	L-T	21	483 473	24 24	25 24	26 24	70	70 69	22 22	23 22		24 22	3 3
Plate 9, 9 (0.4, 0.4)	L-T T-L			21	463 459	— 24	24 25	— 26	70	67 67	— 22	22 23	— 24	1 3			
NA		Plate 25, 76 (1, 3)	L-T T-L	21	448 441	23 —	23 20	24 —	70	65 64	21 —	21 18	22 —	3 1			
HEAT TREATMENTS																	
T851																	
Material composition		Chemical analysis of alloying elements by weight (per cent)															
		Cr	Cu	Fe	Mg	Mn	Si	Zn					Other: Each	Other: Total			
Specification		0 0.10	3.8 4.9	0 0.50	1.2 1.8	0.30 0.9	0 0.50	0 0.25					0 0.05	0 0.15			

TABLE 8.3 2024 Aluminium Alloy (continued)

Mat- erial comp- osition (see below)	Heat treat- ment	Form and thickness, specimen, product mm (in)	Orien- tation	SI Units					British Units					No. of tests	Deri- vation No.
				Temp- erature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temp- erature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T851	Plate 19, 76 (0.8, 3)	L-T T-L S-T	21	448 441 441	26 24 —	29 25 26	35 27 —	70	65 64 64	24 22 —	27 23 24	32 25 —	4 5 1	13
		Plate 16, 76 (0.6, 3)	L-T T-L	21	448 441	32 25	32 26	32 26	70	65 64	29 23	29 24	29 24	2 2	
		Plate 25, 76 (1, 3)	L-T	21	455	26	26	26	70	66	24	24	24	2	
NA		Plate 25, 44 (1, 1.8)	L-T	29	448	—	26	—	84	65	—	23	—	1	
		Plate 19, 44 (0.8, 1.8)	L-T	21	448	25	25	26	70	65	23	23	23	2	
		Plate 16, 76 (0.6, 3)	L-T T-L	21	448 441	22 20	24 20	26 21	70	65 64	20 18	22 18	24 19	5 3	
		Plate 13, 44 (0.5, 1.8)	L-T	21	448	30	30	31	70	65	27	28	28	2	
		Plate 32, 76 (1.3, 3)	T-L	21	448	25	25	25	70	65	23	23	23	2	
		Plate 18, 19 (0.7, 0.8)	L-T	21	462	24	24	24	70	67	22	22	22	2	
NA		Plate 25, 38 (1, 1.5)	L-T	21	465	27	27	28	70	68	25	25	25	2	
NA		Plate 35, 35 (1.4, 1.4)	T-L	21 —80 —196	444 477 545	22 23 24	22 24 24	23 25 24	70 —112 —320	64 69 79	20 21 22	20 22 22	21 23 22	3 2 2	3
NA		Plate 35, 35 (1.4, 1.4)	T-L	21	444	22	22	23	70	64	20	20	21	3	5
HEAT TREATMENTS															
T851															
Material composition	Chemical analysis of alloying elements by weight (per cent)														
	Cr	Cu	Fe	Mg	Mn	Si	Zn						Other: Each	Other: Total	
Specification	0 0.10	3.8 4.9	0 0.50	1.2 1.8	0.30 0.9	0 0.50	0 0.25						0 0.05	0 0.15	

TABLE 8.3 2024 Aluminium Alloy (continued)

Material composition (see below)	Heat treatment	Form and thickness, specimen, product mm (in)	Orientation	SI Units					British Units					No. of tests	Derivation No.
				Temperature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temperature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T851	Plate 25, 35 (1, 1.4)	T-L	21	444	22	23	23	70	64	20	21	21	3	5
		Plate 13, 35 (0.5, 1.4)	T-L	21	444	21	22	23	70	64	19	20	21	3	
NA		Plate 25, 40 (1, 1.4)	L-T T-L	21	454 448	22 20	26 22	30 25	70	66 65	20 18	24 20	27 23	12 8	1
NA	T8510	Extrusion 25-64, 70-114 (1-2.5, 2.8-4.5)	L-T T-L S-L	21	422 416 401	31 17 15	33 18 17	36 17 18	70	61 60 58	28 16 14	30 16 16	33 16 17	3 3 3	13
NA	T8511	Extrusion 25, 89 (1, 3.5)	L-T T-L S-T	21	459 426 425	26 18 18	26 18 18	27 18 19	70	67 62 62	24 16 16	24 16 17	24 16 17	2 2 2	
NA	T852	Forging 51, 152 (2, 6)	T-L	21	399	17	18	20	70	58	15	17	18	2	
		Forging 25, 121 (1, 4.8)	L-S	29	444	-	29	-	84	64	-	26	-	1	
			S-L		420	-	18	-		61	-	16	-	1	
			L-T		444	-	26	-		64	-	24	-	1	
			T-S		450	-	17	-		65	-	15	-	1	
		Forging 19, 178 (0.8, 7)	L-T	28	404	-	21	-	83	59	-	19	-	1	
			T-L	28	373	22	25	29	82	54	20	23	26	2	
Forging 19, 127 (0.8, 5)	L-T	28	389	19	21	23	83	56	17	19	21	2			
	T-L	28	407	-	28	-	82	59	-	26	-	1			
	L-T	29	427	-	24	-	84	62	-	22	-	1			
NA	T852	T-L	29	434	-	17	-		63	-	15	-	1		
		S-T		397	-	19	-		58	-	18	-	1		
		Forging 13, 178 (0.5, 7)	S-T	28	363	19	20	22	83	53	17	18	20	3	
NA		Forging 18, 152 (0.7, 6)	S-T	21	372	19	19	19	70	54	18	18	18	2	4

