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DESIGN AND OPERATION OF WIRE FATIGUE TESTER

by

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SUMMARY OF RESULTS

In conjunction with a metallurgical study of fourdrinier wire wear, fatigue testing of samples of prospective fourdrinier wire alloys was undertaken.

In the fatigue test a fine wire specimen is bent over one-quarter of the circumference of a glass cylinder. The specimen is rotated axially at 3500 rpm and is so subjected to one complete reverse bend per revolution.

To date the fatigue strengths of 8% Sn-phosphor bronze and mangalloy have been compared. The materials have similar fatigue properties although the 8% Sn-phosphor bronze tested appears to have slightly higher fatigue strength than the mangalloy.

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INTRODUCTION

In conjunction with a metallurgical study of fourdrinier wire wear[1], fatigue testing of samples of prospective fourdrinier wire alloys was undertaken.

Although wear resistance is of primary importance in fourdrinier wire for high speed newsprint machines[2], it must be combined with high fatigue strength in a good fourdrinier warp wire material. During operation of the fourdrinier machine the wire is subjected to tension and repeated reverse plane bending as it contacts the various rolls on the fourdrinier machine. The warp wires may also be bent as they pass over the edges or the openings in the suction boxes which remove water from the paper stock. A good warp wire material must therefore resist failure by fatigue.

When reviewing the literature for possible fourdrinier wire alloys it was found that only limited information was available on fatigue properties, with practically no information on the fatigue properties of fine wires. A fatigue test was therefore considered to be a necessary supplement to the wear experiments, particularly since the wear tester did not include a fatigue component[1]. Discussions with various wire manufacturers and wire weavers suggested that the fatigue resistance of wires was compared commercially by rotating a loaded wire bent over a glass sleeve. Accordingly, a test apparatus was built on this principle.

To date, no attempts have been made to carry out corrosion fatigue tests, although the equipment could be readily adapted for this.

DESIGN AND OPERATION OF THE FATIGUE TESTER

In the fatigue test the specimen, in fine wire form, is bent over one quarter of the circumference of a glass cylinder (see Figure 1). The specimen is rotated axially at 3500 rpm and, in this system, the wire is subjected to one complete reverse bend per revolution.

The wire specimen is loaded at one end with a 13-gram cylindrical steel weight which rotates freely in a vertical glass tube to give collimation and prevent whipping of the fine wire. The other end of the wire is fitted into a collet which is fixed to the shaft of the driving motor. The wire, the collet, and the motor shaft are coaxial.

Wire samples 0.008 in. to 0.012 in. diameter, i.e. the range of size used in fourdrinier wire weaving, can be tested with the present collets. Glass cylinders of various diameters may be used on the machine to produce various fibre stresses in the wire specimen during testing.

The maximum circumferential fibre stress P of a cylindrical section, such as a wire, when bent over a curved surface with radius of curvature R, is given by the equation:-

$$P = \frac{Er}{R}$$

where r is the radius of the wire, and E is the modulus of elasticity of the wire material (taken to be 16×10^6 psi in this instance). The total stress is obtained by adding the tension stress in the wire due to the steel weight and, in practice, this is quite a small fraction of the total. Torsional stresses in the driven wires were considered to be small. Little resistance to rotation of the samples was evident during operation and the failed wires exhibited no residual torque effects, such as twisting of surface drawing marks. This indicates that any torsional stresses present were within the elastic limit of the material.

It was found that there was some whipping of the wire between the collet and the glass sleeve, which could perhaps have been overcome by reducing the distance between these points. However, by running the wire between two lightly loaded polishing cloth pads at this point, the whipping was overcome without any apparent effect on the fatigue results. Similarly, the wire tended to go out of alignment by rolling on the surface of the glass tube. This was eliminated by taping a thin piece of card to the surface of the tubes as shown in Figure 1.

The fatigue tester is equipped with an automatic stop switch and a counter which gives the number of cycles to failure.

PREPARATION OF FATIGUE SAMPLES

The alloys to be tested in fatigue are those which show the most durability in the wear tests[1]. The 8% Sn-phosphor bronze and mangalloy tested to date were both commercial fourdrinier wire stock in the form of annealed wire with the properties listed in Table I.

In an earlier fatigue test, carried out by the Engineering Physics Section, wide strips of woven wire cloth were statically loaded in tension and deflected uni-directionally at the mid-point of the sample by a 1/16-in. diameter steel rod. This test simulated, quite closely, the actual flexure conditions found on fourdrinier machines, although there was no reverse bending. Such a test is limited by the availability of test samples in wire cloth form and is, therefore, less applicable to experimental alloys. However, the results of these flexure tests are also included in the report.

