NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

THE PERFORMANCE OF WIRE-RESISTANCE STRAIN GAGES AS INFLUENCED BY THE DRYING TIME OF THREE MOUNTING CEMENTS

by

B.L. Miller, Ph.D., L.D. Anderson
and H. Shoub

[redacted]

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Report R-213

PERSONNEL

The static strain tests were conducted by L.D. Anderson, assisted by C.L. Pittiglio and C.A. Wagley. The cement-drying tests were conducted by W.M. Lawall. Miss K. Tilghman gave general assistance. The work was done under the immediate direction of Dr. B.L. Miller. Many helpful suggestions were made by W.J. Sette.

This report is the work of Dr. B.L. Miller, L.D. Anderson, and H. Shoub.

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THE PERFORMANCE OF WIRE-RESISTANCE STRAIN GAGES AS INFLUENCED BY THE DRYING TIME OF THREE MOUNTING CEMENTS

ABSTRACT

The performance under static strains of Baldwin-Southwark SR-4 wire-resistance strain gages attached to tensile test specimens with three different cements was investigated to establish the drying period required for a cement-mounted gage to respond linearly and at full sensitivity without hysteresis. Supplementary weighing tests on the rate of evaporation of a readily available commercial cement were performed and the results are given. The change of resistance with time of an unstressed, drying gage was observed.

INTRODUCTION

Baldwin-Southwark SR-4 resistance strain gages (1)* (2) have been the subject of a series of tests at the David Taylor Model Basin. Gages of this kind, designed to indicate static and dynamic strain by a change in electrical resistance, consist of a single continuous strand of alloy wire 0.001 inch in diameter, wound in multiple-W fashion and cemented to a strip of thin paper. The free side of the paper is in turn cemented to the surface on which the strain is to be measured. A layer of felt protects the exposed surface of the gage. When the surface elongates, the wire increases in length and decreases in cross-sectional area, causing an increase in resistance. When the surface contracts, the reverse happens.

Two basic conditions govern the reliability of such a gage: The wire used must have proper resistance-strain characteristics, and the cement must be capable of accurately transmitting to the sensitive wire the strain to be measured. A comparison of the performance of SR-4 gages attached with several types of commercial cements is the subject of this report.

A knowledge of the drying time after which a newly mounted SR-4 gage may be used for strain measurements without hysteresis or loss of sensitivity is especially important for tests conducted under strict time limitations. Some inconsistency is encountered in published information. Bulletins (1) (2) describing the gage recommend a drying time of 8 to 10 hours for Duco cement when used for static strain measurements. It is stated that this can be reduced to 2 to 3 hours when heat in the form of a hot-air blast can be applied to a newly affixed gage. However, instructions accompanying the gages direct that, after the cement is applied, 24 hours be allowed to elapse

* Numbers in parentheses indicate references on page 22 of this report.

before strain is measured. Further, a British Admiralty report (3) states that 7 days are necessary to dry Duco cement fully, and that at the end of 24 hours only about 70 per cent of the rated gage sensitivity is attained. In view of these conflicting statements it appeared desirable to investigate the behavior of these gages as a function of the drying time.

Data were obtained on three interrelated phases of the subject. Static strain measurements were made to determine gage sensitivity after various drying times of the cements used for application. The change of resistance with time, of gages affixed with one of the cements and drying on unstressed surfaces, was determined. Data on evaporation of this cement were also taken to compare with the data on gage sensitivity. Table 1 briefly outlines the scope of the several tests.

TABLE 1

Outline of the Tests
Section A

Static strain tests were made using tensile specimens on which there were usually mounted three SR-4 gages, one each with each of the three cements under test. These specimens were pulled after the gages had dried for the specified times.

Tensile Specimen	Cement	Elapsed Drying Time between Application of Gage and Tensile Tests	Maximum Applied Strain
3*	Duco	17 1/2 hours	0.001
3	Duco	17 days	0.001
3	Duco	43 days	0.0014
4	Duco	8 days	0.001
4	Duco	28 days	0.002
4	13-41	8 days	0.001
4	13-41	28 days	0.002
4	3462	8 days	0.001
5	Duco	6 1/2 hours	0.001
5	Duco	29 1/2 hours	0.001
5	Duco	19 days	0.002
5	13-41	4 1/4 hours	0.001
5	13-41	18 days	0.002
5	3462	6 1/2 hours	0.001
5	3462	29 1/2 hours	0.001
5	3462	19 days	0.002
6	Duco	3 hours	0.001
6	Duco	28 hours	0.001
6	Duco	14 days	0.002

(continued)

TABLE 1, Section A (continued)

Tensile Specimen	Cement	Elapsed Drying Time between Application of Gage and Tensile Tests	Maximum Applied Strain
6	13-41	3 hours	0.001
6	13-41	28 hours	0.001
6	13-41	14 days	0.002
6	3462	3 hours	0.001
6	3462	5 hours	0.001
6	3462	28 hours	0.001
7	Duco	1 1/4 hour	0.001
7	Duco	4 1/4 hours	0.001
7	Duco	21 3/4 hours	0.001
7	Duco	12 days	0.002
7	Duco	27 days	0.002
7**	13-41	1 1/4 hour	0.001
7	13-41	4 1/4 hours	0.001
7	13-41	21 3/4 hours	0.001
7	13-41	14 days	0.002
7	13-41	27 days	0.002
7**	13-41	1 1/4 hour	0.001
7	13-41	4 1/4 hours	0.001
7	13-41	21 3/4 hours	0.001
7	13-41	27 days	0.002
8†	3462	1 hour	0.001
8	3462	4 hours	0.001
8	3462	47 1/2 hours	0.001
8	3462	9 days	0.002
8†	3462	1 hour	0.001
8	3462	4 hours	0.001
8	3462	47 1/2 hours	0.001
8	3462	9 days	0.002
8†	3462	1 hour	0.001
8	3462	4 hours	0.001
8	3462	47 1/2 hours	0.001
8	3462	9 days	0.002
4R††	Duco	22 hours	0.001
4R	13-41	22 hours	0.001
4R	3462	22 hours	0.001
5R	Duco	22 hours	0.001
5R	13-41	22 hours	0.001
5R	3462	22 hours	0.001
9	Duco	19 hours	0.001
9	13-41	19 hours	0.001
9	3462	19 hours	0.001

* Only one gage was mounted on this specimen.

