

FATIGUE PROPAGATION BEHAVIOUR OF SHORT CRACKS (1-2 mm) IN STEELS

1. NOTATION

Both SI and British units are quoted.

a	crack length or crack half-length	m	in
C	coefficient in simple crack growth rate equation, $da/dN = C(\Delta K)^n$	$m(m^{3/2}/N)^n$	$in(in^{3/2}/lbf)^n$
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
f_y	yield stress	N/m ²	lbf/in ²
K	stress intensity factor defined as $S(\pi a)^{1/2}\alpha$	N/m ^{3/2}	lbf/in ^{3/2}
K_{cl}	stress intensity factor value at crack closure	N/m ^{3/2}	lbf/in ^{3/2}
K_{max}	maximum value of K in fatigue cycle	N/m ^{3/2}	lbf/in ^{3/2}
K_{min}	minimum value of K in fatigue cycle	N/m ^{3/2}	lbf/in ^{3/2}
K_t	elastic stress concentration factor		
ΔK	stress intensity factor range defined as $(S_{max} - S_{min})(\pi a)^{1/2}\alpha = K_{max} - K_{min}$	N/m ^{3/2}	lbf/in ^{3/2}
ΔK_{eff}	effective stress intensity factor range defined as $K_{max} - K_{cl}$	N/m ^{3/2}	lbf/in ^{3/2}
ΔK_{TH}	threshold value of ΔK for long cracks	N/m ^{3/2}	lbf/in ^{3/2}
N	number of load cycles	c	c
n	index in simple crack growth rate equation, $da/dN = C(\Delta K)^n$		
R	stress ratio defined as S_{min}/S_{max}		
S	stress based upon gross cross-sectional area	N/m ²	lbf/in ²
S_{max}	maximum stress in fatigue cycle	N/m ²	lbf/in ²
S_{min}	minimum stress in fatigue cycle	N/m ²	lbf/in ²
α	geometrical factor in stress intensity factor expression		

2. NOTES

2.1 Introduction

This Data Item presents propagation rate data for short cracks in steels. Some long crack propagation rate data are also presented to illustrate the differences that can exist between the propagation rates of long and short cracks. A short crack may be microstructurally small (having a length close to the dominant microstructural dimension) and/or physically small (not substantially larger than the plastic zone at the crack tip). Since the microstructural unit in steels is very small, most of the data presented in this Item are from tests on physically small cracks of 1 to 2 mm in length, which is larger than the typical microstructural dimension in steels. When employing linear elastic fracture mechanics (described in Data Item No. 80036*) to analyse both long and short cracks significant differences in propagation behaviour are revealed. The purposes of this Data Item are to illustrate the need for short crack data in some designs and to highlight the danger of using long crack data where they are inappropriate.

2.2 The Short Crack Effect

2.2.1 Comparison with Long Cracks

When crack propagation rates are plotted against ΔK , as determined by linear elastic fracture mechanics, and compared, significant differences between the behaviour of long and short cracks are apparent. Long cracks display a threshold value of stress intensity factor range, ΔK_{TH} , below which they do not propagate. However, short cracks will often appear to have no threshold value of ΔK and can grow at values of ΔK below the long crack threshold value, ΔK_{TH} . Also, the crack propagation rates of short cracks, as determined by linear elastic fracture mechanics, are often significantly higher than the crack propagation rates of long cracks at the same values of ΔK and R . The differences in crack propagation rates are usually most pronounced at low to medium values of ΔK and at negative stress ratios, R . In situations where a difference in crack propagation rates is observed, the difference between the rates tends to decrease with increasing ΔK until both the long and the short cracks have the same propagation rate. These differences in crack propagation behaviour are illustrated in Sketch 2.1.

2.2.2 Comparison with Other Alloys

Owing to the fine scale of the microstructure of steels, the full short crack effect only occurs when very small cracks are present. The size of crack which would exhibit short crack behaviour is generally below the 1 to 2 mm range for which data are presented in this Data Item. Consequently the short crack effect in steels is not always as clearly shown as in other materials such as aluminium and titanium alloys (see Data Item Nos. 92023 and 92030†). The difference in crack propagation rates between short and long cracks may vary somewhat with the stress ratio, R , as shown in Figures 1 to 3 for AISI 4340. This is thought to be due to crack closure effects.

