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Preliminary Report

on

DETERMINATION OF CREEP CHARACTERISTICS BY BARR AND BARDGETT METHOD

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Progress Report for February, 1932 on Project Number 491-48

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to The Detroit Edison Company

DETERMINATION OF CREEP CHARACTERISTICS

BY

BARR AND BARDGETT METHOD

Since the phenomenon of creep was first observed in metals at elevated temperatures, various attempts have been made to develop a test which would allow the creep characteristics to be determined in a relatively short period of time.

It was first felt that the accurately determined proportional limit value at any given temperature was a measure of the metal's ability to resist creep at that same given temperature. Results which have since been obtained indicate that such is not the case. It is true that for certain small ranges of temperature, which vary with different metals and alloys, such may be the case. It is our feeling that accurately determined proportional limit values are a true measure of the creep characteristics only at temperature ranges in the immediate neighborhood of the lowest temperature of recrystallization or the equi-cohesive temperature of the given metal or alloy.

The next short time test for determining the creep characteristics was advanced in 1928 by Dr. W. H. Hatfield and was designated by him as the "time-yield" test. This test has not received universal support and its use is largely limited to the laboratories of Dr. Hatfield. The procedure of this test has been changed from time to time and according to present day practice the time yield is defined as that stress which produces in a 48-hour period immediately following the first 24-hour period of the test, a total deformation not exceeding 48 millionths (0.000048) of an inch per inch. Dr. Hatfield further states that the safe working stress will be two-thirds of this time yield value.

Certain German investigators have also been active in their attempt to develop a suitable short time test. In 1927 Pomp and Dahmen developed a test which they felt had considerable merit. They defined the practical limiting creep stress as the stress below which the rate of creep does not exceed 0.001 per cent per hour in the period between the third and sixth hour after the application of the load. In 1930 this definition was somewhat modified by Pomp and Enders.

According to the latest work of these investigators the limiting creep stress may be determined by one of the three following methods:

<u>Method 1</u>: A rate of extension of 0.005 per cent. per hour between the third and sixth hour.

<u>Method 2</u>: A rate of extension of 0.003 per cent. per hour between the fifth and tenth hour.

<u>Method 3</u>: A rate of extension of 0.0015 per cent. per hour between the twenty-fifth and thirty-fifth hour.

While there is no question that these tests as well as the time-yield tests of Hatfield's yield useful information, none of them are finding very extensive use. Their main limitation is that the time of test is so short that all creep values are determined in the so-called first stage of flow. In other words, for the first few hundred hours of a creep test, flow is continuing at a decreasing rate and the majority of experimental evidence to date does not show a relationship to exist between the flow in the first stage and in the second stage, that is, the stage in which flow proceeds at a constant rate.

A new test has recently been developed in England by W. Barr and W. E. Bardgett for determining the creep characteristics of metals at elevated temperatures. This test differs from those now in common use in that instead of the load being kept constant and the rate of creep determined; the load is decreased until the rate of creep becomes very low. While this test is also claimed to give reliable creep characteristics in a relatively short period of time it differs from the other short time methods in that it is extended through the first stage and into the second stage of creep.

The work given in this report was undertaken to determine if the creep characteristics obtained by this method are comparable to those obtained by our usual method of creep tests. The work is, of course, not complete and many more tests will have to be undertaken before any definite conclusions may be reached. It was felt, however, because of the large amount of interest which is being shown in all the attempts to develop a more rapid means for determining of creep characteristics, that a preliminary report would be advisable at this time.

SUMMARY OF CONCLUSIONS

The creep characteristics of five steels were determined by both the usual type of creep test and by the newly-developed Barr and Bardgett test in order to determine if these two methods of tests would yield comparable results. The results obtained are summarized in Table 1.

Table 1

Creep Characteristics of Various Steels at Indicated Temperatures as Determined by the Usual Creep Test and by the Barr and Bardgett Methods

Material	Temp. °F.	*Results from Usual Creep Test Per Cent per 1000 Hours			Barr and Bardgett Test	
		0.01	0.10	1.00	Stress	Time Hours
Grade A	850	7,000	10,500	15,700(1)	20,500	400
		9,700	13,000	17,000(2)		
		11,250	14,000	17,000(3)		
KS	1000	3,200	6,800	14,500(1)	13,700	200
OS	1000	1,880	3,550	7,000(1)	7,200	200
MM-9	1000	4,200	6,600	10,700(1)	17,200	360
D-1	1000	11,250	15,000	20,000(1)	20,000	280

*Values expressed in pounds per square inch.
(1) Up-step method of loading employed.
(2) Single-step method of loading employed.
(3) Down-step method of loading employed.