** Two gages were mounted with 13-41 cement on Specimen 7.

† All three gages on Specimen 8 were mounted with 3462 cement.

†† R indicates the reverse side of a specimen previously used.

(continued)

TABLE 1 (continued)

Section B

Tests were made on the change of resistance with time of gages affixed with a cement and drying on an unstressed surface. The resistance was measured at intervals while the gages dried.

Test Subject	Cement	Maximum Drying Time	Load
Test 1. 3 gages mounted on a tensile bar	Duco	4 days	none
Test 2. 3 gages mounted on a tensile bar	Duco	14 days	none

Section C

Evaporation tests were made of Duco cement drying under conditions of ambient or controlled temperature and humidity. No load was applied to the samples.

Cement Sample	Test Conditions	Total Drying Period days
1A	Cement not covered, no air blast	7
1B	Cement not covered, no air blast	7
1C	Cement not covered, no air blast	7
2A	Cement covered with thickness of gage paper, no air blast	17
2B	Cement covered with thickness of gage paper, no air blast	17
2C	Cement covered with thickness of gage paper, no air blast	17
2D	Cement covered with thickness of gage paper, no air blast	16
2E	Cement covered with thickness of gage paper, no air blast	16
2F	Cement covered with thickness of gage paper, no air blast	16
3A	Cement covered with SR-4 gage, no air blast	5
3B	Cement covered with SR-4 gage, no air blast	5
3C	Cement covered with SR-4 gage, no air blast	5

(continued)

TABLE 1, Section C (continued)

Cement Sample	Test Conditions	Total Drying Period days
4A	Cement covered with SR-4 gage, unheated air blast parallel to surface	5
4B	Cement covered with SR-4 gage, unheated air blast parallel to surface	5
4C	Cement covered with SR-4 gage, unheated air blast parallel to surface	5
5A	Cement covered with SR-4 gage, unheated air blast normal to surface	28
5B	Cement covered with SR-4 gage, unheated air blast normal to surface	28
5C	Cement covered with SR-4 gage, unheated air blast normal to surface	28
6A	Cement covered with SR-4 gage, hot-air blast normal to surface	6
6B	Cement covered with SR-4 gage, hot-air blast normal to surface	6
6C	Cement covered with SR-4 gage, hot-air blast normal to surface	6

The test procedure for each of these three types of tests is presented separately under appropriate headings, as are the test results. Because of its somewhat complex nature, the test setup for the static strain tests is described in a section separate from the procedure for the tests. The results of the several tests are correlated in the discussion of results.

TEST SETUP FOR STATIC STRAIN TESTS

The gages were mounted on steel tensile specimens with three commercial adhesives:

1. Duco Household Cement, a product of E.I. du Pont de Nemours and Company, Inc., Wilmington, Del.;

2. 13-41 SR-4 Cement, marketed by the Baldwin Southwark Division of The Baldwin Locomotive Works, Philadelphia, Pa.; and

3. High solids Durofix Cement 3462, produced by I.C.I. (Paints), Ltd., and lately procurable in this country through the Eastern Sales Office, Finishes Division, E.I. du Pont de Nemours and Company, Philadelphia, Pa.

Two samples of Durofix were tested. The first, procured from England, was in a tacky condition when used, presumably because of evaporation of the solvent. Because of this, a second sample with thinner, made to the same formula by the du Pont Company, was obtained.

Baldwin-Southwark SR-4, Type A-1 resistance strain gages were used for the tests. These are nominally of 120 ohms resistance with a sensitivity factor of about 2 ohms per ohm per unit strain, guaranteed accurate to 1 per cent. The sensitive element is Advance wire which, because of its special properties, does not change resistance appreciably with change of temperature.

Tensile specimens for static strain testing were prepared from cold-rolled steel bars 18 inches long by 2 inches wide and 1/4 inch thick. The finely ground, broader surfaces of these bars were roughened slightly with 000 sandpaper and thoroughly cleaned of all traces of oil or grease with carbon tetrachloride. Immediately before the gages were attached, the bars were laid with the broad surfaces horizontal and the surface of each was swabbed with acetone. A liberal quantity of cement was then applied to the treated surface, and the gage was affixed. Pressure, applied at first by hand and then by a small weight placed on the gage, caused the excess cement to exude around the edges of the gage, leaving only a thin film beneath the paper. To facilitate alignment, part of the gage paper on which center lines were indicated was left extended beyond the felt covering the wire.

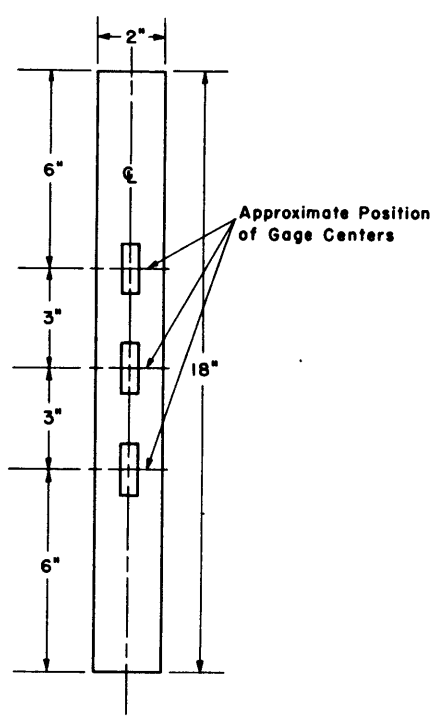

Figure 1 - Location of Wire-Resistance Gages on Tensile Specimens

As shown in Figure 1, three gages were mounted along the axis on one side of each specimen, with their centers 3 inches apart. Usually, a different cement was used to attach each of the three gages on a single tensile specimen.

For most of the tests, neither the temperature nor the humidity was controlled during the drying period. The temperature ranged usually between 75 and 85 degrees fahrenheit, and the relative humidity ranged between 50 and 70 per cent.

