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Preliminary Report

on

EFFECT OF METHOD OF LOADING on THE RESULTING CREEP CHARACTERISTICS of PLAIN CARBON STEELS AT 850°F.

by

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EFFECT OF METHOD OF LOADING
on
THE RESULTING CREEP CHARACTERISTICS
of
PLAIN CARBON STEELS AT 850°F.

In the present report the results are given of an investigation to determine the effect of testing procedure on the observed resulting creep characteristics. As the usual creep test is now conducted, there are three possible ways in which the load may be applied. That is, either the single-step, the up-step, or the down-step method may be used.

In the single-step method, a given fixed load is applied and this is maintained constant for the entire duration of the test. In the up-step method, the original load is only maintained constant until the creep has either stopped, at least within the sensitivity of the measuring apparatus employed, or until it has progressed at a constant rate for a given period of time. Then the load is increased and the process repeated. The down-step method differs from the up-step in that the original load is relatively large, and after the rate of creep has been determined, the load is decreased rather than increased.

The down-step method of loading may be conducted according to either one of two procedures. Either the initially applied, relatively large load may be maintained constant for a sufficient period of time for the rate of creep to be determined, or else it may be maintained constant for only a few hours and the first rate of creep determined only after the load has been reduced.

Although various claims have been made as to the relative merits of these three procedures, very little if any work has been done to actually determine the effect of the method of loading on the resulting creep characteristics. Accordingly, the work herein reported was undertaken to throw light on this question.

Also, attempts are to be made to determine the influence of the method of loading on the "Time-Yield" value of Dr. Hatfield. In a previous report entitled "Comparative Physical Characteristics of Grades A and B Seamless Steel Pipe at Normal Temperatures and at 850°F.," it was shown that the values obtained for Hatfield's "Time-Yield" values, when the up-step method of loading was used, were considerably below those reported by Dr. Hatfield for similar steels. It was later learned that Dr. Hatfield employed the single-step, rather than the up-step method of loading in his tests, and, accordingly, the results herein reported should show what influence the method of loading has on the "Time-Yield" values.

The results given in this report are not complete as only two steels have been considered, namely, two plain carbon steels containing 0.18 and 0.41 per cent carbon respectively, and only one temperature has been considered, which was 850°F. It is entirely possible that the findings obtained for these two steels at this temperature may not show the same relationships as would be obtained for steels of other types at this same temperature, nor is it entirely possible that the same relationships would be found to exist for these two same steels at other temperatures. Results will have to be available from other tests which are now in progress before the findings herein given may be extended.

SUMMARY OF CONCLUSIONS

Creep tests undertaken on Grades A and B carbon steel at 850°F. by three different methods of loading, that is, the up-step, the single-step, and the down-step methods, show the higher carbon steel (Grade B) to possess the maximum creep characteristics in all cases.

It was likewise found that the resulting observed creep characteristics varied appreciably depending upon the testing procedure employed. With both steels the lowest values for a rate of creep of 0.01 per cent per 1000 hours (1.0 per cent per 100,000 hours) were obtained with the up-step method of testing, while the maximum values were obtained with the down-step method. The explanation for this is believed to be as follows. In the up-step method sufficient time is not allowed for the material to assume its minimum rate of flow and the rate reported is, therefore, somewhat high. In the down-step method, the material has undergone considerable strain hardening under the relatively large initial load, and, therefore, assumes its minimum rate of creep more rapidly when the load is reduced to any given value. The observed creep characteristics obtained by these three different methods of loading are given in Table I.

Because of the greater speed with which results can be obtained by the up-step method, and because the results obtained by this method are always on the safe or lower side, it is felt that this procedure does have a practical importance. It is believed, however, that the maximum actual creep characteristics can best be obtained by the single-step method, or by the up-step method in which the time under each load is increased to at least 650 hours, and preferably 1000 hours.

Table I

Effect of Method of Loading
on the
Observed Creep Characteristics of Grades A and B Steel at 850°F.

