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THE CREEP OF LEAD AND LEAD ALLOYS USED FOR CABLE SHEATHING

A REPORT OF AN INVESTIGATION
CONDUCTED BY
THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
IN COÖPERATION WITH
THE UTILITIES RESEARCH COMMISSION
BY
HERBERT F. MOORE
AND
NORVILLE J. ALLEMAN

BULLETIN No. 243
ENGINEERING EXPERIMENT STATION

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RESEARCH PROFESSOR OF ENGINEERING MATERIALS

AND

NORVILLE J. ALLEMAN
SPECIAL RESEARCH ASSISTANT IN ENGINEERING MATERIALS

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THE CREEP OF LEAD AND LEAD ALLOYS USED FOR CABLE SHEATHING

I. INTRODUCTION

1. *Introductory.*—"For all high voltage cables on the underground systems of fourteen large operating companies, about three to four times as many failures are caused by failure of the sheaths to protect the cable mechanically as are caused by failure of the insulation to withstand the voltage. In addition, many cases of sheath defects are located by frequent inspection and repaired before it becomes necessary to remove the cable. Such data indicate the importance of studies of the mechanical problems involved in providing adequate sheath protection."

In connection with this statement, which was made by Mr. D. W. Roper, Superintendent, Street Department, Commonwealth Edison Company,* the following methods of mechanical damage to cable may be noted: (1) cracking, which may occur due to the bending of the cable as it is put in place or due to repeated stresses caused by temperature expansions and contractions, or by vibrations; and (2) "creep," which is the *continuing* deformation of a metal under a steady load. Creep is negligible in the common materials of construction at ordinary temperatures, but becomes noticeable at temperatures of several hundred degrees Fahrenheit. In lead and lead alloys creep under very low stresses is appreciable at ordinary atmospheric temperatures. Creep is to be distinguished from the plastic action which takes place in ordinary metals of construction when the elastic range is exceeded. Under ordinary plastic action deformation takes place, then in a little while internal readjustments take place and the deformation stops even under continued loading. Creep, on the other hand, continues indefinitely.

In an underground electric cable enclosed in a sheathing of lead or lead alloy in which an insulating oil is forced into the cable under slight pressure this question of creep may become of importance. If this pressure in any part of the cable is sufficient to set up appreciable creep the cable would go on expanding at an increasing rate presumably for an indefinite length of time or until rupture occurred. Quite possibly before the creep had reached anywhere near the fracture point insulation troubles would be set up due to voids. In any event

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*Utilities Research Commission Bulletin, Vol. 2, No. 10, October, 1931, p. 2. Mr. Roper's entire article is given in the Appendix to the present bulletin.

a study of the creep of lead and lead alloys used for cable sheathing seems a worth-while undertaking.

2. *Acknowledgments.*—This study has been supported by funds contributed by the Utilities Research Commission, Wm. L. Abbott, Chairman. An Advisory Committee was appointed for this study as follows:

E. O. SCHWEITZER (Chairman), Chief Testing Engineer, Commonwealth Edison Company.

C. E. BETZER, Engineer, Street Department, Commonwealth Edison Company.

R. G. GUTHRIE, Metallurgist, The Peoples Gas Light and Coke Company.

C. A. JAQUES, Engineer of Conduit and Cable, Public Service Company of Northern Illinois.

H. S. PATTON, Assistant to the President, Midland Utility Company.

D. W. ROPER, Superintendent of Street Department, Commonwealth Edison Company.

This committee has acted as an advisory committee for all the work reported in this bulletin, and several meetings have been held to consider the progress of the work. The tests described in this bulletin have been made in the Materials Testing Laboratory, University of Illinois. The investigation has been carried on as a part of the work of the Engineering Experiment Station at the University of Illinois and has been under the general administrative direction of Dean M. S. KETCHUM, director of the Engineering Experiment Station, and of Prof. M. L. ENGER, head of the Department of Theoretical and Applied Mechanics. Acknowledgment is made of the services of C. W. DOLLINS and E. D. WILLIAMS, laboratory assistants with this investigation.

II. MATERIAL, TEST SPECIMENS, AND APPARATUS

3. *Material.*—Specimens of sheathing of various kinds were obtained from users and manufacturers through the Utilities Research Commission. Table 1 gives a list of the different kinds of sheathing from which specimens were cut, or which were tested under internal hydrostatic pressure.

4. *Test Specimens.*—Creep tests of lead were made in two ways: (1) on tensile specimens loaded with dead weights and (2) on specimens of lead sheathing under internal oil pressure. Figure 1 shows

TABLE 1
COMPOSITION AND DIMENSIONS OF SHEATHING

Lab. Mark	Alloy	Outside Diameter in.	Nominal Thickness in.
E	3% Sn	1.0	0.094
G	100% Pb	1.875	0.115
H	100% Pb	1.875	0.125
I	100% Pb	1.875	0.125
J	100% Pb	3.064	0.187
K	¾% Sb	2.875	0.141
L	0.04% Ca	2.625	0.125
M	1% Sb	0.656	0.075
N	1% Sn	1.0	0.109
O	1% Sn	1.0	0.094
P	1% Sb	3.0	0.109
Q	2% Sn	4.25	0.156
R	100% Pb	Flat sheet rolled	0.100

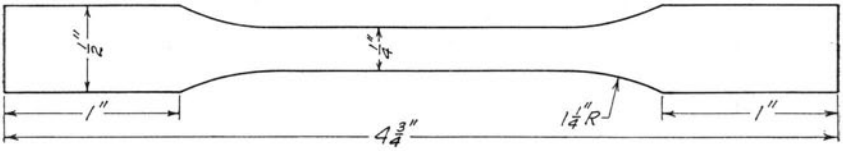

FIG. 1. TENSILE TEST SPECIMEN

the form and size of the tensile specimen used. This specimen was about as long as could be cut in a transverse direction from the smallest cable specimens studied. Some specimens were cut with axes transverse to the axis of the sheathing and others with axes parallel to the axis of the specimen. Flat sheets from which specimens were cut were made by sawing off five-inch lengths of sheathing, splitting longitudinally at the thickest section, and flattening under a 2000-lb. load.* Specimens were formed from these flat sheets by cutting with a sharp draw-knife round a pair of steel templates between which the flattened-out sheathing was clamped.

5. *Test Results and Testing Machines.*—The tensile specimens of lead were tested by being loaded with dead weights. Figure 2 shows a test rack containing twelve such specimens. Tests were run at ordinary room temperature, at 32 deg. F., and at 150 deg. F., covering the range of temperatures usually found in service. For tests at 32 deg. F. the specimens were enclosed in a wooden box, insulated with 4 in. of cork-board, and were viewed through a window which consisted of

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*The pressure of 2000 lb. produces an average pressure of only about 50 lb. per sq. in. over the area of sheet under pressure. Moreover, the center of length of the tension specimen was located at a thin place in the sheet, and hence was probably subjected to a pressure decidedly less than 50 lb. per sq. in.