At specified intervals after the gages had been applied, the tensile specimens were subjected to strain in a universal testing machine, and the change in resistance of the gages was determined by a bridge circuit. In addition, the strain in the specimen was measured with Tuckerman optical strain gages. A detailed description of the equipment follows.

The Tuckerman optical strain gages were of 2-inch base length. One such gage was mounted in a longitudinal direction, directly over and spanning each wire-resistance gage during a test. The thickness of the felt over the wire of the SR-4 gages necessitated the use of half-inch lozenges in the Tuckerman gages. For the optical gage, the smallest readable division was 5 microinches. Simultaneous readings were made on the Tuckerman and wire-resistance gages.

The tensile specimens were loaded in a Baldwin-Southwark universal testing machine. The maximum capacity of this machine, 30,000 pounds, corresponds to a nominal strain of 0.002 in a steel bar with a cross-sectional area of 1/2 square inch. For tests carried up to a strain of 0.001, Templin grips were used in the machine because their ball-and-socket connections minimized bending moment on the bars. For strains greater than 0.001 it was necessary to use the regular testing-machine jaws.

Figure 2 shows the schematic diagram of the alternating-current shunt bridge by which changes in gage resistance were measured. Voltage across the bridge was supplied by an electronic oscillator operating at a frequency of 200 CPS. The amplified unbalance voltage of the bridge was observed on an oscillograph where a null pattern indicated when the bridge circuit was adjusted at balance. Balancing was accomplished by varying a decade resistance which, connected in parallel with a fixed resistor, formed one arm of the bridge. Two small variable capacitors, which could be interchanged, were included to balance reactive components of impedance introduced by the capacitance of the connecting leads and by the input transformer.

The external leads to the bridge were shielded cable; the shields were grounded at a common point to prevent "ground loops." Resistance changes in the test gages, arising from temperature drift, were compensated by a dummy gage similarly cemented to an unloaded bar mounted near the test specimen and connected in the bridge circuit. The test gage selector S_2 was a Yaxley 3-pole, 3-position, 2-gang switch used as a 3-position, single-pole switch with two gangs paralleled and three poles of each gang joined. The measured resistance of this switch was 2.51×10^{-3} ohm, with a variation of 0.13×10^{-3} ohm. The switch resistance was in series with the resistance of

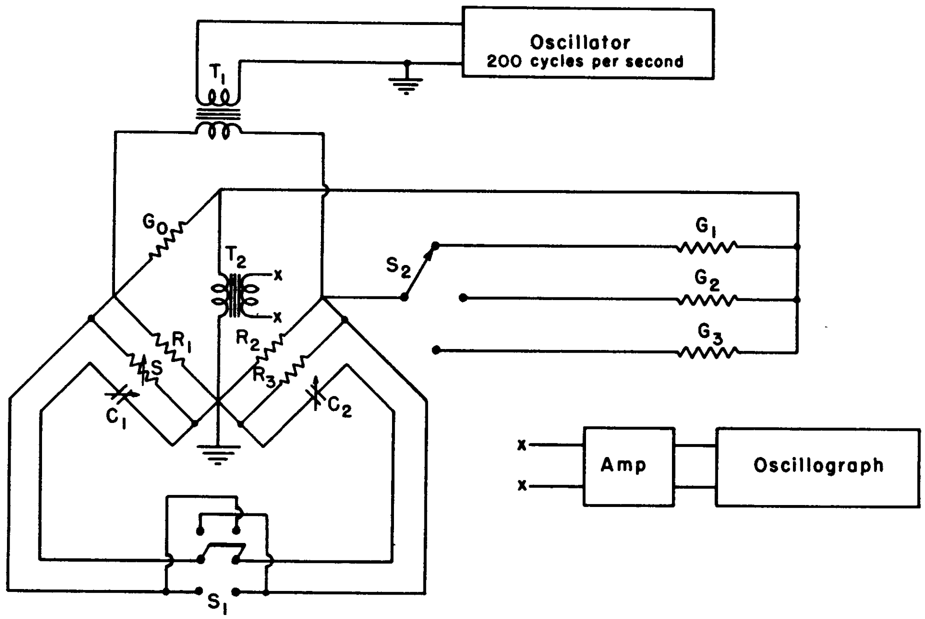

Figure 2 - Schematic Diagram of an Alternating-Current Shunt Bridge

Parts List

G_1, G_2, and G_3	Test gages
G_o	Compensating gage
S	Standard decade resistance box
R_1, R_2	Precision wire-wound, low-temperature coefficient resistors
R_3	Standard decade resistance box. A value was selected to obtain an initial balance at convenient settings of S.
C_1	250 $\mu\mu f$ variable capacitor
C_2	500 $\mu\mu f$ variable capacitor
T_1	Input transformer
T_2	Output transformer
S_1	Capacitor-reversing switch
S_2	Test-gage selector switch

each gage, approximately 120 ohms. The variation in contact resistance was thus a very small percentage of the total resistance of the gage arm; in terms of strain the variation amounted to about 0.5×10^{-6} inch per inch. All bridge terminal connections other than those to the decade boxes were securely soldered. From the change in the decade-box resistance necessary to unbalance the circuit perceptibly on the oscillograph, it was calculated that resistance changes of less than one part per million could be detected.

PROCEDURE FOR STATIC STRAIN TESTS

After several preliminary tests it was decided to test each gage after drying for various hourly periods, and also after drying for several days. Before each test the gage resistance was measured without load; during the test, observations were made of the load on the bar, the Tuckerman-gage reading, and the bridge setting at balance. For tests up to a strain of 0.001, the load was set in turn at 100, 5000, 10,000, and 15,000 pounds; for strains up to 0.002, the loads were 100, 15,000, 20,000, 25,000, and 30,000 pounds. Readings were also taken at these values as the load was removed. A strain of 0.001 was the maximum in all tests except in those repeated after a prolonged drying time, which were taken to a strain of 0.002.

The different test conditions are summarized with the test results in Tables 2, 3, and 4 on pages 13, 14, and 15.