2.2.3 Crack Closure Effects

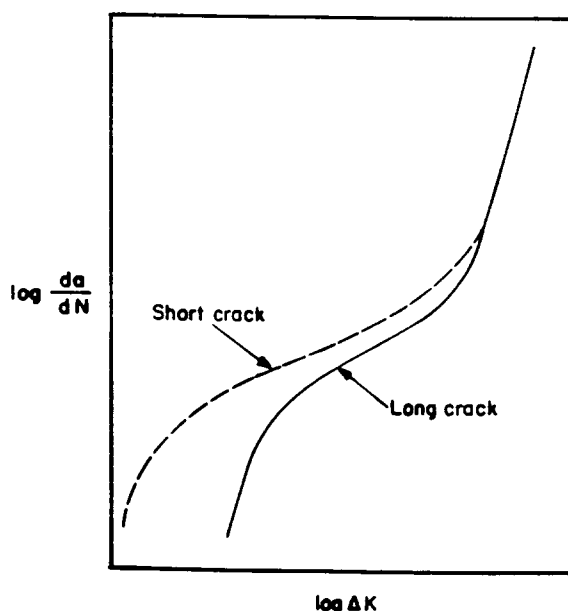
The most significant factors in explaining the differences in crack propagation behaviour between long and short cracks are probably crack tip shielding, and in particular crack closure effects. Long cracks often experience premature crack closure, that is effective closure of the crack prior to the complete removal of the tensile load during the fatigue cycle. Premature crack closure can occur in a variety of ways. Deflected crack paths or rough crack sides can result in the sides of the crack sliding over each other and the crack

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

† Data Item No. 92023. "Fatigue propagation behaviour of short cracks in titanium alloys (in the Fatigue – Fracture Mechanics Sub-series). Data Item No. 92030. "Fatigue propagation behaviour of short cracks in aluminium alloys (in the Fatigue – Fracture Mechanics Sub-series).

becoming wedged at values of K greater than K_{min} . Debris, for example oxide fragments, inside a crack can also cause wedging and premature closure. These factors are largely dependent on the crack being of sufficient length and hence are usually more effective in long cracks than short cracks. The effect of premature crack closure is to shield the crack tip from the effects of the full load cycle so that it only experiences the effective stress intensity factor range, ΔK_{eff} .

The reduction in stress intensity factor range to ΔK_{eff} will only be experienced when K_{min} is less than K_{cl} . Therefore, the effects of premature crack closure will be most significant when load cycles have a large compressive portion. Short cracks are unlikely to experience premature crack closure. They often remain open at K values less than zero giving rise to negative K_{cl} values which increase the value of K_{eff} at the crack tip. As a short crack grows, its K_{cl} value will usually increase resulting in a decrease in the value of ΔK_{eff} and in some cases this reduction may be larger than the increase in ΔK_{eff} due to the increase in crack length. Hence, as the crack grows there is a net decrease in the value of the effective stress intensity factor range, ΔK_{eff} , and the crack propagation rate is reduced when plotted against ΔK , as defined in the notation. A large amount of scatter is apparent when the rates of growth of different cracks are plotted together for the purpose of finding the mean rate, particularly where ΔK is less than ΔK_{TH} .



Sketch 2.1 Comparison of the crack propagation rates of typical long and short cracks at a common value of stress ratio, R

2.2.4 Values of K

For short cracks the assumptions of linear elastic fracture mechanics are not strictly valid. However, it is convenient to use the same method of analysis for both long and short cracks, particularly in a damage tolerance analysis where a short crack is assumed to be the initial defect. It is therefore necessary to allow for the short crack effect since, if only long crack data are used, inaccurate and nonconservative endurance values will be obtained.

It is extremely difficult to calculate a meaningful value of K for short cracks. A shape function must be assumed for the crack. As the crack grows it may change shape requiring a change in the shape function. If the shape function is taken to be constant during growth, large errors in K can result. The calculated stress intensity values, K , are only valid for specific regions of the crack, for example, at the point of maximum length in a semi-elliptical surface crack. Short cracks are very susceptible to local stress fields, which may

differ from that assumed. For example, a short surface crack may experience a stress field resulting from surface treatment or machining that is very different from the nominal stress field. The stress field around the short crack can also be modified by a plastic zone that is large relative to the crack. Short cracks often propagate along favoured crystallographic planes and the orientation of these planes can change from one grain to another. Thus, short cracks will often propagate along a plane that is inclined to the plane normal to the loading (for uniaxial loading). In such a case the short crack will be subjected to mixed mode loading. It is difficult to measure the curvature of the crack tip and its orientation with respect to the plane normal to the loading. These factors are not usually fully allowed for in the calculation of ΔK , and Mode I loading only is usually assumed. Measurement of short cracks is more difficult than measurement of long cracks. In some cases a notional length is calculated based on the surface length of the crack and an assumed shape function to give the length of the crack, a , into the material.

2.3 Presentation of Data

The crack propagation rate data are taken from constant amplitude tests and are presented in terms of crack propagation rate against stress intensity factor range, that is da/dN against ΔK . Where mean curves are provided they have been drawn by eye, using all the data points provided in the relevant derivation. None of the curves has been extrapolated beyond the range of the available data. However, a broken reference line indicating the Paris law (Equation (4.1)) for the upper region of the long crack curves has been added. A table providing details on the testing conditions accompanies each figure. Materials data are set out in Table 6.1. The convention used for denoting crack orientation relative to the grain flow of the material is shown in Appendix A.