RESULTS

About ten samples were run with each glass-cylinder size i.e. at each stress level. To date mangalloy and 8% Sn-phosphor bronze have been tested and the results are shown in Table II in which are plotted the mean values, the horizontal lines through the points indicating the scatter.

Graphically the endurance limit for both alloys is very well defined (see Figure 2). In this experiment, 8% Sn-phosphor bronze appears to have slightly higher fatigue strength (about 42,000 psi up to 15 million cycles) than mangalloy (about 39,000 psi up to 15 million cycles). However, since the diameter of the phosphor bronze wire was somewhat less than that of the mangalloy, this gives a higher stress in the phosphor bronze sample for each given size of tube. This in turn indicates a higher fatigue limit at the knee of the SN curve. The scatter bands of both alloys overlap to some extent, but there is some indication that for a given stress, the phosphor bronze will withstand a greater number of cycles than will the mangalloy.

When the small size of the sample, and the possibility of mechanical damage to such a small sample is considered it will be appreciated that the scatter of the results as shown in Figure 2 is quite acceptable.

The results of the earlier tests on wire cloth samples of phosphor bronze and mangalloy under conditions of uni-directional bending, are shown in Figure 3. Various static tension loads and various mid-span deflections are plotted against cycles to failure, and again it can be seen that in general the phosphor bronze endured a higher number of cycles under given load and deflection conditions, than did mangalloy.

DISCUSSION

The endurance limit for annealed 8% Sn-phosphor bronze is given in the literature(3) as 17,000 psi at 100 million cycles. This result was obtained with sheet-metal fatigue specimens in reverse plane bending. In this experiment the endurance limit for 8% Sn-phosphor bronze was about 42,000 psi up to 15 million cycles and, from the appearance of the curves in Figure 2, it should be close to this value at 100 million cycles.

The difference in these results may be due to the different methods of testing and to differences in the materials. The fine wire will have different grain size, surface finish and mechanical properties than sheet. In addition the annealing treatment of wire does not give a dead soft material so that there may be residual compressive stresses in the surface of the wire which would effectively reduce the fibre stress on bending and thus give improved fatigue life. If this is indeed the case it should be remembered that in practice, the surface layers of the wire are worn off at the knuckles, and that maximum flexure will take place at these points. Thus the fatigue properties of the core material are probably more important than those of the surface in actual practice.

The tests were to be used as a means of comparing the fatigue strength of the various materials rather than to establish absolute values. In evaluating the prospective fourdrinier wire alloys, 8% Sn-phosphor bronze, the conventional fourdrinier wire material, will be used as a standard of comparison.

A particular advantage of this fatigue test is the simplicity and economy of sample preparation.

The consistency of the results indicates that the test is not influenced by extraneous effects such as the sample rubbing on the glass tube. Examination of broken wires showed clean sharp breaks with little or no reduction in area and, with one exception, these fractures occurred at the mid-section of the bent portion. Examination of the surface of the wires under a microscope showed no signs of peening or wear and the original drawing marks on the wires were clean, sharp and not twisted due to torsion. Similarly, there was no trace of metal on the surface of the glass tubes.

In conclusion, the test appears to give reproducible results although the fatigue strength values are considerably higher than those published for flat material of the same nominal analysis in plane bending. These differences may be due to the different characteristics of the tests, or to the particular conditions in the surface of the drawn wire especially the possible presence of residual compressive stress in this surface layer.

If the differences are due to this latter cause, it will be difficult to interpret the fatigue results in relation to the fatigue behaviour of woven fourdrinier screen since in the fourdrinier machine the surface layers are progressively worn from the wire at the bottom knuckles. This exposes the underlying material, and because of the reduced section, the flexure concentrates in these regions. Thus, the fatigue characteristics of a fourdrinier wire screen may change as the screen becomes worn, quite independent of the mechanical changes due to the reduced cross section.

It would appear therefore that experiments should be carried out on the same wire strands after removal of the surface layers by some method such as etching. This would enable the influence of the surface layers to be more accurately assessed.

REFERENCES

1. G. W. Toop and J. O. Edwards, "Design and Operation of Wire Wear Tester and Preparation of Wear Samples", Mines Branch Investigation Report IR 59-92.

2. J. G. Buchanan, C. E. MacDonald, K. E. Vroom and B. W. Burgess, "Study of Newsprint-Machine Wire Life". Published by Pulp and Paper Research Institute of Canada, 133 pp Nov. 1958).

