THE CREEP CHARACTERISTICS

OF

POLYVINYLIDENE CHLORIDE

by

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Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

at the

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1943

Signature of Author_
(Dept. Chem. Eng. January 12, 1943)

Signature of Professor
in Charge of Research_

Signature of Chairman
of Dept. Committee on
Graduate Students_

Graduate House, M. I. T.
Cambridge, Massachusetts
January 11, 1943

Professor G. W. Swett
Secretary to the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In partial fulfillment of the requirements for the degree, Master of Science in Chemical Engineering Practice, I am hereby presenting my thesis, "The Creep Characteristics of Polyvinylidene Chloride".

Respectfully submitted,

John F. Tormey

ACKNOWLEDGMENTS

To Dr. C. E. Reed, for assistance in instituting this work, and to Dr. Herbert Leaderman, for helpful suggestions during the course of the investigation, the author extends thanks.

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I. SUMMARY

The time element in the stress and strain action of natural and synthetic high molecular weight materials has been the object of much investigation. Because the time element is of particular and singular significance in these materials, attempts have been made by a study of the relation that time has with their mechanical action to uncover the true structure of these so-called linear polymers.

A type of testing, wherein time is the predominant factor, has been devised and used upon a variety of textile materials, both natural and synthetic. A theory has been proposed to which these tests conform; the object of this thesis was to employ these same tests upon samples of oriented cordage of polyvinylidene chloride, or Saran.

The tests consisted of stretching samples of the cordage under various loads for long durations of time, releasing this load for an equal time interval, meanwhile making cathetometer readings of the elongations and contractions. Another type of test, the Superposition Test, was also employed.

It was concluded that under the conditions established and encountered, the cordage sample of polyvinylidene chloride did not follow the established theory of behavior. However, there were indications that, with some definite changes in sample size and equipment, better correlation with theory was possible.

Recommendations covering these changes were made, and additional testing was advocated.

II. INTRODUCTION

In investigating the properties of most metals for the purpose of determining their utility as materials of construction, certain established stress, strain, impact, and similar tests are employed by the investigator with good success in obtaining the desired information.

When these same established tests are applied to textile fibers, either natural or synthetic, and to certain filaments of polymeric materials, the results are not so satisfactory, nor do they appear to tell the complete story. The same investigations will not suffice to give us a clear picture of the characteristics of these materials. It has become increasingly evident that time is the differentiating factor between the action of metals and the action of textile fibers and synthetic filaments. It is this time effect and its relationship to the stress-strain action of a single strand of synthetic "plastic", namely polymerized vinylidene chloride, that is the subject of this thesis.

Saran

Before discussing this time effect, some facts about polyvinylidene chloride, or as it is called commercially, "Saran", should be mentioned. Recent patent literature (1) states that Saran is made by polymerizing vinylidene chloride, either alone or as a copolymer with vinyl cyanide or vinyl chloride, adding certain filling materials and plasticizers, fusing the mixture, dyeing to desired color, grinding, and then extruding the resulting thermoplastic in the desired form. Plastic filaments, or the oriented cordage tested in this investigation, are pulled hot from the extrusion unit and oriented, or mechanically worked, into a wide range of tensile strengths. Tensile strengths can be controlled from 4,000 pounds per square inch to 12,000 pounds per square inch, and elastic elongation limited from ten per cent to forty per cent (2).

Structure of Saran

This range of tensile strengths and elongations is possible because of the unique internal structure of Saran. Saran has been reported, by virtue of X-ray photographs of its structure, to possess three physical conditions, amorphous, crystalline, and oriented, anyone of which it may be made to assume by proper heat and mechanical treating.

Vinylidene chloride in the unpolymerized state is unsymmetrical dichloro-ethylene, an ethylene molecule in which the two hydrogens on one of the carbon atoms have been replaced by chlorine atoms. The unsaturation is still present. Upon polymerization, the vinylidene chloride molecules unite, end to end, by virtue of this unsaturation, into long chain, linear, addition polymers of high molecular weight (3), (4), (5). The average molecular weight of Saran is reported as 20,000 (2). In the amorphous state, it appears that these long, linear chains exist in a haphazard, tangled mass, with little or no orientation perceptible to the X-ray. With mechanical working, these chains may be combed out and made to lie alongside each other, more or less parallel. This parallel arrangement gives strength and elasticity to the fiber by virtue of some obvious, but not as yet recognizable, cohesive force which exists between parallel chains. When the molecules are so arranged, the polymer is said to be in its orientated state, It is in this state that the Saran tested in this work existed, and it is to the peculiar bonds, linkages, and forces of the oriented state that Saran, as well as the other synthetic and natural fibers, owe their peculiar stress-strain-time relations.

The third state in which Saran is reported to exist is the cyrstalline state, which it will assume after heating and subsequent cooling. This crystalline state is peculiar to Saran, since most thermoplastics do not display a crystalline structure. However, it is possible that the crystalline state, reported by Goggins and Laury (2), is nothing more than a highly perfect state of orientation and not the three dimensional order usually associated with crystallinity. At any rate, the reported tendency of Saran toward perfect orientation of its linear chains is especially noteworthy.

Commercial Properties

Saran is also highly resistant to the action of acids, alkalis, both weak and strong, and to most, but not all, organic solvents (1). It exhibits a complete absence of water absorption, and its rate of water permeability is very low (2). The other properties of Saran, its durability, machinality, beauty, etc., not especially important for consideration here, make it an excellent commercial thermoplastic.

The Time Element

Whitby and Stafford (6) in their work on the elasticity of rubber were forded to conclude:

> "Time plays an important part in the result of any mechanical manipulation through which these materials (rubber, organic polymers, etc.) pass. Strictly speaking, there is no such thing as a stress-strain diagram in

> these cases, only a stress-strain-time diagram".

They substantiate this view with time data for rubber elongation. The same view is also expressed by Kuveshinky and Kobeko (7) and by Alexandrov (8), all of whom report considerable work in this field. The former reports relationship between elasticity and dielectric orientation, while the latter discusses the "relaxation" time in synthetic polymeric materials. Leaderman (9) has conducted extensive stress-strain time experiments on rayon, nylon, silk, and similar textiles and has established a type of experiment, namely the creep test of long duration, creep recovery, and cyclical loading, to which Saran has been subjected in this investigation.

Creep and Creep Recovery

When a fiber, or an oriented cordage of Saran, is subjected to a constant tensile load, the material rapidly elongates upon the applicaton of the load. This instantaneous deflection is followed by a slower deflection or "creep", which may continue for some hours. Upon removal of the load, the material instantly contracts to an extent closely approximating its initial elongation. Following this instantaneous contraction, there ensues a gradual contraction which may result in the materials' attaining once more its original length. This phenomena is called "creep recovery". One might speak of the instantaneous elongation and contraction as elasticity and the creep and creep-recovery action as delayed elasticity.

However, the term elasticity connotes complete recovery. In some cases of creep, the creep recovery is not perfectly complete, but there remains a small non-recoverable portion, or permanent set. Leaderman has divided creep, therefore, into two components, which are superimposed on each other; primary creep, or creep to which there is complete recovery, and secondary creep, or creep to which there is no recovery. Inasmuch as primary creep alone is of present interest, it seems advisable to eliminate if possible this secondary creep. This is accomplished by "mechanical working" or subjecting the material to certain loads for definite time intervals until the secondary creep component is no longer present.

Superposition Principle

With the ideas of creep and creep recovery is closely related the Superposition Principle, simply expressed by Leaderman (10) as follows:

> "At any instant, the deflection of a solid manifesting only primary creep can be separated into two components. One component is the instantaneous elastic deflection, proportional to the load acting at that instant. The other component is the primary creep or delayed elastic deflection dependent not only on the load acting at that instant but also on the entire previous loading history. Hence, as far as the primary creep component of the deflection is concerned, the material possesses a memory of all past loading actions".

This Superposition Principle has been demonstrated by Leaderman to hold well for single filaments of viscose nylon, and silk, and these tests on Saran were conducted with the same purpose in mind, namely, to determine whether or not Saran obeyed the Superposition Principle.

To apply the Superposition Principle, a creep test under constant load, lasting for several hours, is performed, followed by a creep recovery test of the same duration. These results are plotted, elongation versus time. The material is now subjected to a diversified loading. That is, using the same load as was employed in the long duration test, the experimenter applies and removes the load at various times. If the Superposition Principle holds for the material, and the memory effect is present, we may calculate and reconstruct, from the elongations present in this latter test, a curve exactly similar to the former long-duration creep curve. This is possible, as Leaderman (10) expresses it, if:

> "We assume the effect of the original load, as far as its creep is concerned, to continue indefinitely. Superimposed upon this, we assume a (negative) creep due to an equal negative load applied at the instant of load removal............
> The effect of each load, positive or negative, is assumed to continue indefinitely, and the deflection at any time is simply the sum of the deflections due to each separate loading action. Each of these separate effects can be obtained from the long-duration creep test".

The Superposition Principle can also be tested by an examination of the long-duration creep and cree-recovery tests. By allowing the creep to attain its limiting value and then removing the load, a negative deflection will ensue, whose plot, on appropriate axes, should reproduce the creep curve exactly.

Consequently, long-duration creep curves are the key tool to the investigation of these creep phenomena which display themselves in such a variety of materials. When it has been conclusively proved that the principles of creep and Superposition are perfectly consistent, reproduceable, and present in otherwise related materials, a new means will have been obtained by which the ultimate structure of linear polymers, now deduced only by X-ray and chemical analysis, may be uncovered.

III. PROCEDURE

Creep Test

The sample or oriented Saran cordage was fastened at one end to a firmly mounted bracket. This fastening was accomplished by clamping the cordage between two leather-covered steel bars and screwing the bars to a wooden base. Details of this arrangement are to be found in Figure II.

The cordage, .021 inch in diameter and approximately 70 centimeters in length, was allowed to hang vertically, its other extremity being attached to a light bronze hollow column, which was free to move vertically but whose sidewise motion was prevented by a double pair of rollers, which guided but did not impede the vertical motion of the column. This mechanism is sketched in Figure III. By such a system of fastening, the cordage of Saran was held in the vertical plane at all times. Predetermined loads were applied to the cordage by quickly and manually hooking metal weights to a fastener at the bottom of the bronze column. Cathetometer readings of the elongation were made at definite intervals over the course of twenty-four hours. Temperature readings were also noted. The resulting elongations of the Saran were plotted against the logarithm of the time in minutes.

Creep Recovery

This test is nearly identical with the creep test. After a period of twenty-four hours of inducing creep in the Saran cordage, the load was quickly removed and cathetometer readings of the contration or recovery were made at the same time intervals as the creep test. These results were also plotted against a long time abscissa, on the same graph as the creep curve.

Cyclical Loading

In this test, a definite load was applied to the cordage and allowed to remain for ten minutes. It was then removed and the Saran allowed to contract. After a contraction or creep recovery period of ten minutes, the load was once more applied. This process of loading and unloading continued for sixty minutes. Cathetometer readings of the deflection were made every minute.

