

Effect of fretting on fatigue strength of aluminium alloys

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EFFECT OF FRETTING ON FATIGUE STRENGTH OF ALUMINIUM ALLOYS

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EFFECT OF FRETTING ON FATIGUE STRENGTH OF ALUMINIUM ALLOYS

1. NOTATION

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
N	endurance		
P	pad pressure	N/m ²	lbf/in ²
R	S_{min}/S_{max}		
RMS	root mean square		
S_a	alternating stress	N/m ²	lbf/in ²
S_m	mean stress	N/m ²	lbf/in ²
S_{max}, S_{min}	maximum and minimum stresses respectively	N/m ²	lbf/in ²

1.1 Conversion Factors

Both SI and British units are quoted in the notation.

$$1 \text{ MN/m}^2 = 1 \text{ MPa} = 145.038 \text{ lbf/in}^2$$

2. NOTES

2.1 General

Fretting is the term used to describe the surface damage resulting from relative motion between two contacting surfaces. This results from adhesion between the surface asperities which may be followed by the formation of wear particles as the sliding motion continues. In an air environment the wear particles oxidise and the resulting debris further contributes to surface damage. The principal factors influencing fretting are the contacting materials, contact pressure, slip amplitude, surface finish, temperature and environment. The most important factors are local contact pressure and slip amplitude because increasing these increases the fretting.

Fretting fatigue occurs as a result of surface stresses induced by fretting adding to the stresses produced by the existing applied alternating stresses. The combined stresses reduce crack initiation life and accelerate early crack growth. In the simple example of two rectangular blocks in contact, under a constant pressure, one of which is subject to a tensile load parallel to the contact surfaces, the contact pressure and slip vary over the contacting surfaces. It is found that the alternating frictional forces are highest towards the ends of the contact zone while the contact pressure may be highest at the centre. This creates high alternating surface stresses near the boundary of the contact zone where fatigue cracks originate as a consequence. Once a fatigue crack moves out of the area affected by the surface stresses fretting has little or no effect on crack propagation, unless the frictional stresses alter the overall stress distribution.

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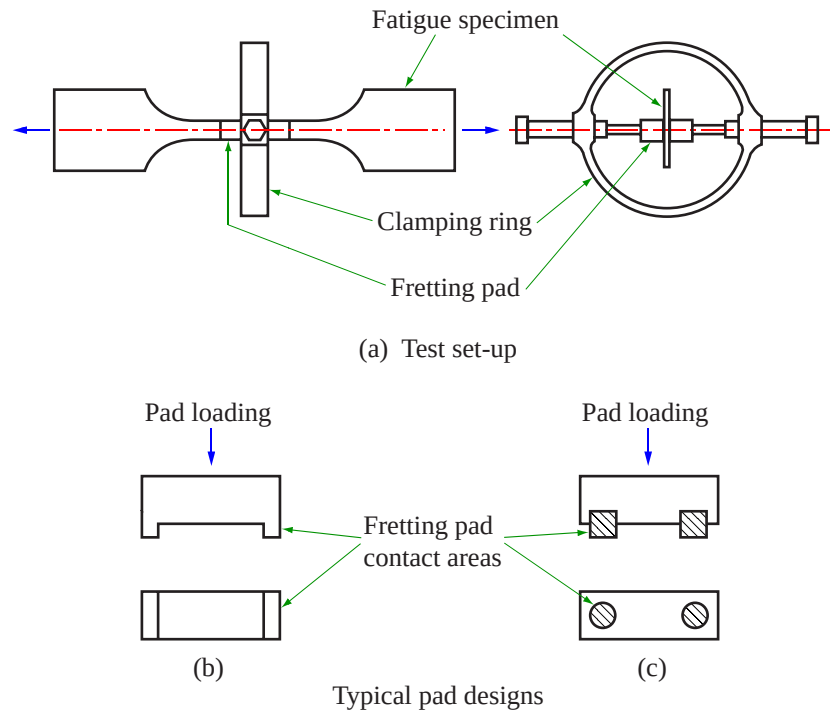
This Data Item illustrates trends that occur due to fretting fatigue. As most of the life is spent in crack propagation, a fracture mechanics approach could be useful in designing a component subject to fretting fatigue. Fracture mechanics models for fretting fatigue have been developed for idealised situations (References 9 and 16), although they are very limited in their application. It is difficult to predict where the maximum fretting stresses will occur in a complicated joint. For example, in the case of two sheets fastened together, interference-fit fasteners may shift the fretting problem from the edge of the holes to the contacting surfaces between the two sheets away from the holes.

