

FATIGUE LIMIT OF UNNOTCHED STEELS (Related to tensile strength)

1. NOTATION

1.1 General Symbols

f_t	tensile strength of material	N/m ²	lbf/in ²
m	parameter characterising shape of mean stress diagram		
N	endurance		
R	stress ratio (S_{min}/S_{max})		
S_a, Q_a	semi-stress range for direct and shear stresses respectively	N/m ²	lbf/in ²
S_m	mean stress	N/m ²	lbf/in ²
S_{min}, S_{max}	minimum and maximum stresses in fatigue cycle respectively		

1.2 Fatigue Limit Symbols

$Q_{a0}(\infty)$	fatigue limit under torsional loading in terms of shear stress	N/m ²	lbf/in ²
$S_{am}(N)$	fatigue strength at endurance N for a given mean stress	N/m ²	lbf/in ²
$S_{a0}(N)$	fatigue strength at endurance N when $S_m = 0$	N/m ²	lbf/in ²
$S_{aAm}(\infty)$	fatigue limit under axial load at a given mean stress	N/m ²	lbf/in ²
$S_{aA0}(\infty)$	fatigue limit under axial load when $S_m = 0$	N/m ²	lbf/in ²
$S_{aB0}(\infty)$	fatigue limit under bending loading when $S_m = 0$	N/m ²	lbf/in ²
$S_{aR}(\infty)$	fatigue limit under axial load at $R = 0$	N/m ²	lbf/in ²

1.3 Suffixes

- 10 relates to 10 per cent probability of survival of a population with a confidence interval of 95 per cent
- 90 relates to 90 per cent probability of survival of a population with a confidence interval of 95 per cent
- a bar over a symbol thus, $\bar{S}_{aA0}(\infty)$, indicates that it relates to a mean fatigue limit of a population with a confidence of 95 per cent.

Both SI and British units are quoted.

2. INTRODUCTION

This Item provides data on the fatigue strength at high endurance of high* alloy and low alloy steel specimens under alternating stress. Data are provided on bending, axial and torsional loading. The data are grouped according to the type of loading and stress ratio applied. In Figures 2, 4, 6 and 9 curves are plotted of fatigue limit against tensile strength for specimens under the various load conditions. This enables an assessment to be made of the maximum alternating stress that may be applied to a component manufactured of steel of a known tensile strength. Austenitic stainless steels, precipitation hardened martensitic stainless steels and maraging steels normally do not exhibit a fatigue limit. For such steels the fatigue strengths at endurance of 10^7 to 10^8 cycles are given, see Figure 11. Data Item No. 71009[†] indicates how these data may be used in a general strategy when designing against fatigue.

3. FATIGUE LIMIT

In order to correlate data from a wide range of sources a definition of fatigue limit has been selected that can be applied consistently to all sources. For a fatigue limit to be valid, the data of a given set must first be examined to determine whether or not a fatigue limit exists. This is done by inspection of a mean line through all the data. Once the existence of a fatigue limit has been established, its value is taken to be the mean of (a) and (b) below.

