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Report
on

INFLUENCE OF RECRYSTALLIZATION TEMPERATURE AND GRAIN SIZE ON THE CREEP CHARACTERISTICS OF NON-FERROUS ALLOYS

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SUMMARY

This paper presents the results of long-time creep tests conducted on non-ferrous alloys of the copper-zinc, copper-zinc-tin, and nickel-copper series; at temperatures both above and below their lowest recrystallization temperature. Certain of the materials investigated were of identical chemical composition, but varied in grain size.

The results presented indicate the creep characteristics to be greatly influenced by the recrystallization temperature and by the grain size. It is shown that not only is there a sharp decrease in a metal's ability to resist creep as the recrystallization temperature is passed, but also there is a change in the nature of the creep characteristics. At temperatures below this temperature, metals are able to resist stresses of appreciable magnitude without measurable continuous creep, while at temperatures above, appreciable continuous creep occurs under the stresses used with a probability that continuous creep would occur at any stress.

Grain size and recrystallization temperature have been found to be so related that at temperatures below the lowest recrystallization temperature, fine-grained materials offer the greater creep resistance, while at temperatures above, the coarse-grained material is superior. These findings support the hypotheses previously advanced by the authors[1] regarding the effect of grain size on a metal's high-temperature stability.

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[1] C. L. Clark and A. E. White "The Stability of Metals at Elevated Temperatures" Engineering Research Bulletin No. 11, Dept. Eng. Research, University of Michigan, Nov. 1928, pp. 68-72.

INFLUENCE OF RECRYSTALLIZATION TEMPERATURE AND GRAIN SIZE ON THE CREEP CHARACTERISTICS OF NON-FERROUS ALLOYS

During the past several years considerable time and effort have been expended by many investigators, both in this country and abroad, in the determination of the creep characteristics of many metals and alloys at elevated temperatures.

A large share of this work, however, has consisted mainly in the procurement of numerical creep data on many metallic materials at various temperatures. While a great need still exists for additional information of this type, it is felt that more attention should now be given to the various factors which influence the creep or flow of metals and alloys at the higher temperatures. This is especially necessary if the demands of industry are to be met for alloys of superior creep resistance at ever increasing temperatures. It is true that alloys have already been developed which show promise of outstanding creep resistance, but the majority of these have been produced by more or less haphazard methods. Before alloys can be developed for this purpose on a truly scientific basis, more will have to be known of the influence of the various factors which affect or influence creep.

While there are a large number of factors which may influence the creep characteristics of metallic materials, those which are believed to be of the greatest importance are: (1) chemical composition, (2) heat treatment, (3) recrystallization temperature, (4) grain size, (5) method of manufacture, (6) testing procedure. Many of the above factors are overlapping and it is difficult to consider one without one or more of the others. Especially is this true of the recrystallization temperature and chemical composition, and to a somewhat lesser extent of grain size and heat treatment.

During the course of a general investigation as to creep characteristics of a number of selected non-ferrous alloys, data were obtained bearing upon the effects of recrystallization temperature and grain size. This paper is accordingly written for the purpose of setting forth the findings of these two factors.

INFLUENCE OF RECRYSTALLIZATION TEMPERATURE

The authors are of the opinion that the recrystallization temperature of a metal is one of the outstanding factors in determining a metal's creep characteristics. Every metallurgist knows that every metal has a recrystallization temperature and that usually the temperature of recrystallization of a given metal is different from that of any other metal. Also, in the same metal, the recrystallization temperature is affected by (1) the amount of deformation, (2) the size of the grains prior to deformation, (3) the purity of the metal, (4) the temperature at which the deformation was effected, and (5) the length of time at heat.

From the above factors producing a variation in temperature, it is readily appreciated that an expression such as "recrystallization temperature" does not in itself make possible one single temperature for any one metal. As a matter of fact, it may be better to think of the recrystallization temperature as a temperature range, rather than as a single temperature. In this paper the term will be used to designate the lowest recrystallization temperature which has been designated by Jeffries and Archer as the equi-cohesive temperature.

