THE COIL SPRING FEDERATION RESEARCH ORGANISATION

A Comparison of the Corrosion Fatigue Protection Properties of Vacuum Deposited and Electroplated Zinc Coatings applied to Helical Compression Springs

Report No. 125

by

J. W. Mee, A.Met., A.I.M.

May 1961

COIL SPRING FEDERATION RESEARCH ORGANISATION

Report No. 125

C.P.S.C./P5

A Comparison of the Corrosion Fatigue Protection Properties of Vacuum Deposited and Electroplated Zinc Coatings applied to Helical Compression Springs

Summary

Helical compression springs have been coated with zinc by a vacuum-evaporation technique and by conventional electroplating and a comparison of the respective corrosion fatigue properties carried out.

The vacuum deposited coating was less adherent than electroplate, and tended to flake off during testing.

The protective coatings did not penetrate completely under the points of the end coils and with electroplated springs failure under corrosion fatigue conditions tended to commence at this point.

The in-air fatigue strength of the coated springs was 2 - 3 tons/sq.in. higher than the value for uncoated springs showing that although the beneficial effect of any compressive stresses in the zinc coat was small it did constitute an improvement which is not apparent with other types of plated metals.

(May 1961)

COIL SPRING FEDERATION RESEARCH ORGANISATION

Report No. 125
C.P.S.C./P5

A COMPARISON OF THE CORROSION FATIGUE PROTECTION PROPERTIES OF VACUUM DEPOSITED AND ELECTROPLATED ZINC COATINGS APPLIED TO HELICAL COMPRESSION SPRINGS

by J.W. Mee, A.Met., A.I.M.

1. INTRODUCTION

Where metallic protective coatings are desirable and hydrogen embrittlement arising from electroplating is a problem any alternative method of metallic deposition is attractive. One such technique viz, peen plating, has already been examined and the results circulated.[1] Another is to deposit metal by vacuum evaporation, this method has been investigated in the present paper and the effectiveness compared with conventional electroplating.

The vacuum and electro-depositions were carried out by the B.S.A. Group Research Centre who also undertook static corrosion tests on the coatings. The load testing, fatigue testing and final examination were carried out in the C.S.F.R.O. laboratories.

2. SPRING MATERIALS AND DESIGN

Helical springs were manufactured from patented hard drawn spring wire to EN.49C specification having the following chemical analysis:

C 0.82% Mn 0.64% Si 0.24% S 0.027% P 0.010% Cu 0.02%

The spring design was as follows:

Wire diameter	0.144 in.
Mean coil diameter	1.156 in.
Free length after prestressing	1.75 in.
No. of active coils	3.3
Total No. of coils	5.3
Spring Rate	120 lbs/in.

After coiling, the spring received a low temperature heat treatment of 350°C for 30 minutes followed by rough end grinding, pre-stressing and finish grinding.

3. EXPERIMENTAL PROCEDURE

Coating the Springs

Preliminary tests were carried out by the B.S.A. Group Research Centre in order to compare the static corrosion properties of the two types of coating at thicknesses of 0.001 in. and 0.0005 in. As a result two batches of 20 springs were zinc coated, one by electroplating and the other by vacuum evaporation both to a nominal thickness of 0.001 in. and supplied to the C.S.F.R.O. for fatigue testing. The surface preparation of the springs and methods of deposition are described in the appendix to this report.

Load Testing

The coated springs were compressed solid once and then load tested to determine the lengths at the initial and maximum stresses at which they were to be fatigue tested.

Fatigue Testing

Fatigue testing was carried out on a machine described in an earlier paper.[2] During corrosion fatigue testing a perspex box fitted over one side of the machine enclosed four springs, which were kept moistened by wicks carrying synthetic sea water to B.S. 1391. Parts of the machine exposed to the corrosive fluid were protected by a coating of wax. Each spring testing station had its own closed electrical circuit incorporating a microswitch and timer so that on failure the timer would stop while testing of the remaining springs would continue uninterrupted.