(a) The highest alternating stress at which an unbroken specimen is recorded

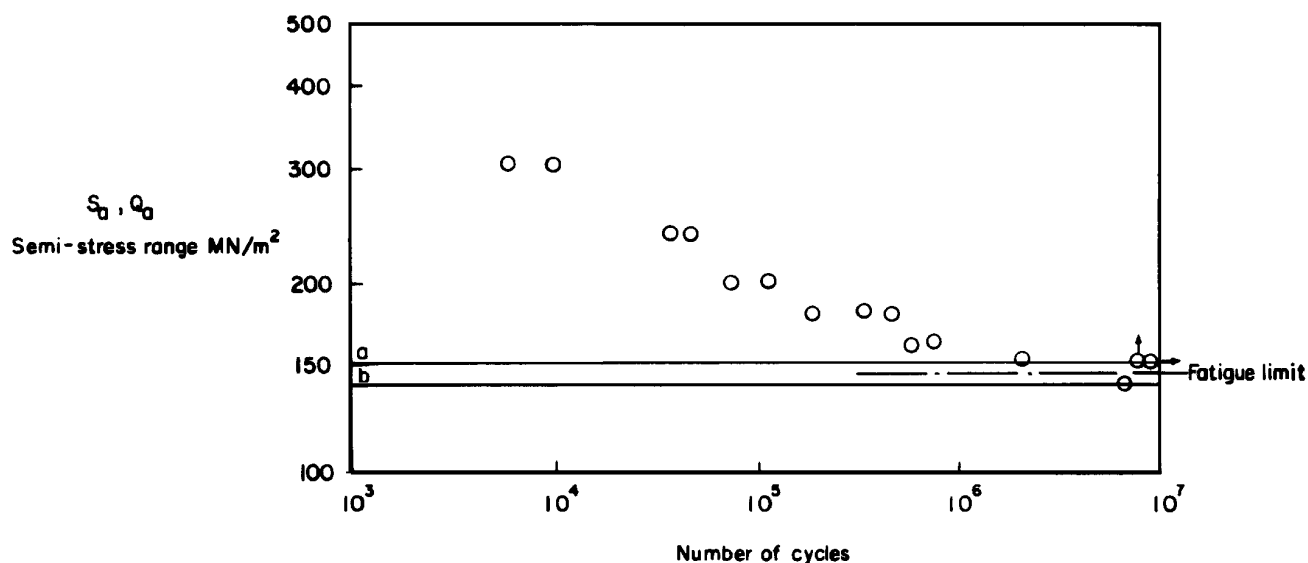
and

(b) the lowest alternating stress at which a broken specimen is recorded.

Normally both (a) and (b) occur at $N > 2 \times 10^6$ as illustrated in Sketch 3.1. Figures 2, 4, 6 and 9 all use this definition. For some materials, however, a fatigue limit is not indicated by the data, and in such cases a fatigue strength at a specified endurance is derived from the mean line of the $S-N$ curve, usually at $N = 10^7$ or 10^8 cycles. Figure 11 gives details of these materials.

* In this Data Item a high alloy steel is defined as a steel containing greater than 5 per cent of any one alloying element.

[†] Data Item No. 71009 "Design against fatigue. Design principles."



Sketch 3.1

4. SPECIMEN AND TEST CONDITIONS

Most test specimens were in the form of round bar, the diameter at the critical section generally being in the range 5.6 mm to 9.0 mm (0.22 in to 0.35 in), although a few specimens were outside this range, being up to 50 mm (2.0 in) in diameter. About 12 per cent of the specimens tested were of sheet, tested in out-of-plane bending and axial ($R = 0$) loading. These had a thickness in the range 0.8 mm to 2.6 mm (0.032 in to 0.102 in) and a neck width in the range 15 mm to 38.1 mm (0.6 in to 1.5 in).

A wide variety of heat treatment conditions is covered by the data. The surface finish of most specimens was obtained by grinding and/or polishing, recorded values of the centre-line-average index being within the range $0.03 \mu\text{m}$ to $0.8 \mu\text{m}$ (1.2×10^{-6} in to 32×10^{-6} in), although a few specimens were fine turned. No subsequent chemical, thermal or mechanical treatment was applied after machining, except for stress relief in a few cases.

Values of f_t used in plotting the data points shown were, whenever possible, those obtained from control tests on specimens from the same batch of material. Occasionally such a value was not available, in which case the appropriate specification value was used.

A number of factors such as specimen size*, surface finish, grain direction and surface treatment are known to affect endurance, but are not considered in this Item. All specimens were cut in the longitudinal direction.

* See Data Item No.87016 "Effect of size on fatigue strength of steel components".

5. PRESENTATION OF DATA

Mean curves are shown through the fatigue limit data constructed as described in Sections 5.1, 5.2, 5.3 and 5.4. These mean curves are presented in Figure 1, where a comparison of the effect of all four loading conditions can be made. In addition curves for 90 and 10 per cent probability of survival for 95 per cent confidence are shown on Figures 2, 4, 6 and 9, and the corresponding probability distributions are shown on Figures 3, 5, 7 and 10 respectively. Tables 8.1, 8.2, 8.3 and 8.4 list the tensile strength of the materials together with the observed values of the fatigue limit, where available, and the mean and 90 per cent values of fatigue limit taken from the curves, where appropriate, for each loading case.

5.1 Reversed Bending, $R = -1$, Figures 2 and 3

Figure 2 presents 125 fatigue limit values for high and low alloy steels under reversed bending with zero mean stress. The data were obtained mostly from specimens tested either as a rotating cantilever (single or two-point loading) or as a rotating beam (four-point loading). Some were obtained from sheet specimens tested in reversed flexure. About 10 per cent of the data represented are from high alloy steels, and these are indicated in the figure.