Care was exercised to obtain Tuckerman and bridge readings simultaneously as there was an occasional slow variation in the strain. The initial strain reading was taken with a 100-pound load on the specimen to reduce errors arising from possible bending of the bar. Discrepancies arise in comparing strain in bent bars as recorded by SR-4 and Tuckerman gages because the effective length acting on the SR-4 gage is the arc whose chord is measured by the Tuckerman gage. It was estimated that if 10 per cent of the strain were caused by bending, the error in the observed gage sensitivity factor would be 0.8 per cent.

PROCEDURE FOR TESTS ON UNLOADED SPECIMENS

In the course of the static strain tests, it was found that of nine gages which had been tested after 1- and 4-hour drying periods, eight showed a decrease in resistance with drying; that is, setting of the cement appeared to cause the gage wire to contract, resulting in a measurable drift of the zero reading. In some cases the decrease amounted to as much as 500 parts per million. However, as these observations were made in connection with tensile tests, other data were sought on the effect of the drying of cement on gage resistance. Accordingly two bars similar to the tensile testing specimens previously described were prepared and three gages were mounted on each with Duco cement. No load was applied. The resistance of the gages was measured at intervals as the cement dried under various conditions of temperature and humidity. From the change in resistance the indicated spurious strain caused by setting of the cement was computed.

PROCEDURE FOR EVAPORATION TESTS OF DUCO CEMENT

Tests were also made of Duco cement to determine the rate of evaporation of the solvents present. In addition to the study of bare cement, samples of cement covered by strain-gage paper or by actual SR-4 gages were investigated. Drying was accomplished under several conditions of temperature and air blast. The relative humidity never exceeded 50 per cent. Table

1, Section C, on page 4, lists the various tests. Cement samples tried under similar physical conditions carry the same numerical identification.

Test strips for holding cement were prepared from thin spring steel 1 inch wide and 1 1/2 inch long. After the strips had been cleaned, one corner of each was turned up to facilitate handling with forceps. Several hundred milligrams of Duco cement were spread to an estimated thickness of about 1/16 inch, over an area of 7/8 inch by 1/2 inch of the strip, with the strip lying flat on a table. To make covered samples, rectangular pieces of strain-gage paper were tamped into the cement with moderate pressure. This caused a small quantity of the adhesive to be exuded about the edges of the paper.

The same technique was followed in mounting the SR-4 gages, except that a 0.6-pound weight was placed on the gages for the first hour's drying.

The strips holding the cement were weighed on an analytical balance reading to 0.1 milligram; this scale was maintained under conditions of constant temperature and humidity. The spring-steel strip, together with the paper, or gage if used, was weighed initially to avoid errors arising from the rapid evaporation of exposed cement. The initial weight of cement on a strip was taken as the decrease in weight of the tube from which the cement was squeezed; care was taken to utilize all of the cement pressed from the tube. When desired, a hot- or cold-air blast was supplied by a small blower, directed normally or tangentially at the cement samples with the surface remaining horizontal. Recordings were made of the weights of the strips after a drying period of 15 or 30 minutes, and hourly thereafter for 6 hours. Following this, weight measurements were made daily.

RESULTS OF STATIC STRAIN TESTS

On the basis of the sensitivity factors of the SR-4 gages supplied by the manufacturer, the bridge readings were converted into strains and plotted against the strains indicated by the corresponding Tuckerman gages. Typical graphs of results for the three cements tested are shown in Figures 3, 4, and 5. Gages responding at 100 per cent of nominal sensitivity would have plotted points lying on a straight line of slope unity with both increasing and decreasing loads. For short drying periods the slopes of the load-increasing and load-decreasing branches may differ appreciably, as in Figure 5, Curve 1. In this case the wire gage is said to exhibit hysteresis. This phenomenon will be analyzed under the discussion of results. The hysteresis values in Tables 2, 3, and 4 are the intercepts of the return lines on the vertical axis.

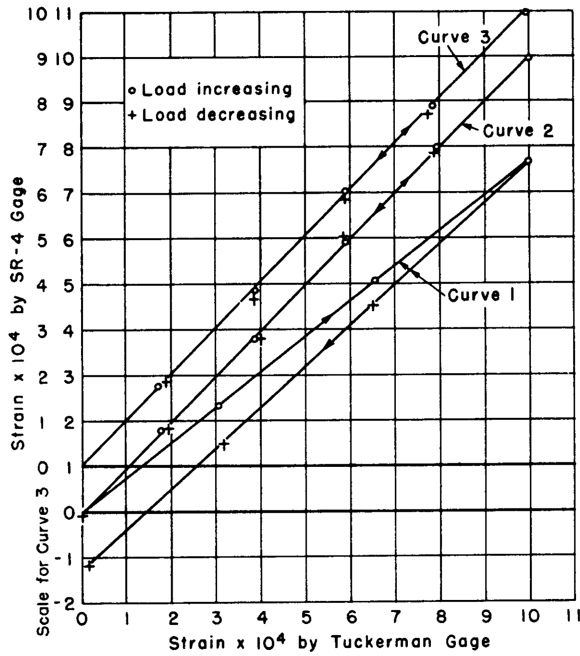

Figure 3 - Results of Test on an SR-4 Gage Attached with Duco Cement, Specimen 7

The drying times for Curves 1, 2, and 3 were 1 1/4, 4 1/4, and 21 3/4 hours, respectively. The temperature was 83 degrees fahrenheit and the relative humidity was 49 per cent for the first 4 1/4 hours, after which ambient conditions obtained.

The points for Curves 2 and 3 are almost coincident, and for that reason two scales are used.