Fatigue testing was carried out at a constant speed of 1500 compressions/min. at an initial stress of 2 tons/sq.in.

Examination of Broken Springs.

The fracture and surface of the broken springs were examined visually. Transverse microsections were taken from two springs coated by each method and the thickness and adherence of the coatings examined.

4. RESULTS.

4.1 Static Corrosion Tests

The results of the static corrosion tests carried out by the B.S.A. Group Research Centre are given in the appendix.

4.2 Fatigue Tests

The S-N curve for similar uncoated springs has already been reported[2] and for comparison purposes it is reproduced in Fig. 1. Fatigue curves for vacuum coated springs tested in air and under corrosive conditions are given in Fig.2, and the corresponding curves for electroplated springs in Fig.3.

4.3 Examination of tested springs

Vacuum coated, tested in air

Microscopical examination of transverse sections of two springs showed that the coating thickness averaged 0.001 in. and appeared to have been deposited in distinct layers. Fig. 4 shows these well defined. The coating had not completely covered the wire where the point of the end coil was laid on to the adjacent coil and in addition some of the coating in this region had worn off during testing. Some of the springs had a flaky outer coating, which had separated from the layer beneath, which had a brighter appearance.

Vacuum coated, corrosion tested

After load testing the vacuum coating on one spring was observed to have flaked at the more highly stressed inside fibres (Fig. 5). Accordingly all coated springs for corrosion testing were given a careful visual examination before fatigue testing commenced to check for continuity of the coating.

Subsequent to corrosion fatigue testing it was noticed that areas of the coating had flaked off giving rise to patches of rust. Rusting had also taken place under the points of the end coils but failure had originated in every case at a rust patch on the inside of an active coil. On areas free from rust the coating was covered with a white corrosion product.

Electroplated springs tested in air

Transverse micro sections from two springs showed the coating to have a thickness of between 0.0005 in. and 0.001 in. and to be adherent to the basis steel. Theoretically one would expect a coating thickness of 0.0007 in. assuming 100% cathode efficiency. Between the point of the end coil and the adjacent coil the plating had not penetrated at all and during testing some fretting had taken place. Failures originated on the active coils generally on the inside.

Electroplated springs, corrosion tested

Very little rusting had taken place on the active coils but on the end coils and particularly where the end coil made contact with the first coil there was considerable rusting and in nearly every case the failure had originated at this point (Fig. 6). Elsewhere white corrosion products covered the zinc coating with a few small isolated rust spots (Fig.7).

5. DISCUSSION OF RESULTS.

Since there was only a limited number of springs available and it was desirable to conserve as many as possible for corrosion fatigue testing, the number of in-air fatigue tests was kept to an absolute minimum, the aim being to fix the fatigue limit and not the position and angle of the sloping portion of the curve. The in-air curves for the two types of coating (Figs. 2 and 3) compare well with the uncoated curve in Fig. 1. One usually associates with zinc plating an increase in fatigue strength due to the compressive stresses induced in the substrate and although in this case there was only a small increase it was nevertheless an improvement.

There was more scatter in the results for the electroplated springs but a slightly better average life at a given stress.

Microscopical examination of sections through the coatings and visual examination of the in-air fatigue tested springs showed the electroplating to be more sound and to have greater adhesion than the vacuum deposited coating.

Static corrosion tests on the two types of coating showed that 0.001 in. of vacuum deposited zinc and 0.0005 in. of electroplated zinc had similar rates of corrosion.

During fatigue testing, areas of the vacuum deposited coating flaked off and allowed the exposed steel to rust rapidly and cause corrosion fatigue failure of the basis steel.

The electroplated coating was sound except under the points of the end coils where corrosion fatigue failures occurred. Fretting at these points may have been additional to the deleterious effect of chemical corrosion but it was not sufficient to affect the fatigue characteristics of similar springs tested in air. After corrosion fatigue testing only a few spots of rust were evident on the active coils. Due to this preferential failure at the end coils the corrosion fatigue curve obtained was not truly comparative.

