

ENDURANCE OF ALUMINIUM ALLOY STRUCTURAL ELEMENTS SUBJECTED TO SIMULATED ACOUSTIC LOADING

1. NOTATION

S_{rms}	root mean square value of stress at a reference position	N/m ²	lbf/in ²
N_r	equivalent endurance, taken as half number of zero crossings to failure of stress-time function	cycles	cycles

2. NOTES

This Data Item gives the results of fatigue tests on aluminium alloy specimens, typical of aircraft structural elements, excited by narrow-band loading of random amplitude with zero mean load to simulate stress response to acoustic loading. The types of element tested are illustrated in Figures 1 and 2.

In Figures 3 to 14, S_{rms} is plotted against N_r for test results grouped according to the type of structural element, material, jointing compound and method of attachment as shown in Table 5.1. A straight line fitted by the least squares method drawn through each group of test points has been given for guidance; it should not be used directly for estimating life because due account must be taken of scatter. Extrapolation of this line beyond 10⁹ cycles, where no data are available, is expected to lead to an underestimate of endurance.

The reference position for S_{rms} is taken as a point on the failure line away from the effects of stress concentration or fretting at rivets; the test points plotted represent mean nominal stresses over the areas covered by strain gauges affixed across the failure line or stresses at the reference position estimated from strain gauges located elsewhere. When using this Data Item to estimate a life using a root mean square stress level obtained from Item No. 72005, 73014 or 74026, it is recommended that the calculated value of stress in close proximity to the failure position should be assumed to be the same as that at the failure position. In practice, away from the effects of stress concentration, this approximation is within the range of accuracy of the simple theory used for stress prediction in these Data Items.

Methods used to detect failure are described in the relevant appendix and typical locations of failures are illustrated in Figures 15 and 16. Typical stress distributions across the failure lines are shown in Figure 17.

Appendices to this Data Item, as listed below, give details of the structural elements tested and the test method used.

- Appendix A – Tests on plain specimens
- Appendix B – Tests on integrally machined specimens
- Appendix C – Tests on riveted-skin specimens
- Appendix D – Tests on rib-flange specimens
- Appendix E – Description of materials
- Appendix F – Description of jointing compounds
- Appendix G – Failure locations.

The loading simulated for the skin-stiffener test specimens is only that for modes where skin-stiffener flexure predominates. Care should be taken in using this Data Item for modes involving twisting of the stiffeners.

In the Addendum to this Item, data are presented on the effect of elevated temperature on the endurance of aluminium alloy structural elements under simulated acoustic loading. The Addendum also includes additional room temperature fatigue test data, not presented in the main body of this Item, on both plain specimens and riveted-skin specimens.

3. INTERPRETATION OF THE RESULTS

3.1 Effect of Method of Attachment

For riveted-skin specimens there is no significant difference in fatigue data between mushroom-head rivets in plain holes and countersunk rivets in cut countersunk holes. Countersunk rivets in hot-pressure-dimpled holes show a lower fatigue endurance than specimens using the other methods of attachment; this may be explained by the residual stresses resulting from the dimpling process.

There is no evidence of the method of attachment of the rib-flange specimens influencing the endurance.

3.2 Effect of Material Specification

All data presented are for aluminium-copper alloys. The available data for aluminium-zinc alloys, subjected to a single stage precipitation heat treatment, indicate lives to the first crack in the same order as those for aluminium-copper alloys. However, the crack propagation characteristics for aluminium-zinc alloys are less favourable than those for aluminium-copper alloys, rendering the former less suitable for use in an acoustic environment. Aluminium-zinc alloys that are given a two stage precipitation heat treatment which improves their resistance to crack propagation are manufactured but acoustic fatigue data for these materials are not yet available.

3.3 Effect of Cladding

In Figure 3 the effect of surface cladding is evident. The endurance for clad material is less than for similar material in the unclad state; however, this difference is less on notched specimens than on plain, and the difference is further reduced where fretting takes place.