The results presented indicate the Barr and Bardgett method of testing to yield considerably higher creep values in all cases, especially if the comparison is made on the basis of the stress required in the usual type of creep test to produce creep at the rate of 0.01 per cent per 1000 hours. If the stress employed is that necessary to produce creep at the rate of 1.0 per cent per 1000 hours, then the agreements are especially good in the case of Steels KS, OS and D-1 at 1000°F., but an appreciable difference still exists in the case of the other two steels.

While the agreement between the actual values obtained from the two methods of test is not good it should be noted that all of the steels arrange themselves in the same order, insofar as their creep characteristics are concerned, regardless of which method of testing is employed. The Barr and Bardgett test may be very valuable, therefore, in selecting the outstanding creep resisting steels for any given series.

The information collected to date is necessarily very limited, and before too general conclusions may be drawn regarding the agreement between these two types of test, or as to the relative value of the Barr and Bardgett test, much additional information will be required.

PRINCIPLE OF THE TEST

This test was developed in England by W. Barr and W. E. Bardgett and is described in British Patent No. 339,890 which is entitled, "An Improved Method of and Apparatus for Determining the Limiting Creep Stress of Materials."

The method consists essentially of applying a known stress to a system consisting of a calibrated weigh bar which is maintained at room temperature and of a specimen the creep characteristics of which are to be determined. This specimen is held at the desired temperature by means of an electrical resistance furnace. As the heated specimen elongates under the applied stress, the stress on the system will be reduced and the amount of reduction is measured by extensometers attached to the calibrated weigh bar. The test is continued until either the heated specimen no longer elongates, at least within the sensitivity of the extensometers employed, or until it continues to elongate at a very slow rate.

It is claimed that the specimen attains very rapidly the stress at which no further creep occurs, or at which it occurs at a very slow rate. Also that this stress of no creep, or of very slow creep, corresponds to the limiting creep stress obtained by the usual creep test.

DESCRIPTION OF APPARATUS

One of the Barr and Bardgett apparatus was ordered from the manufacturers last September, but because of the delay necessary before it could be received in this country, we made two of these machines in our own laboratories. The machine has since been received and differs from ours mainly in that it has been designed to test specimens not greater than 0.345 inches in diameter, while those made by us will test specimens of 0.505 inches in diameter.

A photograph of our machine is shown in Figure 1 while a cross-sectional view is given in Figure 2. The frame is made of comparatively large angle iron which was welded together to form a strong substantial structure. As shown in the diagram, there are three connecting links to which the two specimens are attached. These were made 1 1/2 inches in diameter and are of a high-strength heat-resisting steel, known commercially as Cyclops KM special die steel.

The two test specimens and their adapters when joined together extend through the center of the frame and in order to keep the loading as uniform as possible, the assembly is fastened to the lower part of the machine by means of a spherical nut which rests on a curved seat. The assembly is held at the top by means of a large nut which has ten threads to the inch, and which rests on a ball-bearing socket.

Surrounding the upper specimen, that is, the one the creep characteristics of which are to be determined, is an electrical resistance furnace, a sketch of which is given in Figure 3. This furnace is so wound that the temperature variation over the two-inch gauge length of the test piece is not greater than 10°F. The temperature of the furnace is maintained to within 2°F. by means of a Wilson-Maeulen temperature control. The control couple of this instrument is placed in direct contact with the winding of the furnace.

A drawing of the extensometer which is attached to the weigh bar and which is used to determine the applied stress as well as the change in stress occurring in the system due to the creeping of the specimen under test is given in Figure 4, while a detailed sketch of this instrument is shown in Figure 5. The principle of this instrument is very simple and can be readily seen from the sketch. A reading of one degree on the scale is equivalent to a stress of 24.2 pounds per square inch.