6. CONCLUSIONS AND RECOMMENDATIONS

1. The vacuum deposited coating was not very adherent to the substrate and as a result the coating tended to flake away when the spring was compressed. This permitted corrosion fatigue failure to occur sooner than with the electroplated coating.

2. Both coatings failed to protect the spring completely under the points of the end coils and this deficiency was more pronounced in the case of the electroplated springs.

3. In spite of the early end coil corrosion of electroplated springs their corrosion fatigue properties were better on the average than those of the vacuum coated springs. A vacuum deposited coating of zinc cannot therefore be recommended at the present time in lieu of electroplated zinc for the corrosion protection of springs operating under fatigue conditions.

7. REFERENCES

1. "The Effect of Peen Plating on the Fatigue Properties of a Carbon Spring Steel" by J.W. Mee.
C.S.F.R.O. Report No. 116

2. "The Mechanical and Fatigue Properties of Helical Compression Springs made from Patented Hard Drawn and Oil Tempered Wires" by J.W. Mee.
C.S.F.R.O. Report No. 114

3. "Vacuum Coating and Corrosion Testing of Valve Springs for the C.S.F.R.O." by A. Huartson and G.F. Bidmead.
B.S.A. Group Research Centre Report GRC/G 1729

4. "Accelerated Corrosion Testing of Chromium Plated Articles - Sulphur Dioxide Test" by J. Edwards.
Trans. Inst. Met. Fin., 1958, 35, pp. 55-78

APPENDIX

Zinc coating and static corrosion testing of the springs

(Summary of B.S.A. Group Research Centre Report GRC/G 1729[3])

Test springs were submitted to the B.S.A. Group Research Centre for coating with zinc by vacuum evaporation and electroplating. Protection afforded by the coatings was assessed by an accelerated corrosion test. The deposition techniques employed and the results of the corrosion tests are presented in this appendix.

Surface preparation

The springs were degreased by vapour washing with acetone. The oxide film was removed by anodic pickling at room temperature in 33% ($^{v}/v$) H_2SO_4 at 200 amps/sq.ft. Hydrogen embrittlement was avoided by immersing the springs in the bath after the current was turned on. Pickling was followed by a running water wash, a further acetone wash and a quick transfer to the coating unit or the electroplating bath.

Vacuum deposition

An Edwards Model 12 E.A. vacuum deposition unit was used with an adaptor consisting of two sheathed rollers which enabled the spring to be rotated during evaporation of the zinc. In some cases the rollers became covered with a layer of zinc some of which was picked up by the outside of the spring.

Experiments were carried out using various types of vapour source. The system adopted involved the use of a crucible consisting of a ¼" dia. silica glass tube, sealed at one end and heated by a platinum winding. This permitted observation of the metal during evaporation and close temperature control was possible. The time taken to deposit 0.001 in. was approximately one hour and the thickness was checked by a calibrated Tinsley/B.S.A. magnetic thickness meter.

Electro deposition

Test springs were electroplated in a conventional cyanide bath of the following composition:

Zinc Cyanide	60 grams/litre
Sodium Cyanide	23 grams/litre
Sodium Hydroxide	53 grams/litre

and under the following conditions of operation:

Temperature	35 to 40°C
Current Density	20 amps/sq.ft.
Anode Material	Rolled Zinc
Time to plate 0.001 in.	30 mins.

After plating the springs were washed in water and rinsed in acetone, followed by baking for 40 hours at 200°C to remove any possible hydrogen embrittlement. The coating had a light grey matt appearance compared with the darker grey matt finish of vacuum coated springs.

Corrosion Tests

Exposure to a humid atmosphere containing sulphur dioxide is claimed(4) to assimilate closely outdoor exposure conditions and the C.R.L. standard for this type of test, described in B.S. 1391, was employed.