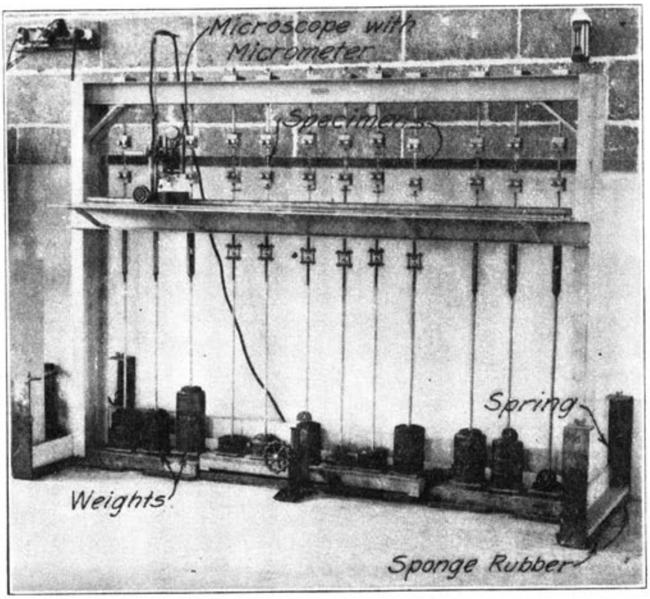

FIG. 2. TEST RACK FOR CREEP TESTS AT ROOM TEMPERATURE

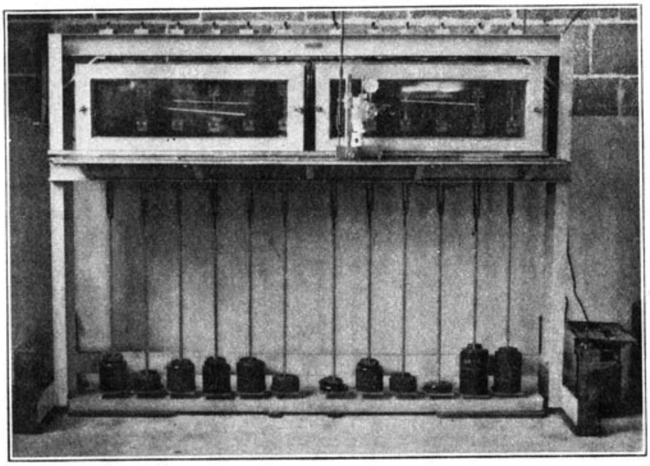

FIG. 3. TEST RACK FOR CREEP TESTS AT 150 DEG. F.

three thicknesses of glass to avoid frosting. The temperature was kept at 32 deg. F. by means of a thermostatically controlled mechanical refrigeration unit. Figure 3 shows a rack for tests at 150 deg. F. The specimens were surrounded by a Celotex insulated box provided

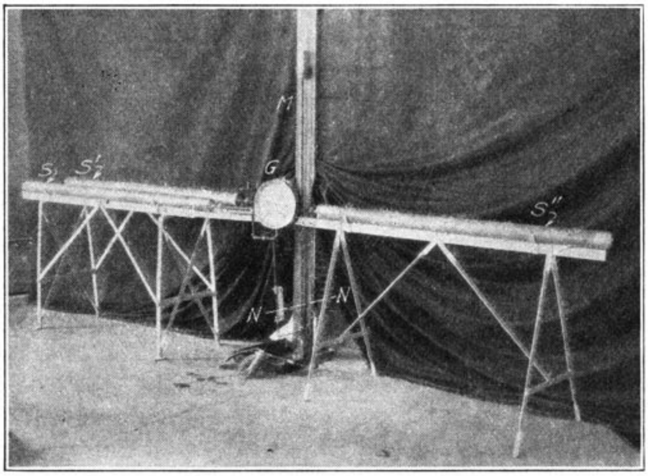

FIG. 4. APPARATUS FOR CREEP TESTS OF CABLE SHEATHING UNDER INTERNAL PRESSURE

with a double-glass window in front. Temperature was maintained by means of electrical heating coils and controlled by means of a bimetallic thermoregulator. The heating coils placed at the rear of the box were shielded by vertical baffles to eliminate radiation and promote air circulation, insuring even specimen temperature.

A special rack for tests at room temperature was fitted with a screw jack by means of which some of the weights were lifted at intervals so that the effect of intermittent loading could be studied.

Short-time tension tests of lead specimens as a preliminary to the long-time creep tests were made. The specimens were the same as those shown in Fig. 1, and the tests were made on a 1000-lb. semi-autographic testing machine. This machine was fitted with a special speed-reducing gear so that tests could be made at a pulling speed as low as 0.02 in. per min.

The apparatus for conducting experiments on full-sized cable sheath under hydraulic pressure is shown in Fig. 4. Three specimens of sheathing (S, S', and S'') are tested in this apparatus. Constant pressure is supplied by the mercury column M, which transmits its pressure to the oil in the sheathing. The oil level is at N-N. The mercury does not touch the sheathing, as this would cause amalgamation of the mercury and lead. The gage G indicates the pressure, from which the circumferential bursting stress can be computed. A constant oil pressure of 25 lb. per sq. in. is maintained.