FIG. I

CREEP TESTING APPARATUS

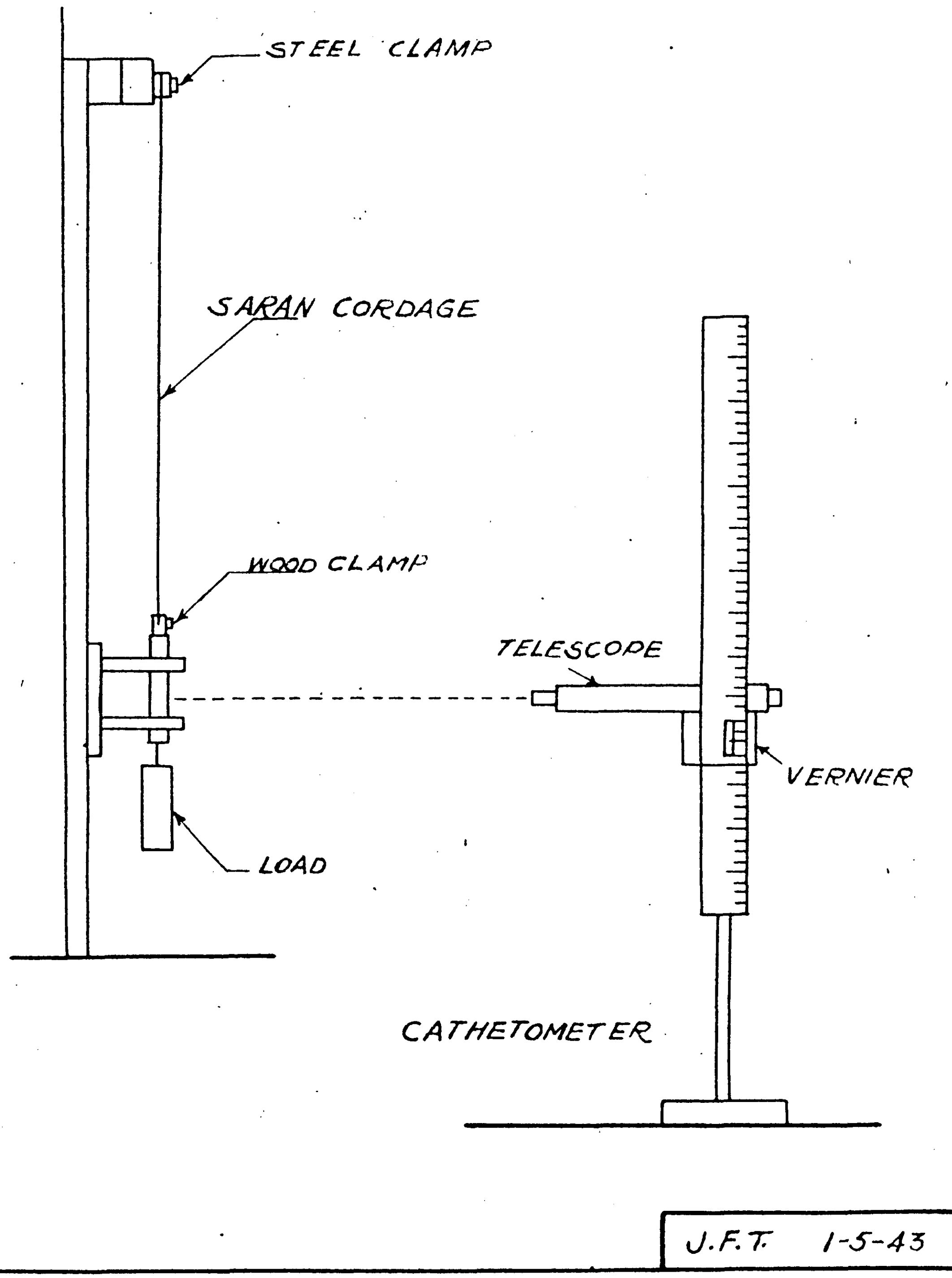
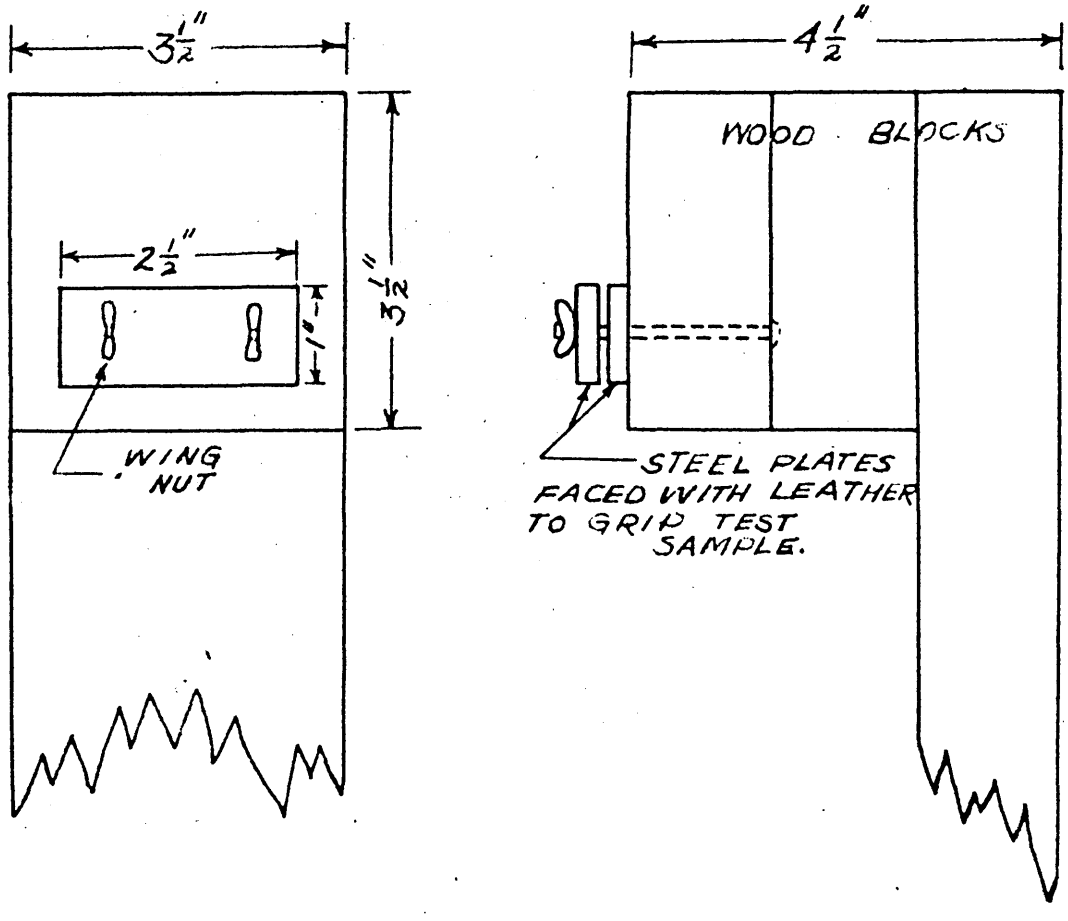


FIG. II

UPPER SECTION OF APPARATUS

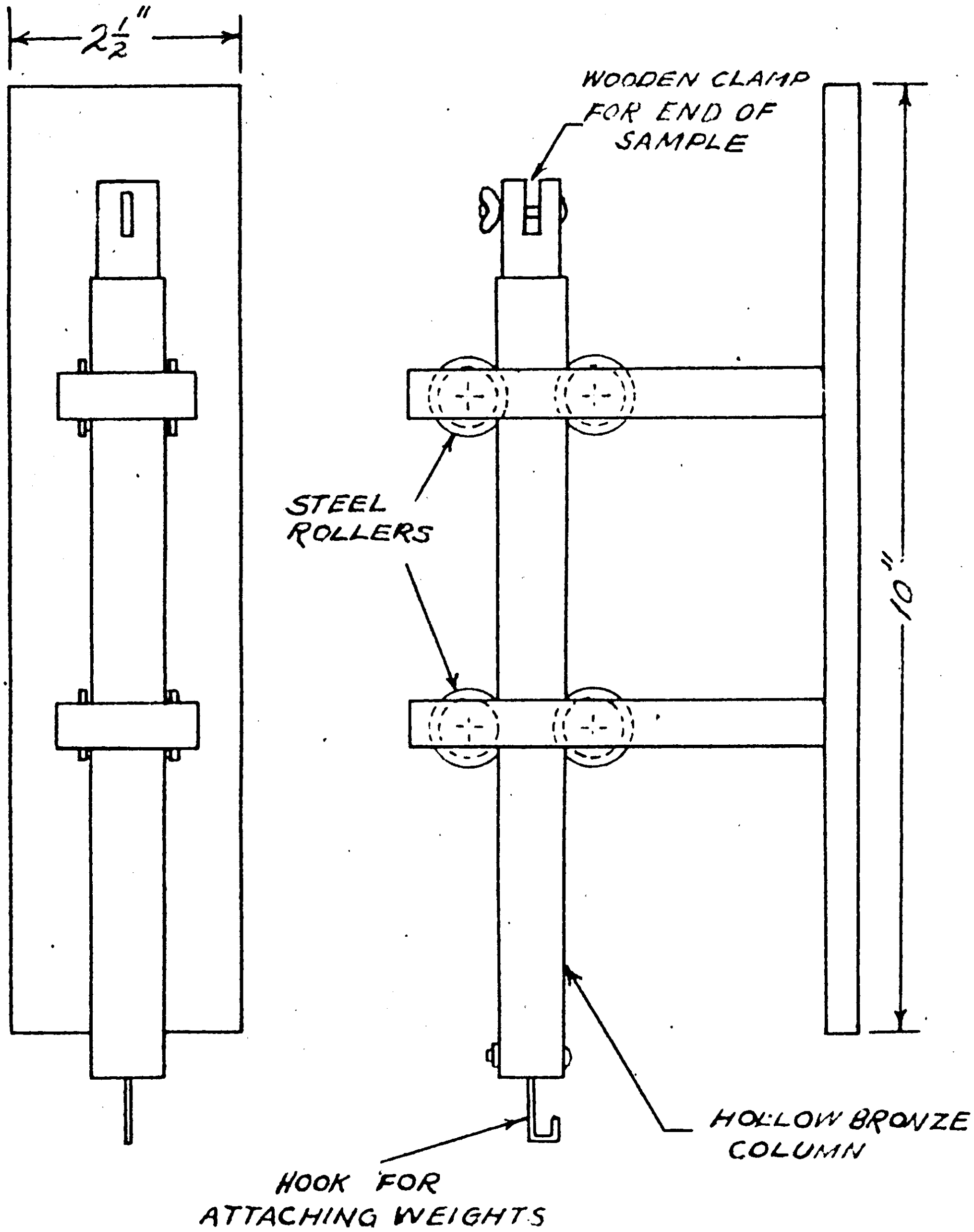


SCALE: 1" = 2"

J. F. T. 1-1-13

FIG. III

LOWER SECTION OF APPARATUS



SCALE: 1" = 2"

J.F.T. 1-4-43

IV. RESULTS

The results of this investigation, comprising creep, recovery, and superposition tests, are presented graphically in this section.

Semi-log plots of all the creep and recovery tests are arranged in the order in which they were performed. In presenting these results in graphical form, it is believed a better evaluation is possible than with tabulated data. However, a portion of the original data, as it was recorded in tabular form, is to be found in the Appendix.

Superposition points are plotted on the same graph as the creep curve obtained from the corresponding specimen and load.

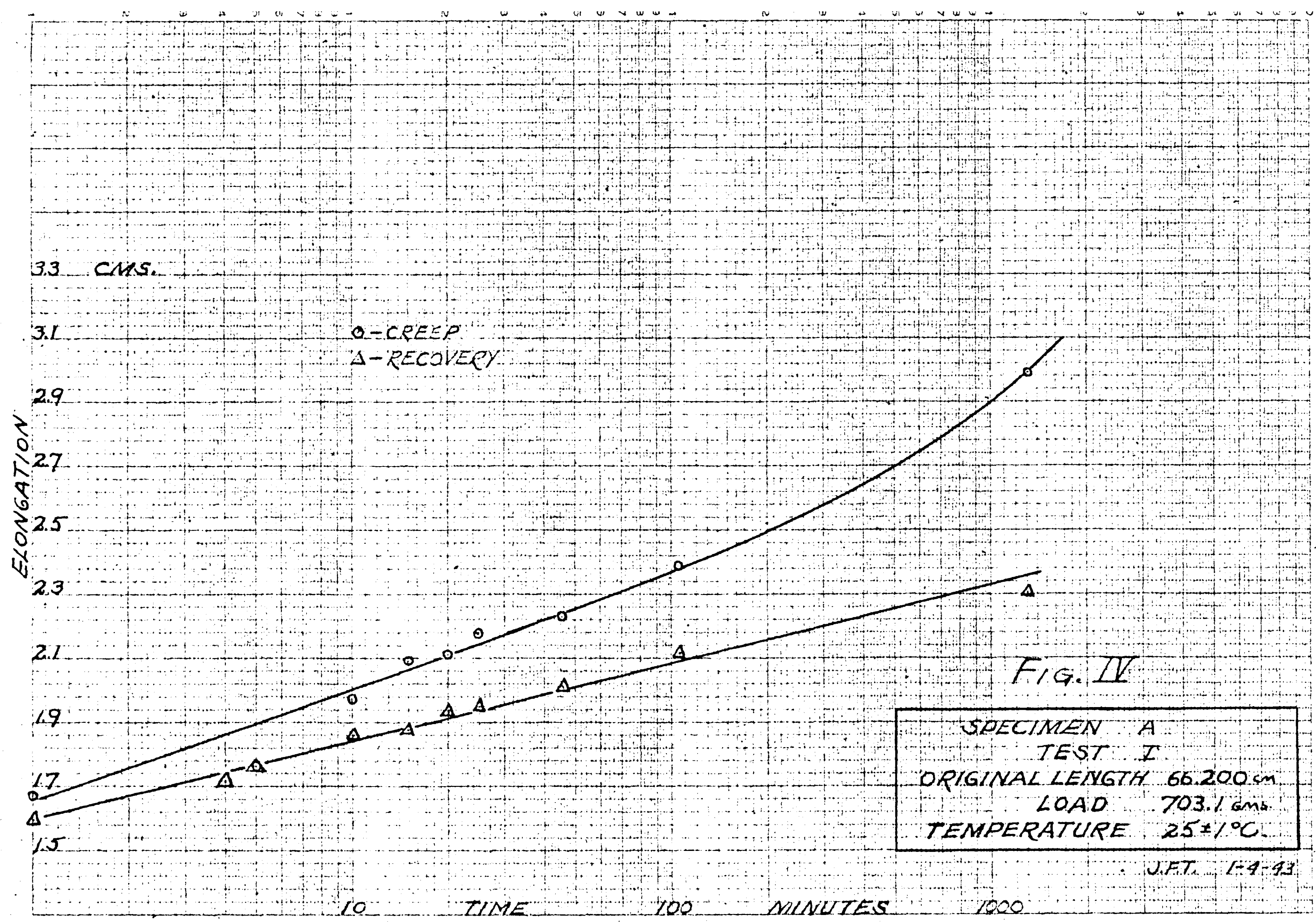
Creep and recovery curves for Specimen A are plotted on Figures IV and V.