2.2 Presentation of Data

Table 5.1 provides an index to the aluminium alloys for which data are available. The table also summarises the various surface treatments used to alleviate fretting fatigue. The data are presented in the form of $S-N$ curves. The results from tests on axial and bending tests are plotted as the maximum tensile stress versus cycles to failure for a given value of R . In one case the loading is random and the data are plotted as RMS stress versus N . In some cases the mean stress is given instead of R . The 'fretting' and 'no fretting' conditions can be compared, for a variety of surface treatments and environments. In each figure the 'no fretting' condition is indicated by a dashed line. A table giving relevant information about the material and tests accompanies each figure.

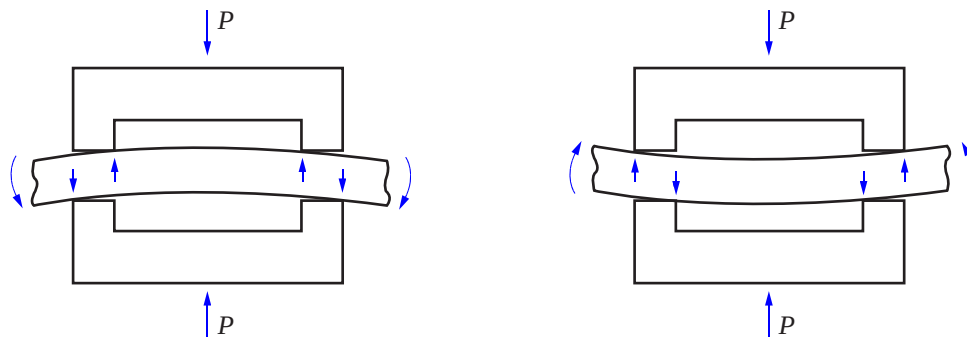
2.3 Test Conditions

In most cases the applied loading was constant amplitude sinusoidal using standard fatigue testing machines. Most of the tests took place in laboratory air at room temperature with no control of the humidity. A few tests were undertaken in an artificial seawater environment which is described in the accompanying table. The seawater was made according to the specification given in Reference 18. The types of specimens used in the tests vary from one derivation to another. Some specimens were punched from sheet, and others were machined from bars. In most cases the fretting pads were made of the same material as the specimen. However, in Figure 16 comparisons are made between the effect of different contact materials on fretting fatigue. The pads consisted of either a pair of studs inserted into a pad holder or a bridge shaped pad which made contact at its ends. The pad pressure was maintained on the specimen by a calibrated clamping ring. A general diagram of a typical test set up is shown in Sketch 2.1. The relative movement between the fretting pads and specimen is a result of strain in the specimen, which depends on the applied load, and on the distance between the feet of the fretting pad.



Sketch 2.1 Showing typical test set-ups

Most of the data plotted are taken from tests done on axially loaded specimens. In some tests the applied loading was plane bending; the points of contact with the fretting pad vary during the loading cycle, thus moving the point of maximum surface stress throughout the cycle. This is illustrated in Sketch 2.2.



Sketch 2.2 Showing how the points of contact between the fretting pad and specimen change during a plane bending test load cycle

3. DISCUSSION OF DATA

The reduction in fatigue strength due to fretting can be seen by comparing the $S-N$ curves for the fretting and no fretting conditions. Fretting causes a drastic reduction in the fatigue strength of all the aluminium alloys presented here, especially when N is greater than about 10^5 cycles. The effects of the various factors that influence fretting fatigue are described below.