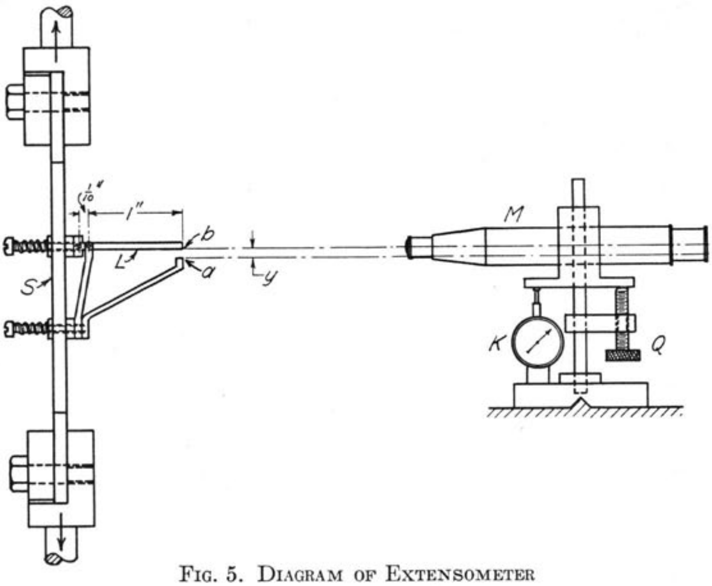

FIG. 5. DIAGRAM OF EXTENSOMETER

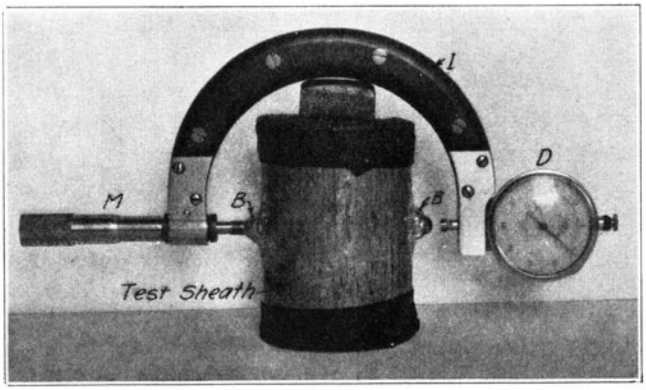

FIG. 6. DIAL MICROMETER FOR MEASURING LATERAL EXPANSION (CREEP) FOR SHEATHING

6. *Strain Measuring Apparatus.*—The principle of the strain apparatus employed for the long-time tension tests is shown in Fig. 5. A pair of clamps fitted with a 10:1 lever L grips the specimen S. The change in distance y measures the creep of the metal over any interval of time. The distance y is measured at intervals by means of the microscope M, which is fitted with cross-hairs. The microscope is moved up and down by means of the screw Q. It is focused at b, a

reference mark on the moving arm, and then at *a*, a reference mark on the frame. The difference in reading between the two positions as shown on the dial micrometer *K* is noted, and the *change* in this difference between readings gives the creep which has occurred. The sensitivity of this apparatus is 0.0001 in.

The apparatus for measurement of lateral expansion of the full-sized lead sheath specimens is shown in Fig. 6. The lateral expansion was measured by a dial micrometer spanning various pairs of steel balls, which were fitted into brass sockets, which, in turn, were soldered to the surface of the test sheath. Any effect due to soldering the brass socket on the metal affects only a small area, while creep depends on all the metal in the specimen. The micrometer head *M* (Fig. 6) was used to change the range of the apparatus and the actual indication of distance between steel balls is shown on the micrometer dial *D*, which is sensitive to one ten-thousandth of an inch. The short length of test sheath shown in Fig. 6 is used as a "standard bar" for the measurement of the expansion of the sheaths. This standard bar is kept close to the test sheaths and is assumed to change temperature with them. A piece of steel fitted with ball contacts for the micrometer serves as a second "standard bar." The readings of the micrometer on these standard bars give the changes in size due to temperature, and suitable allowances for these temperature changes may be made while measuring creep. Readings of lateral expansion (creep) were taken along each test sheath at sections one foot apart.

III. TEST DATA AND RESULTS

7. *Test Data.*—Table 2 gives the results of the short-time tension tests. Nearly all these short-time tests were run using a pulling speed of 0.02 in. per min. To show that speed of pulling has a marked effect, two series of tests on metal L were run, using higher pulling speeds, as noted in Table 2.

Figure 7 shows typical time-creep records for two tension specimens under a constant steady load. A time-creep graph for a metal may, in general, be divided into three parts: (1) a short period of rapid stretch under load, (2) a period of steady "creep" which follows closely a "straight line" relation, and (3) a period of accelerated creep, terminating in fracture. The rate of creep for a specimen is determined from the slope of the middle "straight line" part of the graph (y/x in Fig. 7).

A graph corresponding to those shown in Fig. 7 was plotted for every creep test, and its rate of creep determined and expressed as

TABLE 2

SHORT-TIME TENSILE TEST RESULTS

Speed of head of testing machine is 0.02 in. per min.

Material	Tensile Strength lb. per sq. in.	Elongation after Fracture per cent in 2 in.
E Long.*	2565	33.0
G Long.	2010	31.0
Trans.†	2200	19.0
H Long.	1590	38.0
Trans.	1610	22.0
I Long.	1530	46.5
Trans.	1570	22.0
J Long.	1910	32.0
Trans.	1965	36.0
K Long.	3835	22.5
Trans.	3815	21.75
L Long.	2590	30.5
Trans.	2550	15.0
L Trans. Pulling speed 0.30 in. per min.	4450	12.2
Trans. Pulling speed 0.110 in. per min.	4385	13.0
M Long.	3255	17.0
N Long.	2530	31.5
O Long.	2175	39.6
P Long.	3520	28.5
Trans.	3850	17.5
Q Long.	2800	43.0
Trans.	2850	40.7
R Long.	1800	26.2
Trans.	1870	26.5

*"Long" denotes a specimen whose axis is parallel to the axis of the sheath.

†"Trans." denotes a specimen whose axis is at right angles to the axis of the sheath.

the number of hours necessary for a creep of 1 per cent. This value of 1 per cent is an arbitrary value tentatively selected after discussion with electrical engineers of the Utilities Research Commission. Obviously the selection of a limiting value of creep below which it is assumed that creep does no damage must be based on the experience of users of cable.

Figure 8 shows graphically the data of the creep tests of tensile specimens in the form of diagrams plotted with stress as ordinates and with values of hours necessary for 1 per cent creep plotted to a logarithmic scale as abscissas. A graph for the expansion of one lead

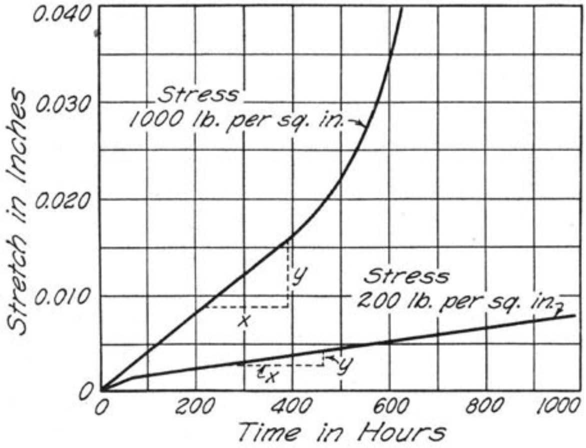

FIG. 7. TIME-CREEP CURVES FOR TENSILE SPECIMENS

sheath under oil pressure is shown in Fig. 13. The numbers on the graphs refer to cross-sections spaced one foot apart along the sheath.

8. *Results of Creep Tests of Tension Specimens.*—The results of creep tests for the tension specimens are shown graphically in Figs. 7 to 9. Figure 10 shows composite graphs for the specimens from commercially pure lead sheathing, lead-antimony sheathing, and lead-tin sheathing. The "scatter" of test results is shown by the width of a shaded band covering all the test results. As might be expected, in view of the fact that the lead-antimony and the lead-tin specimens cover an appreciable range of percentage of alloying ingredients, the width of this band is greater for the lead-antimony and the lead-tin graphs than for the pure lead graphs.