3.4 Effect of Jointing Compound

The effect of the jointing compounds on the position of failure of the riveted-skin test specimens is shown in Figures 15 and 16 and the effect on the stress distribution across the skin is shown in Figure 17. A notable feature of the effect of a type 2 viscoelastic jointing compound on a test specimen having a single row of skin attachment rivets is that the rivet line root mean square stress developed in such a specimen is considerably less than that developed in a specimen having dry joints or in a specimen with type 1 jointing compound for the same level of input force.

A comparison of $S-N$ curve data for riveted-skin specimens with and without the viscoelastic jointing compounds shows that for a given stress level the endurance is little affected by the jointing compound. However, apart from the possible redistribution of stress, there is an advantage in using a viscoelastic jointing compound in that for a given exciting force the stress level is less because of the increase in damping.

3.5 Effect of Test Frequency

The range of response frequencies for the riveted-skin and rib-flange tests is indicated on the Figures of *S-N* data. Over the range of frequency of interest (100-1000 Hz) no effect of frequency on the endurance of the specimens was identified.

3.6 Effect of Temperature

A limited number of the tests on skins attached by double rows of rivets was carried out at a temperature of -40°C . These were insufficient to draw definite conclusions although the fatigue life did not appear to be significantly affected by the reduction in temperature. Information on the effect of elevated temperature on endurance is given in the Addendum to this Item.

3.7 Effect of Thickness

Data presented in Figure 8 indicate that there may be a thickness effect on life as the test data for the 24 swg (0.6 mm) skin show a lower life, at any stress level, than for thicker skins. The evidence of thickness effect is not apparent in Figure 12 where different rivet holes were used. This suggests that the apparent thickness effect in Figure 8 results from stress concentrations at the rivet holes being more severe in the thinner skin in the case of mushroom-head rivets in plain holes.

3.8 Effect of Non-Zero Mean Stress

An increase in the tensile mean stress reduces the value of S_{rms} that would produce failure at a given endurance. Insufficient data are available to allow definite conclusions as to the effect of mean stress on endurance. In the absence of other data an approximate assessment of the effect of mean stress on endurance may be obtained from Item Nos Fat. A.00.01 or A.00.02.

3.9 Effect of Load Truncation

In random vibration fatigue tests it is necessary to truncate the applied loading spectrum to a prescribed value of peak stress above and below the root mean square value.

The effect of the truncation level on fatigue endurance is dependent to a large extent on the root mean square value of the load spectrum concerned in relation to the fatigue limit of the structural element. Bending fatigue tests, about a zero mean load, on an aluminium-copper alloy have shown that truncation at a stress of ± 2.5 times the root mean square value results in lives greater than ten times those for specimens with load truncation at ± 4.0 times the root mean square value when the value of the root mean square stress is below the fatigue limit. Further information on load truncation is given in Reference 9. The truncation levels for data presented here are typical of the values found in normal acoustic environments; hence the data are directly applicable to structural elements subjected to acoustic loading.

4. DERIVATION AND REFERENCE

Derivation

1. BAYERDÖRFER, G.
CARL, R. Unpublished work by Dornier AG.
2. TOWNSEND, N.A.
CORKE, D.M. The fatigue strength between 10^5 and 10^{10} cycles to failure of light alloy skin-rib joints under fully reversed bending loads. Part 2 – random amplitude excitation. Hawker Siddeley Aviation Ltd, Stress Office Report 54. Work under Ministry of Aviation contract KS/1/0115/C.B.43(a)2, May 1963.
3. CUMMINS, R.J.
EATON, D.C.G. Unpublished work by British Aircraft Corporation, May 1969.
4. TOWNSEND, N.A. Fully reversed bending r.m.s. *S-N* curves for light alloy skin-rib joints between 10^5 and 10^9 cycles to failure. Part 1 – unreinforced skins. Hawker Siddeley Aviation Ltd, Stress Office Report AR 10. Work under Ministry of Technology contract KS/1/0401/C.B.43(a)2, June 1970.
5. ARTUSIO, G.
et al. Unpublished work by Fiat, January 1971.
6. CUMMINS, R.J.
EATON, D.C.G. Unpublished work by British Aircraft Corporation, January 1971.
7. BAYERDÖRFER, G. Experimental investigation to establish acoustic fatigue design charts. *J. Sound Vib.*, Vol. 17, No. 1, pp. 55-62, July 1971.
8. THOMSON, A.G.R.
LAMBERT, R.F. Acoustic fatigue design data, Part 2. AGARD-AG-162 – Part 2, 1972.