Many claim that a metal's ability to recrystallize is merely a function of time and, provided sufficient time is allowed, complete recrystallization will occur at any temperature. Whether or not this claim is correct, any statements the authors may make will apply, even under this hypothesis, by inserting the word "apparent" before "lowest recrystallization temperature."

Materials Employed.

Several non-ferrous alloys were employed for this study, the compositions of which are given in Table 1.

The alloys belong to either the copper-zinc, the copper-zinc-tin, or the nickel-copper series. In the copper-zinc alloys, the amount of copper varied from 85.00 to 60.21 per cent, while in the copper-zinc alloys, the amount of this element varied from 77.26 to 58.79 per cent. Only one alloy of the nickel-copper series was considered and that was Monel metal.

All of these materials except two were examined in the hot-rolled condition. The two exceptions were the 70-30 brass and the 70-29-1 Admiralty metal, both of which were given a final cold draw of 1/8 of an inch on a final diameter of 3/4 of an inch.

The materials were all secured from commercial firms, the sources being given in Table 1.

Procedure.

The experimental work consisted in determining the lowest temperature of recrystallization and in conducting long-time creep tests at temperatures both above and below the lowest temperature of recrystallization. The short-time tensile properties of these materials were also determined at elevated temperatures but these results, as well as certain of the creep results, have already been presented.[2]

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[2] C. L. Clark and A. E. White: "Properties of Non-Ferrous Alloys at Elevated Temperatures," Fuels and Steam Power, Trans., A.S.M.E., Vol. 53, No. 8, pp. 183-192, 1931.

Table 1

Chemical Composition, Mechanical Condition, and
Commercial Source of Non-Ferrous Alloys

Designation	Type of Material	Chemical Composition						Condition	Source
		Cu	Zn	Sn	Ni	Fe	Mn		
M	Monel	29.70			67.70	1.77	1.28	Hot rolled	Int. Nickel Co.
A	Admiralty	71.05	27.95	0.97				Final 1/8" cold draw	Am. Brass Co.
B	Brass	70.48	30.44					Final 1/8" cold draw	Am. Brass Co.
E-1	Brass	60.21	39.72	0.16				0.020 grain size	Bridgeport Brass Co.
R-85	Brass	85.00	14.92					0.030 grain size	Bridgeport Brass Co.
E-2	Admiralty	77.26	21.61	1.18				0.020 grain size	Bridgeport Brass Co.
E-3	Tobin bronze	58.79	40.43	0.88				0.025 grain size	Bridgeport Brass Co.

29.70
67.70
1.77
1.28
100.45

For the determination of the lowest temperature of recrystallization, specimens of each alloy were severely cold-worked, after which they were subjected to tempering at various temperatures. They were maintained at temperature for 100 hours, hardness readings being taken before and after the heating operation. The temperature at which a sharp decrease in hardness was obtained was designated as the lowest temperature of recrystallization. The location of this temperature was also checked by metallographic means.

The apparatus used in the long-time creep tests has already been described in the literature.[3] The procedure consists in applying a fixed load and maintaining it constant until either the flow comes to a complete stop, at least within the sensitivity of the apparatus, or until it has assumed a steady rate for at least 200 hours. The load is then either increased or decreased, depending on the amount of flow previously obtained.

Lowest Temperature of Recrystallization.

The results of the tests to determine the temperature of recrystallization are given in Tables 2 and 3, and typical photomicrographs showing the effect of annealing at 400, 500 and 600°F. for 100 hours on the structure of cold-worked 77-22-1 alloy are given in Photomicrographs 1 through 7.

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[3] A.E. White, C.L. Clark, and L. Thomassen: "An Apparatus for the Determination of Creep at Elevated Temperatures", Fuels and Steam Power, Trans., A.S.M.E., Vol. 52, No. 27, pp. 347-351, 1921.