HEAT TREATMENTS

T851

T8510

T8511

T852

Material composition	Chemical analysis of alloying elements by weight (per cent)												Other: Each	Other: Total
	Cr	Cu	Fe	Mg	Mn	Si	Zn							
Specification	0 0.10	3.8 4.9	0 0.50	1.2 1.8	0.30 0.9	0 0.50	0 0.25						0 0.05	0 0.15

TABLE 8.3 2024 Aluminium Alloy (continued)

Material composition (see below)	Heat treatment	Form and thickness, specimen, product mm (in)	Orientation	SI Units					British Units					No. of tests	Derivation No.
				Temperature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temperature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
i	T852	Forging 51, 152 (2, 6)	L-T T-L	21	387 399	31 17	33 18	34 20	70	56 58	28 15	30 17	31 18	3 2	2
ii		Forging 38, 127 (1.5, 5)	L-T T-L	21	380 391	29 19	30 19	31 20	70	55 57	26 17	27 18	28 18	3 3	
iii		Forging 38, 102 (1.5, 4)	L-T	21	451	27	30	32	70	65	25	27	29	3	
iv		Forging 25, 76 (1, 3)	L-T T-L	21	460 476	24 18	25 19	27 21	70	67 69	22 17	23 18	25 19	3 3	
v		Forging 19, 51 (0.8, 2)	L-T T-L	21	445 440	25 22	27 25	28 26	70	65 64	23 20	24 22	26 24	3 3	
i		Forging 13, 152 (0.5, 6)	S-L	21	372	16	18	19	70	54	15	16	17	3	
ii		Forging 13, 127 (0.5, 5)	S-L	21	376	17	17	18	70	55	16	16	16	2	
iii		Forging 6, 102 (0.3, 4)	S-L	21	418	16	17	18	70	61	15	16	16	3	
NA		Forging 32, 127 (1.3, 5)	L-T	21	400	40	40	41	70	58	37	37	37	2	
	Forging 32, 76 (1.3, 3)	L-T	21	400	28	31	34	70	58	26	28	31	3		
HEAT TREATMENTS															
T852															
Material composition	Chemical analysis of alloying elements by weight (per cent)														
	Cr	Cu	Fe	Mg	Mn	Si	Zn					Other: Each	Other: Total		
Specification	0 0.10	3.8 4.9	0 0.50	1.2 1.8	0.30 0.9	0 0.50	0 0.25					0 0.05	0 0.15		
i	0.003	4.46	0.14	1.58	0.58	0.11	0.07					Ti - 0.03			
ii	0.02	4.50	0.17	1.65	0.55	0.12	0.18					Ti - 0.03			
iii	0.02	4.51	0.18	1.65	0.57	0.12	0.16					Ti - 0.03			
iv	0	4.63	0.15	1.54	0.53	0.11	0.07					Ti - 0.02			
v	0	4.63	0.15	1.54	0.53	0.11	0.07					Ti - 0.02			

TABLE 8.3 2024 Aluminium Alloy (continued)

Mat- erial comp- osition (see below)	Heat treat- ment	Form and thickness, specimen, product mm (in)	Orien- tation	SI Units					British Units					No. of tests	Deri- vation No.
				Temp- erature °C	σ_p MN/m ²	K_{Ic} MN/m ^{3/2}			Temp- erature °F	σ_p 10 ³ lbf/in ²	K_{Ic} 10 ³ lbf/in ^{3/2}				
						min.	mean	max.			min.	mean	max.		
NA	T852	Forging 32, 76 (1.3, 3)	L-T	129	NA	—	34	—	265	NA	—	31	—	1	13
			T-L	21	448	40	40	41	70	65	36	37	37	3	
				129	NA	—	26	—	265	NA	—	24	—	1	
		Forging 25, 76 (1, 3)	T-L	21	400	22	23	23	70	58	20	21	21	3	
HEAT TREATMENTS															
T852															