Method of Loading	Stress for Designated Rate of Creep Rate = Per Cent per 1000 Hours 0.01	 0.10	 1.00
Grade A Steel			
Up-Step	6,900	10,500	16,000
Single-Step	9,800	12,900	16,900
Down-Step (1)	11,500	14,000	16,900
Down-Step (2)	11,700	13,500	15,800
Grade B Steel			
Up-Step	12,000	16,900	23,500
Single-Step	13,000	18,800	27,000
Down-Step (1)	14,500	19,000	24,500
Down-Step (2)	14,500	19,000	24,500

(1) Original load maintained constant for at least 600 hours.
(2) Original load maintained constant for only 24 hours.

Likewise, it was found that the method of testing influenced the total amount of plastic deformation which was obtained under any given load. In the majority of cases, the largest amount was obtained with the single-step method of loading, and this method also required the greater time period before creep would proceed at a given constant rate. If, however, in the other two methods of testing, that is, the up-step and down-step methods, allowance was made for the plastic deformation which had occurred under the preceding stresses, the total amount of plastic deformation in the three cases would be more nearly equal.

The effect of the method of loading on the Hatfield "Time-Yield" value was also considered. Again it was found that in practically every case this value would be lower when the single-step method of loading was used than with the up-step or down-step methods. This is again due to the greater amount of plastic deformation obtained, especially during the early stages of the test, with the single-step method of testing.

PROCEDURE

The steels used in this investigation were the same as those considered in the previous report on the "Comparative Physical Characteristics of Grades A and B Seamless Steel Pipe at Normal Temperatures and at 850°F." The steels were furnished in the form of seamless steel pipe and their compositions are given in Table II.

Table II

Chemical Compositions of Grades A and B Seamless Steel Pipe

Designation	Chemical Composition, Per Cent				
	Carbon	Manganese	Silicon	Sulphur	Phosphorus
Grade A	0.180	0.493	0.01	0.017	0.009
Grade B	0.408	0.917	0.21	0.031	0.014

The two steels differ primarily in their carbon, silicon and manganese contents, with the Grade B material containing the higher amount of these three elements in each case. On the basis of the silicon content, the Grade A material is of the rimmed or open type, while the Grade B steel is of the killed type.

The only tests which were considered in this investigation were the creep tests. The apparatus used in these tests has been fully described in the literature.[1] An optical system which is sensitive to 2.8 millionths (0.0000028) of an inch is employed for measuring the elongation of the specimen and the temperature of the specimens is controlled to within ±2°F. Even with this degree of temperature control, however, the measuring system is sufficiently accurate to record the elongation and contraction of the specimen produced by the temperature variations. The elongation readings recorded on the time-elongation curves given in this report are the average of the elongation and contraction ranges.

Three different procedures were used in the creep tests. One consisted of the so-called up-step method of loading. This consists of applying an initial load of rather small magnitude and maintaining this load constant until flow has either stopped, at least within the sensitivity of the measuring apparatus employed, or until it has proceeded at a definite fixed rate for a given period of time, this time period generally being about 200 hours. Then the load is increased and the process repeated.

The second method used was the down-step method, and this differs from the up-step only in that the initial

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[1] A.E.White, C.L.Clark, and L.Thomassen, "An Apparatus for the Determination of Creep at Elevated Temperatures," A.S.M.E., Fuels and Steam Power, Vol. 52, No. 27, p. 347, 1930.

load is relatively large, and the load is decreased rather than increased, after the creep characteristics have been determined for any given stress. Two procedures were used in this method of testing. In one case the initially applied load was maintained constant for a sufficient period of time to allow the rate of creep produced by this load to be determined. In the second case the initially applied load was held constant for only 24 hours and then decreased. The first rate of creep obtained by this second method was, therefore, that which occurred after the first reduction of stress.

The third, and last, method was that known as the single-step method. This differs from the preceding two in that a different specimen is used for each of the loads.

RESULTS

The creep results obtained by the different methods of loading on the two carbon steels at 850°F. are given in Figures 1 to 10 inclusive and in Table III through VI.

Creep Tests on Grade A Steel

As stated previously the three types of load application which were employed in the creep test on this material were the up-step, the single-step and the down-step method. The down-step method was conducted according to two procedures. In one case the original load was maintained constant for 600 hours before it was decreased, while in the other it was maintained constant for only 24 hours. The results obtained on the Grade A material are given in Figures 1 through 5 and in Tables III and IV. Figures 1 through 4 give the time elongation curves which were obtained, while in Figure 5, the stress and the corresponding rate of creep are plotted on logarithmic coordinates.