Reference

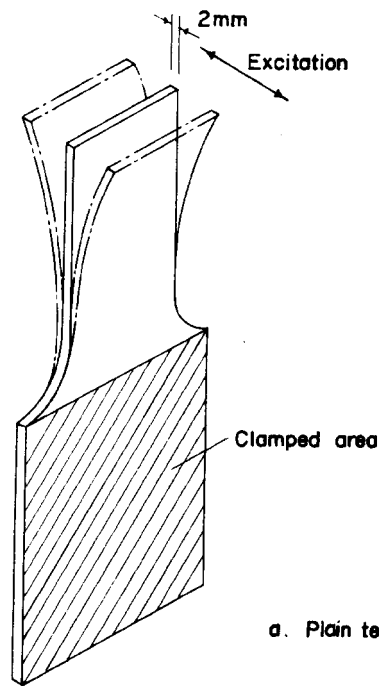
9. KIRKBY, W.T. A review of the work in the United Kingdom on the fatigue of aircraft structures during the period May 1969-April 1971. RAE tech. Rep. 71157, August 1971.

5. SUMMARY OF DATA PRESENTED

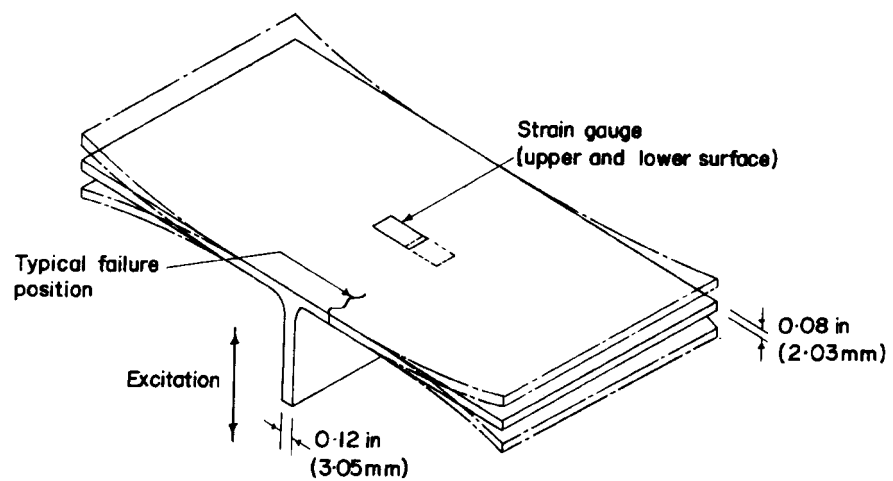
TABLE 5.1

Figure No.	Type of Element	Material	Jointing Compound	Anti-Fretting Compound	No. of Rivet Rows	Hole Type (1)	Rivet Type (1)	Thickness		Response Frequency (Hz)	Rivet Material Specification
								mm	SWG		
3	plain machined stiffener free-free beam	2024-T4	–	–	–	–	–	2.0	–	2000	–
		VES(AL)504	–	–	–	–	–	2.03	–	670-720	–
		VES(AL) 504	–	–	–	–	–	0.53	–	390-540	–
4	riveted skin	ASSEMBLAGE OF DATA PLOTTED ON FIGURES 5-12									
5	riveted skin	3.1364.5	none	none	1	plain	m/h	0.80	–	220	2.4360.1
6	riveted skin	CM001-1D	none	none	2	cut c's'k	c's'k solid	1.63	16	440-480	BAS 7002 ⁽²⁾ (3)
	riveted skin	D.T.D. 710	none	none	2	cut c's'k	c's'k blind	1.42	17	340	
7	riveted skin	D.T.D. 5070	JC 5A	yes	1	plain	m/h	0.91	20	190-320	L86
8	riveted skin	D.T.D. 710	Thiokol	yes	1	plain	m/h	0.56	24	130-330	L86
	riveted skin	D.T.D. 710	Thiokol	yes	1	plain	m/h	0.91	20	160-340	L86