In order that the temperature of the weigh bar, to which the extensometer is attached, may be kept as constant as possible, a water jacket is placed on the specimen adapter

FURNACE

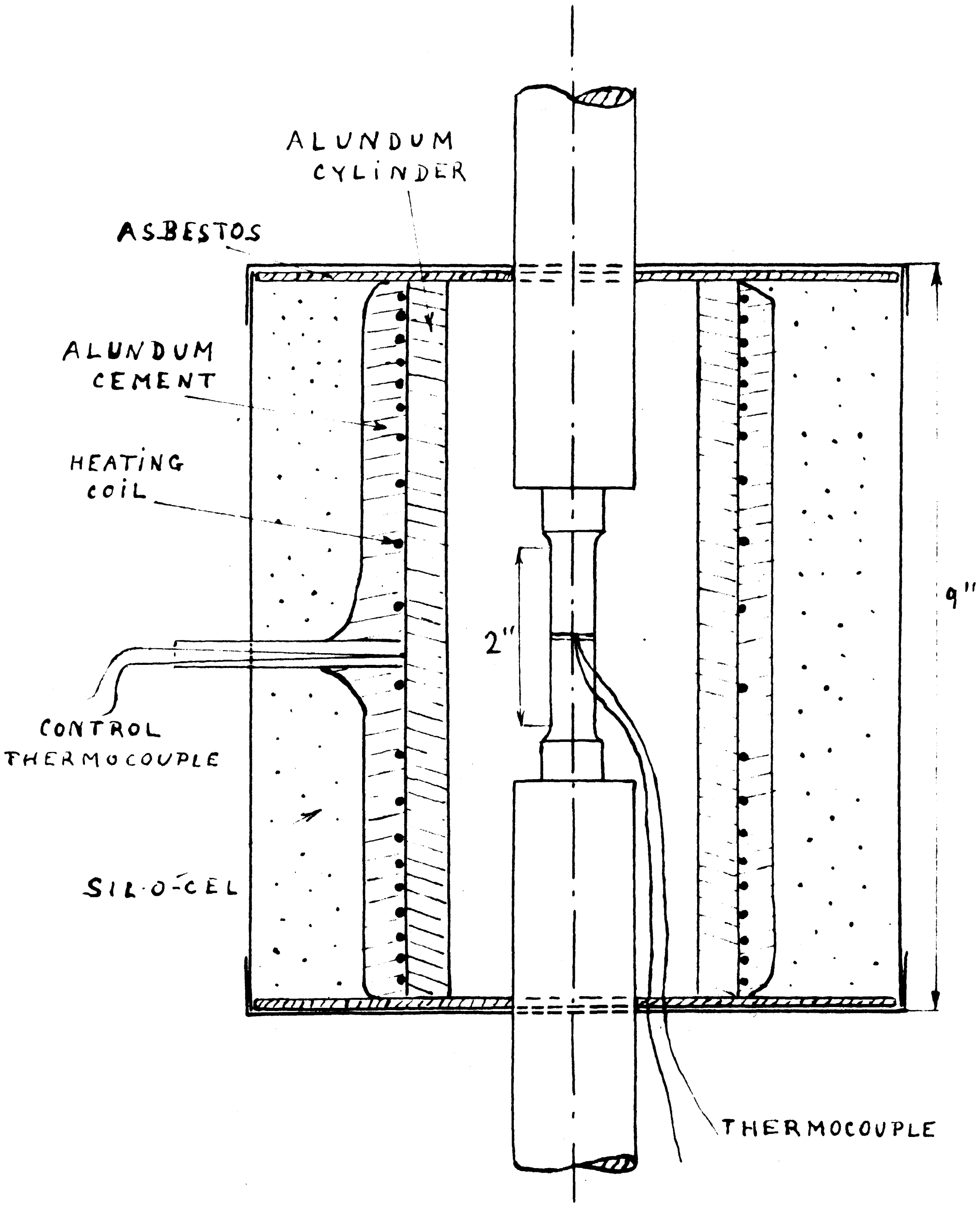