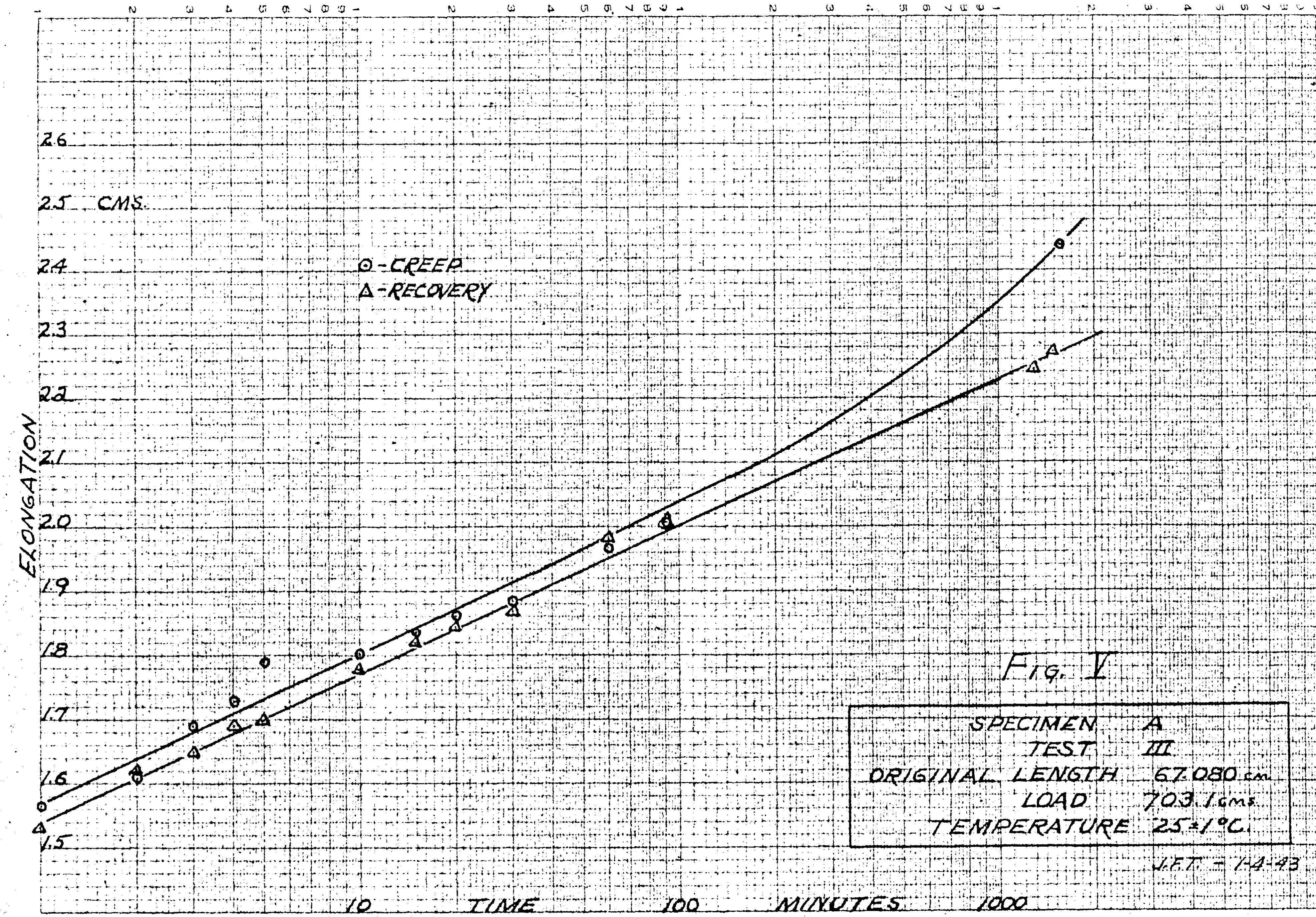
Creep and recovery curves for Specimen B are plotted on Figures VI, VII, VIII, IX, X, XI, XII, XIII, and XIV.

Creep and recovery curves for Specimen C are plotted on Figures XV, XVI, XVII, XVIII, XIX, and XX.

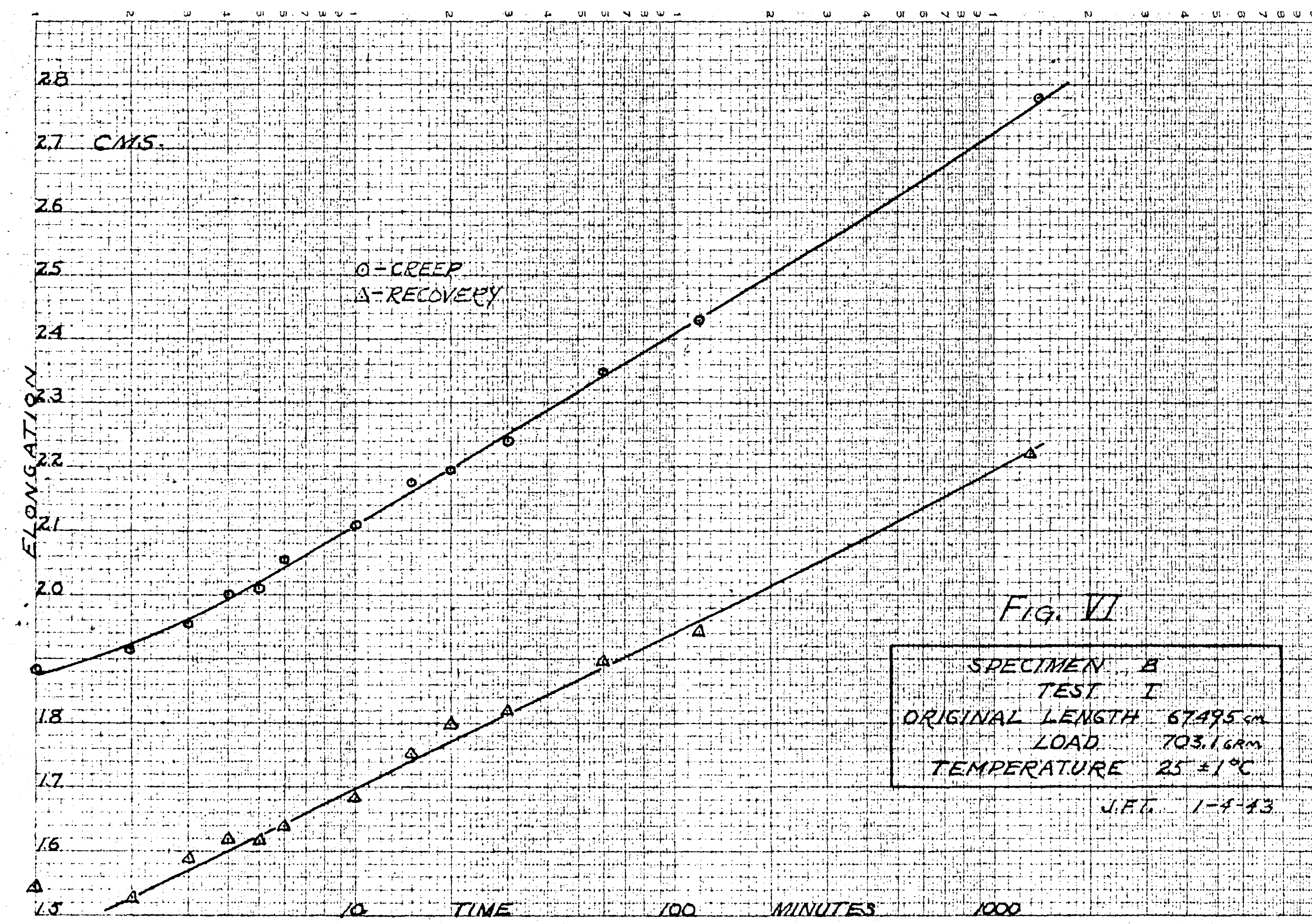
Superposition tests for Specimen B are found on Figures XIII, and XIV.

Superposition tests for Specimen C are found on Figures XVIII, and XIX.


3.3 CMS.
3.1
2.9
2.7
2.5
2.3
2.1
1.9
1.7
1.5
ELONGATION
o - CREEP
Δ - RECOVERY
10
TIME
100
MINUTES
1000
FIG. IV
SPECIMEN A
TEST I
ORIGINAL LENGTH 66.200 cm
LOAD 703.1 Gms.
TEMPERATURE 25±1°C.
J.F.T. 1-4-43



2.6
2.5 CMS.
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
ELONGATION
⊙-CREEP
Δ-RECOVERY
10
TIME
100
MINUTES
1000
FIG. V
SPECIMEN A
TEST III
ORIGINAL LENGTH 67.080 cm
LOAD 703.1 gms.
TEMPERATURE 25±1°C.
J.F.T. – 1-4-43



ELONGATION
CMS.
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.8
1.7
1.6
1.5
⊙ - CREEP
Δ - RECOVERY
10
TIME
100
MINUTES
1000
FIG. VI
SPECIMEN B
TEST I
ORIGINAL LENGTH 67.495 cm
LOAD 703.1 GRM
TEMPERATURE 25° ±1 °C
J.F.T. 1-4-43

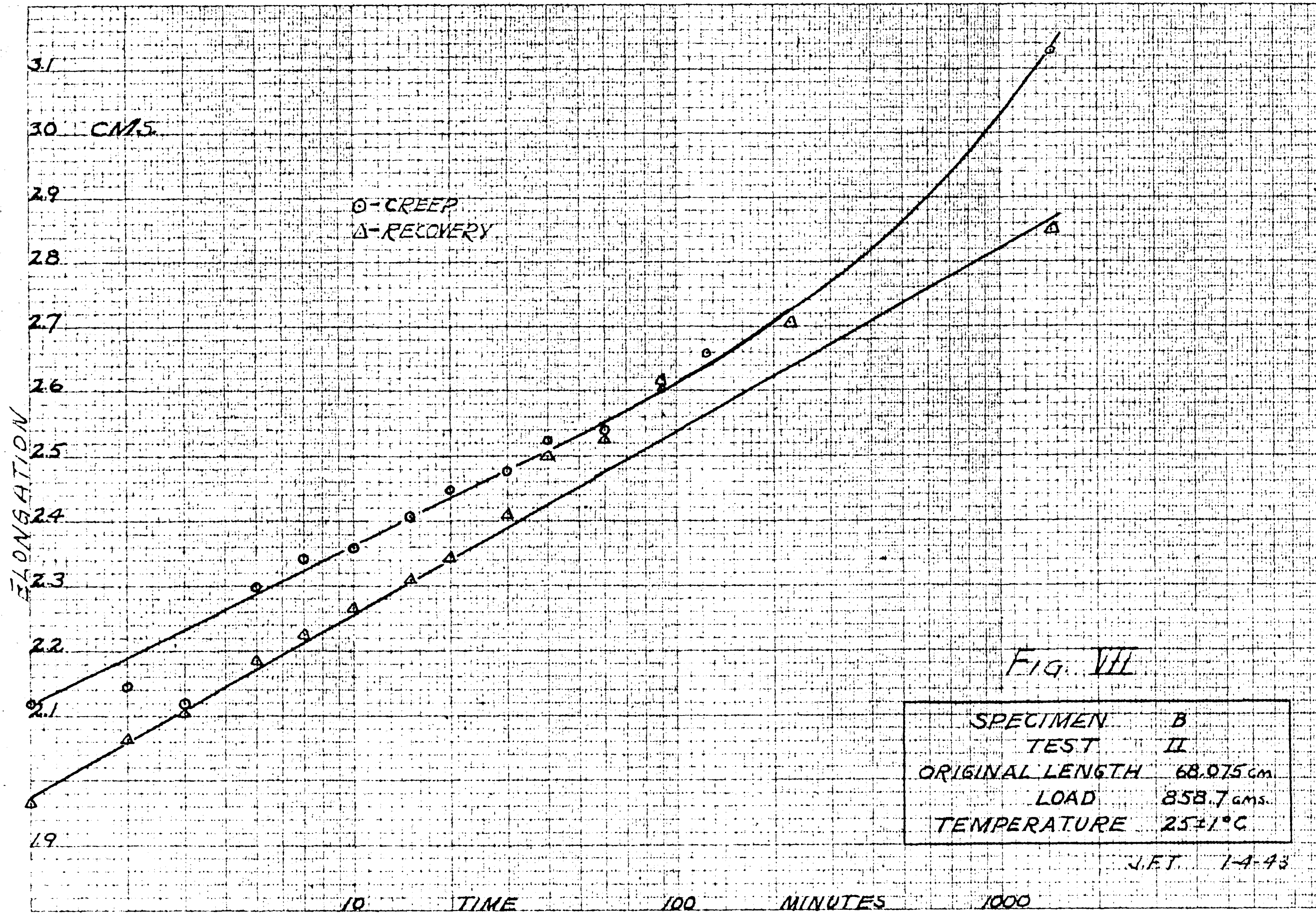

3.1
30 CMS.
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
1.9
ELONGATION
⊙-CREEP
Δ-RECOVERY
10 TIME 100 MINUTES 1000
SPECIMEN B
TEST II
ORIGINAL LENGTH 68.075 Cm.
LOAD 858.7 GMS.
TEMPERATURE 25±1°C
J.F.T. 1-4-43