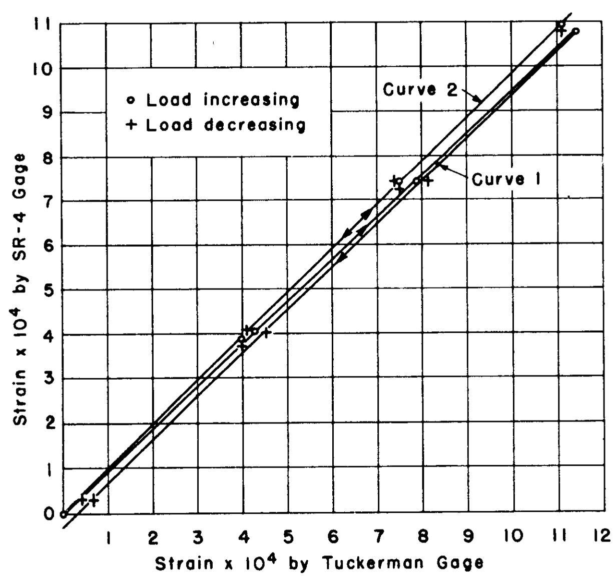

Figure 4 - Results of Test on an SR-4 Gage Attached with Baldwin-Southwark 13-41 Cement, Specimen 7

The drying times for Curves 1 and 2 were 1 1/4 and 21 3/4 hours, respectively. The temperature was 83 degrees fahrenheit and the relative humidity was 49 per cent for the first 4 1/4 hours, after which ambient conditions obtained.

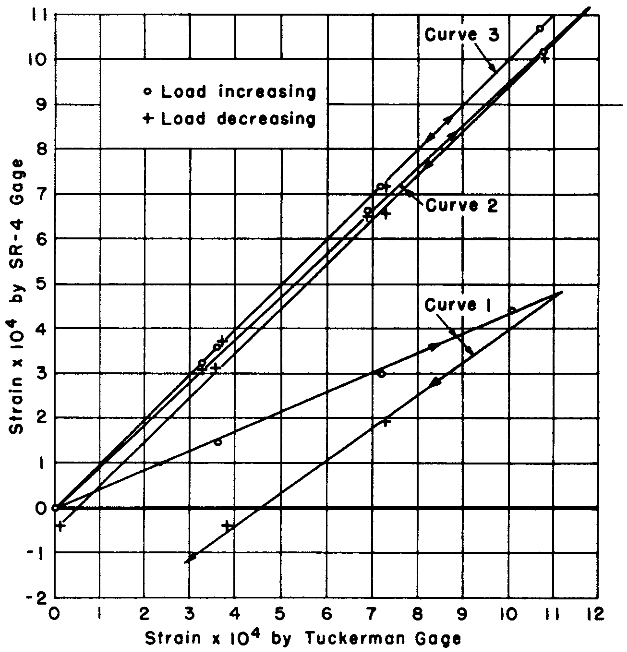

Figure 5 - Results of Test on an SR-4 Gage Attached with Durofix 3462 Cement, Specimen 8

The drying times for Curves 1, 2, and 3 were 1, 4, and 47 1/2 hours, respectively. The temperature was 77 degrees fahrenheit and the relative humidity was 67 per cent for the first four hours after which ambient conditions obtained.

The last recorded point for Curve 1 was taken at a load of 5000 pounds per square inch rather than at the initial load of 100 pounds per square inch.

The results on eight gages mounted with Duco cement, together with pertinent temperature and humidity data for the several tests, are summarized in Table 2. Similarly, the results of tests of eight gages with Baldwin-Southwark 13-41 cement are shown in Table 3. Table 4 presents the results of tests on nine gages with Durofix 3462 cement. The maximum width of the hysteresis loop obtained on loading and unloading is also tabulated. Values of hysteresis less than 10×10^{-6} strain are not listed as these are within the limits of experimental error.

Measurements repeated to establish the consistency of gage performance over long periods of time showed no change in sensitivity even at strains of 0.002.

Gages drying under a relative humidity of 79 per cent in the Basin building, which houses a large open body of water, showed practically full sensitivity with all three cements after 22 hours. Test 5R, in which the cement dried in a refrigerator at a temperature of 38 degrees and a relative humidity of 94 per cent, gave almost full sensitivity for the gage mounted

(Text continued on page 16)

TABLE 2

Summary of Tests of SR-4 Gages Mounted with Duco Cement

Tensile Specimen	Drying Time of Gage	Conditions		Sensitivity Per Cent of Nominal Factor	Maximum Hysteresis microinches per inch	Maximum Applied Strain
		Temperature degrees F.	Relative Humidity per cent			
3†	17 1/2 hours	78.5	53	97	10	0.001
3†	17 days	Ambient		99		0.001
3†	43 days	Ambient		100		0.0014
4	8 days	Ambient		102		0.001
4	28 days	Ambient		102		0.002
5	6 1/2 hours	78.5	60	102		0.001
5	29 1/2 hours	Ambient		101		0.001
5	19 days	Ambient		101		0.002
6	3 hours	84	43	96	20	0.001
6	28 hours	Ambient		101.5		0.001
6	14 days	Ambient		101.5		0.002
7	1 1/4 hour	83	49	78* 90**	130	0.001
7	4 1/4 hours	83	49	100	15	0.001
7	21 3/4 hours	Ambient		100		0.001
7	12 days	Ambient		100	12	0.002
7	27 days	Ambient		100		0.002
4R††	22 hours	77	79	99	20	0.001
5R	22 hours	38	92	96* 99**	33	0.001
9	19 hours	39	90	99* 104**	50	0.001

* This value was observed with increasing load.

** This value was observed with decreasing load.

† The cement used in these tests was considered to be faulty.

†† R indicates the reverse side of a tensile specimen previously used.

TABLE 3

Summary of Tests of SR-4 Gages Mounted with 13-41 Cement

Tensile Specimen	Drying Time of Gage	Conditions		Sensitivity Per Cent of Nominal Factor	Maximum Hysteresis microinches per inch	Maximum Applied Strain
		Temperature degrees F.	Relative Humidity per cent			
4	8 days	Ambient		101.5		0.001
4	28 days	Ambient		101		0.002
5	4 1/4 hours	Ambient		99	10	0.001
5	18 days	Ambient		100		0.002
6	3 hours	84	43	99* 100**	15	0.001
6	28 hours	Ambient		100		0.001
6	14 days	Ambient		100		0.002
7†	1 1/4 hour	83	49	97* 101**	40	0.001
7	4 1/4 hours	83	49	101		0.001
7	21 3/4 hours	Ambient		102		0.001
7	14 days	Ambient		101		0.002
7	27 days	Ambient		99.5	10	0.002
7†	1 1/4 hour	83	49	94.5* 97**	30	0.001
7	4 1/4 hours	83	49	97.5	10	0.001
7	21 3/4 hours	Ambient		97.5		0.001
7	27 days	Ambient		99		0.002
4R	22 hours	77	79	97* 100**	30	0.001
5R	22 hours	38	94	97.5* 99**	20	0.001
9	19 hours	39	90	96* 99**	35	0.001

* This value was observed with increasing load.