Table III summarizes the results which were obtained. It is seen that four stresses were employed in the up-step method of loading, five in the single-step method, and three in each of the down-step methods. The stresses employed ranged from 7,500 to 16,795 pounds per square inch, and the time of test employed for each load varied from 340 to 890 hours.

The results obtained on this material indicate that there is a considerable difference in the observed creep characteristics depending upon the method of loading which is employed. It should be emphasized that since a given heat of steel should possess a definite set of creep characteristics

Table III

Deformations Obtained During Creep Tests at 850°F. on Grade A Steel

Method of Loading	Stress	Elastic Deformation	Total Time of Test Hours	Plastic Deformation During Decreasing Stage of Creep In./In.	Plastic Deformation During Decreasing Stage of Creep Time, Hrs.	Total Plastic Deformation In./In.	Rate of Creep %/1000 Hrs.
Up-Step	7,500	0.000140	340	0.000150	100	0.000240	0.016
Up-Step	9,225	0.000115	475	0.000220	70	0.000430	0.054
Up-Step	11,700	0.000180	675	0.001520	500	0.001800	0.160
Up-Step	14,250	0.000330	429	0.003519	225	0.004594	0.525
Single-Step	7,500	0.000140	340	0.000150	100	0.000240	0.016
Single-Step	9,225	0.000565	605	0.000435	375	0.000485	0.006
Single-Step	11,700	0.000827	890	0.001403	425	0.001693	0.062
Single-Step	14,250	0.001620	865	0.003380	575	0.003960	0.213
Single-Step	16,795	0.002320	600	0.006880	200	0.010920	1.05
Down-Step(1)	16,795	0.002320	600	0.006880	200	0.010920	1.05
Down-Step(1)	14,250	-0.000088	340	0.000000	0	0.000345	0.119
Down-Step(1)	11,700	-0.000080	380	0.000000	0	0.000075	0.016
Down-Step(2)	14,250	-0.000100	600	0.001110	225	0.002040	0.256
Down-Step(2)	12,525	-0.000065	466	-0.000010	30	0.000180	0.037
Down-Step(2)	11,700	-0.000025	385	-0.000010	25	0.000070	0.009

(1) Original stress of 16,795 pounds maintained constant for 600 hours.
(2) Original stress of 16,795 pounds maintained constant for 24 hours.

at any given temperature that the differences obtained are not actual but only observed differences and are entirely due to the different creep testing procedures which were employed. It is also felt that many of the observed differences may be accounted for either on the basis of the time factor or on the fact that in certain of the testing procedures used the material was previously placed in a strained condition.

The effect of the time factor is well shown by the results which were obtained from the two lowest stresses employed in the single-step method of loading. The test under a stress of 7500 pounds per square inch was continued for 340 hours and the rate of creep during this time was 0.016 per cent per thousand hours. With the stress at 9,225 pounds per square inch, the test was continued for 605 hours and the rate of creep obtained was 0.006 per cent per thousand hours. It is impossible for a higher stress to produce a lower rate of creep than does a lower stress and the difference obtained is, without doubt, due to the variation in time. In other words, it is believed that if the test under the lower stress had been continued for a period of 600 hours or longer, the rate of creep would have continued to decrease and would have become less than 0.006 per cent per thousand hours. Since, however, 340 hours is a time period commonly used in the up-step method of testing, it is believed that the value of 0.016 per cent per thousand hours thus obtained should be used as representative of results obtainable with this type of loading.

From Table III it is evident that the down-step method of loading yields the highest observed creep characteristics, while the up-step method yields the lowest. The magnitude of the relative creep characteristics yielded by the three methods is better shown in Figure 5. In this figure logarithmic coordinates are used and the rate of creep is plotted against the stress which produces it. This method of plotting is used because under many conditions of temperature and stress a straight-line relationship is obtained between stress and rate of creep. Results taken from this figure are givèn in Table IV.