FIG. VII

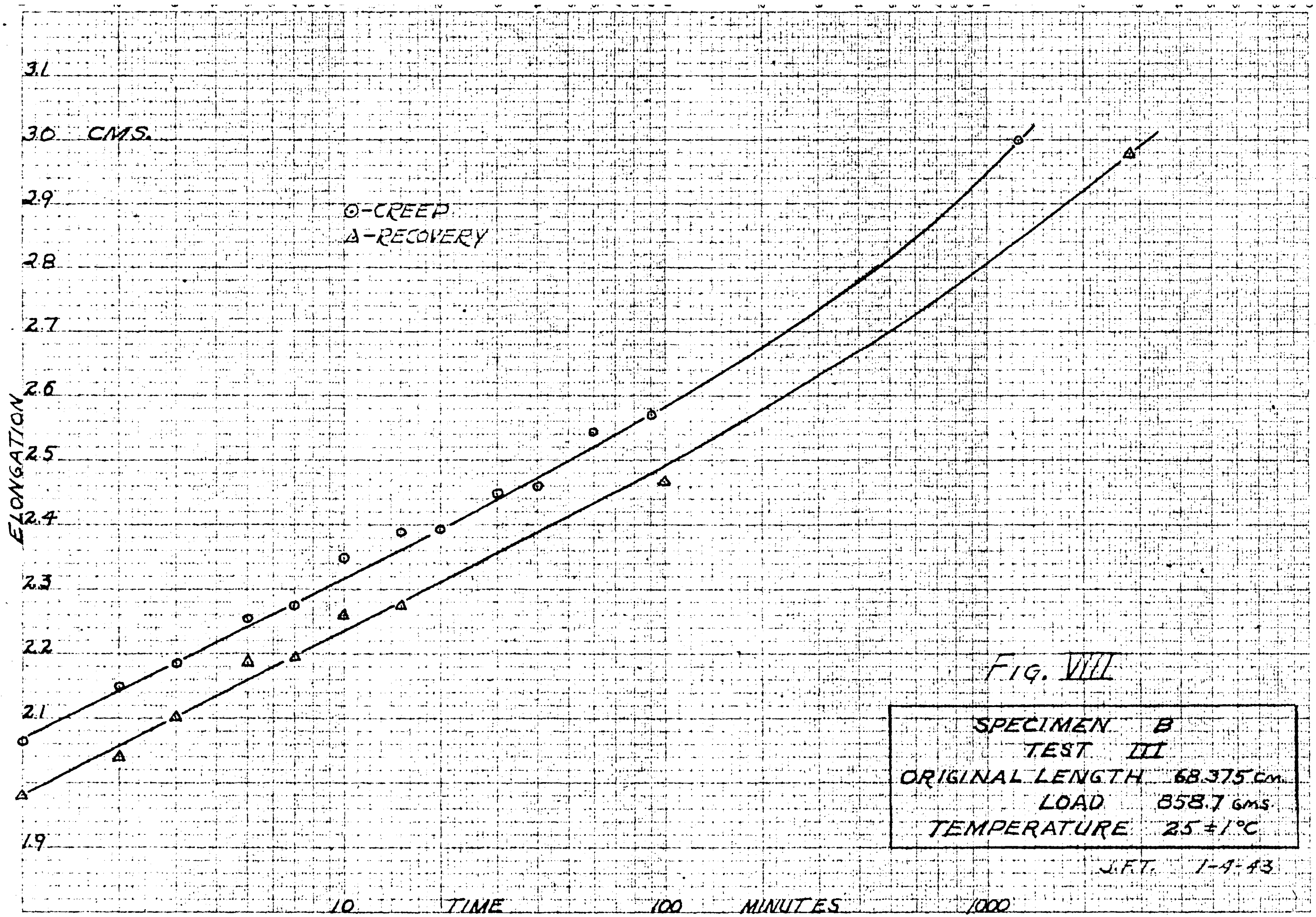

3.1
3.0 CMS.
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
1.9
ELONGATION
⊙-CREEP
Δ-RECOVERY
10
TIME
100
MINUTES
1000
SPECIMEN B
TEST III
ORIGINAL LENGTH 68.375 Cm.
LOAD 858.7 GMS.
TEMPERATURE 25 ± 1°C
J.F.T. 1-4-43

FIG. VIII

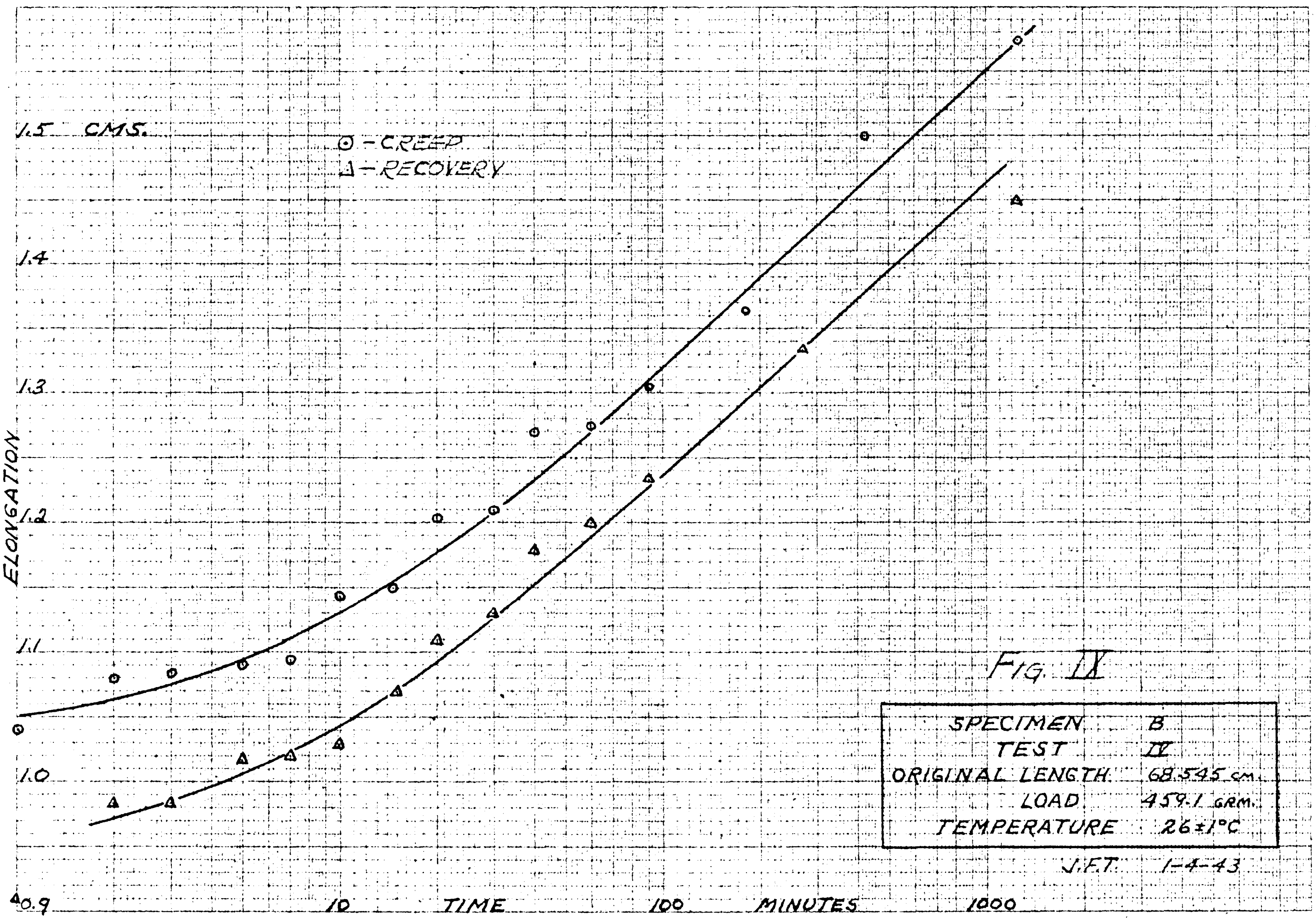

1.5 CMS.
1.4
1.3
1.2
1.1
1.0
0.9
ELONGATION
⊙ - CREEP
Δ - RECOVERY
4
10
TIME
100
MINUTES
1000
SPECIMEN B
TEST IV
ORIGINAL LENGTH 68.545 cm.
LOAD 459.1 GRM.
TEMPERATURE 26±1°C
J.F.T. 1-4-43

Fig. IX

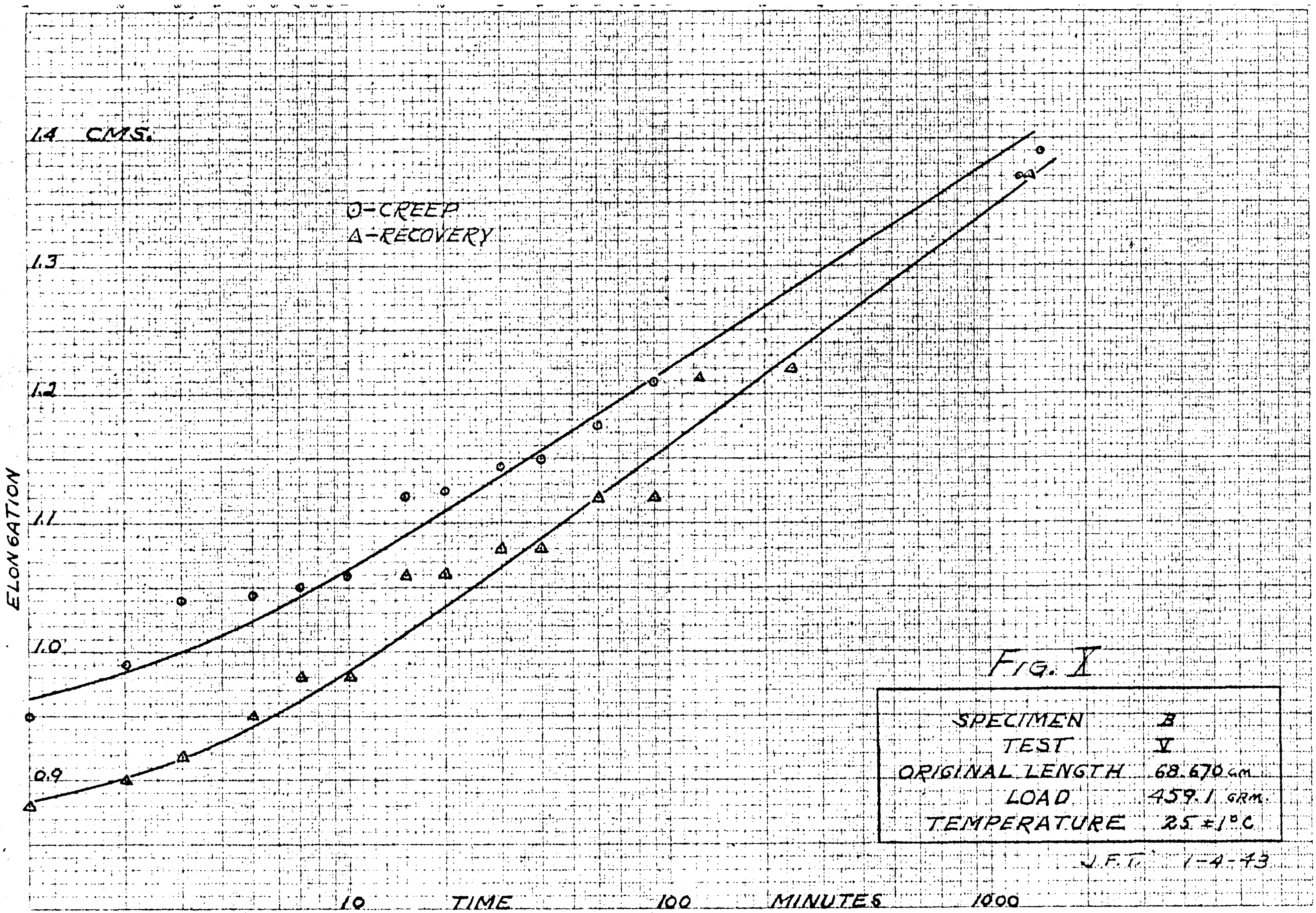

1.4 CMS.
1.3
1.2
1.1
1.0
0.9
ELONGATION
O-CREEP
Δ-RECOVERY
10
TIME
100
MINUTES
1000
SPECIMEN B
TEST V
ORIGINAL LENGTH 68.670 cm
LOAD 459.1 GRM.
TEMPERATURE 25 ± 1°C
J.F.T. 1-4-43