3. C. H. Greenall and G. R. Gohn, "Fatigue Properties of Non-Ferrous Metals", Proc. ASTM 37, 160-191 (1937).

TABLE I

Properties of Fourdrinier Wire Material Tested

Mechanical Properties

	U.T.S. psi	Yield Strength (0.5% Extension)	Elongation (% in 10 in.)
8% Sn-Phosphor Bronze	70,500	36,900	69
Mangalloy	79,700	40,700	48.4

Chemical Analysis

	Cu %	Sn %	Mn %	P %
8% Sn-Phosphor Bronze	91.96	7.76		0.32
Mangalloy	90.77	7.31	1.53	0.29

Grain Size (Mean grain diameter)

8% Sn-Phosphor Bronze	0.009 mm.
Mangalloy	0.005 mm.

TABLE II

Fatigue Test Results for 8% Sn-Phosphor Bronze and Mangalloy

	Glass Cylinder Diameter in.	Circumferential Stress psi	Number of Thousands of Cycles to Failure
8% Sn-Phosphor Bronze, wire diameter 0.0081 in.	2.031	64,360	88.4*
	2.342	55,860	143.4*
	2.520	51,960	271.3*
	2.762	47,360	493.0*
	3.148	41,660	988.0
			1,018.4
			3,195.6
			3,861.8
			11,797.9**
			14,750.6**
Mangalloy, wire diameter, 0.0095 in.	2.031	75,300	32.0*
	2.342	65,200	50.9*
	2.520	60,700	85.6*
	2.762	55,400	109.2*
	3.148	48,700	264.9*
	3.538	43,400	591.5*
	3.923	39,100	1,703.8
			1,730.8
			2,436.2
			2,475.5
			3,160.6
			3,693.7
			16,053.7**
			20,864.1**

* Average of at least 10 results
**Did not fail.