The test springs were supported 1½" above a hot water bath and the vapour condensed on to the springs by a water-cooled coil. Weak sulphur dioxide solution was added to the hot water and the vapour temperature in the condensation zone controlled at 45°C. Sulphur dioxide solution was added twice during each working day and the springs inverted regularly to ensure uniformity of test conditions.

Corrosion tests were continued for 13 days whilst the extent of corrosion was assessed visually. The results are tabulated in Table I.

Table I. Summarised Comparative Corrosion Results.

Exposure Days:	VACUUM-COATED		ELECTRO-PLATED	
	Nom. 0.0005" thick	Nom. 0.001" thick	Nom. 0.0005" thick	Nom. 0.001" thick
1	Rust on flat portions and coils	White corrosion product but no rusting.	White corrosion product but no rusting.	
4	Many rust spots randomly distributed.	Rust in crevices only.	Rust in+ crevices only.	No rusting
6	Many rust spots randomly distributed.	Several rust spots randomly distributed.	Rust in crevices and on flat portions.	No rusting
8	Fairly extensive rusting.	Several rust spots randomly distributed.	Several rust spots randomly distributed.	Slight rusting in crevices. One or two spots on coils.
13	-	Many rust spots randomly distributed.	Many rust spots randomly distributed.	Slight rusting in crevices, several rust spots on coils.

+ Rusting generally commenced on the flat surfaces at the ends of the springs and in the crevices between the flat surfaces and the first coil.

Zinc applied by vacuum deposition was less protective than the same thickness of electroplated zinc. Greatest protection against rusting was provided by 0.001 in. of electroplate and the least by 0.0005 in. of vacuum deposit. The protection afforded by 0.001 in. of vacuum deposit was of the same order as that of 0.0005 in. of electroplate.