FIG. X

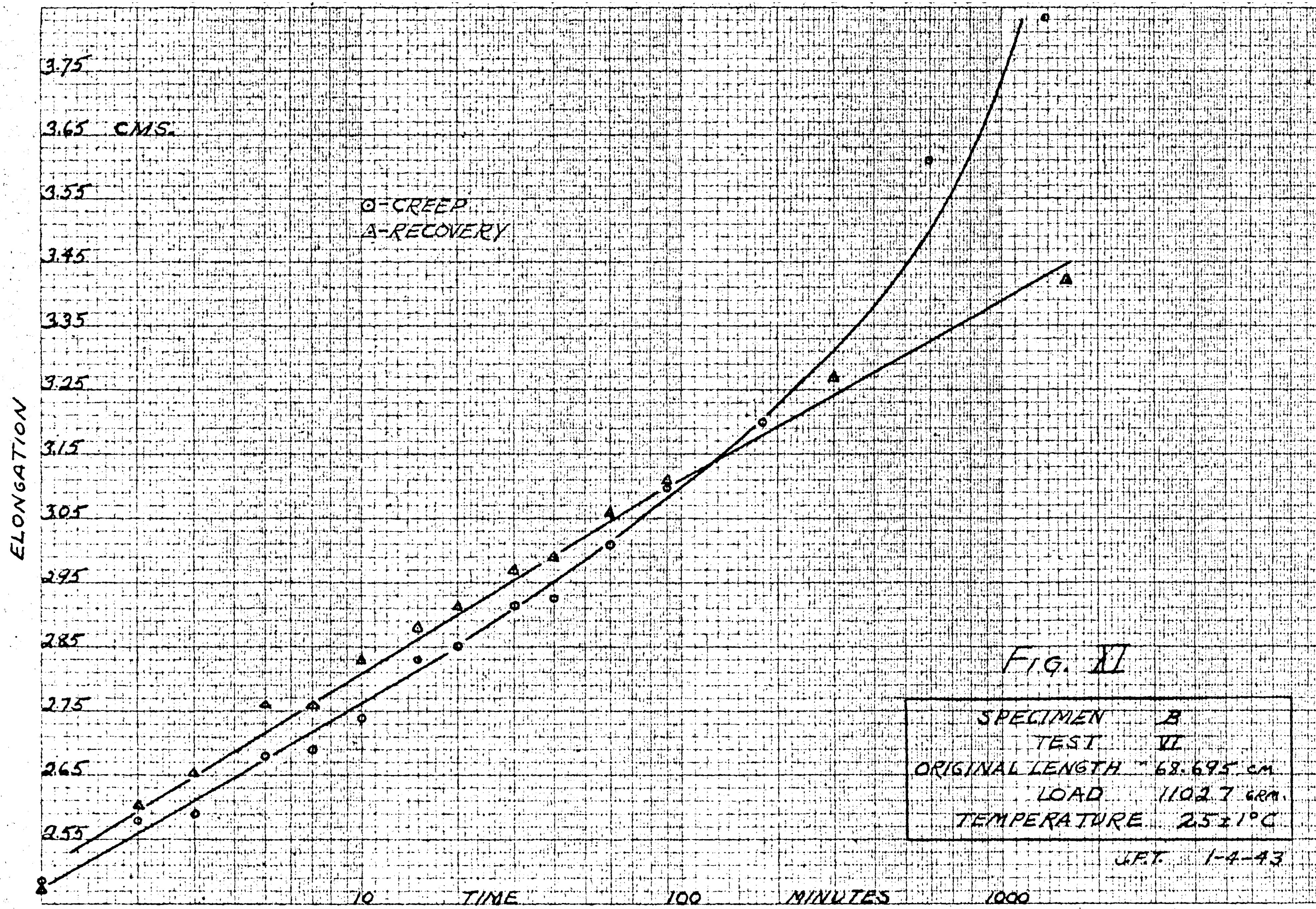
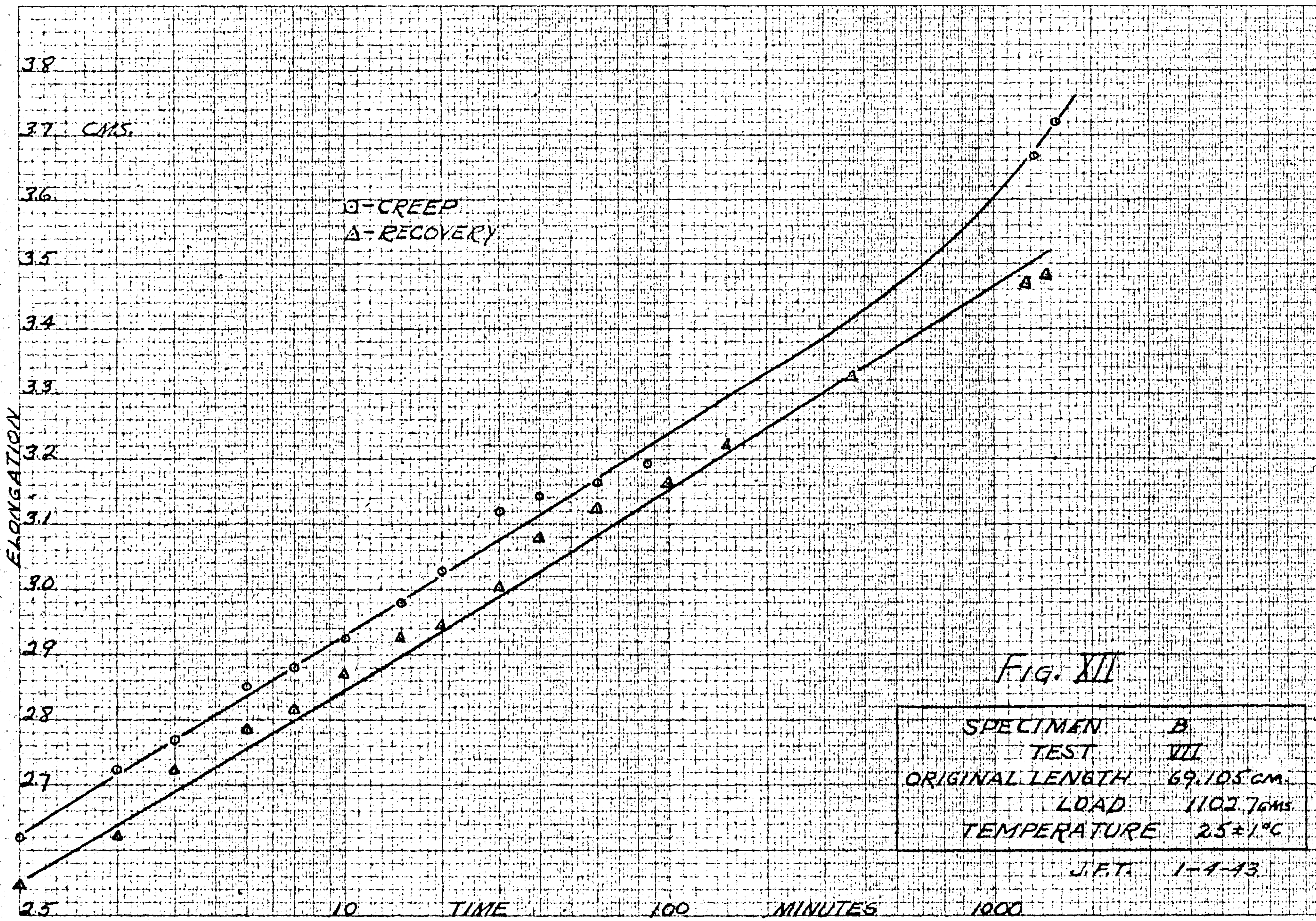
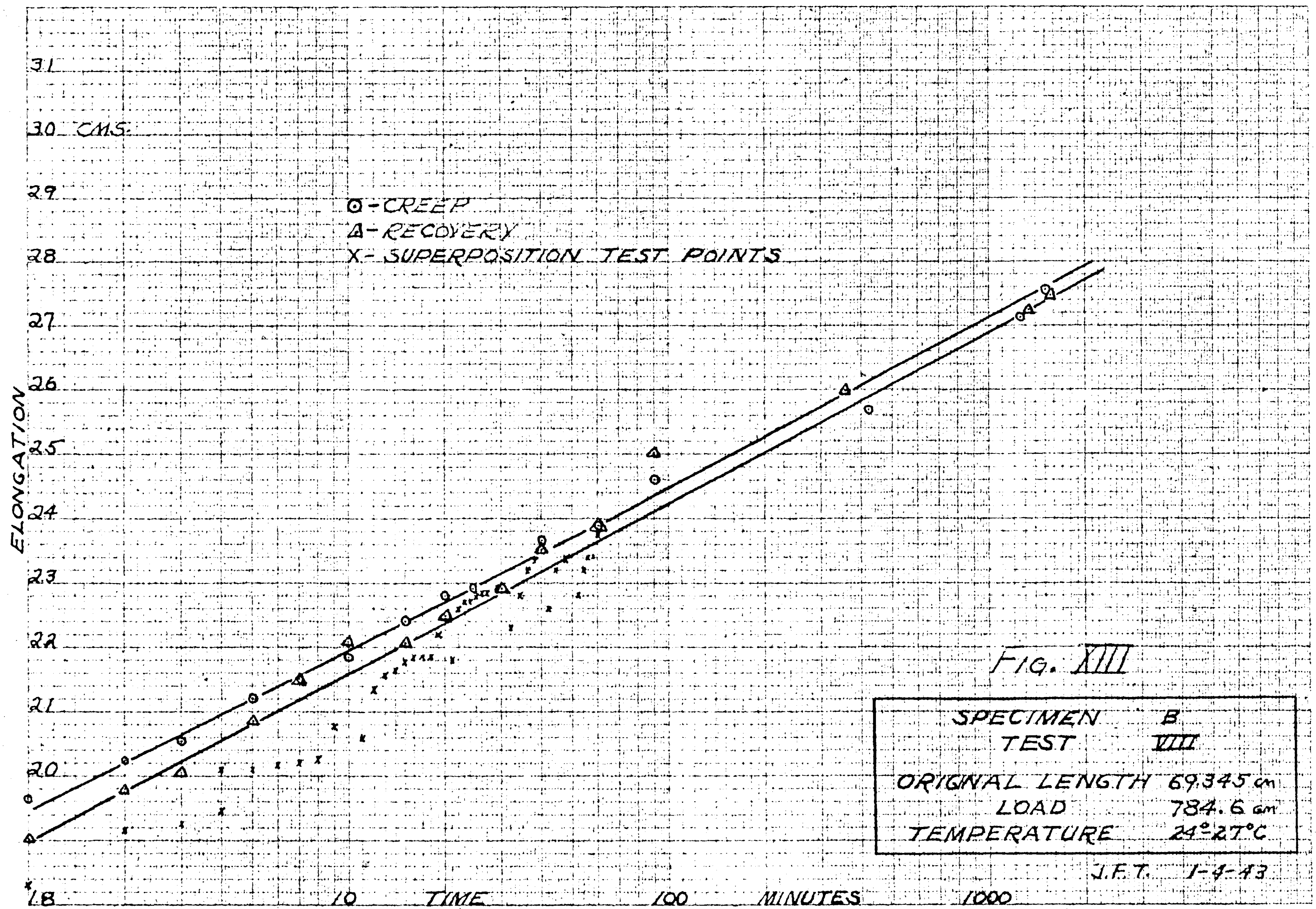

3.75
3.65 CMS.
3.55
3.45
3.35
3.25
3.15
3.05
2.95
2.85
2.75
2.65
2.55
ELONGATION
⊙-CREEP
Δ-RECOVERY
10
TIME
100
MINUTES
1000
SPECIMEN B
TEST VI
ORIGINAL LENGTH 68.695 CM
LOAD 1102.7 GRM.
TEMPERATURE 25±1°C
J.F.T. 1-4-43

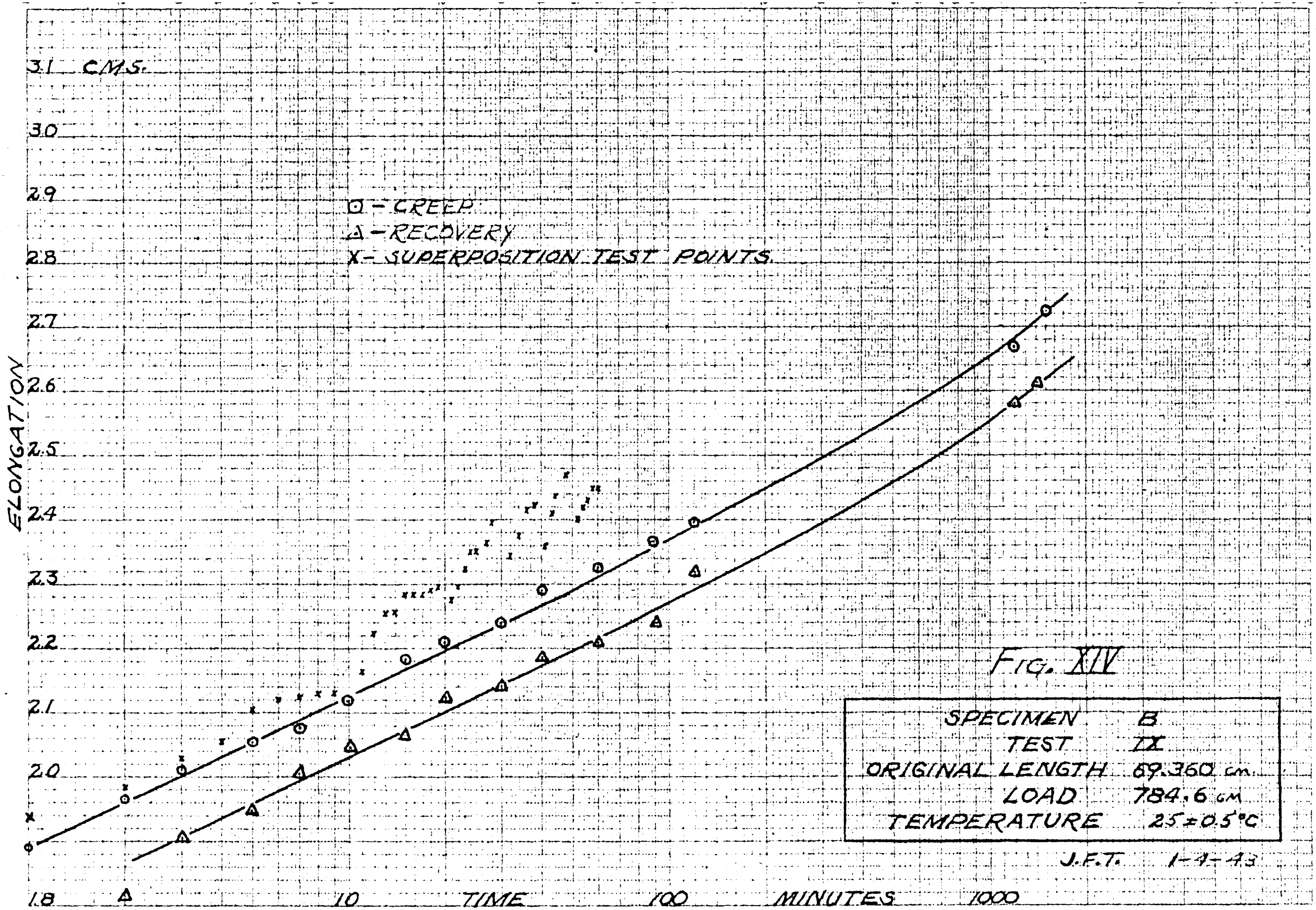
FIG. XI


3.8
3.7 CMS.
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.5
ELONGATION
⊙-CREEP
Δ-RECOVERY
10
TIME
100
MINUTES
1000
FIG. XII
SPECIMEN B
TEST VII
ORIGINAL LENGTH 69.105 CM.
LOAD 1102.7GMS.
TEMPERATURE 25±1°C
J.F.T. 1-4-43