All the curves on the figures that refer to tests with negative stress ratio values, R , include both the tensile (positive) and compressive (negative) portions of the fatigue cycle in the calculation of the stress intensity factor range, ΔK (see Sketch 2.2). Therefore, in this Item, ΔK is given by:

$$\Delta K = (S_{max} - S_{min})(\pi a)^{1/2} \alpha. \quad (2.1)$$



Sketch 2.2 Illustration of ΔK used in Figures 1 to 21

Some published papers, for example where the tests were carried out to BS 6835, use only the tensile part of the fatigue cycle in the calculation of the stress intensity factor range, ΔK , for tests with negative stress ratio values:

$$\Delta K = S_{max}(\pi a)^{1/2} \alpha. \quad (2.2)$$

When comparing data from other sources having negative stress ratio values with the data presented in this Item, care must be taken to ensure that the ΔK values have been calculated using the same method (that is, Equation (2.1)). The difficulties associated with the calculation of K for short cracks, as discussed in Section 2.2, should be noted. It should also be noted that the individual da/dN values are average values of

the measured increase in crack length over a number of cycles.

3. NOTES ON FIGURES

Figures 1 to 21 present propagation rate data for short cracks (1 to 2 mm long) in steels. For comparison, almost all figures show propagation rate curves for long cracks. The data have been ranked in order of decreasing proof stress to allow comparisons to be made between the different materials. Data for two stainless steels are also included: these data have been placed last because the stainless steels are microstructurally different from the other alloys for which data were available.

Figures 1 to 3 show propagation rate curves for short and long cracks in AISI 4340 at stress ratios, R , of -1 , 0 and 0.5 , respectively. The change in propagation behaviour of the short cracks at these three different values of stress ratio, R , can be clearly seen. Figures 2 and 3 show short cracks propagating at similar, but somewhat lower rates than long cracks in AISI 4340. In Figure 1, at a stress ratio value, R , of -1 , short cracks are shown to propagate at somewhat higher rates than long cracks.

Figures 4 to 8 allow some comparison between the crack propagation rates for the steels HY 130 and Q1N. They are medium strength marine structural steels, usually used in the quenched and tempered condition.

In Figure 4, fatigue crack propagation data are presented for short and long cracks in HY 130, tested in laboratory air at a stress ratio of 0.1 . There is no evidence of a short crack effect. Figure 5, which presents data for short and long cracks tested at the same stress ratio ($R = 0.1$), but in 3.5 per cent sodium chloride solution, shows short cracks propagating at higher rates than long cracks. Furthermore, comparison of Figures 4 and 5 shows that both long and short fatigue cracks propagate faster in aqueous sodium chloride than in laboratory air.

Figure 6 shows data for the propagation of short and long cracks in 3.5 per cent sodium chloride solution at a stress ratio of 0.45 for the same material (HY 130). If this figure is compared to Figure 5, it can be seen that the increase in stress ratio causes little, if any, increase in the propagation rate of cracks in this material over the limited range of ΔK studied. This figure also shows that at the higher stress ratio, R , of 0.45 , the short crack effect is less pronounced.

Figure 7 shows fatigue crack propagation data for HY 130, tested in air and aerated sea water at a stress ratio, R , of 0.5 . Again, little evidence of a short crack effect is shown. If this figure is compared with Figure 6, it can be seen that cracks propagate at a similar rate in seawater or 3.5 per cent sodium chloride solution.

Figure 8 shows fatigue crack propagation data for Q1N in both air and in aerated sea water at $R = 0.5$. In this steel there is again little evidence for a short crack effect in air. However, a small but significant increase in the growth rates of short cracks compared to long cracks was observed when testing in seawater.

These figures show that the similar steels, HY 130 and Q1N, show little difference in the fatigue crack propagation behaviour in aqueous environments although, in air, HY 130 with the higher yield strength appears to have a slightly higher fatigue crack growth rate.

Figure 9 shows fatigue crack propagation data for a 0.17 per cent carbon construction steel, type E460 (a French steel), tested in ambient air and in vacuum. In a vacuum, there is some evidence of a short crack effect, whilst in ambient air, short cracks propagate at higher rates than long cracks. There is some evidence to suggest that, if the propagation curves of short and long cracks were extrapolated down to a threshold stress intensity range, the threshold value would be lower for short cracks than for long cracks.

In Figure 10, fatigue crack propagation data for short and long cracks at $R = 0.1$ in A508 steel are shown;

this 0.15 per cent carbon steel is used in the fabrication of nuclear reactors. The data show that short cracks propagate at higher rates than long cracks at lower values of ΔK ; however the propagation rates become similar at higher values of ΔK .