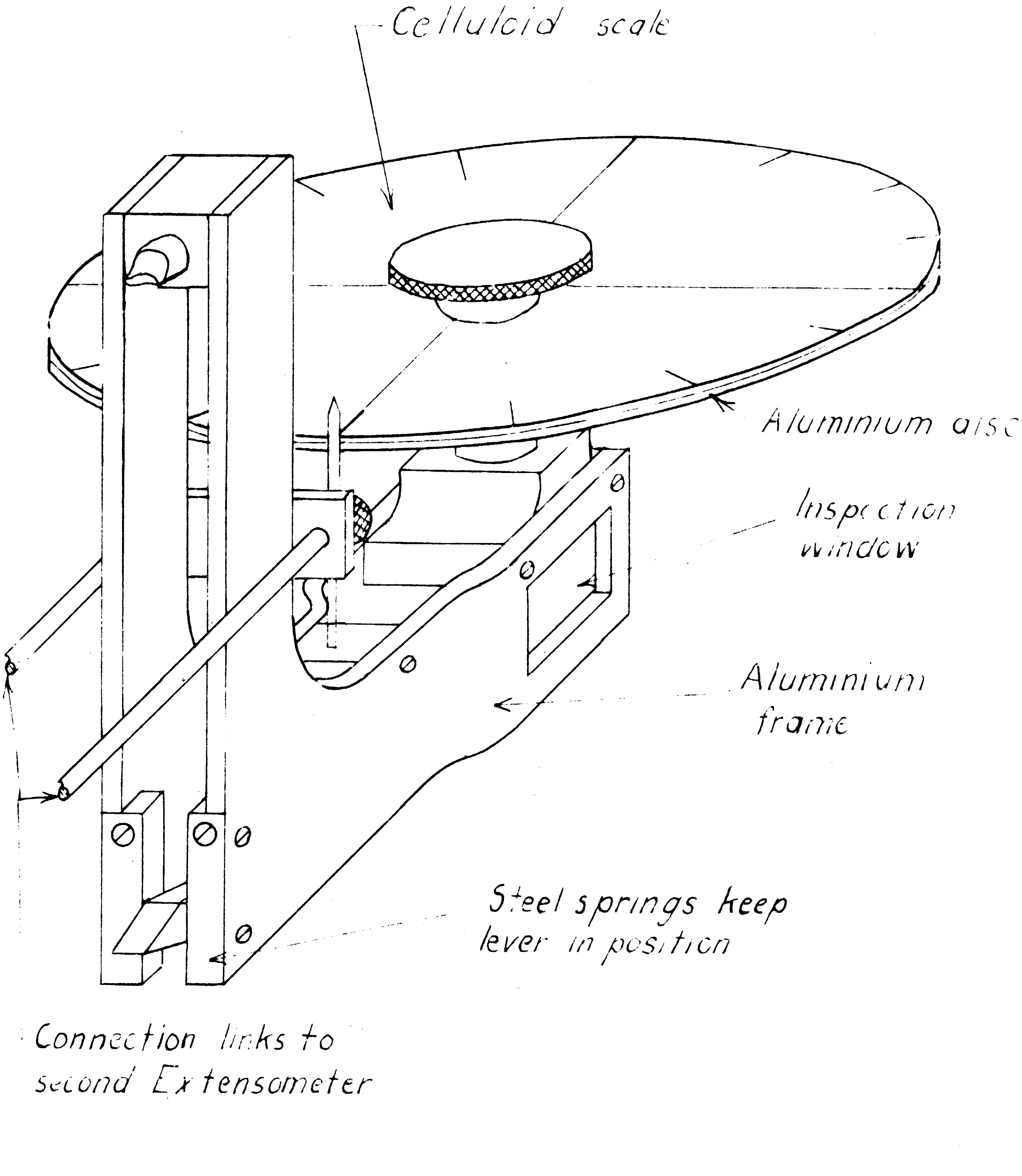
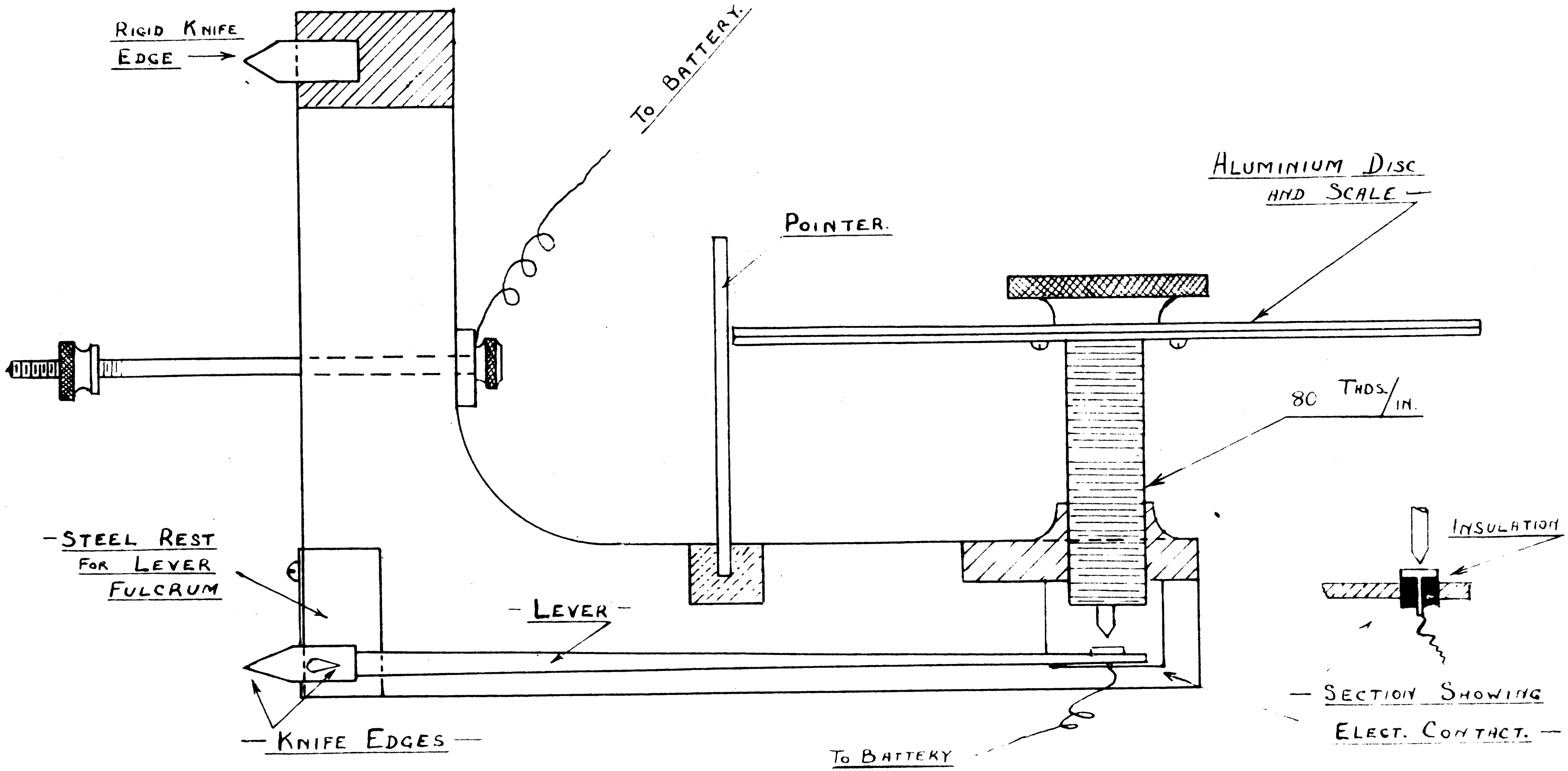