A mean line is shown that has been constructed from a least squares parabolic fit through the data. It can be seen from Figure 2 that the relationship between the tensile strength of a steel and its fatigue limit is approximately linear up to a tensile strength of about 900 MN/m^2 ($130\,000 \text{ lbf/in}^2$). The data indicate that this relationship then deviates progressively from the linear until a constant fatigue limit having a mean value of 715 MN/m^2 ($104\,000 \text{ lbf/in}^2$) at a tensile strength of 1800 MN/m^2 ($260\,000 \text{ lbf/in}^2$) is reached.

The upper and lower curves of Figure 2 project the behaviour of the population from the sample analysis shown in Figure 3. The lower curve indicates a 90 per cent probability of survival* based upon a 95 per cent confidence level, and the upper curve represents a 10 per cent probability of survival, based upon the same confidence level. Appendix A details the equations used in these calculations, and should be used when calculating alternative probabilities of survival and confidence levels.

Figure 3 is plotted on Normal (Gaussian) distribution probability paper, and represents the deviation of the sample data from the mean line shown in Figure 2. In Figure 3 the distribution of the data around the mean line indicates that the data approximate to a Normal distribution. Owing to the divergence of a small percentage of data at the extremes, extrapolation of this line should be treated with caution.

5.2 Axial Loading, $R = -1$, Figures 4 and 5

Figure 4 presents 32 fatigue limit values for high and low alloy steels under reversed axial loading (that is, having a zero mean stress). Two of the fatigue limit values are for specimens of high alloy steels, these being indicated.

The mean curve through the data is constructed from a least squares parabolic fit. The curve indicates no initial linear region, unlike the bending case. Only two results are available above $f_t = 1100 \text{ MN/m}^2$ ($160\,000 \text{ lbf/in}^2$) so that the value at which the curve becomes horizontal cannot be established with any confidence. The scatter of the data in Figure 4 is greater than that in Figure 2, (which is for bending with $R = -1.0$).

The upper and lower lines of Figure 4 project the behaviour of the population from the sample analysis shown in Figure 5. These represent the 10 per cent and 90 per cent probabilities of survival for a 95 per cent confidence level.

* That is, the probability of attaining a given mean fatigue limit.

Figure 5 is plotted on Normal (Gaussian) distribution probability paper, and represents the deviation of the sample data from the mean line in Figure 4. The distribution of the data around the mean line shows that this can be taken as a Normal distribution, but the divergence of the data at the extremes indicates that extrapolation of the line should be carried out with caution. Calculation of alternative probabilities of survival and confidence levels should be carried out using the information provided in Appendix A.

5.3 Reversed Torsional Loading, $R = -1$, Figures 6, 7 and 8

Figure 6 presents 56 fatigue limit values for high and low alloy steels under reversed torsional loading having a zero mean stress. The results are plotted as $Q_{a0}(\infty)$ against f_t . In this figure some 5 per cent of the data were obtained from high alloy steels. The mean curve through the data was constructed from a least squares parabolic fit.

The initial region of the mean curve of Figure 6 indicates a linear relationship between the fatigue limit and the tensile strength, which continues up to a tensile strength of about 800 MN/m² (116 000 lbf/in²). The curve then deviates progressively from this linear relationship until, at about 1800 MN/m² (260 000 lbf/in²), the fatigue limit becomes constant with increasing tensile strength. This maximum fatigue limit in torsion is at about 445 MN/m² (65 000 lbf/in²), compared to 715 MN/m² (104 000 lbf/in²) in bending.

The upper and lower curves of Figure 6 project the behaviour of the population from the sample analysis shown in Figure 7. These are the 10 per cent and 90 per cent probabilities of survival for a 95 per cent confidence level.

Figure 7 is plotted on Normal (Gaussian) distribution probability paper, and represents the deviation of the sample data from the mean line in Figure 6. The distribution of data around the mean line indicates that the data approximate to a Normal distribution, but the divergence of the data at the upper end indicates that extrapolation should be treated with caution. Calculation of alternative probabilities of survival and confidence levels should be carried out using the information provided in Appendix A.