Figure 11a gives a comparison of average creep at the three temperatures studied for each of the three metals, lead, lead-antimony, and lead-tin. Figure 11b gives a comparison of the three metals for each of the test temperatures used—32 deg. F., room temperature, and 150 deg. F. The lines plotted are the "average" lines for the bands in Fig. 10.

A comparison of the results of the tests of specimens from the sheath made of lead-calcium alloy with the results for lead, lead-antimony, and lead-tin specimens may be made by the use of Fig. 8.

The graphs vary markedly in character. For some metals they show a sharp "knee" (e.g., 1 per cent antimony alloy M, 32 deg. F.). Other graphs show no well-defined "knee" (e.g., commercially pure

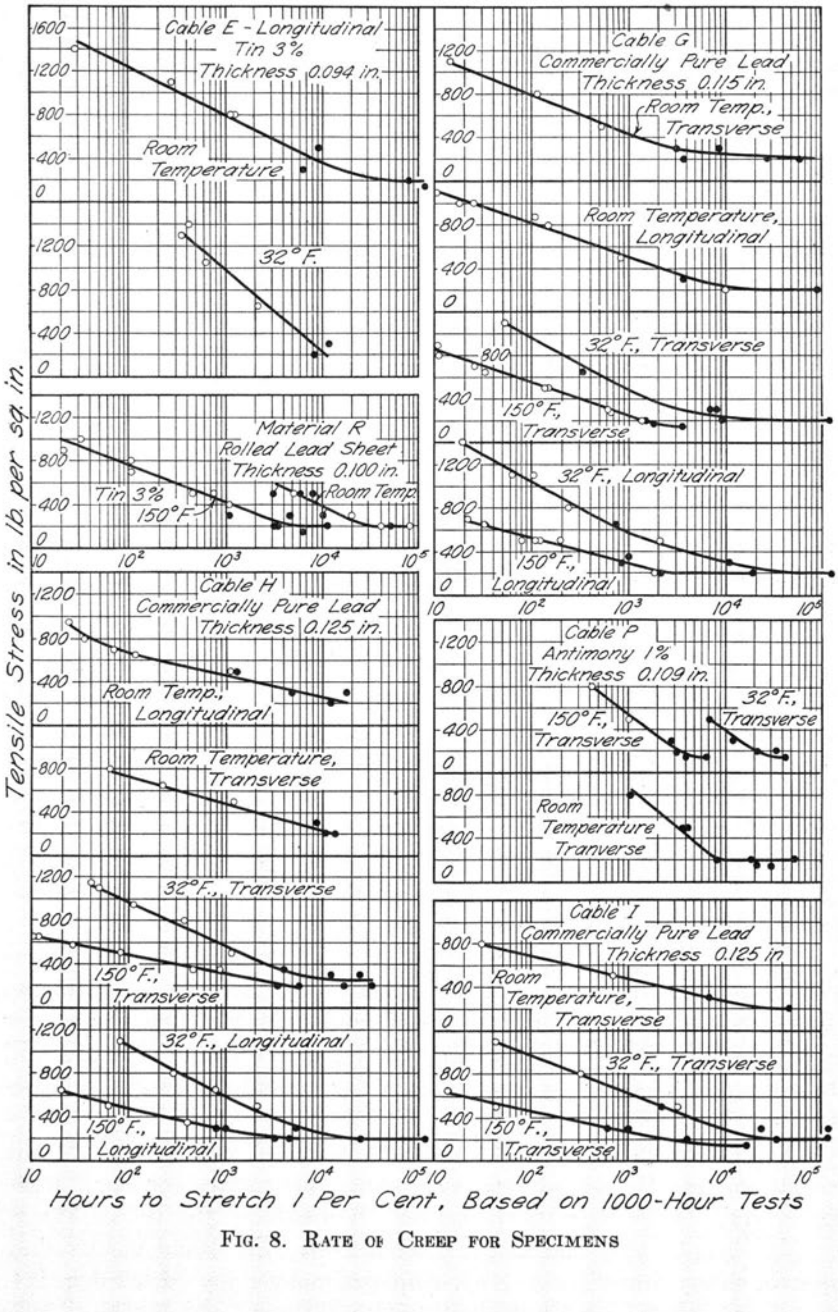

FIG. 8. RATE OF CREEP FOR SPECIMENS

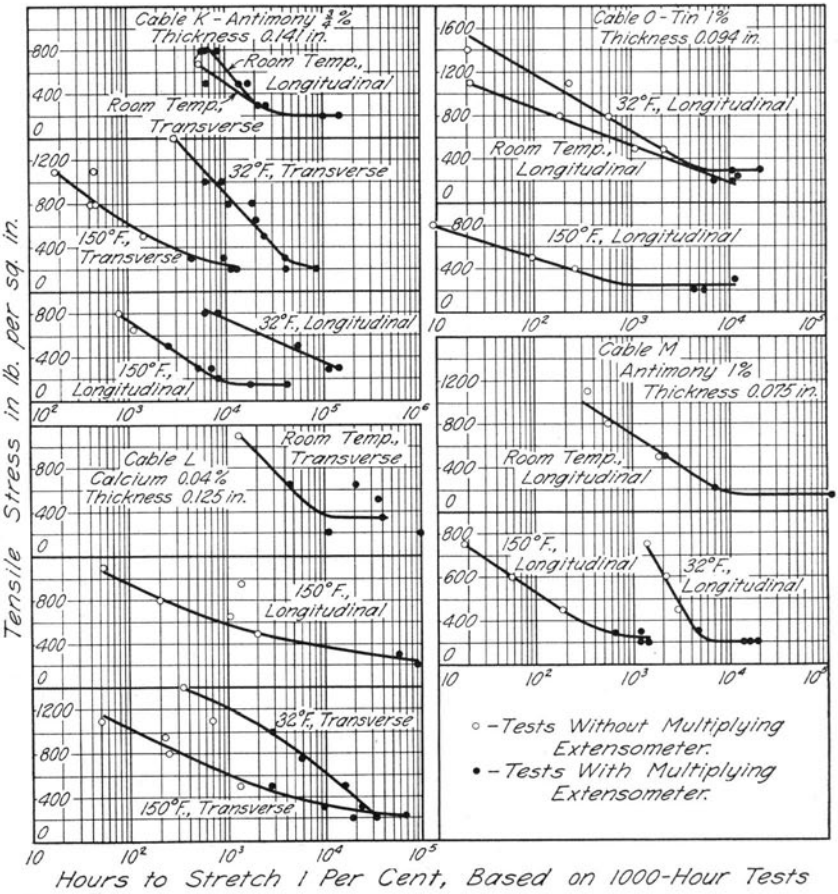

Fig. 8 (Concluded). Rate of Creep for Specimens

lead I, room temperature). A few graphs seem to approach a fairly definite horizontal asymptote (e.g., commercially pure lead G).