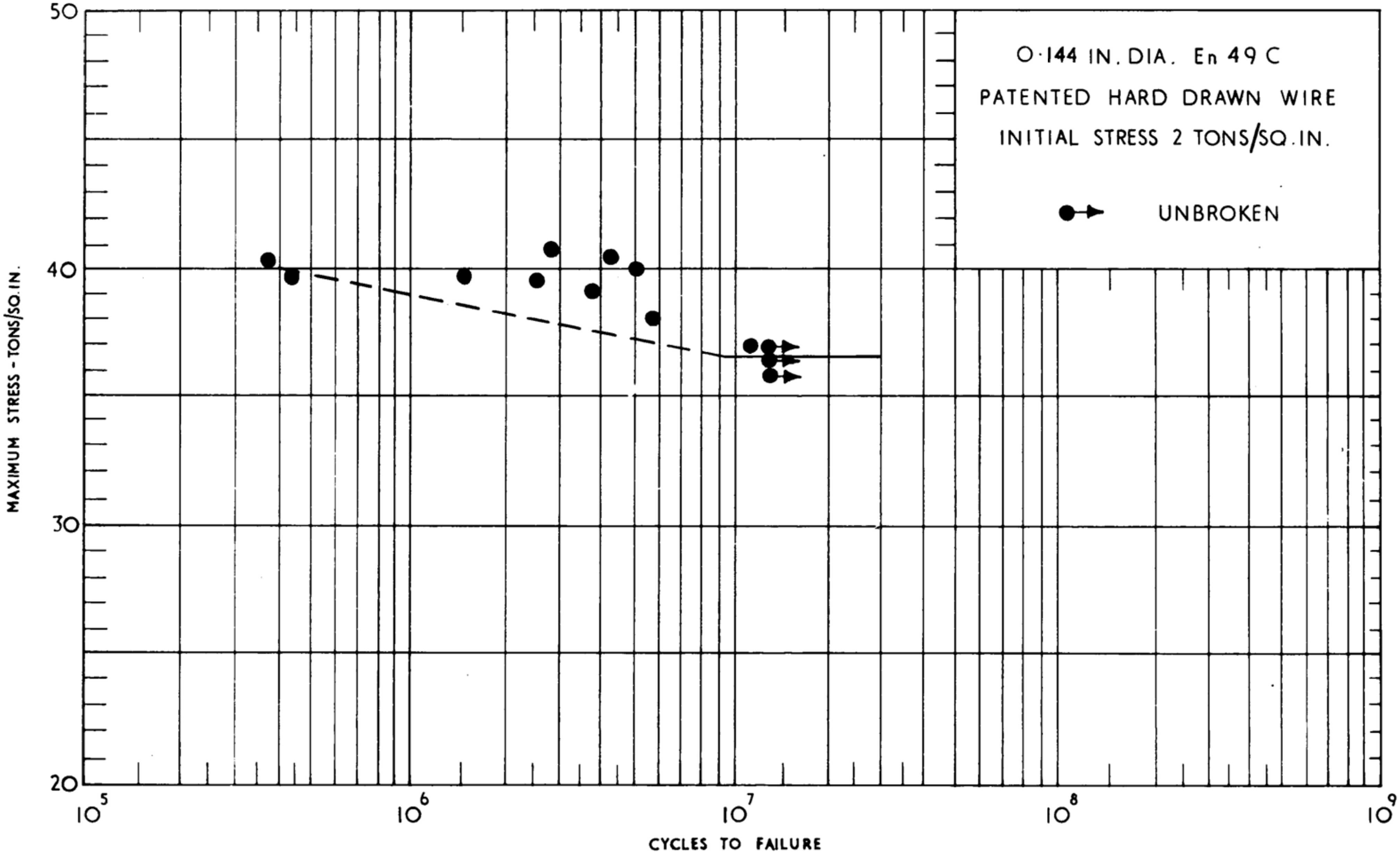


FIG.1. IN-AIR FATIGUE CURVE FOR UNCOATED SPRINGS.