Figure 5 and Table IV show that the differences in the observed creep characteristics obtained by the different methods of loading are greater at the lower rates of creep than what they are at the larger. For example, the stresses required to produce creep at the rate of .01 per cent per thousand hours ranged from 6,900 pounds for the up-step method

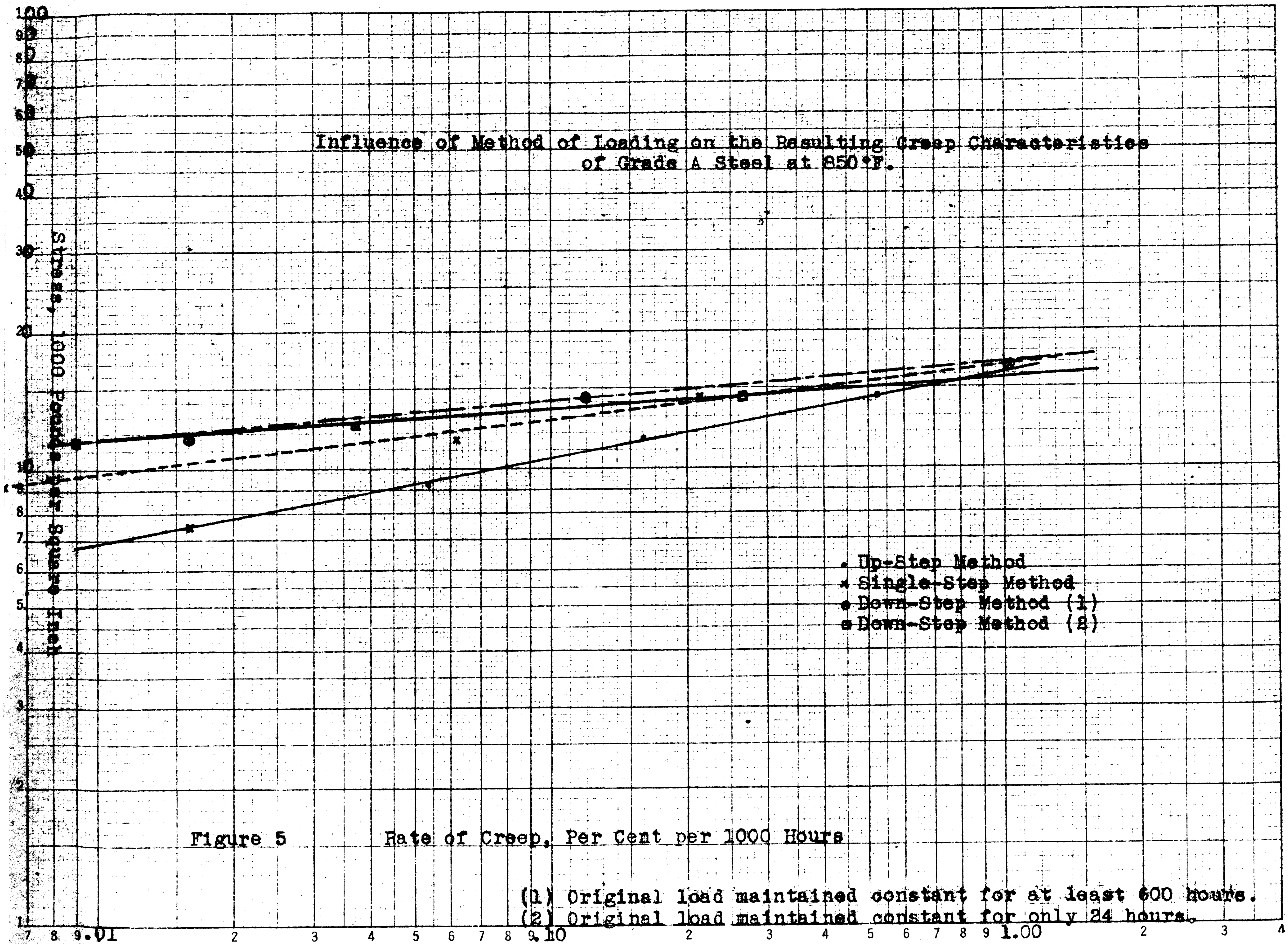

Figure 5

(1) Original load maintained constant for at least 600 hours.
(2) Original load maintained constant for only 24 hours.