Figure 8 repeats the data of Figure 6 and shows two curves, the upper, solid curve being the mean line through the torsional data from Figure 6, and the lower, broken curve, representing the mean line through the bending data of Figure 2 modified using von Mises criterion* thus,

$$Q_{a0}(\infty) = \frac{1}{\sqrt{3}} S_{aB0}(\infty). \quad (5.1)$$

It can be seen from Figure 8 that designing for torsion using bending data modified by the factor derived from the von Mises criterion is conservative. It must be noted that although the von Mises criterion is most commonly used in connection with yielding, it has been suggested for use with fatigue crack initiation data, see References 43 and 45.

5.4 Axial Loading, $R = 0$, Figures 9 and 10

Figure 9 presents 27 fatigue limit values for high and low alloy steels under zero to tension loading, that is, axial loading where the mean stress is equal to the semi-stress range. Some of the data are for high alloy steels and these are indicated.

The mean line through the data was obtained using a linear least squares fit. Within the range of those data there is no deviation from this linear region. There are no data available for $f_t > 1100$ MN/m² (160 000 lbf/in²) and so the curve should not be extrapolated beyond its end point.

* See Table 3.1 of Data Item No. 73004 "Criteria of yielding for ductile materials under static load".

The upper and lower curves of Figure 9 project the behaviour of the population from the sample analysis shown in Figure 10. These are the 10 per cent and 90 per cent probability of survival boundaries for a 95 per cent confidence level.

Figure 10 is plotted on Normal (Gaussian) distribution probability paper, and represents the deviation of the sample data from the mean line in Figure 9. The distribution of the data around the mean line shows that this can be taken as a Normal distribution. The divergence of the data at the extremes indicates that extrapolation should be carried out with caution. Calculation of alternative probabilities of survival and confidence levels should be carried out using the information provided in Appendix A.

5.5 Fatigue Strength of High Alloy Steels in Bending, $R = -1$, Figure 11

The curves given in Figure 11 are for steels containing high percentages of particular alloying elements (generally greater than 5 per cent). Curves indicating the mean of test results and 90 per cent boundaries of the results are given. The curves are grouped according to the various types of steel over the range of tensile strength for which data are available, and refer to steels for which only a fatigue strength at a particular endurance can be provided.

The data that are available for austenitic stainless steels suggest that there may be a fatigue limit at an endurance of approximately 10^7 reversals. However, since only a few results are available it is suggested that the curves should be interpreted as the fatigue strength $S_{a0}(10^7)$.

No definite fatigue limits were established for precipitation hardened martensitic stainless steels and maraging steels within the range of endurance up to $N = 10^8$ reversals. The curves for these steels should therefore be taken to indicate the fatigue strength $S_{a0}(10^8)$ and are not applicable for $N > 10^8$.

5.6 Effect of Mean Stress on Fatigue Strength at High Endurance of Low Alloy Steels, Figure 12

In Figure 12 test results are shown that each represent a fatigue limit or fatigue strength at high endurance. It must be noted that in this figure the fatigue limits are not as defined in Section 3, but are the fatigue limits obtained by the authors of the papers from which data have been obtained. Curves are provided for

$$S_{am}(N)/S_{a0}(N) = 1 - (S_m/f_t)^m \quad (5.2)$$

for values of m of 1.0, 1.5 and 2.0. Figure 12 demonstrates that for low alloy steels of tensile strength up to 1400 MN/m^2 ($200\,000 \text{ lbf/in}^2$) it is usually conservative to use the linear relationship in which $m = 1$.

5.7 Tabular Presentation of Data

Tables 8.1, 8.2, 8.3 and 8.4 list the steels on which Figures 2, 4, 6 and 9 are based. The tables present the material specifications, which are grouped in ascending order of tensile strength, according to the country of origin. The test and specification values of tensile strength for the steels are recorded where available. The last four columns of the tables represent the various loading conditions, bending, axial and torsion, all for $R = -1$, and axial loading for $R = 0$. Each of these is further sub-divided into three columns, representing, in order, the actual recorded value of fatigue limit obtained from the appropriate $S-N$ curve, the value obtained from the mean curve for the particular loading condition at the required tensile strength and the value obtained from the 90 per cent probability of survival curve (at 95 per cent confidence). Where an actual value is not available the box is empty. All values derived from the curves are indicated in parenthesis, and where the curve does not extend to the necessary tensile strength no value is provided.

6. DERIVATION AND REFERENCES

6.1 Derivation

The derivation lists selected sources that have assisted in the preparation of this Item.