	riveted skin	D.T.D.710	Thiokol	yes	1	plain	m/h	1.22	18	180-330	L86
	riveted skin	3.1364.5	Thiokol	none	1	plain	m/h	0.80	–	220	2.4360.1
9	riveted skin	D.T.D. 5070	JC 5A	yes	1	cut c's'k	c's'k	1.22	18	190-330	L86
	riveted skin	D.T.D. 710	JC 5A	yes	1	cut c's'k	c's'k	1.22	18	250-280	L69
	riveted skin	D.T.D. 746	JC 5A	yes	1	cut c's'k	c's'k	1.22	18	260-290	L69
10	riveted skin	D.T.D. 710	Thiokol	yes	1	cut c's'k	c's'k	1.22	18	180-300	L86
	riveted skin	CM001-1D	Viton	none	2	cut c's'k	c's'k	1.63	16	440-480	BAS 7002 ⁽²⁾
11	riveted skin	3.1364.5	none	none	1	h.p.d.	c's'k	0.80	–	220	2.4360.1
12	riveted skin	D.T.D. 710	JC 5A	yes	1	h.p.d.	c's'k	0.56	24	170-310	L86
	riveted skin	D.T.D. 710	JC 5A	yes	1	h.p.d.	c's'k	0.91	20	85-380	L86
	riveted skin	D.T.D. 710	JC 5A	yes	1	h.p.d.	c's'k	1.22	18	180-310	L86
13	rib flange	D.T.D. 5070	–	–	–	–	–	0.91	20	145-165	–
14	rib flange	D.T.D. 710	–	–	–	–	–	0.56	24	150-200	–
	rib flange	D.T.D. 710	–	–	–	–	–	0.91	20	150-300	–
	rib flange	D.T.D. 710	–	–	–	–	–	1.22	18	195-230	–

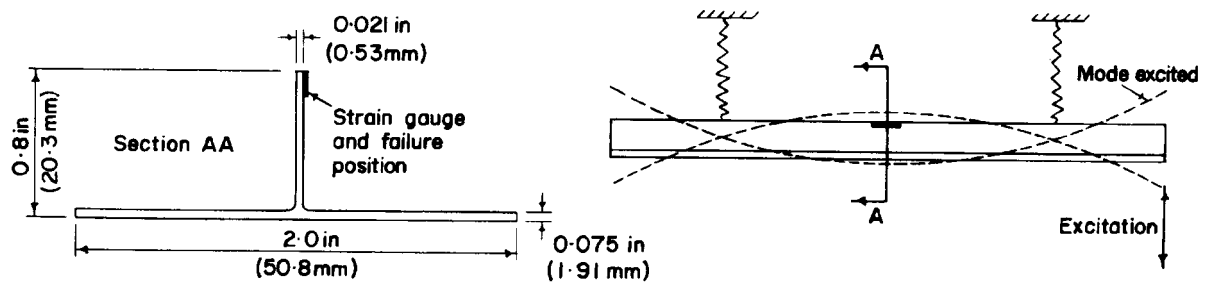
- (1) m/h = mushroom-head
h.p.d. = hot-pressure-dimpled
c's'k = countersunk
- (2) BAC specification
- (3) monel and stainless steel.