3.1 Loading Effects

3.1.1 Effect of pad pressure

In this Data Item various pad pressures ranging from 3 to 112 MPa (450 to 16 240 lbf/in²) have been used. Figures 9 and 12 compare the effect of different pad pressures on the fatigue life of 2014-T6 and DTD683. There was a significant loss of fatigue strength when the low pad pressure was applied but increasing the pressure caused little or no change.

3.1.2 Effect of slip amplitude

Slip amplitude depends on the strain in the specimen and therefore on the applied stress range. For a given stress range the slip amplitude can be altered by varying the distances between the feet of the fretting pad. This effect upon fretting fatigue is shown in Figures 7 and 13. Larger slip amplitudes caused greater reductions in fatigue life up to a limit above which increasing the slip amplitude had no further effect on fatigue life.

3.1.3 Variable amplitude loading

Figure 8 shows the effect of fretting fatigue under Gaussian narrow band random loading. The experimental set-up for Figure 8 is similar to that for Figure 7. By comparing these two figures it can be seen that the reduction in fatigue strength under random loading was less than that under constant amplitude loading.

3.2 Effect of Environment

3.2.1 Seawater

An artificial seawater solution and a dilute (1:10) seawater solution, Reference 18, have been used to determine the effects of seawater on the fretting fatigue life of aluminium alloys. The seawater solution was continuously sprayed on the specimens unless otherwise stated in the tables. From Figure 1 it can be seen that a seawater environment reduced the fatigue strength of DTD5070B under both fretting and plain fatigue conditions. DTD5070B is clad, and therefore the effect of seawater on the unclad material may be slightly different. From Figure 3 it can be seen that a seawater spray also reduces the fatigue strength of the unclad alloy, CM 002, under both fretting and plain fatigue conditions.

3.3 Effect of Surface Coatings and Treatments

Several coatings and surface treatments have been found to be successful in reducing fretting and fretting fatigue. However, coatings that reduce fretting may not necessarily reduce fretting fatigue. In all cases only the specimen surface is treated. Some treatments are beneficial while some are detrimental to fatigue life. More details of the surface coatings can be obtained from the derivations. The following sections discuss the effects of some surface coatings and treatments used in an attempt to reduce fretting fatigue.

3.3.1 Shot peening

The results of tests on specimens shot peened with '14 grade' spherical cast iron shot are shown in Figure 15. Other specimens were glass bead peened to Almen 8-12N and the results are as shown in Figure 4. In both cases the fretting fatigue strength was improved compared with the unpeened but fretted specimens. In the case of the CM 002 alloy the plain fatigue strength of the glass bead peened specimens was comparable to, or better than, that of the unpeened material.

3.3.2 LS 6140 coating

This is an isocyanate cured epoxy resin that contains various chromate additions. From Figure 2 it can be seen to have had a beneficial effect on the fretting fatigue strength of clad DTD5070B in air. This coating provided very little protection against fretting fatigue in a seawater environment.

3.3.3 Melinex coating

Figure 14 shows the effect on fretting fatigue of coating the specimen with a 0.08 mm (0.003 inch) terylene sheet. This prevented contact between the metal surfaces and no fretting fatigue occurred.

3.3.4 Emralon 820 and Emralon 810 coatings

These are resin bonded polytetrafluoroethylene (p.t.f.e.) coatings. The Emralon 820 cures at room temperature while the Emralon 810 must be cured at 135°C. The Emralon 810 was the more successful of the two in preventing fretting fatigue in DTD683, especially at long endurance, as can be seen from Figure 14.

3.3.5 Grease

A grease loaded with molybdenum disulphide was inserted between the fretting pads and specimen. A slight improvement in fretting fatigue strength can be seen from Figure 14.

3.3.6 LR 8123 coating

This is a phenolic resin that contains zinc chromate and molybdenum disulphide. This was completely effective in preventing fretting fatigue below about 10^6 cycles. For longer lives it was only partially effective. Refer to Figure 14.

3.3.7 Alumina blasting

Alumina blasting with alumina grit, less than 22 mesh, caused some improvement to the fretting fatigue strength of DTD683, as shown in Figure 15. This treatment was also applied after shot peening to remove some of the surface damage.