Fig. 3.



— EXTENSOMETER —

FIG. 4.



— Longitudinal Section. —

Fig. 5.

immediately above the weigh bar. The entire lower part of the apparatus is also enclosed by transite board to keep the temperature as constant as possible.

TEST PROCEDURE

After the apparatus has been properly assembled and the specimen to be tested has been maintained at the correct temperature for at least 24 hours, a zero reading of the extensometers is taken. By means of levers attached to the upper large nut, the proper stress is applied by turning this nut until the extensometers on the weigh bar give the correct reading for the stress desired.

Readings are then taken on the extensometer at hourly intervals for the first day, and twice daily thereafter, and the reduction of stress on the system is thus determined. Stress is then plotted against time and the test is continued until the stress-time curve appears to be approaching a definite asymptote, or until creep has stopped completely, at least within the sensitivity of the measuring apparatus employed.

RESULTS

Because of the length of time required to construct these apparatuses and to get them in proper working order, a large number of tests have not as yet been run. Certain have been completed, however, and these are listed in the following table.

Table 2

Steels Subjected to Barr and Bardgett Tests

Steel Designation	Type	Temperature of Test Deg. Fahr.
Grade A	0.18 C.	850
KS	Killed 0.10 C.	1000
OS	Open 0.10 C.	1000
MM-9	Mn.-Mo.	1000
D-1	Cr.-W.-Si.	1000

The results obtained from these tests are given in the following figures and tables.

Grade A Steel at 850°F. The results obtained from this test are given in Figure 6. The test was continued for a period of 400 hours and during this time the stress was reduced from an original value of 24,750 pounds to one of 20,500 pounds. Also, from the appearance of this curve during the last 100 hours of the test, it is evident that the stress would not have been appreciably reduced even though the test

had been continued for a much longer period of time.

Our regular type of creep test was also conducted on this same steel at 850°F. and in Table 3 the results obtained are compared with those from the Barr and Bardgett test.

Table 3

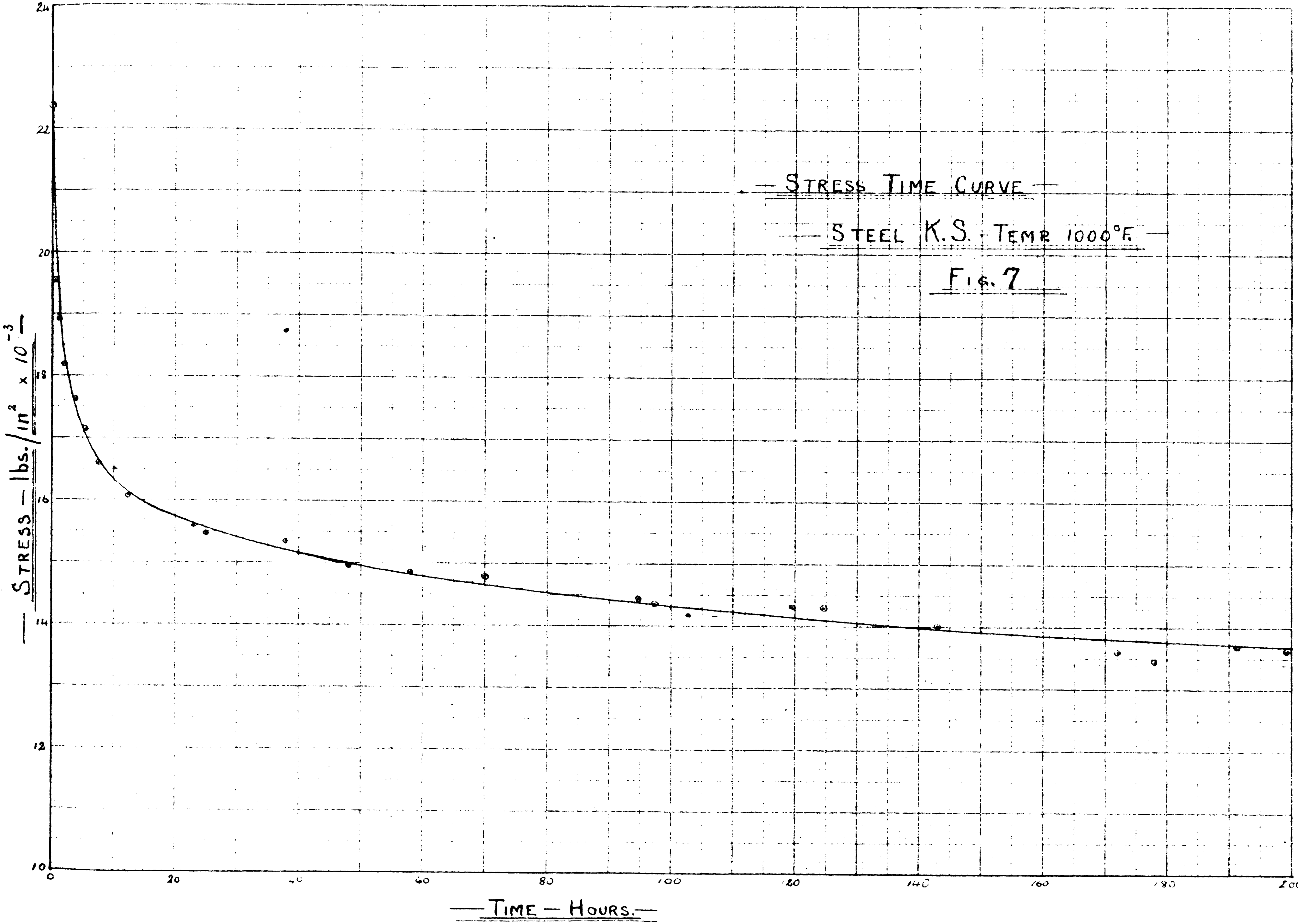
Creep Characteristics of Grade A Steel at 850°F. as Obtained from the Usual Creep Test and from the Barr and Bardgett Test