a. Plain test specimen



b. Machined stiffener test specimen



c. Free-free beam

FIGURE 1

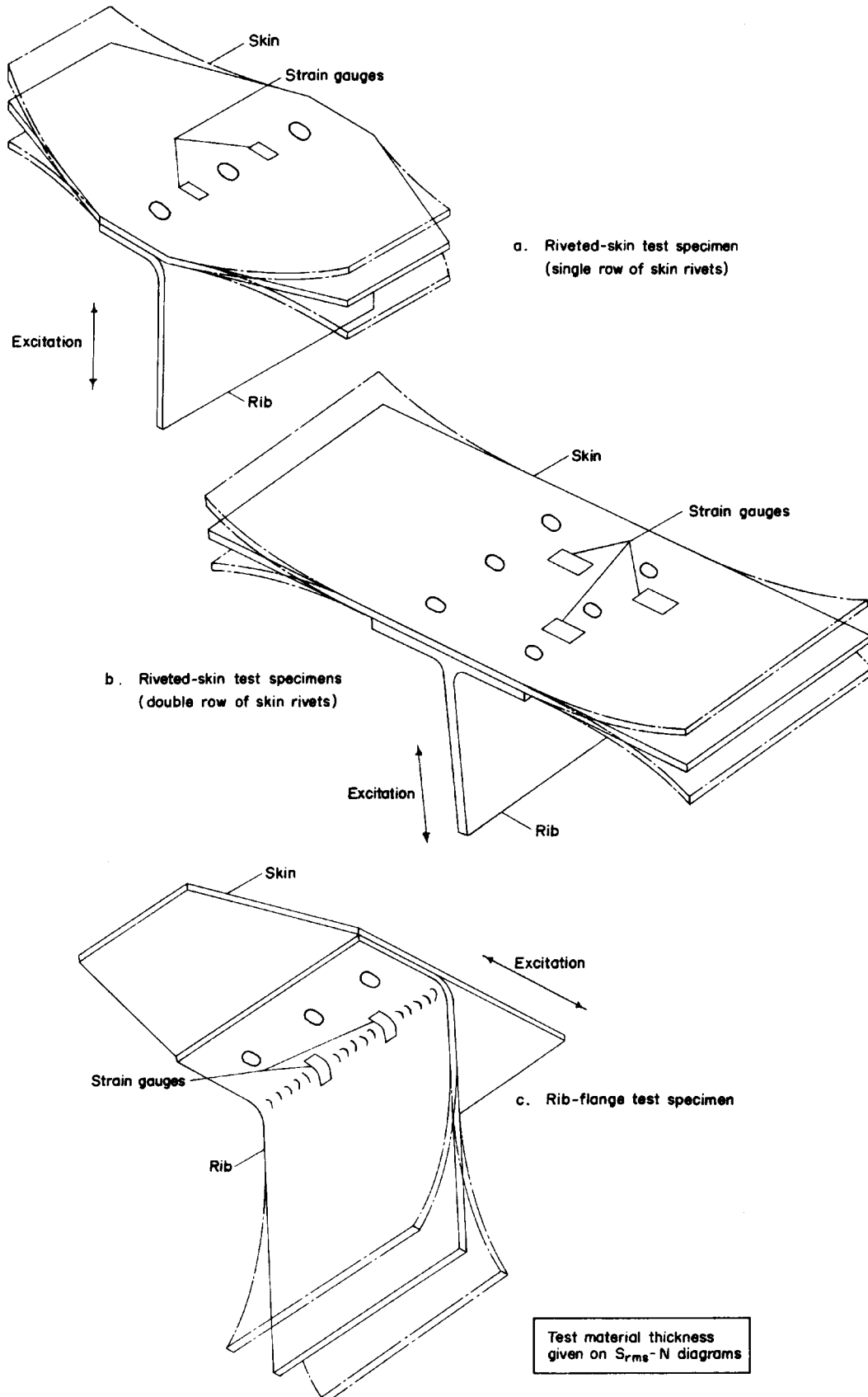