3.3.8 Metal spraying

Metal spraying with an aluminium - 1 per cent zinc alloy has been applied after alumina blasting. It improved the fretting fatigue strength of DTD683, as shown in Figure 15, compared with applying alumina blasting by itself. However, care must be taken to ensure that pretreatments applied to the metal surface before spraying do not reduce the fatigue strength.

3.4 Effect of Different Contact Materials

Figure 16 shows the effect of different contact materials on the fretting fatigue strength of an aluminium-magnesium alloy. The copper and brass fretting pads caused a much smaller reduction in fatigue life than did the steel and aluminium alloy fretting pads. Steel caused the greatest reduction in fatigue strength. The fretting pads in Figures 7 and 8 also are of steel.

4. DERIVATION AND REFERENCES

4.1 Derivation

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

1. BOWERS, J.E.
FINCH, N.J.
GOREHAM, A.R. The prevention of fretting fatigue in aluminium alloys. Proceedings of the Institution of Mechanical Engineers, Applied Mechanics Group, Volume 182, Part 1, p. 703, 1967-68.
2. WHARTON, M.H.
et al. The effect of different contact materials on the fretting fatigue strength of an aluminium alloy. *Wear*, Volume 26, p. 253, 1973.
3. RYMAN, R.J.
BILLINGHAM, A.J. An investigation of the fretting fatigue strength of BS L65 aluminium alloy under sinusoidal and narrow band random cyclic stressing. DRIC-BR-33069, Orpington, England: Defence Research Information Centre, 1973.
4. HOEPPNER, D.W.
GOSS, G.L. A fretting fatigue damage threshold concept. *Wear*, Volume 27, p. 61, 1974.
5. EDWARDS, P.R.
RYMAN, R.J. Studies in fretting fatigue under service loading conditions. Proceedings of the 8th International Committee on Aeronautical Fatigue (ICAF) Symposium, Lausanne, June 1975.
6. SYERS, G. The development of anti-fretting media for use on aluminium alloys at elevated temperatures and in corrosive environments. Report Number LLR 10251. Research conducted by Rolls-Royce, Leavesden, with the support of the Procurement Executive, U.K. MoD, December 1976.
7. ALIC, J.A.
KANTIMATHI, A. Fretting fatigue, with reference to aircraft structures. Society of Automotive Engineers Transactions, No. 790612, 1979.

4.2 References

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

8. HOEPPNER, D.W.
GOSS, G.I. A new apparatus for studying fretting fatigue. *Review of Scientific Instruments*, Volume 42, No. 6, p. 817, 1971.
9. EDWARDS, P.R.
COOK, R. Fracture mechanics prediction of fretting fatigue under constant and variable amplitude loading. International Committee on Aeronautical Structures, Proceedings of 11th Congress, Lisbon, p. 505, September 1978.
10. GABEL, B.K.
BETHKE, J.J. Coatings for fretting prevention. *Wear*, Volume 46, Part 1, p. 81, 1978.
11. SCHIJVE, J.
HOEYMAKERS, A.H.W. Fatigue crack growth in lugs. *Fatigue of Engineering Materials and Structures*. Volume 1, Part 2, p. 185, 1979.
12. POON, C.J.
HOEPPNER, D.W. A statistically based investigation of the environmental and cyclic stress effects on fretting fatigue. *Journal of Engineering Materials and Technology*. Volume 103, Part 3, p. 218, July 1981.

13. BILL, R.C. Fretting wear and fretting fatigue - How are they related? ASME, paper 81 - Lub-13, October 1981.
14. SCHÜTZ, W. Material evaluation under fretting conditions. ASTM STP 780, 1982.
15. BLAKEBOROUGH, A. CULLIMORE, M.S.G. Fretting in the fatigue of wire rope. Advances in fracture research. Proceedings of the 6th International Conference on Fracture. New Delhi, India, 1984.
16. NIX, K.J. LINDLEY, T.C. Application of fracture mechanics to fretting fatigue. *Fatigue and Fracture of Engineering Materials and Structures*. Volume 8, Part 2, p. 143, 1985.
17. SATO, K. FUJII, H. KODAMA, S. Crack propagation behaviour in fretting fatigue. *Wear*, Volume 107, 1986.
18. B.S.I. BS 3900 part F4. Resistance to continuous salt spray, 1985.