- | | | |
|-----|--|--|
| 1. | GOUGH, H.J.
POLLARD, H.V.
CLENshaw, W.J. | Some experiments on the resistance of metals to fatigue under combined stresses. Aeronautical Research Council Reports and Memoranda No. 2522. London, 1951. |
| 2. | FINDLEY, W.N.
MERGEN, F.C.
ROSENBERG, A.H. | The effect of range of stress on fatigue strength of notched and unnotched SAE 4340 steel in bending and torsion. 56th Annual Meeting, Am. Soc. Testing Mats, 1953. |
| 3. | OBERG, T.T.
WARD, E.J. | Fatigue of alloy steels at high stress levels. WADC TR 53-256. 1953. |
| 4. | FRITH, P.H. | Fatigue tests on rolled alloy steels made in electric and open-hearth furnaces. British Iron and Steel Institute, Report No. 50, October 1954. |
| 5. | CLEDWYN-DAVIES, D.N. | The effect of grinding on the fatigue strength of steels. Proceedings of the Institution of Mechanical Engineers, London, Volume 169, No. 2, pp. 83-91, 1955. |
| 6. | FINDLEY, W.N.
COLEMAN, J.J. | Theory for combined bending and torsion fatigue with data for SAE 4340 steel. Fatigue of Metals Conference, New York and London, 1956. |
| 7. | CHODOROWSKI, W.T. | Fatigue strength in shear of an alloy steel. Fatigue of Metals Conference, New York and London, 1956. |
| 8. | O'CONNOR, H.C.
MORRISON, J.L.M. | The effect of mean stress on the push-pull fatigue properties of an alloy steel. Fatigue of Metals Conference, New York and London, 1956. |
| 9. | WEDDEN, P.R.
COOPER, W.E. | The effect of surface treatment and cadmium electrodeposition on the fatigue properties of some high tensile steels. UK Ministry of Aviation, S and T Memo 19/58, 1958. |
| 10. | BARDGETT, W.E. | Lead additions: Effect on fatigue properties of EN24 and EN36 steels. Iron and Steel, August, 1956. |
| 11. | — | Armco precipitation hardening stainless steels technical data manual. |
| 12. | HAVER, G.F.
HOWDEN, B.S.
PATCHEN, J.W.
TEWARI, U. | Aerospace structural metals handbook. Air Force Materials Laboratory Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 1967. |
| 13. | RATCLIFFE, M.E. | Corrosion fatigue and air fatigue tests on 85 ton aircraft steel to B.S.S. 99. UK Ministry of Aviation S and T Memo 38/60, 1960. |

14. FENNER, A.J.
TAIT, J. The fatigue strength of railway wagon axles with unmatched middles. National Engineering Laboratory Report No. 100, July 1963.
15. FROST, N.E.
GREENAN, A.F. Further experiments on the propagation of edge-cracks in plate specimens. National Engineering Laboratory Report No. 132, February 1964.
16. PRZEGALINSKI, S.
BAK, R.
WOINAROWSKI, J. The influence of nickel on the fatigue of construction steels. Fatigue resistance of metals and metal parts. Institute of Iron Metallurgy, Gliwice, Buch, Warsaw, Poland. pp. 275-281, 1964.
17. ALDRIDGE, P.T. The influence of heat treatment on the fatigue strength of a carbon-manganese steel. Royal Armament Research and Development Establishment, Mem. 37/65, August 1965.
18. – Unpublished data from De Havilland Central Materials Lab. Report, 1969.
19. – The English Electric Company Ltd, Aircraft Division, test section. Test note No. 757. 1969.
20. – Hawker Siddeley AVRO Whitworth Division. Research met 267/2. 1969.
21. – Hawker Siddeley AVRO Whitworth Division. Research met 264/1. 1969.
22. – Properties and selection: Irons and steels. Metals handbook. 9th Edition, Vol. 1. pp. 44. American Society of Metals, 1978.
23. NRIM Program of the fatigue data sheet project for engineering materials manufactured in Japan. National Research Institute for Metals. Fatigue Data Sheet No. 0, Tokyo, Japan, 1978.
24. NRIM Data sheets on fatigue properties of S25C (0.25C) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 1, Tokyo, Japan, 1978.
25. NRIM Data sheets on fatigue properties of S35C (0.35C) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 2, Tokyo, Japan, 1978.
26. NRIM Data sheets on fatigue properties of S45C (0.45C) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 3, Tokyo, Japan, 1978.
27. NRIM Data sheets on fatigue properties of S55C (0.55C) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 4, Tokyo, Japan, 1978.
28. NRIM Data sheets on fatigue properties of SCr440 (0.40C-1Cr) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 8, Tokyo, Japan, 1979.