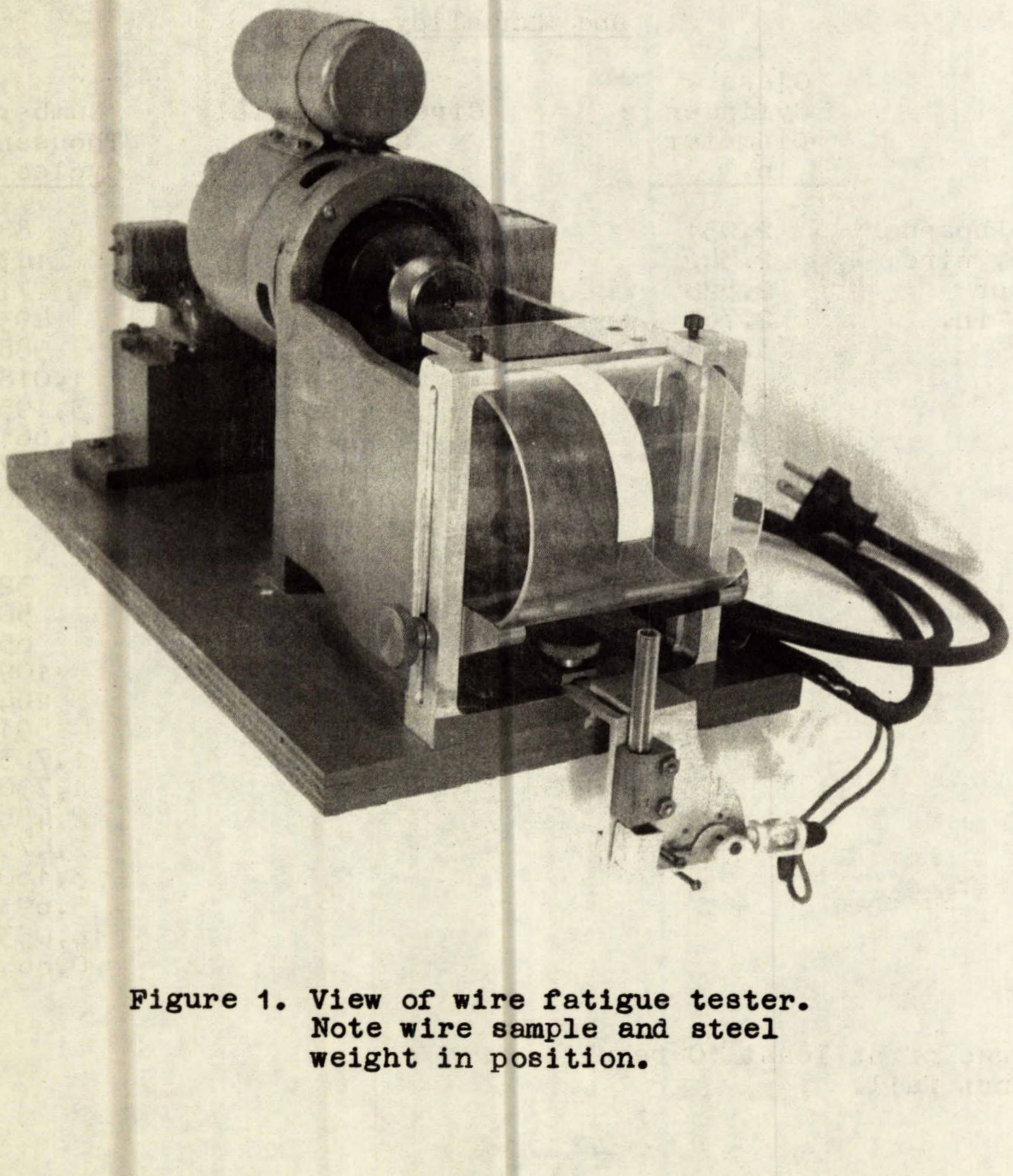

Figure 1. View of wire fatigue tester.
Note wire sample and steel
weight in position.

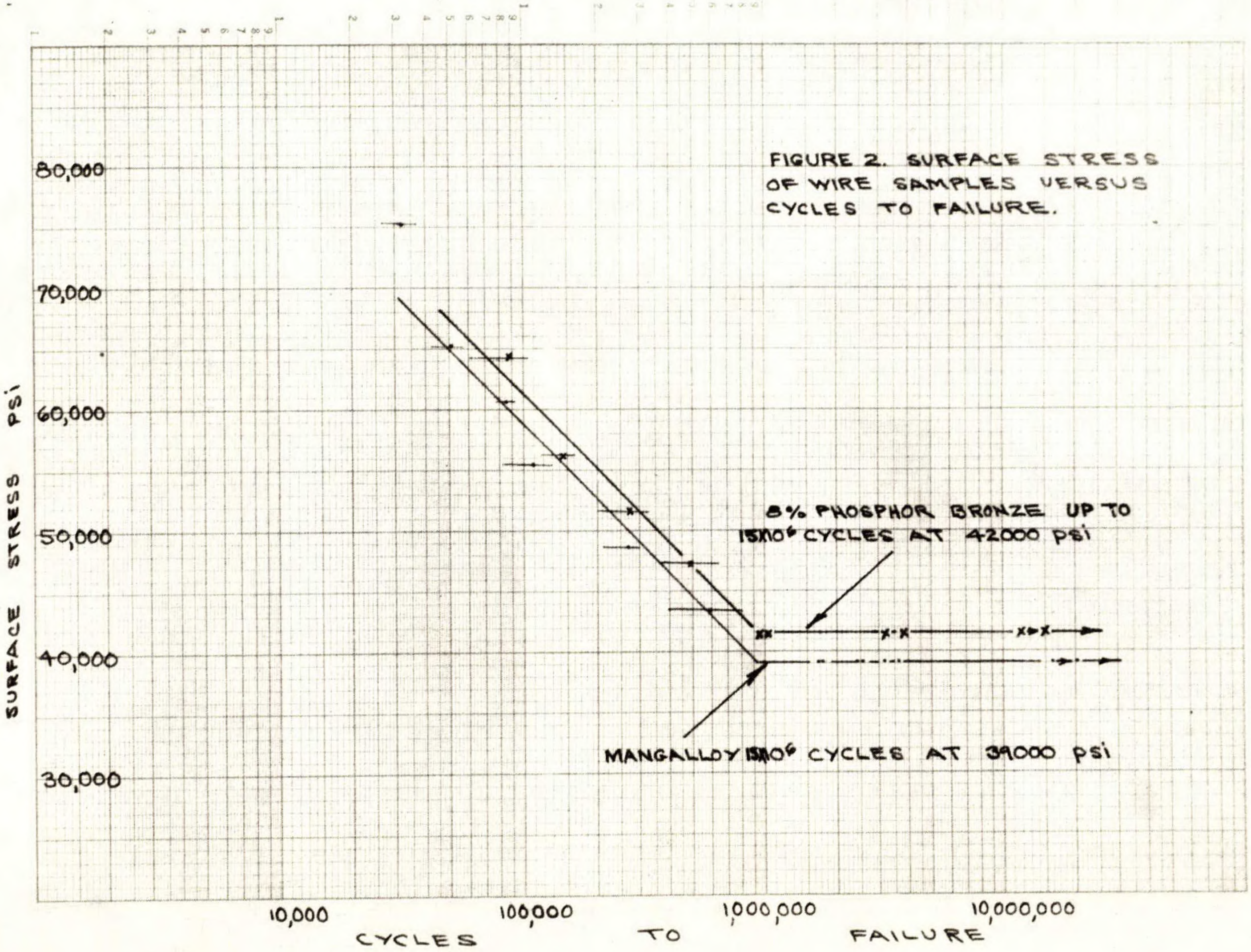

FIGURE 2. SURFACE STRESS OF WIRE SAMPLES VERSUS CYCLES TO FAILURE.