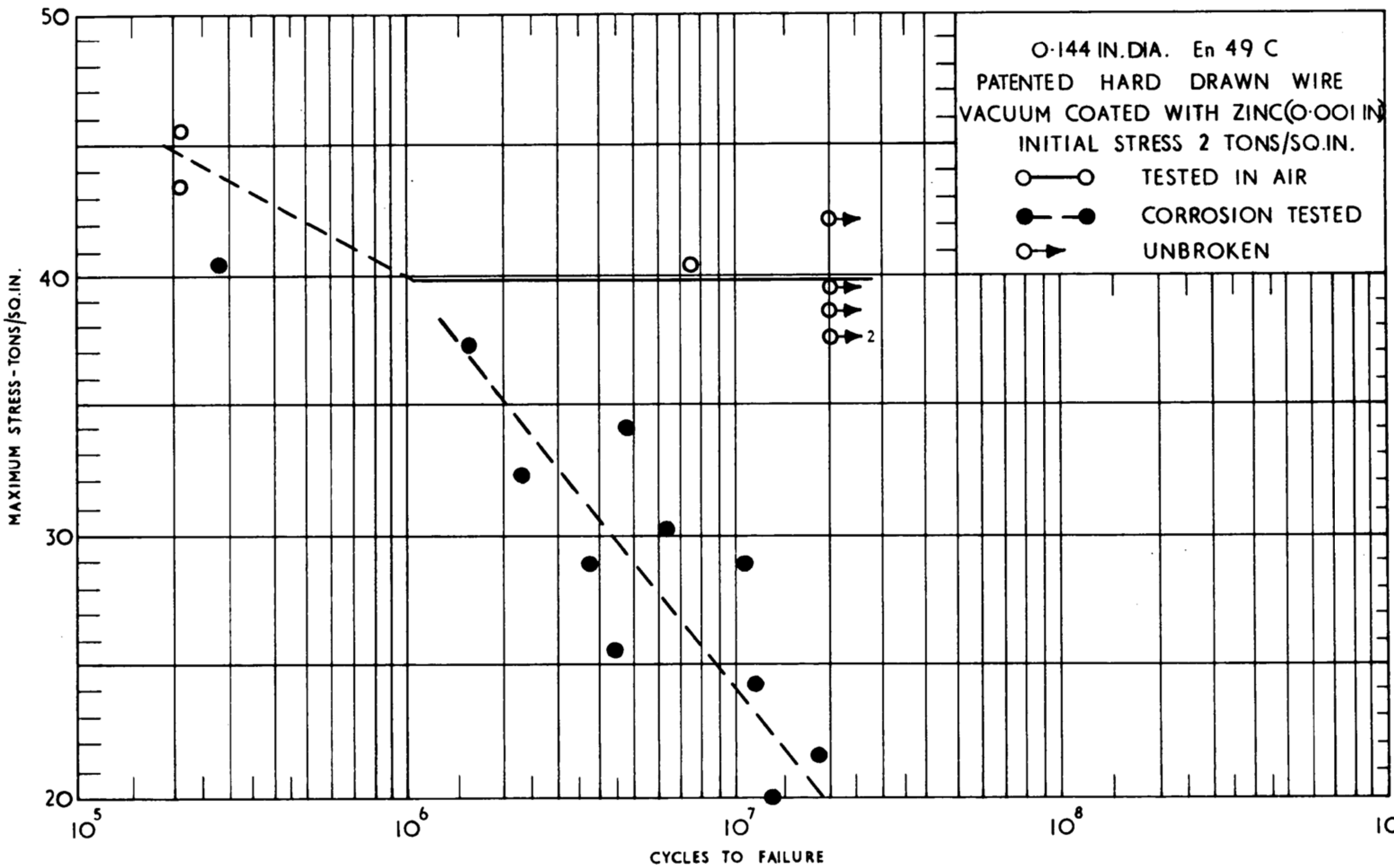


FIG. 2. IN-AIR AND CORROSION FATIGUE CURVES FOR ZINC VACUUM COATED SPRINGS.