FIGURE 2

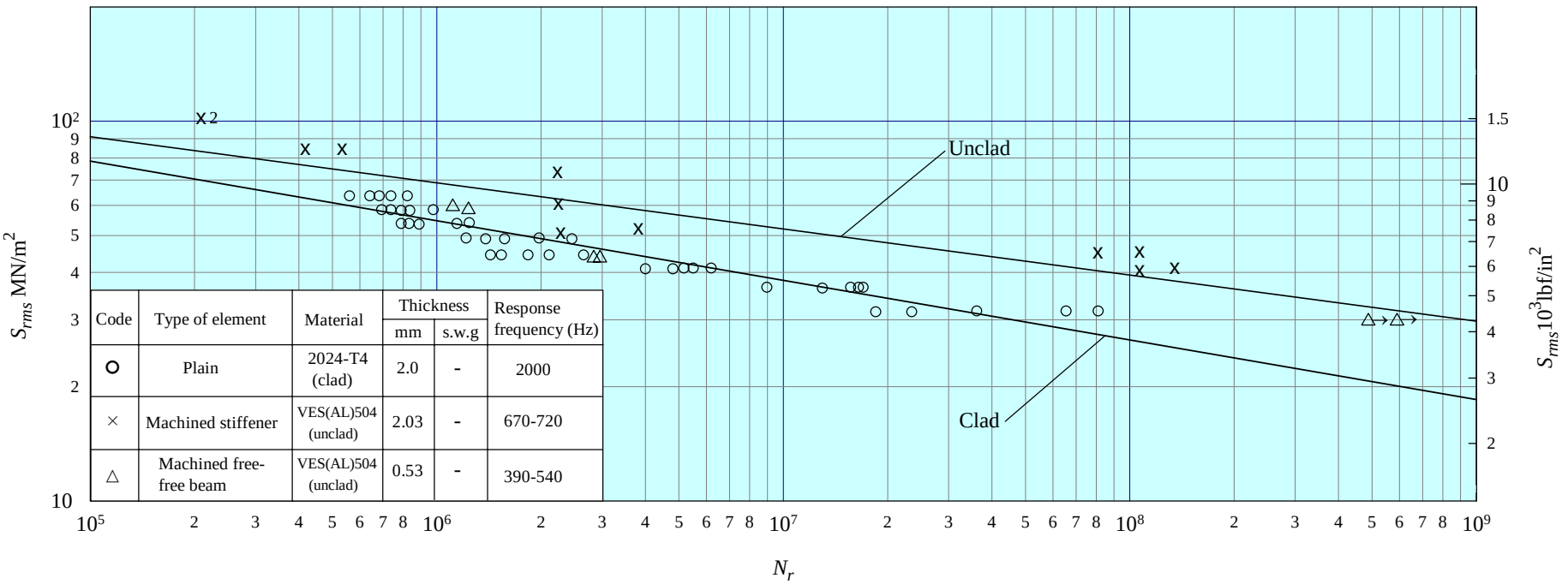


FIGURE 3 S-N DATA FOR PLAIN AND INTEGRALLY MACHINED SPECIMENS