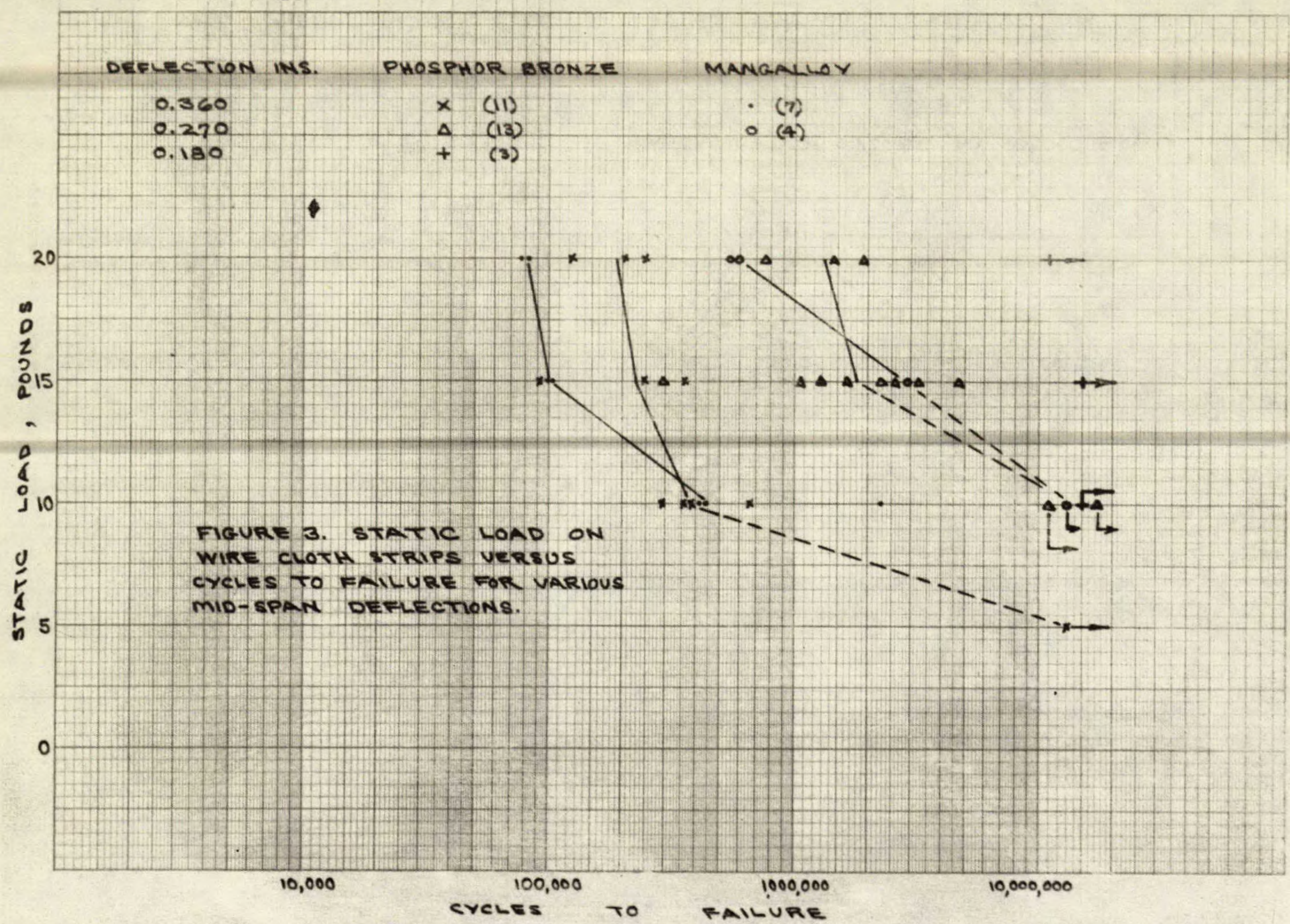

FIGURE 3. STATIC LOAD ON WIRE CLOTH STRIPS VERSUS CYCLES TO FAILURE FOR VARIOUS MID-SPAN DEFLECTIONS.