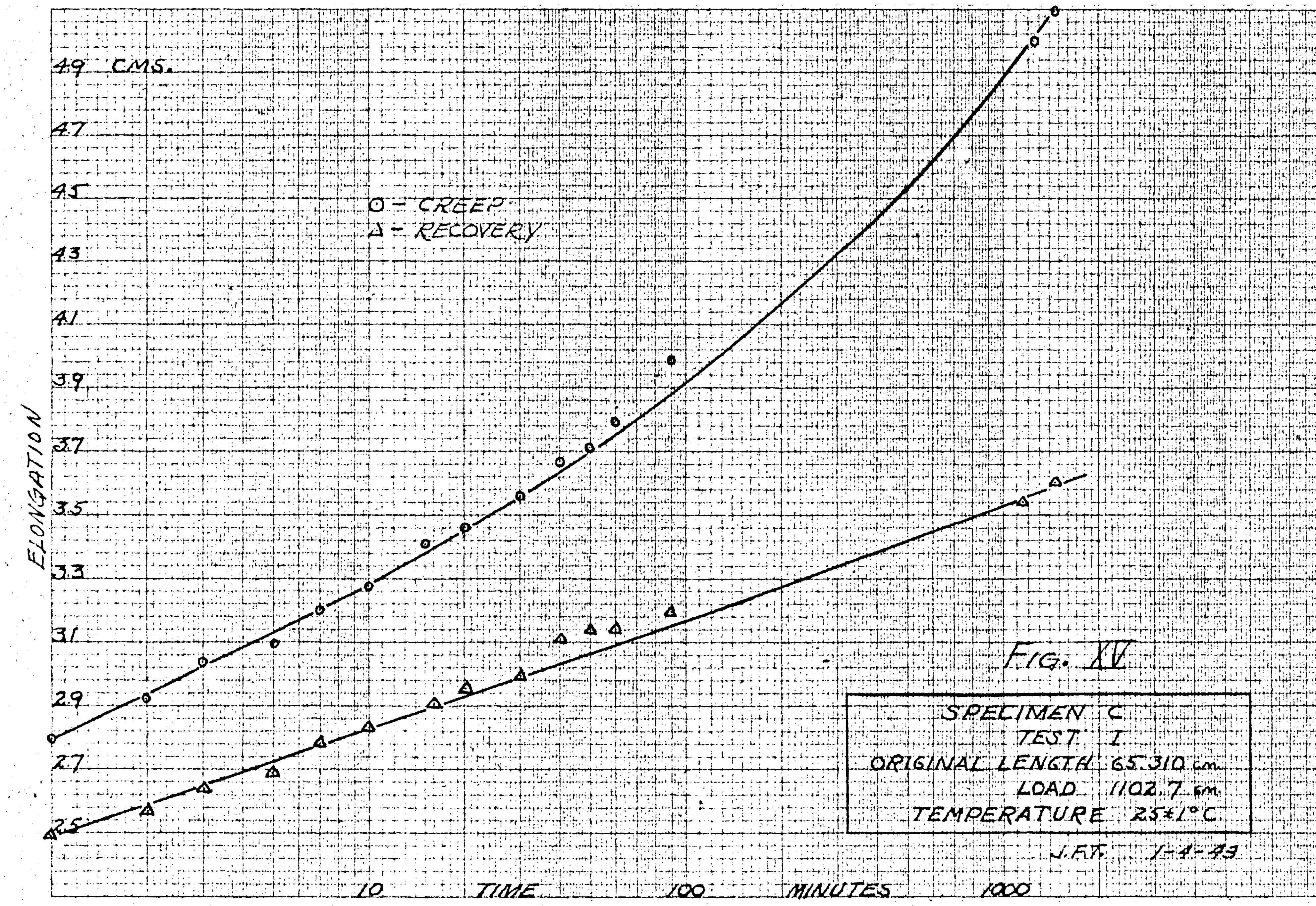
31
30 CMS.
29
28
27
26
25
24
23
22
21
20
18
ELONGATION
⊙ - CREEP
Δ - RECOVERY
X - SUPERPOSITION TEST POINTS
10
TIME
100
MINUTES
1000
SPECIMEN B
TEST VIII
ORIGNAL LENGTH 69.345 cm
LOAD 784.6 gm
TEMPERATURE 24°-27°C
J.F.T. 1-4-43

FIG. XIII



CMS.
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.8
ELONGATION
⊙ - CREEP
△ - RECOVERY
X - SUPERPOSITION TEST POINTS.
10
TIME
100
MINUTES
1000
SPECIMEN B
TEST IX
ORIGINAL LENGTH 69.360 cm.
LOAD 784.6 GM
TEMPERATURE 25 ± 0.5°C
J.F.T. 1-4-43

FIG. XIV


49 CMS.
47
45
43
41
39
37
35
33
31
29
27
25
ELONGATION
O - CREEP
Δ - RECOVERY
10
TIME
100
MINUTES
1000
FIG. XV
SPECIMEN C
TEST I
ORIGINAL LENGTH 65.310 cm.
LOAD 1102.7 gm.
TEMPERATURE 25±1°C.
J.F.T. 1-4-43

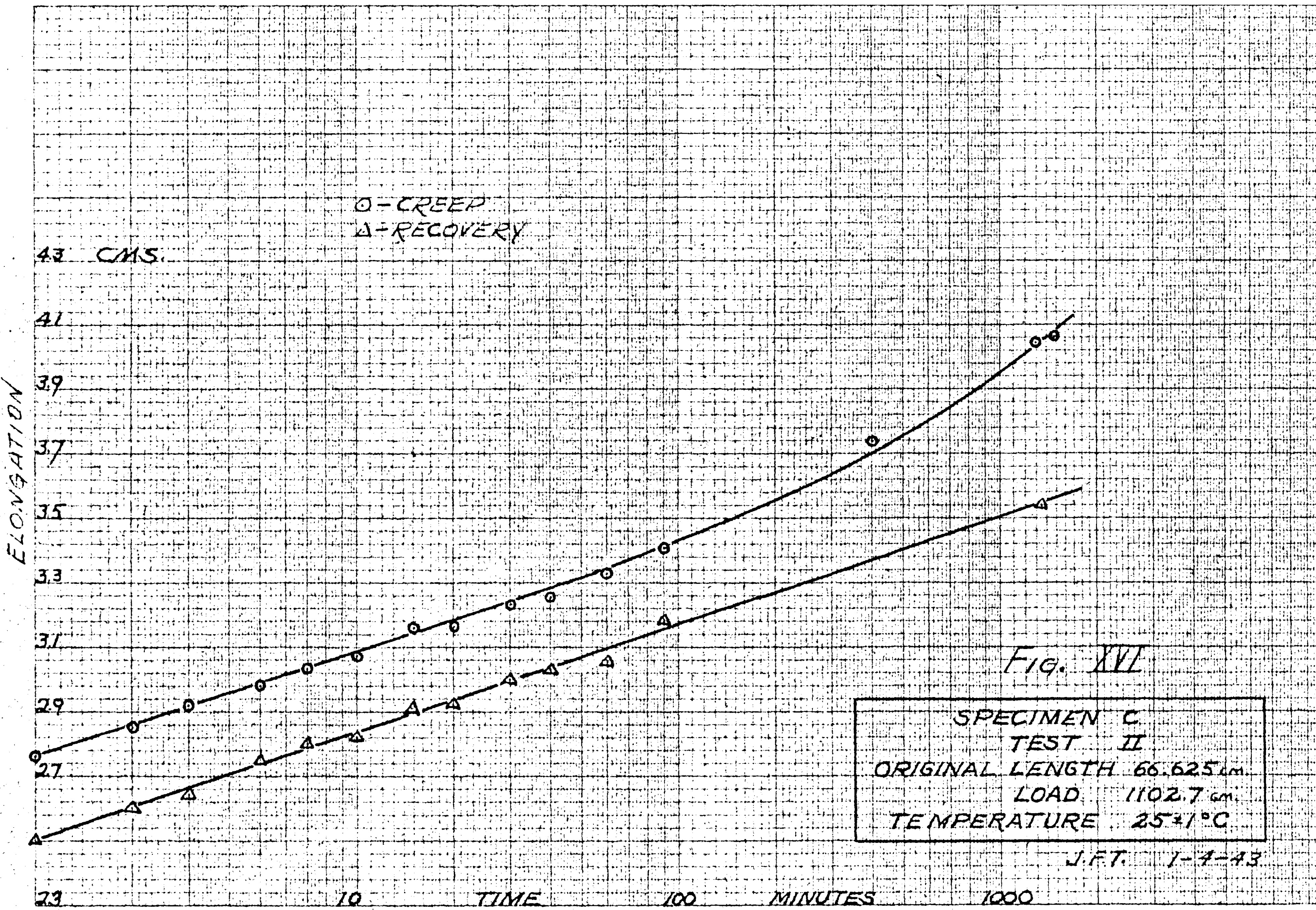

O - CREEP
Δ - RECOVERY
43 CMS.
41
39
37
35
33
31
29
27
23
ELONGATION
10
TIME
100
MINUTES
1000
SPECIMEN C
TEST II
ORIGINAL LENGTH 66.625 cm.
LOAD 1102.7 gm.
TEMPERATURE 25±1°C
J.F.T. 1-4-43

FIG. XVI

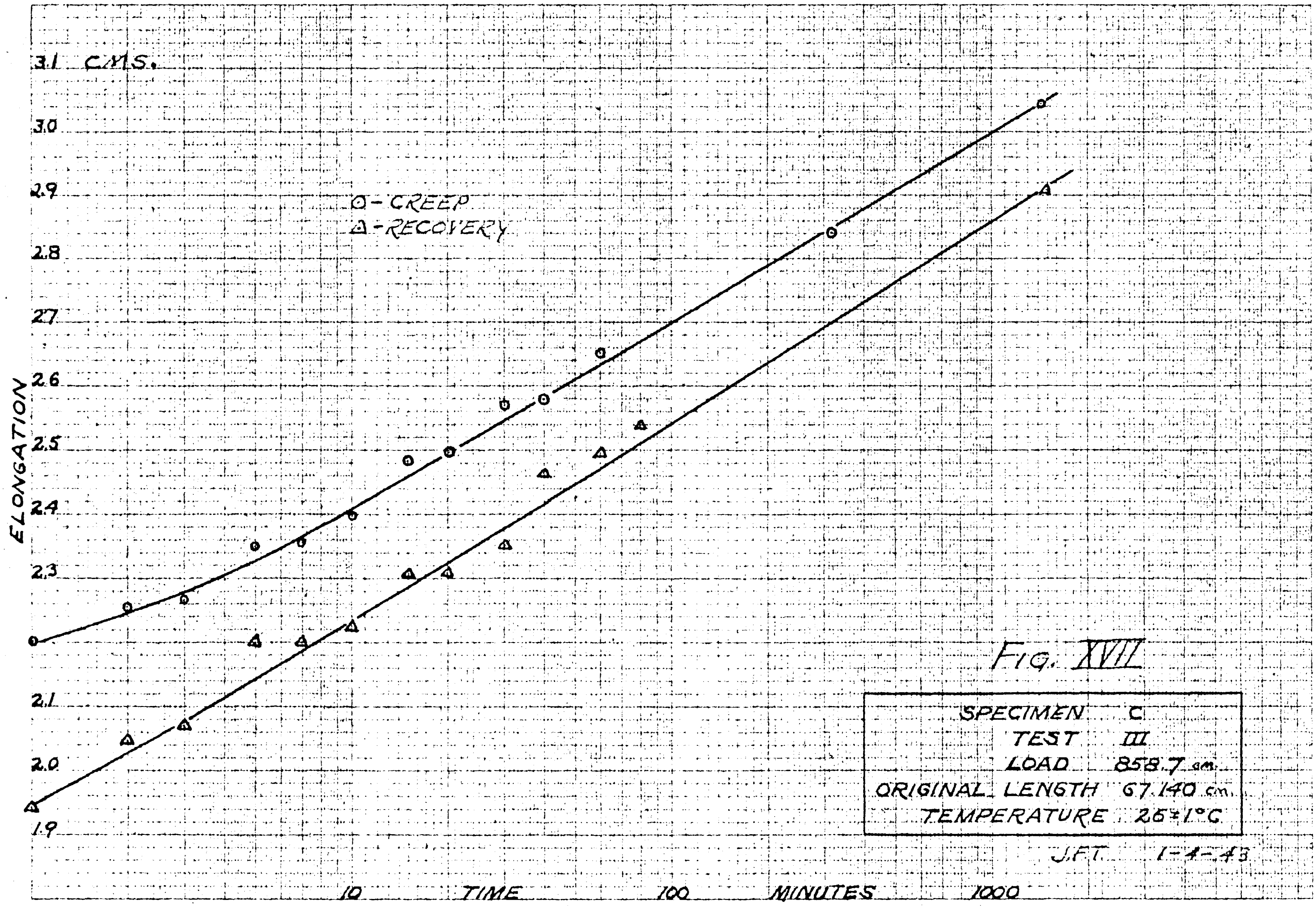

3.1 CMS.
3.0
2.9
2.8
27
2.6
2.5
2.4
2.3
2.1
2.0
1.9
ELONGATION
⊙ - CREEP
△ - RECOVERY
10
TIME
100
MINUTES
1000
SPECIMEN C
TEST III
LOAD 858.7 gm.
ORIGINAL LENGTH 67.140 cm.
TEMPERATURE 26±1°C
J.F.T. 1-4-43