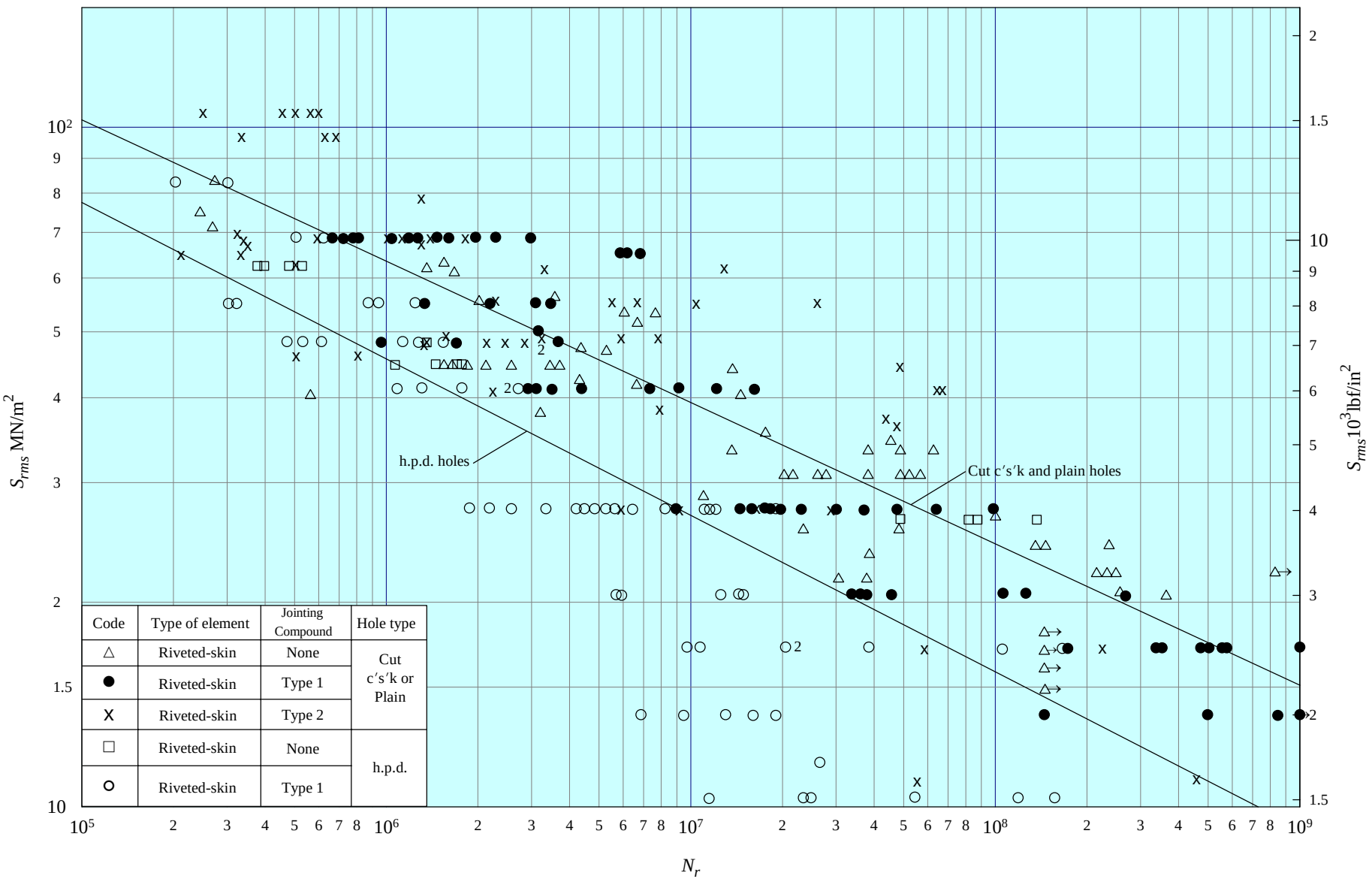


FIGURE 4 S-N DATA FOR RIVETED-SKIN SPECIMENS

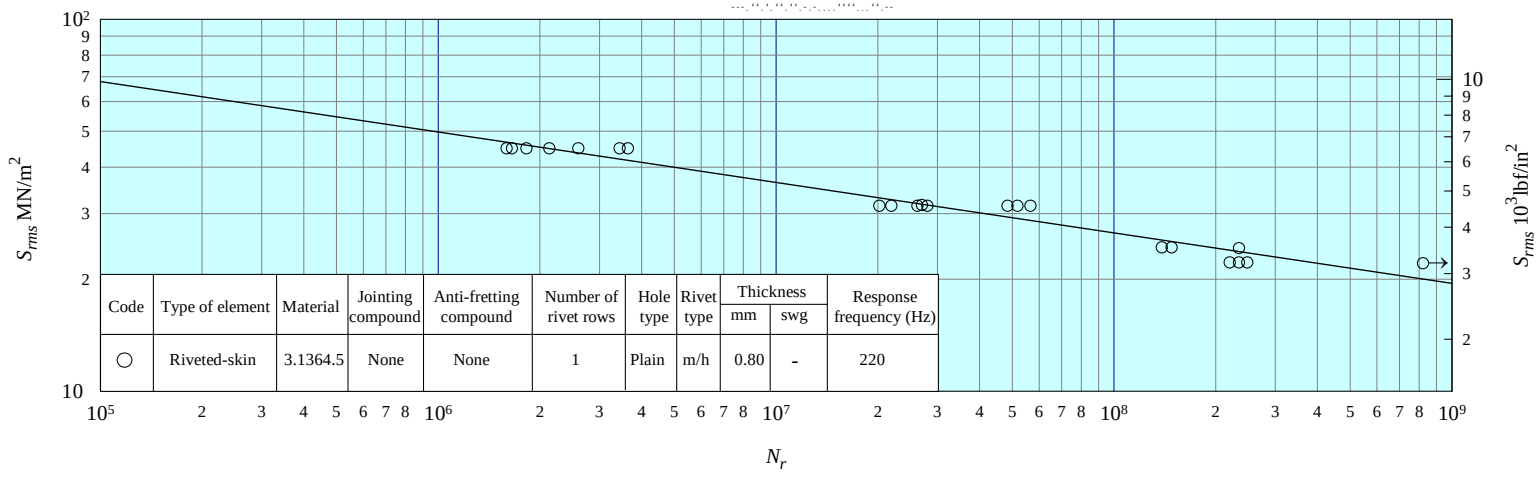