Table IV

Effect of Method of Loading
on the
Observed Creep Characteristics of Grade A Steel at 850°F.

Method of Loading	Stress for Designated Rate of Creep Rate = Per Cent per 1000 Hours 0.01	 0.10	 1.00
Up-Step	6,900	10,500	16,000
Single-Step	9,800	12,900	16,900
Down-Step (1)	11,500	14,000	16,900
Down-Step (2)	11,700	13,500	15,800

(1) Original load of 16,725 pounds held constant for 600 hours.
(2) Original load of 16,725 pounds held constant for 24 hours.

to 11,700 pounds for the down step method. However, the stresses required to produce creep at the rate of 1.0 per cent per thousand hours only ranged from 15,800 pounds to 16,900 pounds.

The fact that the up-step method of loading yields the lowest observed creep characteristics is believed to be due to the time factor. It is felt that in this method of testing sufficient time is not allowed under any given stress for the metal to assume its minimum creep value. The fact that the down-step method produced maximum values may be explained on the assumption that sufficient strain hardening occurred under the original large load to enable the metal to assume its minimum creep rate in a shorter period of time. Certain data in Table III substantiate this claim. For example, it is seen that with the down-step method of loading the time required for the material to assume a constant rate of creep only ranged from 0 to 30 hours. With the other methods of loading the corresponding time ranged from 70 to 575 hours.

It is also to be observed that the down-step method in which the original load was held constant for 600 hours gives a slightly greater resistance to creep after the first reduction of stress, that is, with a load of 14,250 pounds, than does the method whereby the original stress is maintained constant for only 24 hours, while at the lowest stress employed, 11,700 pounds per square inch, the converse is true.

The explanation for the first of the above observations is believed to be as follows. When the specimen is subjected to the relatively high stress for the longer period of time, a greater resistance to continuous deformation is built up and thus when the stress is somewhat reduced it deforms at a smaller rate. This statement is supported by the shape of the time-elongation curve which shows that when the original stress is only maintained for

24 hours, considerable plastic deformation occurs at a decreasing rate when the stress is first reduced before creep proceeds at a constant rate. When the original stress is maintained for 600 hours, creep occurred at a constant rate immediately upon the reduction of stress.

The second of the above observations may be explained on the assumption that for the lower rates of creep, the rate of recrystallization assumed greater importance, and that since the specimen which had been held under the original stress for 600 hours has undergone greater deformation, it will also recrystallize at a more rapid rate.

Creep Tests on Grade B Steel

Tests similar to those above were also conducted on Grade B steel at 850°F. The results obtained are shown in Figures 6 through 10 and in Tables V and VI. Figures 6 to 9 inclusive give the time-elongation curves which were obtained, while Figure 10 shows the results plotted to logarithmic coordinates.

The results are summarized in Table V. Six stresses were employed in the up-step method of loading, six in the single-step method, two in one down-step method, and three in the other down-step method. The stresses em-

Table V

Deformations Obtained During Creep Tests at 850°F. on Grade B Steel

Method of Loading	Stress	Elastic Deformation	Total Time of Test Hours	Plastic Deformation During Decreasing Stage of Creep In./In.	Plastic Deformation During Decreasing Stage of Creep Time, Hrs.	Total Plastic Deformation In./In.	Rate of Creep %/1000 Hrs.
Up-Step	7,500	0.000265	340	0.000313	240	0.000360	0.00
Up-Step	9,225	0.000159	305	0.000125	215	0.000130	0.00
Up-Step	11,700	0.000160	600	0.000230	455	0.000240	0.00
Up-Step	14,400	0.000160	490	0.000320	320	0.000375	0.035
Up-Step	16,795	0.000160	355	0.000200	75	0.000450	0.086
Up-Step	19,055	0.000160	245	0.000235	50	0.000725	0.275
Single-Step	7,500	0.000265	340	0.000313	240	0.000360	0.00
Single-Step	9,225	0.000561	738	0.000439	550	0.000449	0.00
Single-Step	11,700	0.000650	785	0.000510	785	0.000510	0.00
Single-Step	14,250	0.000800	640	0.000350	50	0.000320	0.00
Single-Step	16,795	0.000945	670	0.000665	100	0.001000	0.049
Single-Step	19,055	0.001060	680	0.001040	175	0.001570	0.113
Down-Step(1)	19,055	0.001060	680	0.001040	175	0.001570	0.113
Down-Step(1)	16,795	0.000090	775	0.000000	0	0.000245	0.031
Down-Step(2)	16,795	-0.000090	600	0.000290	250	0.000510	0.036
Down-Step(2)	15,400	-0.000080	453	-0.000010	25	0.000080	0.016
Down-Step(2)	14,250	-0.000045	383	0.000000	0	0.000070	0.009