All the specimens tested showed some creep even at stresses as low as 200 lb. per sq. in. Evidently, if any absolute limiting creep stress exists, it is somewhat lower than this value. However, an examination of Fig. 8 shows that in the specimens tested in tension there was a distinct tendency for the graphs to change slope as the stress becomes less, and, as noted previously, several of the graphs show a fairly well-defined "knee," while some seem to be asymptotic to a fairly well-defined horizontal (stress coördinate) line.

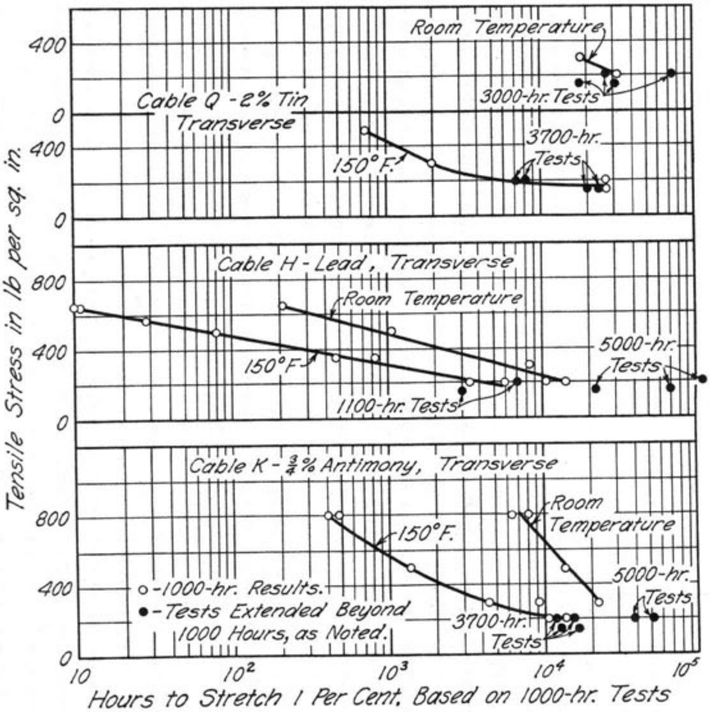

FIG. 9. COMPARISON OF RESULTS OF 1000-HOUR CREEP TESTS WITH RESULTS OF MORE PROLONGED CREEP TESTS

The following arbitrary method of locating a creep limit is suggested, and has been used in this bulletin: Locate the apparent creep limit at a stress for which the slope of the graph—ordinates stress, abscissas hours (log scale) to cause 1 per cent creep—has one-tenth the value which it has for a stress of 1000 lb. per sq. in. The value of 1000 lb. per sq. in. is suggested because the rate of creep for that stress corresponds to a "straight-line" portion of nearly all the graphs, and may be regarded as the "initial" slope of the graph. Figure 12 shows the method of applying this arbitrary rule. The slope of the graph for 1000 lb. per sq. in. stress is given by bc/ab; bd is laid off equal to one-tenth bc; ad is drawn and $a'd'$ parallel to it. The point of tangency of $a'd'$ with the graph is located at t, and tq or its equal Ot' is the arbitrarily determined creep limit. While this value cannot be regarded as an absolute creep limit it does locate a stress for which the lowering of rate of creep with diminishing stress is very greatly diminished from the initial ratio, and below which creep will