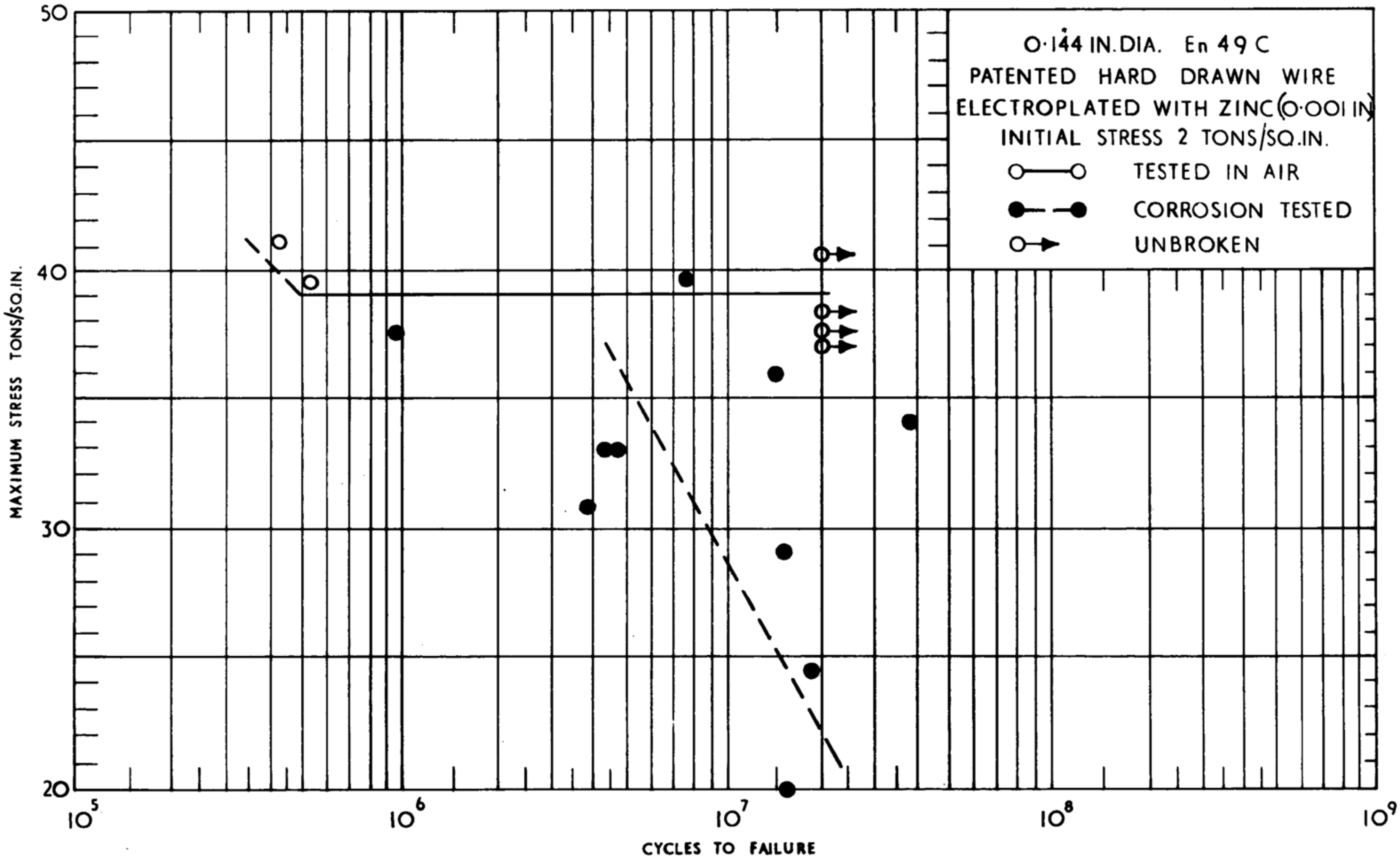
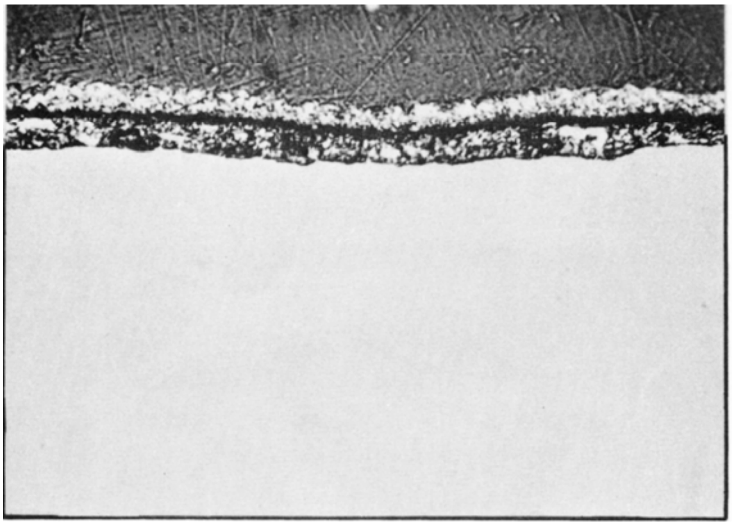
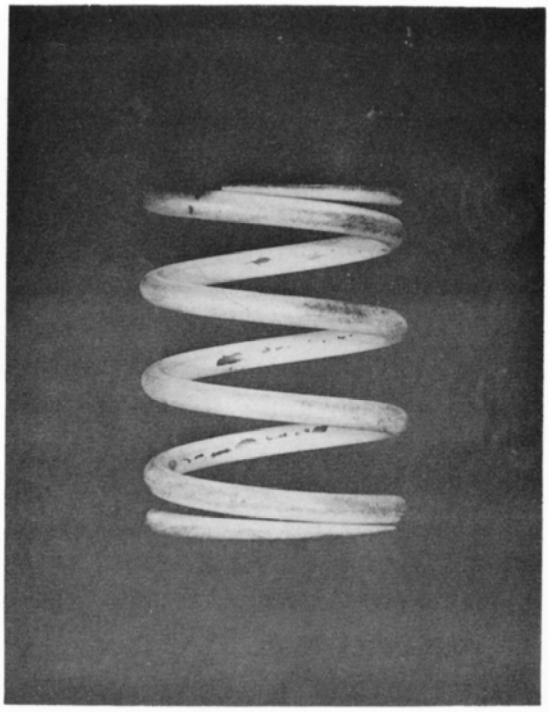