5. TABLES AND FIGURES

TABLE 5.1 INDEX TO ALUMINIUM ALLOYS

<i>Material specification/designation</i>	<i>Surface treatments</i>	<i>Figure Number</i>
Al-2.5Cu-1.5Mg		
DTD5070B	None Coated with LS 6140 + MoS ₂ Coated with LS 6140 – 6M	1 2
CM 002	Coated with isocyanate cured epoxy resin + MoS ₂ Coated with chromate primer PR 5 + polyurethane gloss FE 93 + (isocyanate cured epoxy resin + MoS ₂) Shot peened	3, 4
Al-3.8Cu –1.25Mg		
2024-T4	None	5
Al-4.4Cu-0.5Mg-0.85Si-0.8Mn		
2014-T6 (L65)	None	6, 7, 8, 9
Al-5.7Zn-2.5Mg		
7075-T7351	None	10
7075-T6	None	11
Al-6.1Zn-2.5Mg		
DTD683	None Coated with LR8123 (phenolic resin) Coated with Melinex (terylene) Coated with Emralon 810 and 820 (p.t.f.e.) Ragazine LM grease Shot peened Alumina blasted Metal sprayed	12, 13, 14, 15
Al-4.4Mg-0.7Mn	None	16

TABLE 5.2

Material Specimen Fretting pad		DTD5070B clad (similar to AMS 2618) DTD5070B clad						Table 5.2 Figure 1	
Composition Nominal Actual		2.5Cu–1.5Mg–1.2Ni–1.0Fe Not given							
Heat treatment		Solution treated and artificially aged							
f_p MN/m ² (lbf/in ²)		380 (55 110)							
f_t MN/m ² (lbf/in ²)		409 (59 320)							
Type of Loading		Axial							
Material Form		Clad sheet							
Curve number and symbol	R	S_m		Freq. Hz	Pad pressure		Surface treatment	Environment	Derivation Number
		MN/m ²	lbf/in ²		MPa	lbf/in ²			
1 +	0	–	–	47	–	–	None	Laboratory air	6
2 *	0	–	–	47	46	6670	None	Laboratory air	6
3 ○	0	–	–	47	–	–	None	Dilute seawater solution	6
4 ×	0	–	–	47	46	6670	None	Dilute seawater solution	6