** This value was observed with decreasing load.

† Two gages were mounted with 13-14 cement on Specimen 7.

TABLE 4

Summary of Tests Using 3462 Cement to Mount SR-4 Gages

Tensile Specimen	Drying Time of Gage	Conditions		Sensitivity Per Cent of Nominal Factor	Maximum Hysteresis microinches per inch	Maximum Applied Strain
		Temperature degrees F.	Relative Humidity per cent			
4†	8 days	Ambient		95		0.001
5†	6 1/2 hours	78.5	60	98* 100**	20	0.001
5†	29 1/2 hours	Ambient		98	10	0.001
5†	19 days	Ambient		102		0.002
6†	3 hours	84	43	62* 75**	170	0.001
6†	5 hours	84	43	95	20	0.001
6†	28 hours	Ambient		99		0.001
8††	1 hour	77	67	76* 95**	150+	0.001
8	4 hours	77	67	100* 102**	30	0.001
8	47 1/2 hours	Ambient		100	15	0.001
8	9 days	Ambient		100	10	0.002
8††	1 hour	77	67	44* 79**	200+	0.001
8	4 hours	77	67	94* 98**	50	0.001
8	47 1/2 hours	Ambient		99	10	0.001
8	9 days	Ambient		100		0.002
8††	1 hour	77	67	48* 77**	200+	0.001
8	4 hours	77	67	97	30	0.001
8	47 1/2 hours	Ambient		100	10	0.001
8	9 days	Ambient		98.5		0.002
4R	22 hours	77	79	98	20	0.001
5R	22 hours	38	94	Gage did not adhere		
9	19 hours	39	90	98* 100**	25	0.001

* This value was observed with increasing load.

** This value was observed with increasing load.

† The 3462 cement used to mount gages on these specimens was received in a tacky condition. All other tests with this type of cement were made with a sample supplied by E.I. du Pont de Nemours and Company, Inc.

†† All three gages on Specimen 8 were mounted with 3462 cement.

\+ Hysteresis exceeds this value because, when the load on the specimen was decreased, the last recorded point was taken at a load of 5000 pounds per square inch rather than at the initial load of 100 pounds per square inch.

with 13-41 cement and a factor low by several per cent for the gage mounted with Duco. The du Pont version of Durofix 3462 failed to adhere under these conditions when first tried. However, in a second test, a gage mounted with this cement, Specimen 9, Table 4, gave rated response within 2 per cent even though loosening had occurred around the edges of the gage paper before the experiment was completed.

RESULTS OF TESTS ON UNLOADED SPECIMENS

Three of the gages mounted with Duco on a steel bar and allowed to dry at ambient temperature and humidity without application of load showed initially large increases in resistance as the gages dried. This upward drift of the zero was reversed in less than 2 hours, and for 2 days thereafter the resistance gradually diminished; the total decrease corresponded to strains of about 150 parts per million. In the two succeeding days, the resistance fluctuated erratically within limits corresponding to strains of about 25 parts per million.

The performance of gages dried under constant temperature and humidity was similar to that of gages dried under ambient conditions. The upper and lower limits of equivalent strain change of these gages are plotted in Figure 6. The drying period shown covers the first 48 hours and the strain changes are taken relative to the comparatively stable state attained at the end of 5 days of drying. It will be seen that during the first 48 hours the resistance of the gages followed the pattern just described for gages drying under ambient conditions. Other observations, not tabulated in this report, showed that in the next 3 days there were random changes in resistance equivalent to strains of up to 10 parts per million. After 5 days under constant temperature, somewhat more stable conditions prevailed; in the 5 days following, the strains corresponding to random resistance changes were found to be only 3.5 to 5 parts per million. Upon completion of these 10 days of drying, the bar was removed from the conditions of constant temperature and humidity. For the next 4 days, with a temperature variation of 6 degrees fahrenheit, the greatest resistance variation equalled a strain of only 3 parts per million.

RESULTS OF TESTS ON EVAPORATION OF DUCO CEMENT

Data on the measured evaporation of solvents from Duco cement samples exposed to the atmosphere are plotted in Figure 7. The graph shows the percentage decrease in weight of the Duco as a function of drying time. In Figure 8, the two curves show the drying time under normal room conditions and under hot-air blast, of cement samples under SR-4 gages. In 1 hour the hot-air blast effectively reduced the Duco to 25 per cent of its initial