Material	Temp °F.	*Results from Usual Creep Test Per Cent per 1000 Hours			Stress from Barr and Bardgett Test at 400 Hours
		0.01	0.10	1.00	
Grade A	850	7,000	10,500	15,700(1)	20,500
		9,700	13,000	17,000(2)	
		11,250	14,000	17,000(3)	

*Values expressed in pounds per square inch.
(1) Up-step method of loading.
(2) Single-step method of loading.
(3) Down-step method of loading.

From the above values it is evident that the result obtained by the Barr and Bardgett method is considerably greater than those obtained by our usual creep testing method.

Killed Carbon Steel at 1000°F. The results obtained from the Barr and Bardgett test on killed carbon steel, Steel KS, at 1000°F. are shown in Figure 7. The initial stress was



Stress Time Curve
Steel K.S. Temp. 1000°F.
Stress — lbs./in² x 10⁻³
Time — Hours.

Fig. 7

22,400 pounds per square inch and at the end of the test, which was 200 hours, this stress had been reduced to 13,700 pounds. When the test was stopped the specimen was still continuing to elongate, that is, the stress was continuing to decrease at a relatively rapid rate.

Our usual type of creep test was also conducted on this steel at 1000°F. and a comparison of the results obtained by the two methods is shown in Table 4.

Table 4

Creep Characteristics of Killed Carbon Steel at 1000°F. as Obtained from the Usual Creep Test and from the Barr and Bardgett Test

Material	Temp. °F.	*Results from Usual Creep Test Per Cent per 1000 Hours			Stress From Barr and Bardgett Test at 200 Hours
		0.01	0.10	1.00	
KS	1000	3,200	6,800	14,500(1)	13,700

*Values expressed in pounds per square inch.
(1) Up-step method of loading.

As in the case of Grade A steel at 850°F., the result obtained from the Barr and Bardgett test is considerably above those obtained from the usual creep test, with the exception of the value expressing a flow rate of 1.0 per cent per 1000 hours.

Open-Steel at 1000°F. The results obtained from the Barr and Bardgett test on open steel, that is, Steel OS, at 1000°F., are given in Figure 8. During the period of 210 hours this test was conducted the stress was reduced from an initial value of 21,750 pounds per square inch to one of 7,200 pounds. Also, from its appearance the curve appears to be approaching a stress of about 7,000 pounds as its asymptote.

A comparison of the value obtained from this test and those from the usual type of creep test is given in Table 5.

Table 5

Creep Characteristics of Open Carbon Steel at 1000°F. as Obtained from the Usual Creep Test and from the Barr and Bardgett Test

Material	Temp. °F.	*Results from Usual Creep Test Per Cent per 1000 Hours			Stress from Barr and Bardgett Test at 200 Hours
		0.01	0.10	1.00	
OS	1000	1,800	3,550	7,000(1)	7,200

*Values expressed in pounds per square inch.
(1) Up-step method of loading.

It is evident from the above values that again the Barr and Bardgett test yields a higher value than those obtained from the usual type of creep test. The value for 1.0 per cent creep in 1000 hours, however, is in very good agreement with the limiting creep stress obtained by the Barr and Bardgett test.