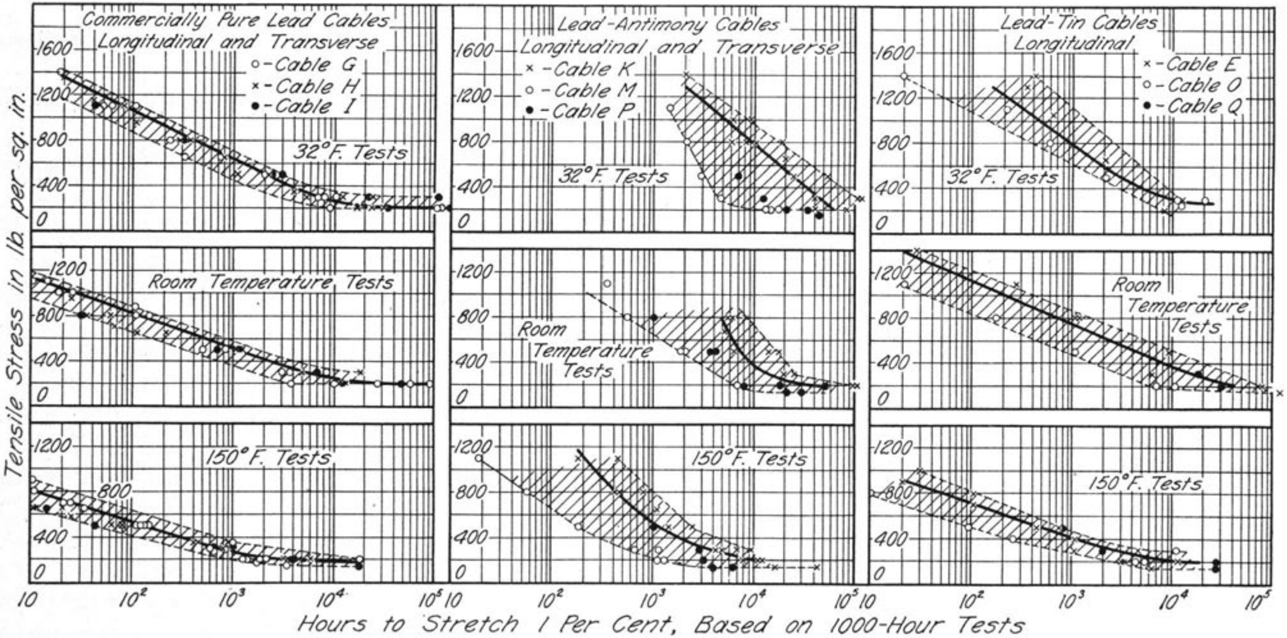

Fig. 10. Composite Graphs for Commercially Pure Lead and Lead Alloys

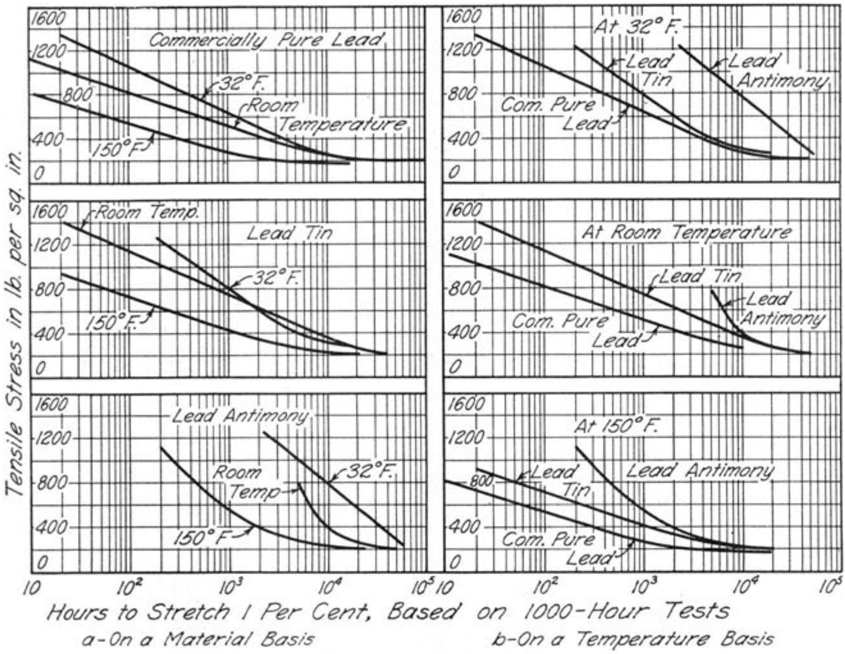

FIG. 11. COMPARATIVE AVERAGE CREEP ON MATERIAL BASIS AND ON TEMPERATURE BASIS

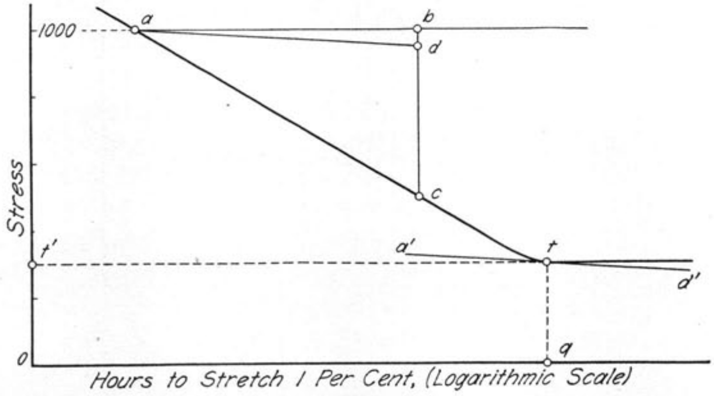

FIG. 12. METHOD OF DETERMINING APPARENT CREEP LIMIT

certainly proceed very slowly indeed. Such an arbitrary limiting stress may serve practical needs, as do the arbitrarily determined elastic limits of metals. This method is offered as tentative; further study may develop a better method.

TABLE 3

RESULTS OF CREEP TESTS OF SPECIMENS OF LEAD AND LEAD ALLOYS

Metal	Direction of Axis of Specimen	Temperature deg. F.	Stress for Creep of 1 per cent lb. per sq. in.			Apparent Creep Limit* lb. per sq. in.
			in 1 week	in 1 month	in 1 year	
3% Tin Alloy....... E	Long.	32	1550	1080	250	...
	Long.	Room	1130	860	370	200†
	Long.	150	670	460	200	200†
Commercial Pure Lead........... G	Long.	32	920	630	310	220
	Trans.	32	850	550	250	230
	Long.	Room	750	550	250	220
	Trans.	Room	700	490	250	230
	Long.	150	475	320	200	200
	Trans.	150	475	290	...	...
Commercial Pure Lead........... H	Long.	32	950	620	270	200
	Trans.	32	880	620	270	250†
	Long.	Room	620	500	270	...
	Trans.	Room	670	510	250	...
	Long.	150	440	310	...	...
	Trans.	150	450	350	...	...
Commercial Pure Lead........... I	Trans.	32	900	680	300	225†
	Trans.	Room	650	500	275	200
	Trans.	150	420	300	160	150
¾% Antimony Alloy K	Long.	32	1420	1170	770	...
	Trans.	32	...	1970	950	210
	Long.	Room	...	1820	720	220
	Trans.	Room	...	1220	550	220
	Long.	150	1200	800	175	150
	Trans.	150	1120	710	250	...
0.04% Calcium Alloy L	Trans.	32	1525	1280	650	...
	Trans.	Room	...	1350	400†	350†
	Long.	150	850	630	380	...
	Trans.	150	940	670	320	210
1% Antimony Alloy M	Long.	32	...	1470	200	200
	Long.	Room	1130	770	190	150
	Long.	150	520	270	260	200†
1% Tin Alloy....... O	Long.	32	1060	730	290†	290†
	Long.	Room	800	570	200	...
	Long.	150	430	260	240	240
1% Antimony Alloy P	Trans.	32	...	...	440	160†
	Trans.	Room	...	970	190	190
	Trans.	150	...	630	150	150
Rolled Lead Sheet... R	Long. and Trans.	Room	...	870	400	200

*Slope of Test Graph 1/10 of that under stress of 1000 lb. per sq. in.
†Rather uncertain; results show considerable "scatter."

9. *Creep Limits and Rates of Creep for Metals Tested.*—By using the method of locating apparent creep limit described in the preceding paragraph, the values given in the right-hand column of Table 3 have been determined. The highest creep limit value at room temperature was found for the calcium alloy, but the test results for this metal show considerable "scatter," and the value should be checked by further tests (now in progress). The calcium alloy did not show an

especially high value for 150 deg. F., but the time required to approach this limit was more than ten times that for any other metal. The ¾ per cent antimony alloy, longitudinal specimens (cable K) showed a high value for 32 deg. F., and its value for 150 deg. F. was also high. At the higher stresses cables L (calcium), K (¾ per cent antimony), and P (1 per cent antimony) stand out as having very slow creep rates.

No very systematic variation in apparent creep limit was shown for changes of temperature from 32 deg. F. to 150 deg. F. There seems to be as much variation between different metals as between specimens of one metal at different temperatures.

However, when the stress necessary to cause 1 per cent creep in one week and in one month was considered, a marked difference was found between the tests at different temperatures. This was found to be particularly true for the alloyed materials. A decidedly higher stress is necessary to cause a creep of 1 per cent per week at 32 deg. F. than is required at 150 deg. F. There also appear more clearly marked differences between the different metals.

Based on the data obtained so far, and subject to revision as further long-time test data become available, the tentative conclusion seems to be justified that, with the possible exception of the calcium alloy and the ¾ per cent antimony alloy K, a stress of 200 lb. per sq. in. seems a fair average value to assign as a practical creep limit for the alloys studied, over the range of temperature covered in the tests, but that under higher stresses creep becomes more rapid as the temperature is increased from 32 deg. F. to 150 deg. F.