29. NRIM Data sheets on fatigue properties of SCM435 (0.35C-1Cr-0.2Mo) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 9, Tokyo, Japan, 1979.
30. NRIM Data sheets on fatigue properties of SCM440 (0.40C-1Cr-0.2Mo) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 10, Tokyo, Japan, 1979.
31. BRIGGS, J.Z.
PARKER, T.D. The super 12% Cr steels. American Society of Metals. pp. 121. 1979.
32. WEISER, P.F. Steel castings handbook. 5th Edition. 1980.
33. NRIM Data sheets on fatigue properties of SMn438 (0.38C-1.5Mn) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 16, Tokyo, Japan, 1980.
34. NRIM Data sheets on fatigue properties of SMn443 (0.43C-1.5Mn) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 17, Tokyo, Japan, 1980.
35. NRIM Data sheets on fatigue properties of SNC631 (0.31C-2.7Ni-0.8Cr) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 24, Tokyo, Japan, 1981.
36. NRIM Data sheets on fatigue properties of SNCM439 (0.39C-1.8Ni-0.8Cr-0.2Mo) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 25, Tokyo, Japan, 1981.
37. NRIM Data sheets on fatigue properties of SNCM447 (0.47C-1.8Ni-0.8Cr-0.2Mo) steel for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 26, Tokyo, Japan, 1981.
38. NRIM Data sheets on fatigue properties of SUS430 (17Cr) stainless steel bars for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 29, Tokyo, Japan, 1982.
39. NRIM Data sheets on fatigue properties of SUS403 (12Cr) stainless steel bars for machine structural use. National Research Institute for Metals. Fatigue Data Sheet No. 30, Tokyo, Japan, 1982.
40. IWASAKI, T.
et al. Fatigue strength of base metal and spot welded joints in HSLA steels for automotive applications. Nippon Kokan technical report. Overseas No. 34, pp. 31-39, Japan 1982.
41. SHINOZAKI, M.
et al. Fatigue of automotive high strength steel sheets and their welded joints. S.A.E. technical paper, series 830032. International Congress and Exposition, Detroit, Michigan, 1983.
42. SPERLE, J.O. Fatigue strength of high strength dual phase steel sheet. International Journal of Fatigue, Vol. 7, No. 2, p. 82, April 1985.

6.2 References

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

- | | | |
|-----|--|---|
| 43. | FORREST, P.G. | <i>Fatigue of metals</i> . Pergamon Press, London, 1962. |
| 44. | ESDU | Endurance of high strength steels (in bending). Data Item No. 71027. ESDU International Ltd, London, UK September 1971. |
| 45. | FROST, N.E.
MARSH, K.J.
POOK, L.P. | <i>Metal Fatigue</i> . Oxford Engineering Science Series. Clarendon Press. Oxford 1974. |
| 46. | ESDU | The statistical analysis of data from Normal distributions, with particular reference to small samples. Data Item No. 91041. ESDU International plc, London, UK, December 1991. |
| 47. | ESDU | An introduction to the statistical analysis of engineering data. Data Item No. 92040. ESDU International plc, London, UK, December 1992. |

7. EXAMPLE

It is required to estimate the fatigue limit of a steel under bending loading for $R = -1$, axial loading for $R = -1$, torsional loading for $R = -1$ and axial loading for $R = 0$. The steel is manufactured from DTD 740 and has a tensile strength of 636 MN/m^2 .

Using Tables 8.1, 8.2, 8.3 and 8.4 an initial check can be made to see if the steel DTD 740 is present. In this case the steel is not present in any of the tables, and the curves must be used to estimate the required fatigue limits.

For the first loading condition, bending loading for $R = -1$, the curve in Figure 2 should be used. At the given tensile strength, the upper curve in the figure gives a fatigue limit at which the steel has a 10 per cent probability of survival, the centre curve gives the mean fatigue limit, and the lower curve gives the fatigue limit for a 90 per cent probability of survival. Thus, for a tensile strength of 636 MN/m^2 the mean value of the fatigue limit is 355 MN/m^2 and the fatigue limit for a 90 per cent probability of survival is 302 MN/m^2 .

Similarly, values of fatigue limit can be taken for the other loading conditions from their respective curves. In this example the results can be seen tabulated below.