(1) Original stress of 19,055 pounds maintained constant for 680 hours.
(2) Original stress of 19,055 pounds maintained constant for 24 hours.

ployed ranged from 7500 to 19,055 pounds per square inch and the time periods for each test varied from 305 to 785 hours.

The results indicate Grade B steel to be considerably more resistant to creep at this temperature than Grade A steel. In fact, in the up-step method of loading, this material was able to withstand a stress of 11,700 pounds without continuous creep. In the single-step method a stress of 14,250 pounds did not produce continuous creep.

The method of loading exerts the same general effect on the observed creep characteristics of this steel as were found with the Grade A material. That is, the up-step method of loading produced the lowest observed creep value, while the down-step method yielded the maximum value.

The differences in the observed creep characteristics as obtained by the different methods of loading can best be seen from Figure 10 in which the stress and the corresponding rate of creep are plotted on logarithmic coordinates. Values taken from this figure are given in Table VI.

From Figure 10 and Table VI it is evident that as in the case of Grade A steel there is an appreciable difference in the observed creep characteristics depending upon the testing procedure employed. In this case, however, the differences

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Logarithmic, 2½ × 2 Cycles.

Influence of Method of Loading on the Resulting Creep Characteristics of Grade B Steel at 850°F.

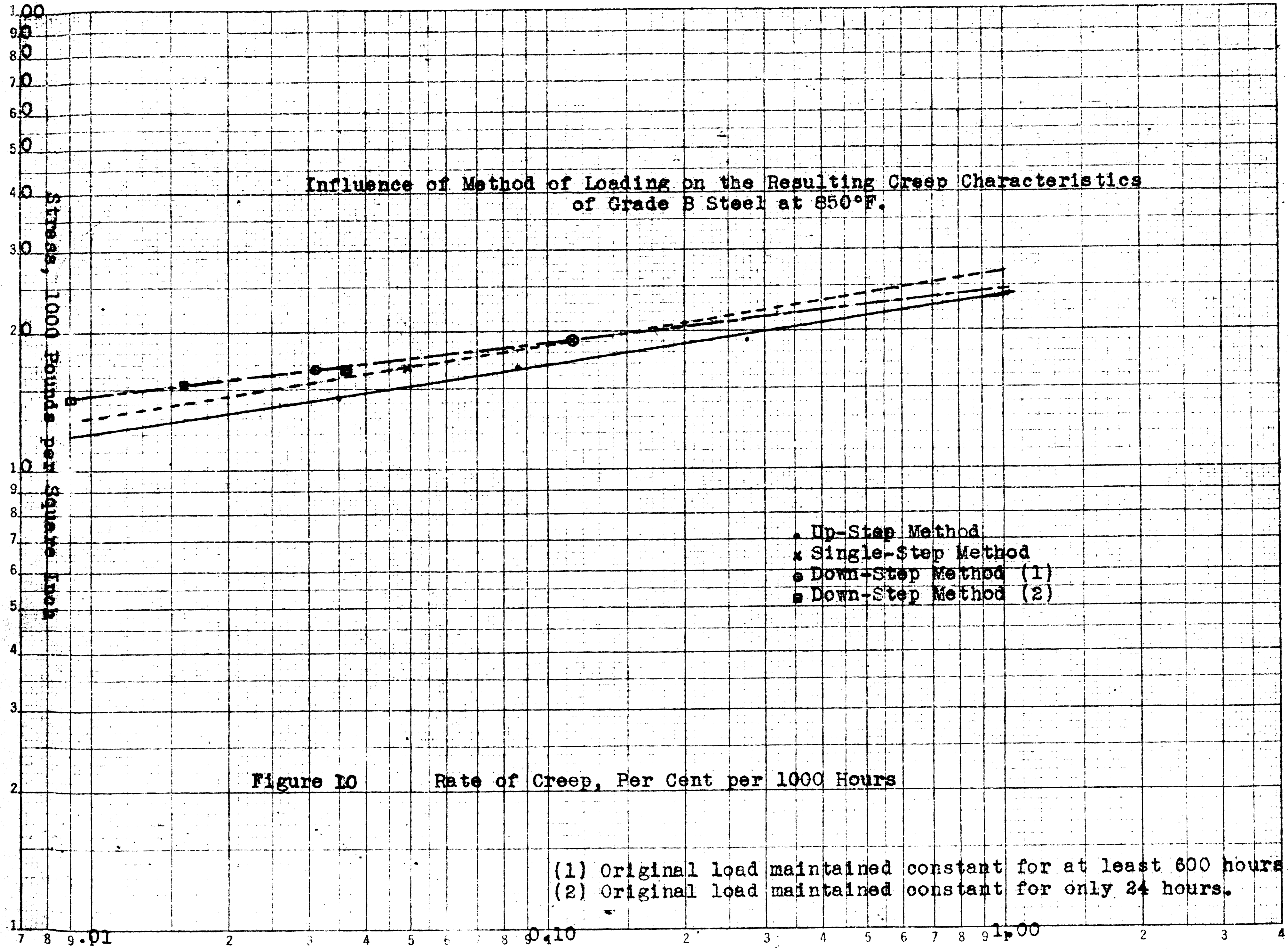

Figure 10

(1) Original load maintained constant for at least 600 hours.
(2) Original load maintained constant for only 24 hours.

Table VI

Effect of Method of Loading
on the
Observed Creep Characteristics of Grade B Steel at 850°F.

	Stress for Designated Rate of Creep Rate = Per Cent per 1000 Hours		
Method of Loading	0.01	0.10	1.00
Up-Step	12,000	16,900	23,500
Single-Step	13,000	18,800	27,000
Down-Step (1)	14,500	19,000	24,500