10. *Creep Tests for More than 1000 Hours.*—Figure 9 shows the graphs for tests which have already run beyond 1000 hours, together with the graphs for tests for 1000 hours. The test results for more than 1000 hours are shown by solid black circles. It will be noted that these points fall along the graph for the 1000-hour tests. These and other prolonged creep tests are still in progress, and the results so far obtained give no ground for changing the conclusions drawn from the 1000-hour tests.

11. *Rate of Increase in Diameter of Sheathing under Internal Pressure.*—Figure 13 shows graphically the increase in diameter of one of the full-sized specimens of sheathing tested under a hydrostatic pressure of 25 lb. per sq. in. The rate of increase in diameter, measured in days necessary to increase the diameter 1 per cent, is obtained by the average slope of the lines in the figure for each test sheath,

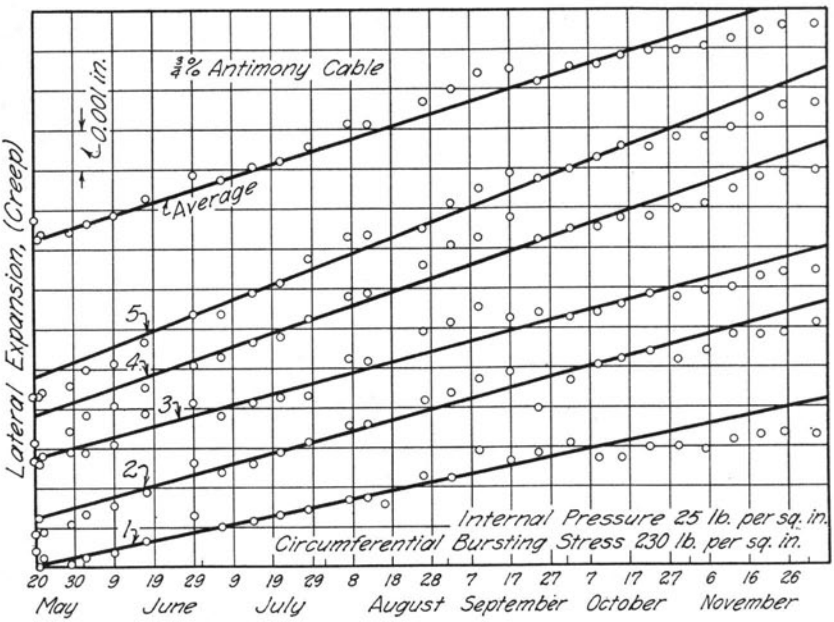

FIG. 13. LATERAL EXPANSION (CREEP) FOR SHEATHING UNDER INTERNAL PRESSURE

respectively.* Table 4 gives the summarized results of the test so far. Definite creep appears to be taking place for each test sheath, and the average rate of expansion in diameter seems to be rather less than the rate of creep for tension specimens under the same stress. The slow but regular rate of increase in diameter apparently indicates that no *absolute* creep limit has been determined even at stresses as low as 200 lb. per sq. in., and the specimens of antimony and of tin alloy apparently show a somewhat higher rate of increase in diameter at the low stresses applied than does the specimen of commercially pure lead sheathing.

The temperature over the 197-day period varied from 73 to 84 deg. F., the maximum being reached at a time corresponding to the increased stretch readings.

12. *Miscellaneous Test Results.*—As noted, one test rack for tension specimens was fitted with an arrangement for removing the load at intervals from six of the specimens. These specimens were tested

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*Each line in Fig. 13 gives the increase in diameter for a definite cross-section of the test sheath. See p. 11 for the details of location of cross-sections.

TABLE 4

CREEP TESTS OF CABLE SHEATHING UNDER INTERNAL PRESSURE

Internal Hydrostatic Pressure 25 lb. per sq. in.

Material	Diameter* of Sheathing in.	Bursting Stress (Circumferential) lb. per sq. in.	Time under Pressure days	Increase of Diameter in.	Time for 1 per cent Increase in Diameter days	Time for 1 per cent Creep Nearest Corresponding Tension Specimens† days
Commercial Pure Lead.	2.716	230	197	0.0037	1445	1130
¾% Antimony Alloy......	2.724	230	197	0.0062	866	675
2% Tin Alloy..	2.555	200	197	0.0098	514	375

*Average of outside and inside diameters.
†Average of different metals tested in tension.

with the load "on" eight hours and "off" sixteen hours. The rate of creep under these conditions for *the actual time under load* showed a slight but not marked increase over the rate of creep under continuous load.

A comparison of tests of specimens cut longitudinally and transversely from the test sheaths furnished shows no clear difference in "creep" properties. In some cases the transverse specimens show higher rate of creep, in others the longitudinal. The arbitrary creep limits determined do not seem to vary widely between these two.

One set of specimens was cut from sheet lead bought at a plumber's shop in Champaign, Illinois. This lead was thinner than the lead from the sheaths, the rate of creep was somewhat less, but the arbitrary creep limit was about the same as the general run of specimens from the sheaths. The results are shown by Material R, Fig. 8. This would indicate that it might be possible to study various alloys of lead by means of extruded ribbons of lead from a comparatively small amount of alloy. This would be much less expensive than the actual making of sheaths in a lead press.

13. *Further Lines of Study.*—As indicated in the preceding paragraph a systematic study of various alloys of lead produced in small quantities and furnished in the form of extruded ribbons would apparently be the most promising way of carrying on the study of specific alloys. A large amount of profitable work could be done in this field.

Tests are in progress of the strength of specimens so cut that the welded seam of the sheathing crosses the specimen at the middle of its length. The object of these tests is to determine whether the weld found in most extruded sheathing is markedly weaker than the base metal.

Metallographic study of the crystal structure of lead and its alloys after it has been subjected to various periods of creep under various stresses might be expected to add some important data. Whether a general change of crystalline structure accompanies creep, whether the action is along definite planes, like ordinary plastic slip, or whether creep is accompanied by definite cracking, as has been found to be the case in aluminum,* are questions of further study.

IV. CONCLUSIONS

14. *Summary and Conclusions.*—This bulletin describes an investigation of the "creep" under load of lead and some of its alloys used in the construction of cable sheathing. Specimens of pure lead and of lead alloyed with antimony, tin, and calcium were studied.