FIG. XVII

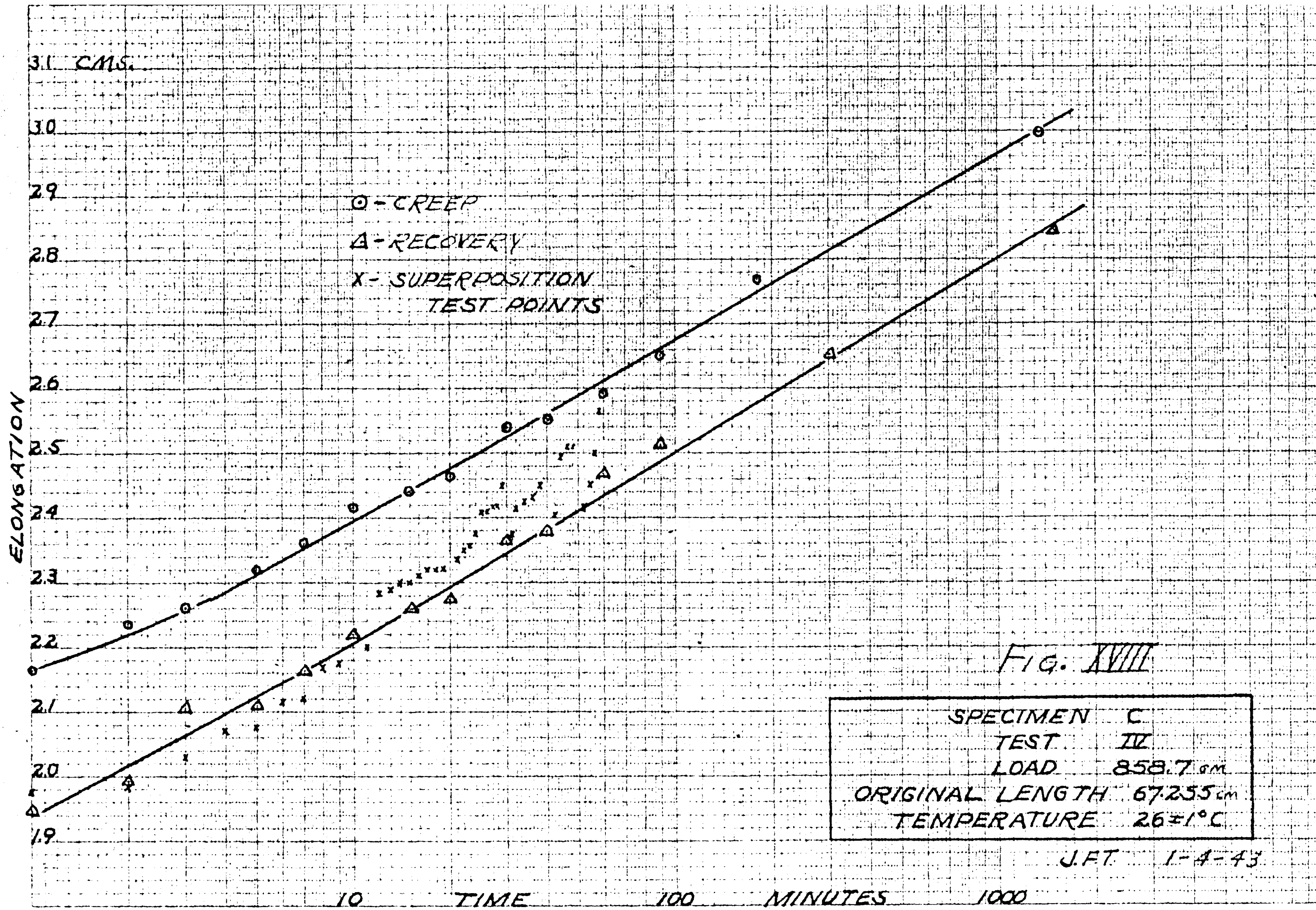
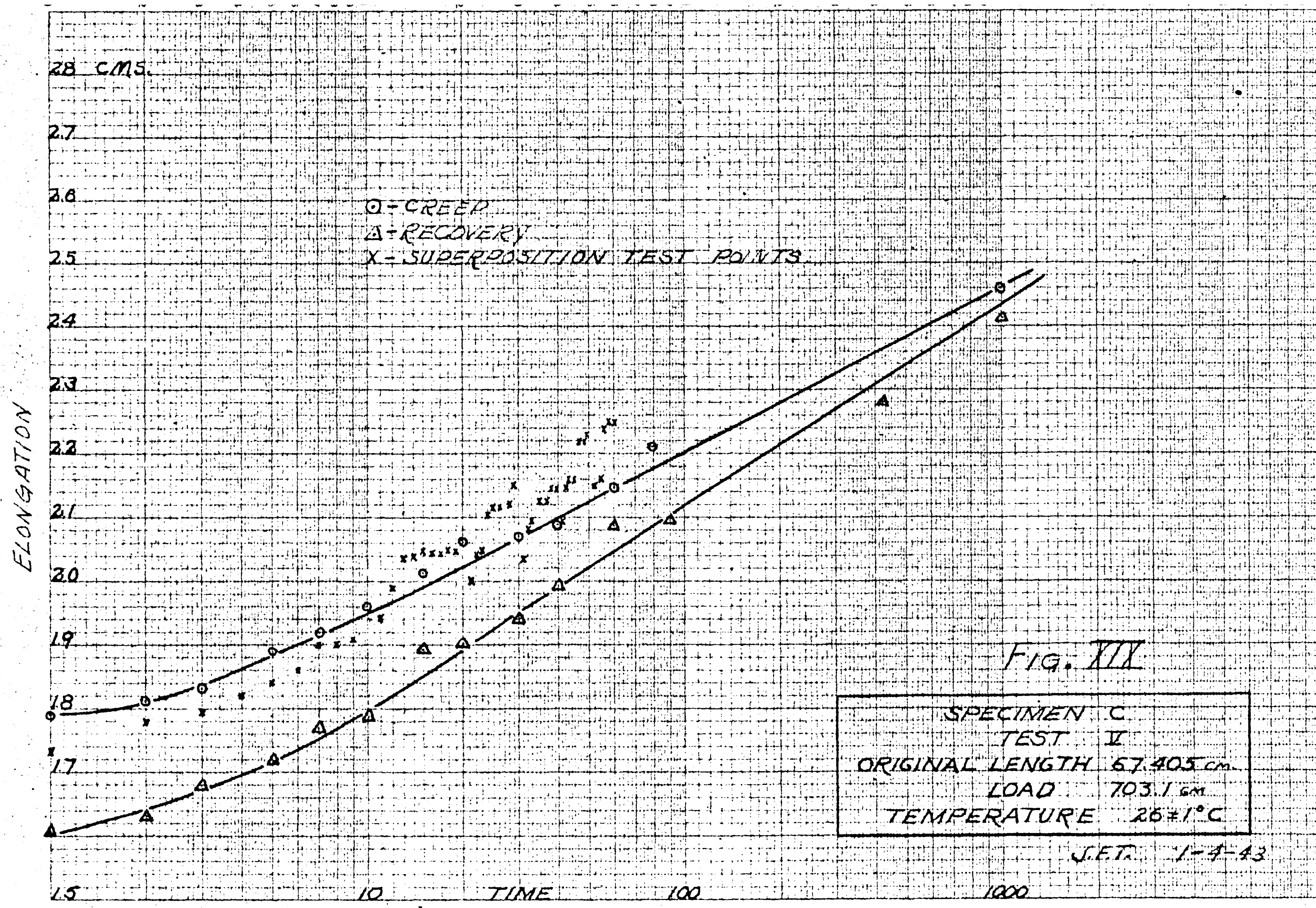

3.1 CMS.
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
ELONGATION
⊙ - CREEP
Δ - RECOVERY
X - SUPERPOSITION
TEST POINTS
10
TIME
100
MINUTES
1000
SPECIMEN C
TEST IV
LOAD 858.7 gm
ORIGINAL LENGTH 67.255 cm
TEMPERATURE 26±1°C
J.F.T. 1-4-43

FIG. XVIII



28 CMS.
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.5
ELONGATION
TIME
10
100
1000
⊙ - CREEP
Δ - RECOVERY
X - SUPERPOSITION TEST POINTS
SPECIMEN C
TEST V
ORIGINAL LENGTH 67.405 cm.
LOAD 703.1 GM
TEMPERATURE 26±1°C
J.E.T. 1-4-43

FIG. XIX

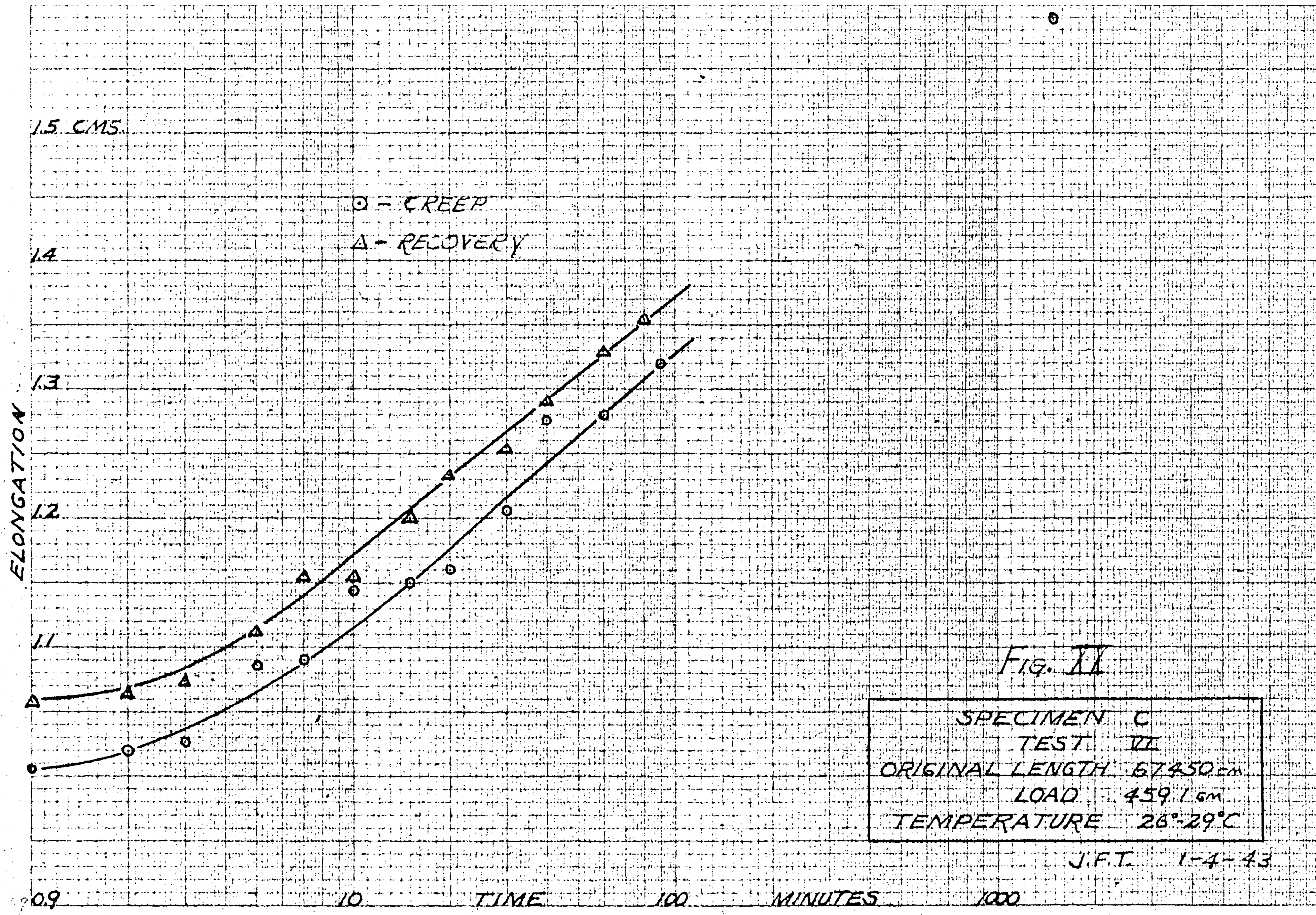

1.5 CMS.
1.4
1.3
1.2
1.1
0.9
ELONGATION
⊙ - CREEP
Δ - RECOVERY
10
100
1000
TIME
MINUTES
SPECIMEN C
TEST VI
ORIGINAL LENGTH 67.450 cm
LOAD 459.1 gm
TEMPERATURE 26°-29°C
J.F.T. 1-4-43

FIG. XI

V. DISCUSSION OF RESULTS

With the aim of obtaining smooth, reproducable curves of the elongation-versus-time relationship for Saran, this thesis was undertaken. But, after a critical survey of the preceding results, it is fairly obvious that this particular aim has not been attained. Several factors were present which considerably influenced the varied course of the results, and so serious were these factors that no favorable conclusions as to the status of polyvinylidene chloride in the Superposition Theory can be hazarded. However, certain quite definite points may be derived from these results which may be of assistance in further work on this material.

Before discussing these conclusions, a more direct consideration of the curves is in order.

Specimen A

These two curves, Figures IV and V, are typical of the action of the other two specimens, which is as it should be if we assume the material to be of consistent composition and structure. The first curve shows considerable permanent set, nearly half of the original elongation, while the second curve displays only a smal; amount of set. Mechanical working, or the physical pulling and stretching of the cordage into tighter, more compact molecular chain bundles, is evident.

The creep and recovery curves for this specimen are too curved, too divergent, and too separated for any feasible application of the Superposition Rule.

<u>Specimen B</u>

Figures VI, VII, IX, X, and XI of this group are of little positive value in applying the principles of creep and superposition to Saran. In these five plots, the points are so scattered above and below the mean line that some factor is apparently disturbing the harmonious elongation of the cordage sample. Possible reasons for this disturbing element will be discussed in another part of this section.

Moreover, Figures IX and X display marked curvature, indicating that the applied load is too light to enable the material to display its creep qualities. The plot of creep versus log time is, so far as present investigators are concerned, a straight line.

Figure XI, displaying a crossing of the creep and the recovery curves, ranges so far from theoretical considerations as to be also eliminated.