Table 2

Effect of Increasing Drawing Temperatures on the Hardness of Severely Cold-Worked Non-Ferrous Alloys of the Copper-Zinc, Copper-Zinc-Tin, and Nickel-Copper Series

		Rockwell "B" Hardness at Designated Drawing Temperatures °F.									
Designation	Type	70°	200°	300°	400°	500°	600°	700°	800°	900°	1000°
R-85	85-15	79	77	76.5	74.0	72	50				
E-2	77-22-1	85	85	82	85	82	72				
E-1	60-40	82	81	82	75	70	59				
E-3	59-40-1	88	85	84	79	75	70				
B	70-30	89	96	98	98	67					
A	70-29-1	95	96	100	101	72					
M	Monel	300*	300*		300*		290*		295*		235*

* Vicker's Brinell

Table 3

Temperature of Recrystallization of Non-Ferrous Alloys of the Copper-Zinc, Copper-Zinc-Tin, and Nickel-Copper Series

Designation	Type	Temperature of Recrystallization, °F. Computed from	
		Hardness Tests	Metallographic Examination
R-85	85-15	Over 500, under 600	Over 500, under 600
E-2	77-22-1	Over 500, under 600	Over 500, under 600
E-1	60-40	Over 300, under 400	Over 300, under 400
E-3	59-40-1	Over 300, under 400	Over 300, under 400
B	70-30	Over 400, under 500	Over 400, under 500
A	70-29-1	Over 400, under 500	Over 400, under 500
M	Monel	Over 800, under 1000	Over 800, under 1000

The Monel metal has the highest recrystallization range of any of the alloys considered, and those remaining fall into two groups. Those containing 70 per cent or more of copper have a range above 400 and under 600°F., while those containing 60 per cent of copper or less have a range between 300 and 400°F.

Creep Results.

The results of the long-time creep tests are given in Figures 1 through 3. Rather than include the large number of time-elongation curves which have been obtained as a result of the creep tests, the method shown in the figures has been resorted to. This method is based on previous work which has shown that, if the logarithm of the rate of creep be plotted against the logarithm of the stress producing that deformation, a straight-line relationship results, at least under certain conditions.

This method allows a large number of results to be presented in a condensed form. It also simplifies the interpretation of the findings. For example, either the rate of deformation corresponding to a given stress or the stress corresponding to a given rate of deformation may be readily determined.

Figure 1 gives the results of the creep tests on the copper-zinc alloys using logarithmic plotting. It will be observed that the points in all cases fall on practically straight lines and that these lines may be classified into two groups with all the lines in any one group approximately parallel to each other. The 70-30 and 85-15 brass at 400°F. and the 60-40 brass at 300°F. fall into one group, while the other is composed of the 70-30 and 85-15 brass at 600°F. and the 60-40 brass at 400°F. Referring to Table 3, it is seen that the lines with the smaller slope represent results obtained at temperatures below the lowest recrystallization temperature, while the lines with the greater slope were obtained at temperatures above the lowest recrystallization temperature.

In order to verify these findings, specimens of the 70-30 brass were subjected to metallographic examination in the "as received" condition and after having been subjected to the creep tests at 400, 600, and 800°F. The results are shown in Photomicrographs 8 through 11. From these it is evident that no apparent structural change has occurred during the creep test at 400°F., even though this test lasted for over 2000 hours, while at 600°F. considerable recrystallization has occurred, and at 800°F. the recrystallization was not only complete but some grain growth had occurred.

Figure 2 gives the corresponding creep test results on the copper-zinc-tin alloys. Again the points fall on approximately straight lines, and the lines may be divided into two groups depending on their slope. The lines with the least slope give the results from the 70-29-1 and 77-22-1 alloys at 400°F. and of the 59-40-1 alloy at 300°F., while the lines with the greater slope express the results obtained from the 70-29-1 alloy at 600°F. and 800°F., the 77-22-1 alloy at 600°F., and the 59-40-1 alloy at 400°F. From Table 3, it is seen that, as before, this division is closely connected with the recrystallization temperature.

The metallographic structures of the 70-29-1 alloy in the "as received" condition and after the creep tests, shown in Photomicrographs 12 through 15, may, as in the case of the 70-30 brass, be used to verify the above conclusions. It is observed that the structure of the specimen subjected to the creep test at 400°F. for over 2000 hours is essentially the same as that of the "as received" material, while the specimens subjected to the creep tests at 600 and 800°F. have undergone recrystallization.

Figure 3 gives the results obtained from Monel metal at the various temperatures. The same general conditions are seen to exist as before. That is, the points fall on approximately straight lines, and the slope of the lines vary, depending on whether the temperature considered is above or below the lowest recrystallization temperature.