FIGURE 5 S-N DATA FOR RIVETED-SKIN SPECIMENS

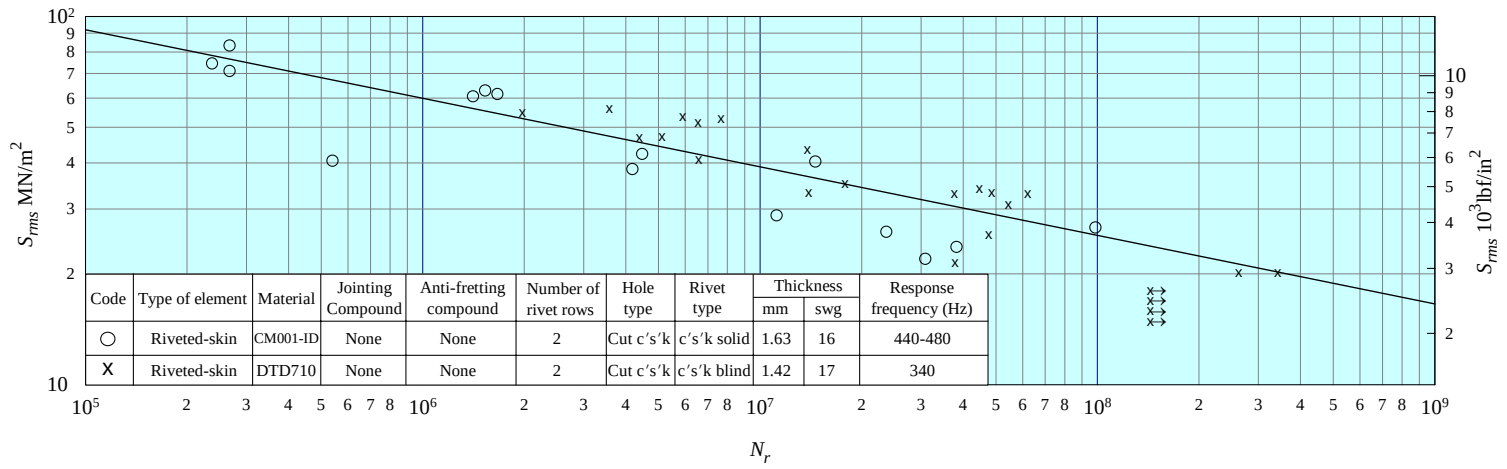


FIGURE 6 S-N DATA FOR RIVETED-SKIN SPECIMENS