The fatigue crack propagation rates for both short and long cracks in air in E460 and A508 are very similar. Comparison of Figures 9 and 10 shows that the data for E460 in air lie within the scatter band of the A508 data.

Figures 11 and 12 show the fatigue crack propagation of short and long cracks in AISI 1045 at two different values of the stress ratio, R . At a stress ratio $R = 0.05$ there is evidence of a short crack effect, in that, at lower values of ΔK , there is a higher crack growth rate. At a stress ratio $R = 0.5$ there is very little effect of crack length on fatigue crack propagation rates. At $R = 0.5$, the fatigue crack propagation rates are consistently higher than at $R = 0.05$ for both short and long cracks.

Figures 13 to 15 show the effect of the stress ratio, R , on the propagation behaviour of short, intermediate and long cracks in SAE 0030 (UNS J 03010). At all values of R that were used in the tests, short cracks were found to propagate at higher rates than long cracks except at higher growth rates where the data for short and long cracks tend to converge. In general, the fatigue crack growth rate for both short and long cracks is shown to increase with increasing R value.

EN5 is a lower strength structural steel most often used in the normalised condition, the condition for which the fatigue crack propagation data for short and long cracks are given in Figure 16. There is an increase in the rate of propagation of short cracks over that for long cracks in this material, tested in sea water at high values of ΔK .

In Figures 17 to 19 the effect of the stress ratio, R , on the propagation behaviour of short, intermediate and long cracks in AISI 1020 is presented. As with the steel SAE 0030, short cracks were found to propagate at higher rates than long cracks for all values of R reported, except at higher growth rates where the data for short and long cracks tend to converge. Again, similar behaviour is shown to that for the SAE 0030 steel: the fatigue crack growth rate for both short and long cracks is shown to increase with increasing R value.

In Figure 20, fatigue crack propagation data are presented for short and long cracks in austenitic stainless steel 304 at $R = -1$. These show an increase in propagation rate of over three orders of magnitude for short cracks. Curve 3 shows the mean curve taken from Data Item No. 84003*, for a range of stress ratio, R , between 0 and 0.07. As can be seen in the figure, this line is consistent with the long crack propagation rates given in Derivation 2 (curve 2), and emphasises the short crack effect. This large factor in growth rate could be due to the very small size of cracks examined. For this reason, the data are considered to be tentative.

Figure 21 shows two curves for short cracks propagating in the stainless steel AISI 316, at two different values of stress ratio: $R = 0.05$ and $R = 0.3$. At the higher value of the stress ratio, $R = 0.3$, crack propagation rates are lower than those for a lower value of stress ratio, $R = 0.05$, for similar values of ΔK , albeit over a very small range. For this reason, and the fact that the data are available over such a small range, they are considered to be tentative.

In general, there appears to be no consistent relationship between either short or long crack propagation behaviour and yield strength for all of the steels for which data are presented. Where a short crack effect is evident, there are two consistent observations: the threshold ΔK is lower for short cracks and the crack growth rate at low ΔK values is higher.

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

4. CALCULATION OF CRACK GROWTH

The growth of a crack over a number of cycles may be predicted by integrating the crack growth rate curves given in Figures 1 to 21. This may be easily done over any portion of the curve that may be adequately represented by the simple linear Paris equation:

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

Similarly, curved portions may be represented by a series of straight lines. Examples of the use of these curves are given in Data Item Nos. 82015*, 84001† and 84003. Since the curves are presented on a logarithmic scale, n represents the slope and C the ordinate intercept of the straight line. Equation (4.1) can be integrated analytically, using the method described in Data Item No. 80036, to obtain an estimate of the total number of loading cycles required for a crack to grow from one length to another.

5. DERIVATION AND REFERENCES

5.1 Derivation

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

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et al. Short crack propagation and closure effects in A508 steel. *Fatigue Engng Materials Struct*, Vol. 6, No. 4, pp. 349-358, 1983.
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3. ESDU Fatigue crack propagation rates and threshold stress intensity factors in high alloy and corrosion resistant (stainless) steel. Data Item No. 84003. *Fatigue – Fracture Mechanics Sub-series*. ESDU International, London, April 1984.
4. JONES, B.F. Fatigue crack growth rates of steel in aqueous environments: the influence of environmental, microstructural and geometric factors. In: *Embrittlement by the localised crack environment*. TMS-AIME, Warrendale, PA, 1984.
5. SHIN, C.S.
SMITH, R.A. Fatigue crack growth from sharp notches. *Int. J. Fatigue*, Vol. 7, No. 2, pp. 87-93, 1985.
6. TANAKA, K.
WEI, R.P. Growth of short fatigue crack in HY130 steel in 3.5% NaCl solution. *Engng Fracture Mech.*, Vol. 21, No. 2, pp. 293-305, 1985.
7. ZEGHLOUL, A.
PETIT, J. ΔK_{eff} rationalization of short crack behavior: environmental and microstructural influence. In: *Small fatigue cracks*. Proceedings of 2nd International Conference/Workshop, Santa Barbara, CA, January 5-10, 1986.