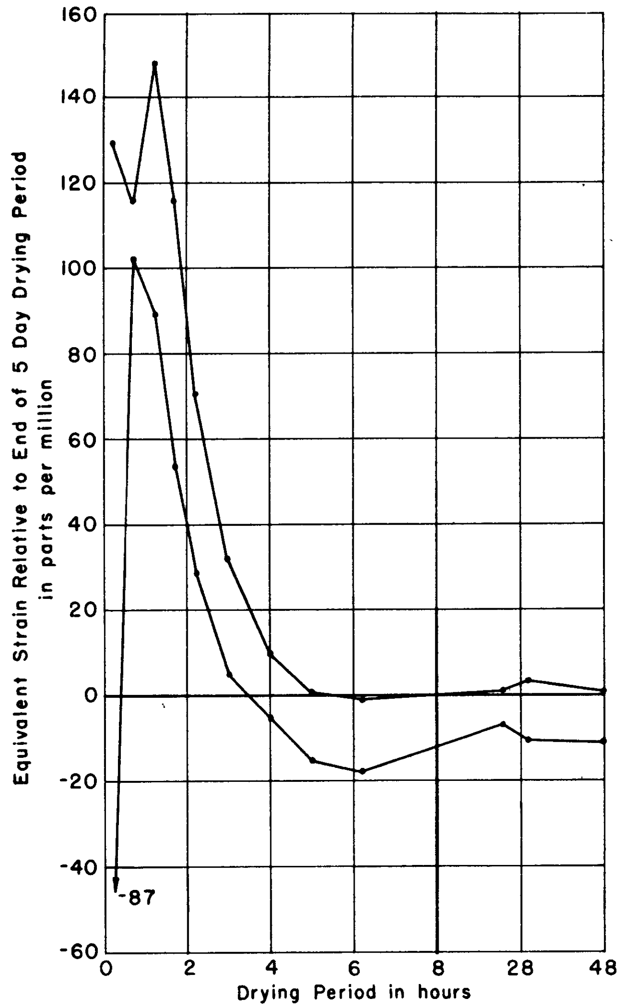

Figure 6 - Limits of Equivalent Strain Changes in Three Gages during Drying

The maximum and the minimum values observed for the three gages are plotted. The strain changes are taken relative to the comparatively stable state attained at the end of 5 days of drying.

weight. A similar result could be accomplished without heat in approximately 6 hours. Also, the final weight was lowered to about 17 per cent of the initial value with the hot blast, whereas the minimum weight attained under normal atmospheric conditions was about 21 per cent of the original weight. However, when heat was removed, the cement which was dried under blast recovered a small percentage of weight, presumably by absorption of atmospheric moisture. When a blast of air at normal temperatures was directed at the drying gages, no increase in the rate of evaporation of cement was observed.

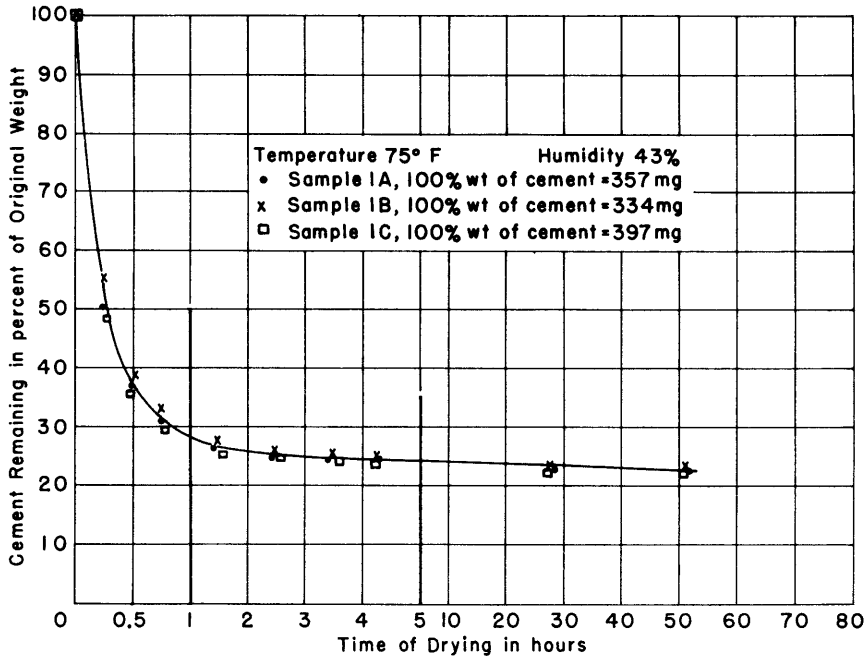

Figure 7 - Evaporation of Duco Cement

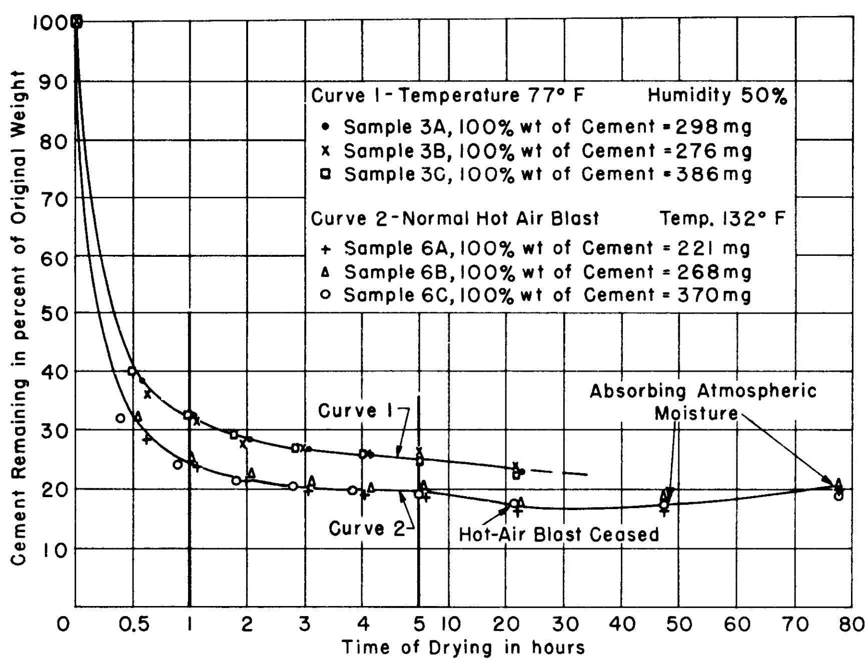

Figure 8 - Evaporation of Duco Cement under SR-4 Strain Gage

Curve 1 reaches a value of approximately 21 per cent at 122 hours.

DISCUSSION OF RESULTS

As stated in the Introduction, a knowledge of the drying time necessary for accurate strain measurements with SR-4 gages is important for tests conducted under the strict time limitations frequently encountered. Although drying may be accelerated by a hot-air blast, such means are not always available and, under certain conditions, as in the application to large metallic surfaces, they may be ineffective. Therefore, many of the tests of this report were conducted under normal conditions of temperature and humidity.

Table 2 on page 13 shows that, under ambient atmospheric conditions, gages attached with Duco cement, with the sole exception of Specimen 3, had approximately 100 per cent of nominal sensitivity after drying 4 1/4 hours or more. The exception is the gage affixed with cement suspected of being faulty. Tests made after the lapse of as many as 43 days, when the cement could be considered fully dry, showed no change in calibrations of the gages.