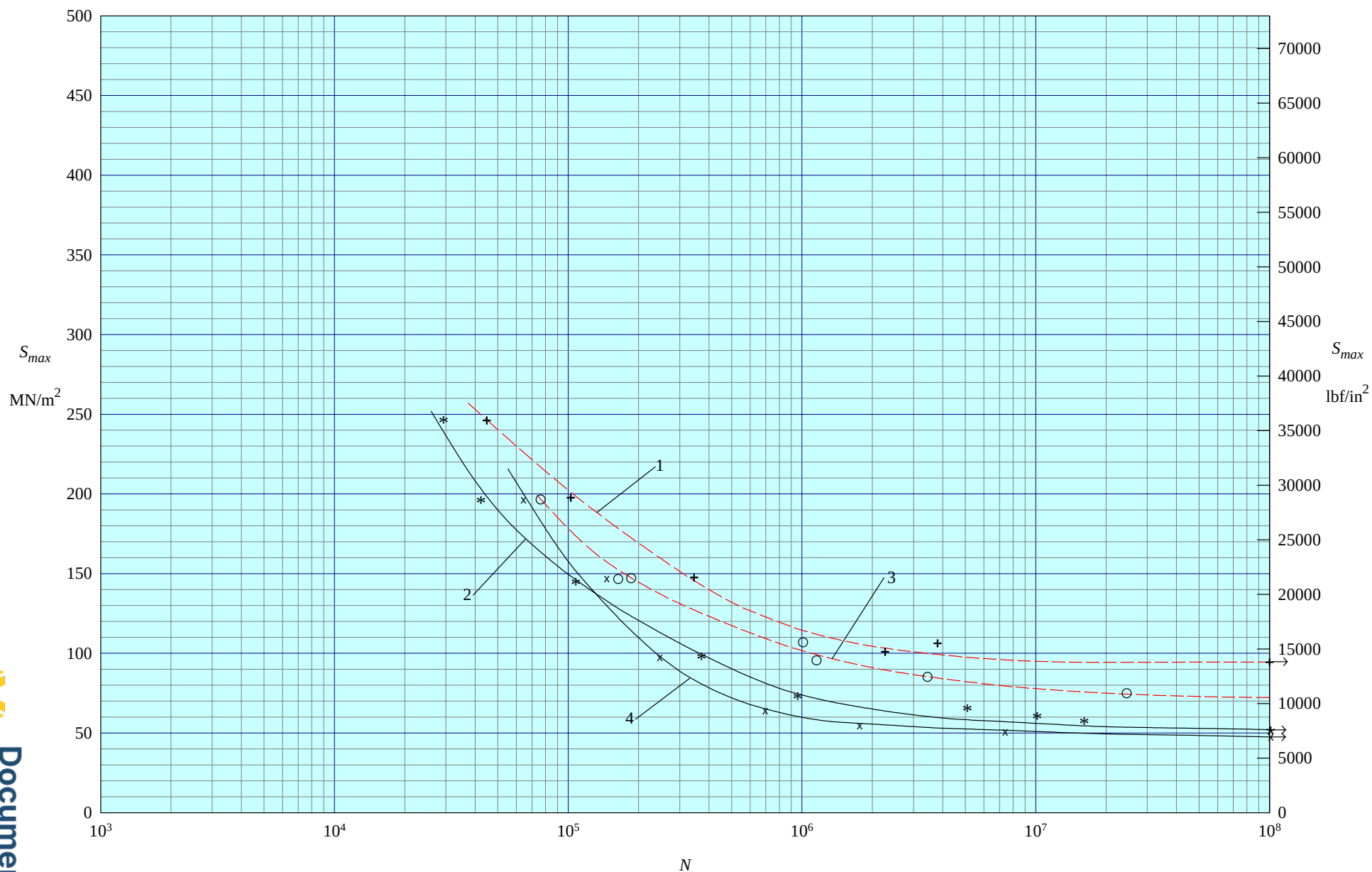


FIGURE 1 THE EFFECT OF ENVIRONMENT ON THE FRETTING FATIGUE STRENGTH OF DTD5070B CLAD SHEET

TABLE 5.3

Material Specimen Fretting pad		DTD5070B clad (similar to AMS 2618) DTD5070B clad						Table 5.3 Figure 2	
Composition Nominal Actual		2.5Cu–1.5Mg–1.2Ni–1.0Fe Not given							
Heat treatment		Solution treated and artificially aged							
f_p MN/m ² (lbf/in ²)		380 (55 110)							
f_t MN/m ² (lbf/in ²)		409 (59 320)							
Type of Loading		Axial							
Material Form		Clad sheet							
Curve number and symbol	R	S_m		Freq. Hz	Pad pressure		Surface treatment	Environment	Derivation Number
		MN/m ²	lbf/in ²		MPa	lbf/in ²			
1 +	0	–	–	47	–	–	None	Laboratory air	6
2 *	0	–	–	47	46	6670	None	Laboratory air	6
3 ○	0	–	–	47	46	6670	Coated with LS 6140 + MoS ₂	Laboratory air	6
4 ×	0	–	–	47	46	6670	Coated with LS 6140 + MoS ₂	Seawater solution	6
5 △	0	–	–	47	46	6670	Coated with LS 6140 – 6M	Seawater solution	6
6 □	0	–	–	47	46	6670	Coated with LS 6140 – 6M	Seawater solution sprayed for 15 minute periods every 6 hours	6