* Data Item No. 82015 "Fatigue crack propagation rates and threshold stress intensity factor ranges for titanium alloy plate, bar and forgings" (in the *Fatigue – Fracture Mechanics Sub-series*).

† Data Item No. 84001 "Growth of cracks under constant amplitude fatigue loading: example calculations" (in the *Fatigue – Fracture Mechanics Sub-series*).

8. STEPHENS, R.I.
et al. The behavior of short and long fatigue cracks at threshold and near-threshold levels. In: Fracture mechanics; eighteenth symposium. American Society for Testing and Materials, Philadelphia, USA. ASTM STP 945, 1988.
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10. AKINIWA, Y.
et al. Dynamic measurement of crack closure behaviour of small fatigue cracks by an interferometric strain/displacement gauge with a laser diode. *Fatigue Fract. Engng Mater. Struct.*, Vol. 14, No. 2/3, pp. 317-328, 1991.

5.2 References

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

11. LANKFORD, J.
DAVIDSON, D.L. The role of metallurgical factors in controlling the growth of small fatigue cracks. In: Small fatigue cracks. Proceedings of the 2nd International Conference/Workshop, Santa Barbara, California, January 5-10, 1986.
12. MURAKAMI, Y. *The stress intensity factor handbook*. Volumes 1 and 2, Pergamon Press, 1987.
13. BSI British standard method for determination of the rate of fatigue crack growth in metallic materials. British Standards Institution BS 6835, 1988.
14. NEWMAN, J.C. Jr.
EDWARDS, P.R. Short-crack growth behaviour in an aluminum alloy – an AGARD cooperative test programme. AGARD-R-732, 1988.

6. TABLES AND FIGURES

TABLE 6.1 GUIDE TO MATERIALS

Material	Composition* (percentage by weight)	Heat Treatment*	Mechanical Properties*			Figure No.
			f_t MN/m ² (10 ³ lbf/in ²)	f_y MN/m ² (10 ³ lbf/in ²)	f_p MN/m ² (10 ³ lbf/in ²)	
AISI 4340	0.39C 0.27Si 0.69Mn 1.75Ni 0.79Cr 0.25Mo 0.003S 0.008P 0.007Al 0.1 Cu < 0.001Ca < 0.002Mg	1 h soak at 840°C, vacuum temper at 440°C for 2 h, furnace cool in nitrogen.	1505 (218)	—	1413 (205)	1, 2, 3
HY 130	0.08C 0.23Si 0.70Mn 4.66Ni 0.40Cr 0.39Mo 0.03V 0.004S 0.010P 0.02Al 72 ppmN 16 ppmO	—	1014 (147)	—	972 (141)	4, 5, 6
HY 130	0.10C 0.25Si 0.77Mn 4.88Ni 0.50Cr 0.50Mo 0.06V 0.007S 0.008P 0.06Cu	Quenched and tempered.	—	950 (138)	—	7

*As quoted in the relevant derivation.

TABLE 6.1 GUIDE TO MATERIALS

Material	Composition* (percentage by weight)	Heat Treatment*	Mechanical Properties*			Figure No.
			f_t MN/m ² (10 ³ lbf/in ²)	f_y MN/m ² (10 ³ lbf/in ²)	f_p MN/m ² (10 ³ lbf/in ²)	
Q1N	0.17C 0.21Si 0.34Mn 2.36Ni 1.23Cr 0.34Mo < 0.05V 0.014S 0.008P 0.02Al 0.08Cu	Quenched and tempered.	—	600 (87)	—	8
E460	0.17C 0.34Si 1.27Mn 0.022Ni 0.021Nb 0.001S 0.022P	Quenched and tempered after hot rolling and tempered at 690°C for 0.3 h.	600 (87)	460 (67)	—	9
A508	0.152C 0.3Si 1.25Mn 0.84Ni 0.20Cr 0.49Mo 0.010S 0.006P 0.021Al	Water quench, followed by tempering at 660°C, water cooling, stress relieving at 550°C for 40 h, then at 610°C for 10 h.	576 (84)	419 (61)	—	10
AISI 1045	0.43-0.50C 0.60-0.90Mn 0.050S (max) 0.040P (max)	—	622 (90)	382 (55)	—	11, 12
SAE 0030	0.30C (max) 0.80Si (max) 0.70Mn (max) 0.045S (max) 0.040P (max)	—	496 (72)	303 (44)	—	13, 14, 15
EN5	0.29C 0.12Si 0.67Mn 0.04S 0.03P	Normalised.	—	300 (44)	—	16

*As quoted in the relevant derivation.