Gages mounted with Baldwin-Southwark 13-41 cement gave the best performance of any gages for the short drying periods. Gages applied with this cement on Specimen 7, Table 3, showed 94.5 per cent or more of rated sensitivity after drying only 1 1/4 hour, with only a small amount of hysteresis. Accordingly, where tests are to be conducted on short notice, use of this cement appears desirable.

Table 4 on page 15 indicates that gages attached with Durofix 3462 usually required more time to reach maximum sensitivity than did gages mounted with the other two cements. Also, the results obtained with Durofix cement in tests under similar conditions were less consistent, perhaps because thinning of the cement was not adequately regulated.

Tests with Durofix 3462 were temporarily abandoned after Specimens 4, 5, and 6 had been tested, because it was found that gages so applied usually loosened in about 2 weeks after attachment. As this cement had previously been cited (3) as the most satisfactory of those tested, failure was attributed to the very tacky condition of the original sample. Fresh Durofix and thinner were later acquired from the du Pont de Nemours Company and mixed to the consistency of Duco. Specimen 8 was prepared with three gages affixed with the new cement. Although the sensitivity of the gage at the end of an hour was generally lower than that of gages applied with Duco or Baldwin-Southwark 13-41, full sensitivity was obtained in a 6-hour drying period. However, even after favorable 6-hour results had been obtained with the new cement, the gages again became loosened in about 2 weeks. This was in marked contrast to the performance of the other two cements, which held the gages firmly bonded even after several months.

The reduced sensitivity of a gage when the cement is not fully dried may be ascribed largely to the low strength of the cement while setting. The data indicate that as load was applied to a specimen, gages that were insufficiently dry showed a smaller strain than that occurring in the specimen to which they were attached. It follows that the cement between the specimen and the gage had not yet acquired the strength necessary to stretch the gage. The readings obtained as the load was relaxed did not always fall on the curve obtained as the load was applied; thus hysteresis resulted as in Curve 1 of Figure 5. The slope for the return curves generally exceeded the slope obtained as the load was applied. This may be due in part to the fact that the cement naturally contracts as it dries. Such contraction would result in low sensitivity for increasing load and higher sensitivity for decreasing load. There is also some possibility that the cement hardened appreciably during a test which took about 15 minutes to complete. On the basis of these possibilities, it would be expected that after completion of a test, the resistance of a rapidly drying gage would be less, as was found to be the case.

As shown by Figures 7 and 8, on page 18, the most rapid drying of Duco cement occurred in the first hour, with almost complete evaporation of solvents in 4 hours, followed by continued minor loss in weight for many days. This last insignificant change is apparently of no effect, as the results show that a 4-hour drying period gave approximately full gage sensitivity. It was noted that some samples of tacky cement, although presumably containing less volatile substance than normal, usually required a greater time for complete drying, perhaps because the tacky cement could not be applied in as thin a film as could the more fluid product.

The measurements of the resistance of gages mounted on unloaded steel bars are in agreement with the other tests of Duco cement in indicating that after 4 hours the cement has nearly set. The large changes in resistance occurring would require consideration should it be desired to use Duco-mounted gages which had dried for less than 4 hours. Changes occurring after the first 4 hours could in many cases be considered negligible. However, where measurements of small strains are to be made over an extended period, it appears desirable to allow the gages to set for several days or to obtain check readings periodically on the unloaded condition of the gage.

Statements in the British Admiralty report (3) mentioned in the Introduction, on the drying rate of several cements, have not been verified by these tests. The present results indicate the attainment of approximately full sensitivity by a gage in much less time than that established in the Admiralty report. A possible explanation is the retardation of evaporation by the greater thickness of British gages, which have from two to four layers of paper compared to the single sheet of the American product. Tests of drying showed that most rapid evaporation during the first hour occurred in uncovered cement samples. However, it should be noted that the rate of drying of paper-covered samples of cement, although initially slower, apparently did not decrease as rapidly, because the percentage of Duco remaining after 2 days was about the same under both covered and uncovered conditions.

Disturbing a gage while the cement was still drying was found apparently not harmful, as gages subjected to strain at the end of an hour responded at full sensitivity when completely dried.

CONCLUSIONS

SR-4 Type A-1 strain gages respond linearly, at full sensitivity and practically without hysteresis, to static strains up to 0.002 when affixed with Duco, Baldwin-Southwark 13-41, or Durofix 3462 cement, and fully dried.

Approximately full gage sensitivity, indicating sufficient drying, was attained in a 4 1/4-hour drying period without application of heat with these three cements under normal room conditions of temperature and humidity for strains up to 0.001. However, very slow drying continued for a number of days.

Small variations of resistance were found to occur in unstressed Duco-mounted gages during 2 weeks of drying. The fluctuations noted represented appreciable strains especially in the first 2 days of drying.

Baldwin-Southwark 13-41 cement was found slightly superior in time of achieving satisfactory dryness, and gages mounted with it showed the least hysteresis.

A cold-air blast on a gage did not materially increase the drying rate of the cement. On the other hand a hot-air blast accelerated the drying and brought the cement to a higher final degree of dryness than was possible without the heat for any tested length of time. However, this extra evaporation was in part attributed to the removal of atmospheric moisture.

Gages applied with Duco or Baldwin-Southwark 13-41 cements at near-freezing temperature and high humidity required a longer drying time than those applied under ambient conditions. Durofix did not always bond under these conditions.

Strain gages mounted with Duco or Baldwin-Southwark cements were firmly bonded and apparently reliable even 3 months after application. Durofix cement usually loosened in about 2 weeks, and this process possibly could have started soon after the complete drying of the product. Thus there is some question of the reliability of this cement after only several days of use.

REFERENCES

(1) "Bonded Metalectric Strain Gage," Baldwin-Southwark Bulletin 164-X, May 1941.

(2) "SR-4 Strain Gage," Baldwin-Southwark Bulletin 164, June 1941.

(3) "The Performance of Resistance-Type Strain Gauges," Engineering Laboratory, Royal Naval College, Greenwich, February 1943.