Tests were made on tension specimens hung on test racks at temperatures of 32 deg. F., 150 deg. F., and room temperature. The majority of the tests were discontinued after 1000 hours, but others, still in progress, have reached 5000 hours. Creep was measured with a sensitivity of one ten-thousandth of an inch. Creep tests were also made on three full-sized pieces of sheathing under a constant internal oil pressure. The following conclusions may be drawn from the tests:

(1) Some continuing creep under steady load was observed for all metals tested, even for stresses as low as 150 lb. per sq. in., although an ordinary tension test of the metals showed tensile strengths varying from 1530 to 3850 lb. per sq. in.

(2) The short-time tensile tests showed that for one of the alloys tested the pulling speed had a marked effect on the tensile strength. Increase of the pulling speed increased the tensile strength.

(3) Although no absolute creep limit was found for the metals tested there was evidence that the relation between stress and rate of creep changed in character as the stress was reduced. A graph plotted with stress as ordinates and hours for 1 per cent creep as abscissas (abscissas to a log scale) showed a distinct "flattening out" for most of the metals tested, and in some cases seemed to be approaching a horizontal asymptote.

(4) An arbitrary method of determining a value which might serve as a practical creep limit is described, and has been used in this bulletin; with this arbitrary value as an index, the tests carried out so

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*Hanson, D., Journal (British) Institute of Metals, Vol. XLV, No. 1, page 229, (1931).

far seem to show that, with the exception of one calcium alloy and one antimony alloy, a stress of 200 lb. per sq. in. is apparently a fair average value to assign as a practical creep limit for the alloys studied, over the range of temperature covered in the tests, 32 deg. F. to 150 deg. F.

(5) While there was no marked change of arbitrary creep limit observed under the range of temperature studied, there was a distinct acceleration of creep for the higher stresses with increase of temperature.

(6) A few tests which have been in progress for more than 5000 hours have so far given no ground for changing conclusions drawn from the 1000-hour tests.

(7) Definite creep was observed in the tests of full-sized specimens of sheathing under internal oil pressure giving stresses at about 200 lb. per sq. in. The average rate of creep seemed to be somewhat less for these full-sized specimens than for the tension specimens of similar material.

APPENDIX

SHEATHS ON UNDERGROUND POWER CABLES*

D. W. ROPER†

For all high voltage cables on the underground systems of fourteen large operating companies, about three to four times as many failures are caused by failure of the sheaths to protect the cable mechanically as are caused by failure of the insulation to withstand the voltage. In addition, many cases of sheath defects are located by frequent inspection and repaired before it becomes necessary to remove the cable. Such data indicate the importance of studies of the mechanical problems involved in providing adequate sheath protection.

Up to October 15 of this year, thirteen replacements of 66 kv. cable of the Commonwealth Edison Company have been necessary because of manufacturing defects in the lead sheaths. Ten replacements were necessary because of failure of the insulation.

A few years ago, comparatively heavy oils or compounds were used in cable insulation and the joints were filled with compounds which did not flow at ordinary temperatures. If cracks or splits developed in the sheaths, it seemed that their presence was not soon made manifest as the compounds would not flow out and water entered very

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*Reprinted by permission from the Bulletin of the Utilities Research Commission, Vol. 2, No. 10, Oct. 1931.

†Superintendent, Street Department, Commonwealth Edison Company, Chicago, Illinois.

slowly if at all. In the last few years, improvements in cables, especially for extra high voltages, have been produced by using lighter oils, which are fluid at room temperature, in the cable and joints with reservoirs maintaining positive pressures in the joints. Now when an opening develops through the sheath, oil flows out and unless it is replenished at the reservoirs, electrical breakdown of the insulation is imminent. The leak is located by determining which length is taking the excessive amount of oil.

The integrity of the sheaths is even more important for oil-filled cables where the insulation is impregnated with a very thin oil which is kept under about 12 lb. per square inch pressure. The use of thin oil in extra high voltage cables and joints is an important advancement in the art and, in order that it may be successfully employed, efforts should be concentrated upon obtaining the necessary improvements in sheaths.

Several types of manufacturing defects are found. A longitudinal split may open along a line where the lead, as it flowed around the cable in the lead press, was too cold to weld together firmly. The edges of the die often smooth over the surfaces and obscure the defect from view. When the cable is bent, the defect opens readily. Laminated or stratified lead is produced when the sheath does not form one integral mass, but instead separates in the die into two concentric layers for a short distance. The latter kind of troubles was most numerous in sheaths containing about 2 per cent of tin. Dross or foreign substances and unsymmetrically extruded sheaths are other common defects.

Many failures are caused by mechanical injuries to the sheath incident to the handling of the cable or to work done in the vicinity of the cable. Such troubles have been reduced during the last few years by better training and supervision of the workmen, improved methods and better design of the conduit systems.

As each section of cable expands and contracts upon heating and cooling incident to daily load cycles, it moves at the manhole ends through distances up to about one inch. Rubbing on the end of the duct will cause destructive wearing unless proper shields are used. The bending of the cable in the manhole often cracks the sheath. Such cracking is minimized by properly designing the manhole to allow bends in the cable of ample radius, and using fireproof covering which will not concentrate the bending at a few points on the cable.

Expansion of the insulating material during heating in normal service causes internal pressures which stress the lead and may cause stretching. Also cable of the ordinary type as furnished has some entrained gas. On account of these voids and additional space that may be created due to stretching, oil travels from the joints into the cables. Five years of experience has shown no cessation in this tendency for oil to migrate into the cable and the increasing volumes of oil in the cable may lead to high pressures that will cause undesirable sheath stretching. With this and the other conditions described herein, the research at the University of Illinois described in another article in this Bulletin appears important. The other article suggests that the creeping of lead begins at about 200 lb. per square inch. Stresses occurring in service are often of about this magnitude and are occasionally higher.

For cables used in the telephone industry, the lead sheaths have been improved by the addition of about one per cent of antimony, which increases the hardness. Vibration tests of strips of metal held at one end and moved through a small amplitude about 12 cycles per second at the other end indicated that such alloys were greatly superior to commercially pure lead. For power cables, the problem is not mainly one of slight vibrations as with telephone cable, but is one of relatively slow bending of large amplitude. For the latter such alloys have not been found to be superior to lead.

In tests made by the Commonwealth Edison Company, pieces of cable were placed in a dummy manhole, joined and covered with fireproofing material as is done in service and were subjected to the same bending motions that occur during normal operation. This motion was accelerated to make ten hours of testing equivalent to one year of normal service. In such tests, alloys of lead with antimony, tin and calcium have not been found to be superior to commercially pure lead. More rapid bending of small strips of metal, similar to the tests made by the telephone companies, indicated a superiority of the alloys. It has not been proven that such tests are accurate indications of the serviceability of the metals for power cable sheaths. The studies are continuing.

Of course, the possibilities of improving cable sheaths have not as yet been fully covered by the studies. Research work is in progress both to determine the limitations of the present materials and to discover, if possible, more suitable materials.

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