TABLE 6.1 GUIDE TO MATERIALS

Material	Composition* (percentage by weight)	Heat Treatment*	Mechanical Properties*			Figure No.
			f_t MN/m ² (10 ³ lbf/in ²)	f_y MN/m ² (10 ³ lbf/in ²)	f_p MN/m ² (10 ³ lbf/in ²)	
AISI 1020	0.18-0.23C 0.30-0.60Mn 0.050S (max) 0.040P (max)	—	413 (60)	262 (38)	—	17, 18, 19
AISI 304	0.055C 0.600Si 1.02Mn 10.25Ni 18.35Cr 0.06Mo 0.004S 0.023P 0.004Al 0.011Ti 0.0232N	—	627 (91)	—	230 (33)	20
AISI 316	0-0.08C 0-1.0Si 0-2.0Mn 10.0-14.0Ni 16.0-18.0Cr 2.0-3.0Mo 0-0.03S 0-0.045P	Solution annealed at 1050°C for 0.5 h, followed by air quench to remove residual stress.	574 (83)	—	256 (37)	21

*As quoted in the relevant derivation.

TABLE 6.2 GUIDE TO FIGURE 1

Material: AISI 4340 5.1 mm (0.20 in) plate					
Curve No. (Symbol)	Derivation No.	Stress ratio, R	Orientation	Crack type	Notes
1 (X)	9	-1	L-T	Short [shorter than 2 mm (0.079 in)]	Single edge notched tension specimens, either a semi-elliptical surface crack at the centre of the notches or a quarter elliptical corner crack at an edge was assumed, crack growth was measured using the plastic replica method.
2 (O)	9	-1	L-T	Long [longer than 2 mm (0.079 in)]	Centre crack tension specimens.