FIG. 3. IN-AIR AND CORROSION FATIGUE CURVES FOR ZINC ELECTROPLATED SPRINGS.



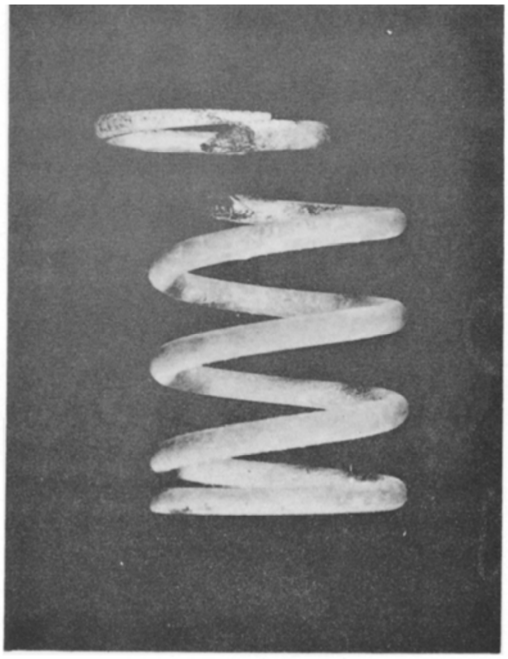
x 500

FIG. 4 TRANSVERSE SECTION THROUGH VACUUM DEPOSITED COATING SHOWING TWO DISTINCT LAYERS



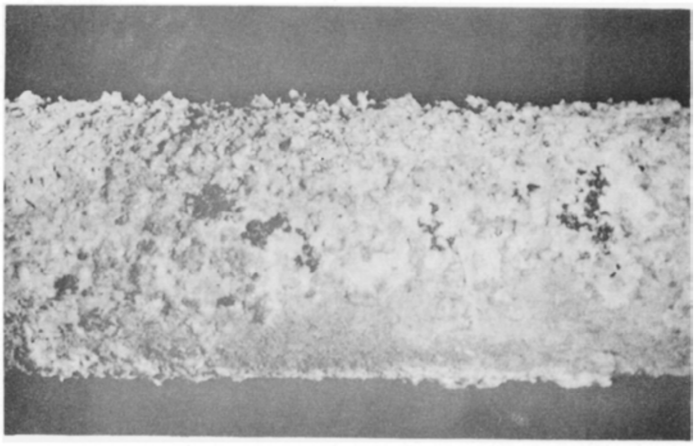
x $1\frac{1}{4}$

FIG. 5 FLAKING OF THE VACUUM DEPOSITED COATING ON THE INSIDE OF THE COILS AS A RESULT OF LOAD TESTING



x $1\frac{1}{4}$

FIG. 6 SPRING ELECTROPLATED WITH ZINC SHOWING CORROSION FATIGUE FAILURE UNDER POINT OF END COIL



x 10

FIG. 7 SURFACE OF ELECTROPLATED SPRING AFTER CORROSION FATIGUE TESTING SHOWING RUST SPOTS AND WHITE CORROSION PRODUCTS