TABLE 7.1 Results for DTD 740, having a tensile strength of 636 MN/m^2

$S_{aB0}(\infty)$ for $R = -1$ (MN/m^2)			$S_{aA0}(\infty)$ for $R = -1$ (MN/m^2)			$Q_{a0}(\infty)$ for $R = -1$ (MN/m^2)			$S_{aR}(\infty)$ for $R = 0$ (MN/m^2)		
S_a	$\bar{S}_a$	S_{a90}	S_a	$\bar{S}_a$	S_{a90}	Q_a	$\bar{Q}_a$	Q_{a90}	S_a	$\bar{S}_a$	S_{a90}
–	355	302	–	393	301	–	240	209	–	260	245

It must be noted that the 10 and 90 per cent probability of survival curves are based upon a 95 per cent confidence level. Appendix A details the statistical method used, and explains how values for alternative confidence levels and/or probabilities of survival may be calculated.



8. TABLES

TABLE 8.1 BRITISH SPECIFICATIONS

Material specification	Heat treatment	f_t (MN/m ²)		$S_{aB0}^{(\infty)}$ $R = -1$ (BENDING) (MN/m ²)			$S_{aA0}^{(\infty)}$ $R = -1$ (AXIAL) (MN/m ²)			$Q_{a0}^{(\infty)}$ $R = -1$ (TORSION) (MN/m ²)			$S_{aR}^{(\infty)}$ $R = 0$ (AXIAL) (MN/m ²)		
		Spec.	Test	S_a	$\bar{S}_a$	S_{a90}	S_a	$\bar{S}_a$	S_{a90}	Q_a	$\bar{Q}_a$	Q_{a90}	S_a	$\bar{S}_a$	S_{a90}
Mild steel DDQ	–	292	286		(158)	(105)	230	(236)	(143)		(104)	(72)		(104)	(84)
Basic open hearth steel to BS 24 prt 1	Oil quenched 850°C, 1.5 – 2.5 min, Tempered 510°C	579	588	238	(322)	(269)		(371)	(278)		(215)	(184)		(238)	(218)
Basic open hearth steel to BS 24 prt 1	Oil quenched 850°C, 1.5 – 2.5 min, Tempered 510°C	579	588	272	(322)	(269)		(371)	(278)		(215)	(184)		(238)	(218)
Acid open hearth steel to BS 24 prt 1	Oil quenched 850°C, 2 – 3 min, Tempered 510° C	579	608	284	(333)	(280)		(378)	(285)		(222)	(190)		(247)	(227)
Acid open hearth steel to BS 24 prt 1	Oil quenched 850°C, 2 – 3 min, Tempered 510° C	579	608	265	(333)	(280)		(378)	(285)		(222)	(190)		(247)	(227)
Acid open hearth steel to BS 24 prt 1	Oil quenched 850°C, 2 – 3 min, Tempered 510° C	579	608	243	(333)	(280)		(378)	(285)		(222)	(190)		(247)	(227)
18/8 Austenitic stainless steel	1 h at 600°C in vacuum	–	689	359	(374)	(321)		(407)	(314)		(253)	(221)		(283)	(263)
Austenitic stainless steel DTD 166B	–	–	800	440	(432)	(379)		(443)	(350)		(292)	(260)		(333)	(313)
BS En36 3% Ni-Cr	Oil quenched 780°C, Tempered 400°C	–	848	429	(455)	(402)		(456)	(363)		(307)	(275)		(354)	(334)
BS En 24 1½% Ni-Cr-Mo	Oil quenched 840°C, Tempered 700°C	–	865	490	(463)	(410)		(461)	(368)		(312)	(280)		(361)	(341)

Note that numbers in parentheses indicate values taken from figures.

TABLE 8.1 BRITISH SPECIFICATIONS (Continued)