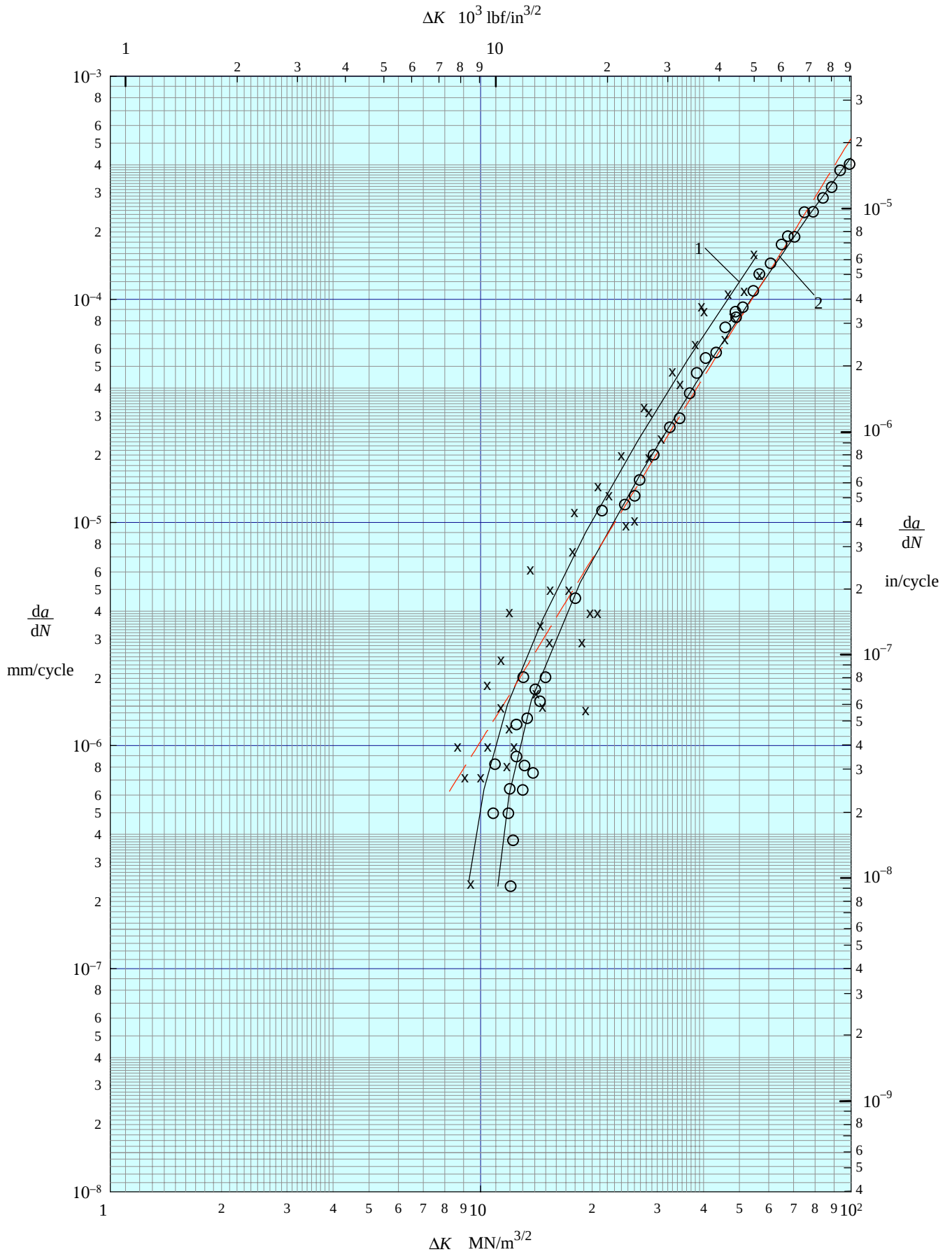


FIGURE 1 AISI 4340

TABLE 6.3 GUIDE TO FIGURE 2

Material: AISI 4340 5.1 mm (0.20 in) plate					
Curve No. (Symbol)	Derivation No.	Stress ratio, R	Orientation	Crack type	Notes
1 (X)	9	0	L-T	Short [shorter than 2 mm (0.079 in)]	Single edge notched tension specimens, either a semi-elliptical surface crack at the centre of the notch or a quarter elliptical corner crack at an edge was assumed, crack growth was measured using the plastic replica method.
2 (O)	9	0	L-T	Long [longer than 2 mm (0.079 in)]	Centre crack tension specimens.