Down-Step (2)	14,500	19,000	24,500

(1) Original load of 19,055 pounds maintained constant for 650 hours.
(2) Original load of 19,055 pounds maintained constant for 24 hours.

are not as great at the lower rates of creep, and they are more uniform over the entire creep range. The stress required for a rate of creep of 0.01 per cent per thousand hours ranged from 12,000 pounds for the up-step method to 14,500 pounds for the down-step method. For a rate of creep of 1 per cent per thousand hours, the creep stresses range from 23,500 to 27,000 pounds. In this latter case, however, it is the single-step method rather than the down-step which yields the highest results.

The explanation for the observed differences are believed to be the same as those discussed under Grade A steel.

Effect of Method of Loading on Hatfield's Time Yield Value

As Dr. Hatfield's "Time-Yield" value is now defined, it is that stress which, during the 48-hour period immediately following the first 24 hours of the test, produces a total plastic deformation of 48 millionths (0.000048) of an inch per inch.

In the following table are given values which show the deformation occurring during the 48-hour period immediately following the first 24-hour period for Steels A and B when subjected to creep tests by the single-step, the up-step and the down-step methods of testing. In this table are also given the computed values for the "Time-Yield" value.

The values in Table VI clearly indicate that in practically every case a larger plastic deformation is obtained in the period between the 24th and 72nd hour when the single-step method is employed than with the up-step or down-step methods. According to these values the time-yield value for Grade A steel at 850°F. would be 6,850 pounds per square inch when the single-step method of loading is employed, 7,800 pounds for the up-step, and 13,500 or 13,300 for the down-step method of loading. The corresponding stress for 1 per cent creep per 100,000 hours varies from 6,900 to 11,700 pounds per square inch, depending on the method of loading employed.