Material specification	Heat treatment	f_t (MN/m ²)		$S_{aB0}(\infty)$ $R = -1$ (BENDING) (MN/m ²)			$S_{aA0}(\infty)$ $R = -1$ (AXIAL) (MN/m ²)			$Q_{a0}(\infty)$ $R = -1$ (TORSION) (MN/m ²)			$S_{aR}(\infty)$ $R = 0$ (AXIAL) (MN/m ²)		
		Spec.	Test	S_a	$\bar{S}_a$	S_{a90}	S_a	$\bar{S}_a$	S_{a90}	Q_a	$\bar{Q}_a$	Q_{a90}	S_a	$\bar{S}_a$	S_{a90}
BS Cm151	–	–	910	484	(483)	(430)		(472)	(379)		(326)	(294)		(381)	(361)
BS 2S96	–	–	924	453	(490)	(437)		(476)	(383)		(330)	(298)		(388)	(368)
S11 Basic electric arc steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 607°C	829	931	498	(493)	(440)		(478)	(385)		(332)	(300)		(391)	(371)
S11 Basic electric arc steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 610°C	826	942	506	(497)	(444)		(480)	(387)		(335)	(303)		(396)	(376)
S11 Acid open hearth steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 655°C	851	942	523	(497)	(444)		(480)	(387)		(335)	(303)		(396)	(376)
S11 Basic electric arc steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 585°C	845	947	519	(500)	(447)		(481)	(388)		(336)	(304)		(398)	(378)
S11 Acid open hearth steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 620°C	775	947	512	(500)	(447)		(481)	(388)		(336)	(304)		(398)	(378)
S11 Basic electric arc steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 585°C	845	947		(500)	(447)		(481)	(388)		(336)	(304)		(398)	(378)
S11 Acid open hearth steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 680°C	775	947		(500)	(447)		(481)	(388)	269	(336)	(304)		(398)	(378)
BS En24	–	–	955	506	(503)	(450)		(483)	(390)		(339)	(307)		(401)	(381)

Note that numbers in parentheses indicate values taken from figures.



TABLE 8.1 BRITISH SPECIFICATIONS (Continued)

Material specification	Heat treatment	f_t (MN/m ²)		$S_{aB0}(\infty)$ $R = -1$ (BENDING) (MN/m ²)			$S_{aA0}(\infty)$ $R = -1$ (AXIAL) (MN/m ²)			$Q_{a0}(\infty)$ $R = -1$ (TORSION) (MN/m ²)			$S_{aR}(\infty)$ $R = 0$ (AXIAL) (MN/m ²)		
		Spec.	Test	S_a	$\bar{S}_a$	S_{a90}	S_a	$\bar{S}_a$	S_{a90}	Q_a	$\bar{Q}_a$	Q_{a90}	S_a	$\bar{S}_a$	S_{a90}
S11 Basic electric arc steel	Oil quenched 830°C	700	967	591	(508)	(455)		(486)	(393)		(342)	(310)		(407)	(387)
S11 Basic electric arc steel (60 tons/in ²)	Oil quenched 830°C	700	975	504	(512)	(459)		(488)	(395)		(344)	(312)		(410)	(390)
S11 Basic electric arc steel (60 tons/in ²)	Oil quenched 830°C, Oil quenched 650°C	700	975		(512)	(459)		(488)	(395)	301	(344)	(312)		(410)	(390)
BS 2S106	–	–	1010	503	(526)	(473)		(495)	(402)		(353)	(321)		(426)	(406)
Austenitic stainless steel DTD 166B	–	–	1014	520	(523)	(470)		(496)	(403)		(354)	(322)		(427)	(417)
BS En19	–	–	1027	519	(533)	(480)		(499)	(406)		(357)	(325)		(433)	(413)
BS Cm152	–	–	1041	594	(538)	(485)		(501)	(408)		(361)	(329)		(439)	(419)
BS En24 1½% Ni-Cr-Mo	Oil quenched 840°C, Tempered 600°C	–	1055	606	(544)	(491)		(504)	(411)		(364)	(332)		(446)	(426)
BS 2S97	–	–	1079	540	(553)	(500)		(508)	(415)		(370)	(338)		(456)	(436)
BS Cm151	–	–	1089	577	(557)	(504)		(510)	(417)		(372)	(340)		(461)	(441)
BS Cm154	–	–	1103	623	(562)	(509)		(512)	(419)		(375)	(343)		(467)	(447)
BS En36 3% Ni-Cr	Oil quenched 780°C, Tempered 400°C	–	1148	556	(578)	(525)		(520)	(427)		(385)	(353)			
BS En25 Neutral open hearth steel	Oil quenched 850°C, Tempered 520°C	1141	1220	651	(602)	(549)		(529)	(436)		(399)	(367)			
BS En26 Basic open hearth steel	Oil quenched 830°C, Tempered 640°C	1096	1222	653	(603)	(550)					(399)	(367)			

Note that numbers in parentheses indicate values taken from figures.