It is interesting to note that in the case of the open and killed carbon steels, the two steels arrange themselves insofar as their creep characteristics are concerned, in the same order by the Barr and Bardgett test as with the usual type of creep test.

Steel MM-9 at 1000°F. The results of the Barr and Bardgett tests on Steel MM-9 which is a Mn.-Mo. steel at 1000°F. are given in Figure 9. The initial stress was 23,500 pounds per square inch, and at the end of 340 hours, this had been reduced to a value of 17,200 pounds.

These results are compared to those obtained from the usual type of creep test in Table 6.

Table 6

Creep Characteristics of Steel MM-9 at 1000°F. as Obtained from the Usual Type of Creep Test from the Barr and Bardgett Test

Material	Temp. °F.	*Results from Usual Creep Test Per Cent per 1000 Hours			Stress from Barr and Bardgett Test at 360 Hours
		0.01	0.10	1.00	
MM-9	1000	4,200	6,600	10,700	17,200

*Values expressed in pounds per square inch.

As in all the previous cases, the value obtained from the Barr and Bardgett test is considerably above those obtained from the usual type of creep test. Again, however,

this steel and the open and killed carbon steel arrange themselves in the same relative order by the two methods of testing.

Steel D-1 at 1000°F. The results of the Barr and Bardgett tests on Steel D-1, which is a chromium-tungsten-silicon steel, at 1000°F. are given in Figure 10. An original stress of about 26,000 pounds was applied and at the end of 280 hours this had been reduced to 20,000 pounds. The sharp initial decrease in stress was not nearly as marked with this steel as with those considered previously.

These results are compared to those obtained from the usual type of creep test in Table 7.

Table 7

Creep Characteristics of Steel D-1 at 1000°F.
as Obtained from the Usual Type of Creep Test
from the Barr and Bardgett Test

Material	Temp. °F.	*Results from Usual Creep Test Per Cent per 1000 Hours			Stress From Barr and Bardgett Test at 280 Hours
		0.01	0.10	1.00	
D-1	1000	11,250	15,000	20,000	20,000

*Values expressed in pounds per square inch.

Again the Barr and Bardgett test result is considerably above those of the usual creep testing method with the exception of the stress which will produce creep at the rate of 1.00 per cent per 1000 hours.

The comparative creep strength of this steel, however, is superior to the remaining steels considered regardless of which type of testing is employed. A constant difference, however, is not obtained with the two methods of test.

CONCLUSIONS

Creep tests were conducted on Grade A steel at 850°F., and in four steels at 1000°F. by both the usual method for conducting creep characteristics and by the newly-developed Barr and Bardgett test. The four steels tested at 1000°F. were an open carbon steel, a killed carbon steel, a manganese-molybdenum steel, and a chromium-tungsten-silicon steel. The results obtained allow the following conclusions.

The results obtained indicate the Barr and Bardgett method to yield considerably higher creep values in all cases, especially when they are compared to the stresses required to produce creep at the rate of 0.01 per cent per 1000 hours (1.0 per cent per 100,000 hours). If the value chosen for comparison be the stress required for a rate of creep of 1.0 per cent per 1000 hours, then the agreement is much better. In fact, with the killed steel, the open steel, and the chromium-tungsten-silicon steel at 1000°F., the agreement between the two tests is almost perfect. For the remaining two steels, the discrepancy in the results, even when this larger creep rate is used for comparison, is rather large.

For all the steels, except Steel D-1, the ratio between the stress required for 0.01 per cent creep per 1000 hours and the limiting creep value for the Barr and Bardgett test appears to be from 3:1 to 4:1. With Steel D-1, the ratio is somewhat less than 2:1. Before any general statement may be made regarding this ratio, a considerably larger number of tests will have to be conducted.

Even though the agreement between the values obtained from the two types of tests is not good, it is interesting to note that the steels arrange themselves in the same relative order by the two tests. That is, Steel D-1 is found to be the outstanding steel at 1000°F. by both methods while the open carbon steel, Steel OS, is found to be the least resistant to creep.

On the basis of the results obtained to date, therefore, it would appear that the chief value of the Barr and Bardgett test would be to pick out from any given group the outstanding steels insofar as their creep characteristics are concerned. The regular creep test should then be conducted on these outstanding steels to determine their actual creep characteristics.

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