Table VI

Deformation During 48-Hour Period
Immediately Following First 24-Hour Period

Method of Loading	Stress Lb./Sq.In.	Deformation During Period from 24th to 72nd Hour Inches per Inch	Hatfield's Time-Yield Value Lb./Sq.In.	Creep Stress 1%/100,000 Hr
		Grade A Steel		
Single-Step	7,500	0.000060		
Single-Step	9,225	0.000070		
Single-Step	11,700	0.000210	6,850	9,800
Up-Step	9,225	0.000085		
Up-Step	11,700	0.000150	7,800	6,900
Down-Step(1)	14,250	0.000060		
Down-Step(1)	11,700	0.000020	13,500	11,500
Down-Step(2)	12,525	0.000035		
Down-Step(2)	11,700	0.000020	13,300	11,700
		Grade B Steel		
Single-Step	7,500	0.000043		
Single-Step	9,225	0.000090		
Single-Step	11,700	0.000075		
Single-Step	14,250	0.000030		
Single-Step	16,795	0.000200	10,600	13,000
Up-Step	9,225	0.000053		
Up-Step	11,700	0.000054		
Up-Step	14,250	0.000080		
Up-Step	16,795	0.000115	11,500	12,000
Down-Step(1)	19,055	0.000100		
Down-Step(1)	16,795	0.000015	17,700	14,500
Down-Step(2)	16,795	0.000090		
Down-Step(2)	15,400	0.000025		
Down-Step(2)	14,250	0.000020	15,900	14,500

(1) Original load maintained constant for at least 600 hours.
(2) Original load maintained constant for only 24 hours.

With Grade B steel at 850°F. the "Time-Yield" value for the single-step method of loading is 10,600 pounds per square inch, with the up-step method 11,500 pounds, and with the down-step method either 17,700 or 15,900 pounds. The corresponding stress for 1 per cent creep per 100,000 hours varies from 12,000 to 14,500 pounds per square inch depending on the method of loading employed.

CONCLUSIONS

Creep tests conducted on Grades A and B plain carbon steel at 850°F. by three different testing procedures allow the following general conclusions to be drawn regarding the effect of method of loading on the resulting creep characteristics.

The higher carbon steel, that is, the Grade B material, was found to possess the maximum creep characteristics at 850°F. regardless of whether these values were determined by the up-step, the single-step, or the down-step methods. For a rate of flow of 0.01 per cent per 1000 hours (1.0 per cent per 100,000 hours), the difference between the two steels for any given method of loading varied from 2,800 to 5,100 pounds per square inch.

The observed creep values were also found to vary considerably depending upon the method of testing employed. With both steels, the minimum stress values for a rate of flow of 0.01 per cent per 1000 hours (1.0 per cent per 100,000 hours) were obtained with the up-step method of testing, and the maximum values were obtained with the down-step method. In the case of the lower carbon steel, Grade A, these values ranged from 6,900 pounds for the up-step method to 11,700 pounds for the down-step method. The corresponding values for the higher carbon steel, Grade B, varied from 12,000 to 14,500 pounds.

The explanation of these apparent discrepancies in the observed creep characteristics is believed to be as follows. At this temperature, creep, especially during the early stages of the test, is due to a combination of strain-hardening and recrystallization. The recrystallization process is necessarily very slow and the rate of creep will become constant only after an appreciable amount of strain hardening has occurred. In the up-step method of testing, the initial loads employed are relatively small and the rate of strain hardening is also slight. A considerable period of time is, therefore, required before the rate of creep assumes its minimum value. Evidently, the test was not continued a sufficient length of time in order for the rate of creep to be at its minimum value. The results reported are, therefore, low. With the down-step method the conditions are different in that the initial stress is relatively large and a large degree of strain hardening occurs in a relatively short period of time. When the load is, therefore, reduced, creep proceeds at a uniform rate almost from the start of the test.

The total amount of plastic deformation obtained also varies depending upon the testing procedure which is used. In practically every case, the greatest amount was obtained with the single-step method. If allowance is made in the other two methods, however, for the plastic deformation which occurred under the previous loads, the difference between the three methods would probably not be very marked.

The effect of the method of loading on the resulting "Time-Yield" value was also determined. Again, it was found that, because of the relatively large amount of deformation which occurs during the first hundred hours or so of the single-step tests, the "Time-Yield" values obtained by this method were below those obtained by the up-step or down-step methods.