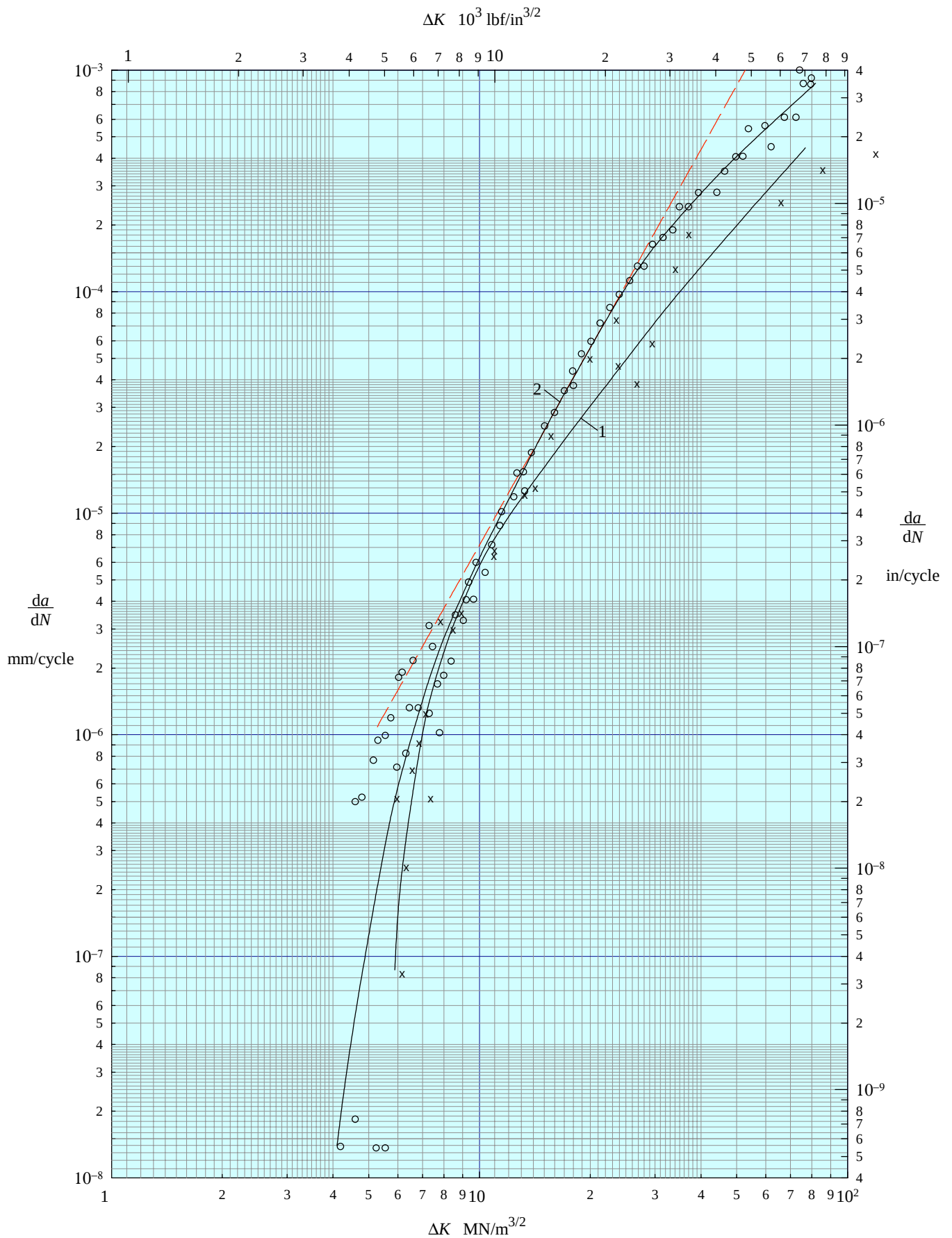


FIGURE 2 AISI 4340

TABLE 6.4 GUIDE TO FIGURE 3

Material: AISI 4340 5.1 mm (0.20 in) plate					
Curve No. (Symbol)	Derivation No.	Stress ratio, R	Orientation	Crack type	Notes
1 (X)	9	0.5	L-T	Short [shorter than 2 mm (0.079 in)]	Single edge notched tension specimens, either a semi-elliptical surface crack at the centre of the notches or a quarter elliptical corner crack at an edge was assumed, crack growth was measured using the plastic replica method.
2 (O)	9	0.5	L-T	Long [longer than 2 mm (0.079 in)]	Centre crack tension specimens.

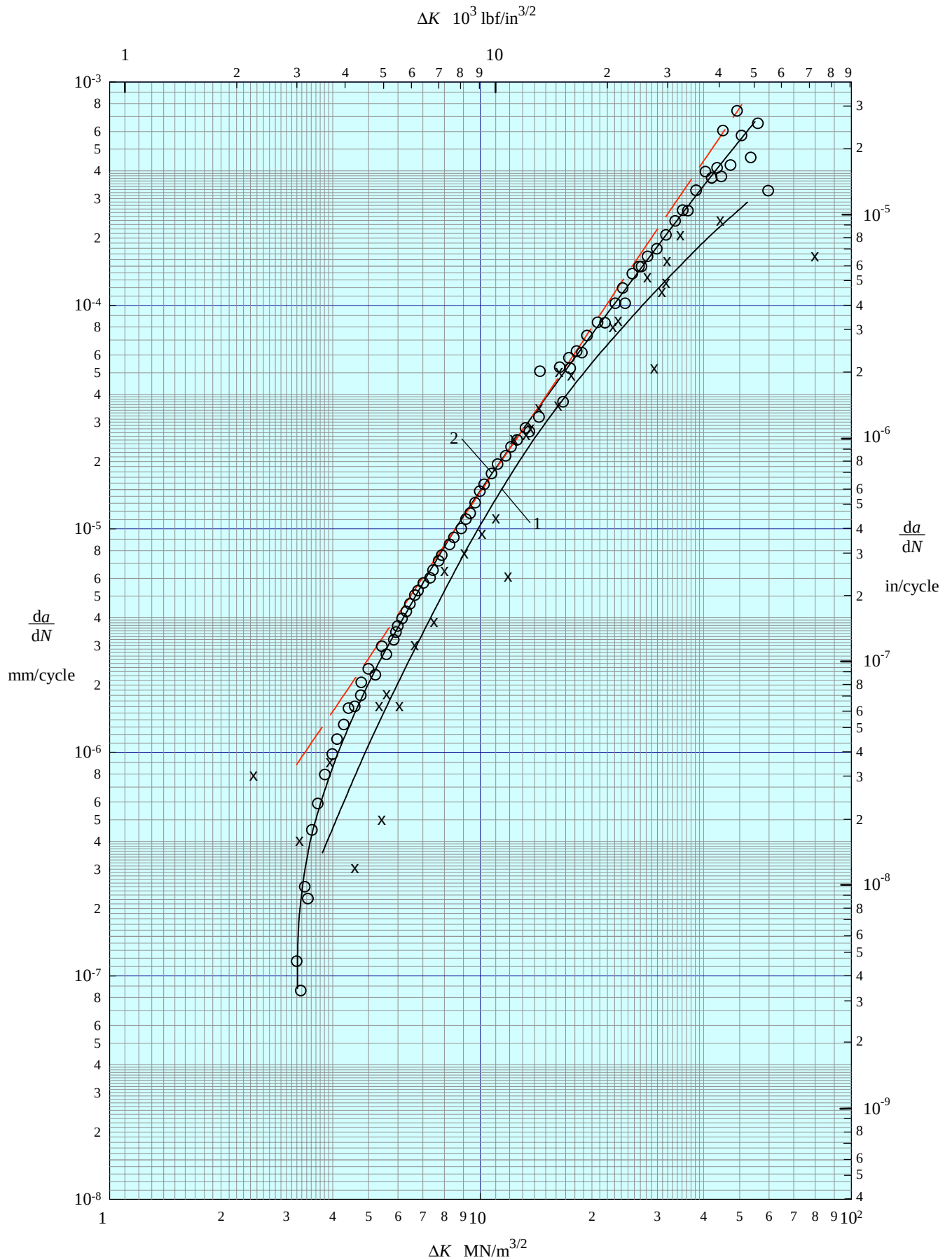


FIGURE 3 AISI 4340