In studying Figures VIII, XII, XIII, and XIV, however, some adherence to theory is noted. The curves of creep and recovery are parallel and reasonable close, showing that the material is similarly responsible to positive and negative loads, and that, with better equipment, even more similar curves might be obtained for Saran. Figure XIII is very good in this respect, though the individual points are scattered to a slight extent.

Specimen C

In this group of graphs, Figure XVI is noteworthy in that the points, for both creep and creep recovery lie on straight, parallel lines. The considerable load of this test, 1100 grams, may have been of such magnitude as to cancel those mechanical or frictional errors that could provide scattered points. This curve best exemplies the Superposition Principle in Saran; and as such, shows that the material may possibly provide some basis for application of the superposition rules. Figure XVIII is also theoretically sound.

On the unfavorable side are Figures XV, XVII, XIX, and XX. Here again, scattered points, diverging lines, curved lines, and permanent set serve to make these plots useless as far as application of the theory is concerned.

Superposition Tests

According to the data of Leaderman (10), the superposition test points should fall nearly upon the creep curve of long duration, if the principles of superposition are to be upheld. Inspection of Figures XIII, XIV, XVIII, and XIX shows that this is not the case for Saran. At least, it is not under the conditions employed in these tests. However, there is not reason to conclude that superposition does not apply to the material, polyvinylidene chloride, merely because it is not here apparent. Further testing under other conditions of time, temperature, and strain may reveal close harmony with the theory. As indicated in the graphs, the superposition points form a family of united and ascending convex curves and not the straight creep curve of theory. The regularity of this family indicates that the failure to follow theory here is due, not to a mechanical flaw, but to a more serious, unaccountable property of the polymer itself.

Probably Sources of Error - General

The curved lines, the large permanent set, the poor superposition correlation - all these indicate that the range of loads used was not adequate to bring out the desired properties in Saran. The fact that at low loads, the curve was concave upward with a straightening out of this curve upon an increase in load, would indicate that higher loads should be used in testing Saran. Moreover, more extensive mechanical conditioning is advisable to remove all the permanent set.

It is quite possible that the large diameter, 0,021 inch, of the specimens tested was also a factor in producing this non-correlation of practice and theory. Filaments of Saran, with less of a tendency for "Packing" upon elongation, seem to offer a feasible alternative.

To establish a working range for further creep tests, a series of stress and strain tests should be performed on Saran. These may then be consulted in order to deduce that range of loads wherein the creep properties of Saran may be viewed, free from elastic effects.

Sources of Error - Experimental

Two important sources of experimental error were encounteredin the tests. These were the frictional resistance of the guide rollers and the error in setting and reading the cathetometer.

The former error may be detected in those curves in which the points are scattered. Figure IX is a typical example. The points ascend in a series of steps, rather than as a smooth curve. Frictional resistance in the rollers, preventing differential increases in length with differential "relaxation" within the Saran, but allowing elongations only when a certain force had been gathered, would produce this step wise curve. Only finer, more precise equipment, or equipment of entirely different operation, will eliminate this error.

Although readings precise to 0.005 centimeter were possible with the cathetometer employed in this thesis, accuracy corresponding to this precision was not borne out in the readings. Difficulty in setting and sighting the cathetometer in the short space of time between readings could not be overcome, as is evident, in some of the data.

Timing error was negligible.

VI. CONCLUSIONS

1. Under the conditions employed and encountered in this experimental work, oriented cordage of polyvinylidene chloride, or Saran, does not follow the theory of Superposition.

2. There are some indications that, under different operating conditions, a more favorable approach to the theory can be attained.

VII. RECOMMENDATIONS

1. Standard stress-strain tests should be made on Saran before any further creep or Superposition work is attempted.

2. Heavier loads and finer cords of Saran are indicated by the data to provide better harmony with theory. These should be used.

3. If the roller type of attachment is used, it is recommended that some mechanical changes be made to minimize the frictional resistance.

4. With proper cognizance of the above points, additional creep tests on polyvinylidene chloride are recommended.

VIII. APPENDIX

A. EXPANDED PROCEDURE

Material Tested

The Saran samples used in these tests were all cut from the same continuous length of material. Consequently, discrepancies in theory due to compositional, extrusion, or mechanical working differences should be negligible.

The material was oriented Saran cordage, with an average diameter of 0.021 inch, and a reported breaking load of 40,000 pounds per square inch (2). The exact composition of this particular Saran sample was not available, nor was equipment available for preliminary stress-strain tests to be conducted on the Saran.

Pretreatment and Mechanical Conditioning

The lengths to be tested were cut to approximately 70 centimeters and hung in the laboratory for from three to six days in order that they might attain an equilibrium with the temperature and humidity of the laboratory. Previous to the actual testing, the cordage was allowed to hang in the testing apparatus for twenty-four hours, being stressed only by the weight of the bronze column, amounting to 120.5 grams. Moreover, the samples were mechanically treated by subjecting them to loads equal to or in excess of the testing loads to be used later. This mechanical treatment lasted from sixteen to twenty-four hours with an equal time being allowed for recovery.

Creep Apparatus

This has been previously mentioned in the Procedure. Figures I, II, and III illustrate the details of construction. The apparatus was solidly fastened to a concrete pillar for complete stability.

Cathetometer

The cathetometer employed was of the standard laboratory type with telescope and vernier scale. The telescope was focussed on a finely etched cross-marking on the side of the bronze column, and this marking was kept in view throughout the elongations and recoveries of the attached cordage by sliding the telescope vertically along the cathetometer scale. Positional readings were taken from the vernier scale.

Timing

On the creep and recovery tests, cathetometer readings were made at 1, 2, 3, 5, 7, 10, 15, 20, 30, 40, 60, and 90 minutes, and at convenient, though not necessarily fixed, times thereafter. During the cyclical loading tests, readings were made with the cathetometer every sixty seconds. Elapsed time was indicated by a clock that announced each minute with a distinctive and audible note.

Temperature

The temperature of the surroundings immediately adjacent to the apparatus did not go below 24°C nor above 27°C during the course of the experiments. In any one particular creep test, the temperature variance was never more than 1°C.

Temperature was obtained by a mercury-in-glass thermometer, and recorded regularly.

Humidity

Since Saran has shown a water absorption of 0.00% over a period of twenty-four hours, the factor of humidity did not seem to be an important one. However, the tests were performed in a dim, artificially ventilated and conditioned room, and it is believed a relatively constant humidity was present.

TABLE I

CREEP AND RECOVERY - SPECIMEN A - TEST III

Load - 703.1 grams

Time in Minutes	Scale Position	Creep in Centimeters
0	5.460	0.000
1	3.895	1.565
2	3.850	1.610
3	3.770	1.690
4	3.730	1.730
5	3.670	1.790
10	3.665	1.795
15	3.625	1.835
20	3.595	1.860
30	3.575	1.880
60	3.490	1.965
90	3.405	2.050
1530	3.025	2.435

Time in Minutes	Scale Position	Creep Recovery
0	3.025	0.000
1	4.555	1.530
2	4.650	1.625
3	4.680	1.655
4	4.720	1.695
5	4.725	1.700
10	4.805	1.780
15	4.850	1.825
20	4.875	1.850
30	4.900	1.875
60	5.020	1.995
90	5.040	2.015
1260	5.270	2.245
1440	5.300	2.275
1530	5.300	2.275

TABLE II

CREEP AND RECOVERY - SPECIMEN B - TEST VIII

Load - 858.7 grams

Time in Minutes	Scale Position	Creep in Centimeters
0	5.520	0.000
1	3.445	2.075
2	3.370	2.150
3	3.335	2.185
5	3.265	2.255
7	3.425	2.275
10	3.170	2.350
15	3.130	2.390
20	3.125	2.390
30	3.065	2.450
40	3.055	2.460
60	2.970	2.545
90	2.945	2.570
1260	2.520	3.000
1380	2.520	3.000

Time	Scale Position	Creep Recovery
0	2.520	0.000
1	4.500	1.980
2	4.580	2.040
3	4.625	2.105
5	4.710	2.190
7	4.715	2.195
10	4.785	2.260
15	4.795	2.270
100	4.995	2.470
2700	5.350	2.830
2880	5.350	2.830

TABLE III

CREEP AND RECOVERY - SPECIMEN B - TEST VIII

Load - 784.6 grams

Time in Minutes	Scale Position	Creep in Centimeters
0	4.550	0.000
1	2.585	1.965
2	2.525	2.025
3	2.495	2.055
5	2.430	2.120
7	2.400	2.150
10	2.365	2.185
15	2.310	2.240
20	2.270	2.280
25	2.270	2.280
40	2.185	2.365
60	2.160	2.390
90	1.090	2.460
420	1.980	2.570
1260	1.835	2.715
1440	1.790	2.760

Time	Scale Position	Creep Recovery
0	1.790	0.000
1	3.695	1.905
2	3.770	1.980
3	3.800	2.010
5	3.880	2.090
7	3.940	2.150
10	4.000	2.210
15	4.000	2.210
20	4.040	2.250
30	4.085	2.295
40	4.150	2.360
60	4.185	2.395
90	4.295	2.505
360	4.405	2.615
1340	4.525	2.735
1530	4.535	2.745

TABLE IV

CREEP AND RECOVERY - SPECIMEN C - TEST II

Load - 1102.7 grams

Time in Minutes	Scale Position	Creep in Centimeters
0	5.055	0.000
1	2.295	2.760
2	2.195	2.860
3	2.140	2.915
5	2.075	2.980
7	2.020	3.035
10	1.985	3.070
15	1.895	3.160
20	1.890	3.165
30	1.825	3.230
40	1.800	3.255
60	1.730	3.325
90	1.645	3.410
400	1.320	3.735
1290	1.000	4.055
1450	0.990	4.065

Time in Minutes	Scale Position	Recovery
0	0.990	0.000
1	3.495	2.505
2	3.590	2.600
3	3.635	2.645
5	3.745	2.755
7	3.785	2.795
10	3.815	2.825
15	3.900	2.910
20	3.915	2.920
30	3.995	3.005
40	4.025	3.035
60	4.040	3.050
90	4.175	3.185
1340	4.540	3.550

TABLE V

CYCLICAL LOADING FOR SUPERPOSITION TEST

Specimen B - Load 784.6

Time in Minutes	Scale Reading	Calculated Creep
0	4.525	0.000
1	2.695	1.830
2	2.610	1.915
3	2.600	1.925
4	2.580	1.945
5	2.525	2.010
6	2.520	2.015
7	2.515	2.020
8	2.510	2.025
9	2.460	2.075
removed	--	--
11	4.295	2.060
12	4.370	2.135
13	4.390	2.255
14	4.400	2.265
15	4.410	2.275
16	4.420	2.285
17	4.420	2.285
18	4.420	2.285
19	4.455	2.320
applied	--	--
21	2.575	2.180
22	2.495	2.260
23	2.485	2.270
24	2.485	2.270
25	2.475	2.280
26	2.470	2.285
27	2.470	2.285
28	2.470	2.285
29	2.465	2.290
removed	--	--
31	4.270	2.205
32	4.295	2.230
33	4.340	2.275
34	4.345	2.280
35	4.350	2.285
36	4.390	2.320
37	4.395	2.325
38	4.405	2.335
39	4.410	2.340
applied	--	--

TABLE V

CYCLICAL LOADING FOR SUPERPOSITION TEST

Time in Minutes	Scale Reading	Calculated Creep
41	2.540	2.240
42	2.520	2.260
43	2.460	2.320
44	2.460	2.320
45	2.440	2.340
46	2.440	2.340
47	2.435	2.345
48	2.435	2.345
49	2.420	2.360
removed	--	--
51	4.265	2.245
52	4.300	2.280
53	4.330	2.310
54	4.340	2.320
55	4.340	2.320
56	4.360	2.340
57	4.360	2.340
58	4.360	2.340
59	4.380	2.380
60	4.380	2.380

TABLE VI

CYCLICAL LOADING FOR SUPERPOSITION TEST

Specimen C - Load 703.1 grams

Time in Minutes	Scale Reading	Calculated Creep
0	4.280	0.000
1	2.545	1.735
2	2.500	1.780
3	2.485	1.795
4	2.460	1.820
5	2.440	1.840
6	2.420	1.860
7	2.380	1.900
8	2.380	1.900
9	2.375	1.905
removed	--	--
11	4.070	1.945
12	4.115	1.990
13	4.160	2.035
14	4.160	2.035
15	4.170	2.045
16	4.170	2.045
17	4.170	2.045
18	4.175	2.050
19	4.175	2.050
applied	--	--
21	2.490	2.000
22	2.440	2.050
23	2.435	2.055
24	2.380	2.110
25	2.375	2.115
26	2.375	2.115
27	2.370	2.120
28	2.370	2.120
29	2.340	2.150
removed	--	--
31	4.035	2.035
32	4.080	2.080
33	4.090	2.090
34	4.090	2.090
35	4.125	2.125
36	4.125	2.125
37	4.125	2.125
38	4.145	2.145
39	4.145	2.145
applied	--	--

TABLE VI

CYCLICAL LOADING FOR SUPERPOSITION TEST

Time in Minutes	Scale Reading	Calculated Creep
41	2.440	2.085
42	2.385	2.145
43	2.370	2.160
44	2.370	2.160
45	2.365	2.165
46	2.310	2.220
47	2.310	2.220
48	2.310	2.220
49	2.300	2.230
removed	--	--
51	4.015	2.105
52	4.060	2.150
53	4.060	2.150
54	4.070	2.160
55	4.150	2.240
56	4.150	2.240
57	4.150	2.240
58	4.160	2.250
59	4.160	2.250
60	4.160	2.250

C. LOCATION OF ORIGINAL DATA

The original data from which the results of this thesis have been obtained are in the possession of the author.

Part B of this appendix presents some, but not all, of the data recorded during the experimental work.

D. LITERATURE CITATIONS

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