The data given in these three figures are presented in Table 4. Attention is directed to the sharp change in the slope of the line expressing the logarithmic relationship between the stress and the rate of creep produced by that stress as the recrystallization temperature is passed. Above

Table 4.

Influence of Recrystallization Temperature Range on Slope Resulting from Plotting Logarithm of Stress against Logarithm of Rate of Creep

Type	Recrystallization Temperature Range Deg. Fahr.	Creep Test Temperature Deg. Fahr.	Position with respect to Recrystallization temperature	Angle of Slope in Degrees
59-40-1	300-400	300	Below	9.5
59-40-1	300-400	400	Above	13.5
60-40	300-400	300	Below	7.5
60-40	300-400	400	Above	21.5
70-30	400-500	400	Below	9.0
70-30	400-500	600	Above	24.0
70-29-1	400-500	400	Below	9.0
70-29-1	400-500	600	Above	16.5
70-29-1	400-500	800	Above	26.0
77-22-1	500-600	400	Below	8.0
77-22-1	500-600	600	Above	17.5
85-15	500-600	400	Below	9.0
85-15	500-600	600	Above	22.0
Monel	800-1000	600	Below	8.3
Monel	800-1000	800	Below	7.0
Monel	800-1000	1000	Above	23.0
Monel	800-1000	1200	Above	24.5

this temperature range, the slope of the line is very much greater than it is below this temperature range.

The authors are aware of a statement previously made to the effect that logarithmic plotting of the type herein used produced parallel lines for a large number of materials over a wide range of temperatures. The results now given appear to indicate that such may not always be the case, and it is believed the above statement was based largely on results from materials which were all tested either above or below their lowest recrystallization temperature. In fact, the results included here lend further support to this latter supposition, for the logarithmic lines expressing the results from all the materials, that is, the Monel metal, the copper-zinc, and the copper-zinc-tin alloys, at temperatures below their lowest recrystallization temperature, were approximately parallel. For temperatures above the lowest recrystallization temperature, a similar parallelism does not exist with the different materials. While the lines for the copper-zinc and Monel metal are approximately parallel, those for certain of the copper-zinc-tin alloys have a decidedly smaller slope. This may be accounted for by the fact that the temperatures at which these latter alloys were tested were not so far above the lowest recrystallization temperature as was true for the other two classes of materials.

Again, were the creep-stress lines for the metals herein considered which were tested at temperatures above the equicohesive temperature extrapolated to any considerable amount they would cross the extrapolated creep-stress lines for the same metals when tested at temperatures below the equicohesive temperature. This would produce an apparent parodox in that it would reverse all of the present day accepted metallurgical facts to the effect that, for a given metal, under a given stress the rate of creep is the higher the higher the temperature. One, however, is not justified in extrapolating too far for two radically different types of phenomena are taking place.

In the case of the alloys tested above the equicohesive temperature flow taking place in the metal is largely plastic in character. In time, therefore, the creep-stress line would flatten out because of the reduction of cross section of the metal and approach one of the stress lines as an asymptote. In the case of the alloys tested below the equicohesive temperature much elastic as well as possibly some plastic deformation is occurring. This elastic deformation results in the strain hardening of the metal. This in time would tend to decrease the rate of creep. The slopes of the creep-stress lines therefore would not tend to become less until a marked reduction of area had occurred.

In no case would it seem advisable to extrapolate to a value in which the rate of creep for 1000 hours exceeded ten (10) per cent, because by so doing the amount of reduction which the metals would suffer would be sufficient to change the conditions. Up to some such value, however, the data presented and the resultant findings seemed apparently to hold.

Another change, in addition to the change of slope of the logarithmic lines, occurs as the lowest temperature of recrystallization is passed, that is, a change in the creep characteristics themselves.

The authors have always believed that as long as a metal was subjected to stresses below a certain fixed maximum at temperatures below their lowest temperature of recrystallization sufficient strain hardening would occur to stop any measurable creep, or continuous deformation, and, likewise, if the temperature considered was above the lowest recrystallization temperature, then continuous measurable deformation would occur under practically any stress, regardless of its magnitude.

The results obtained support this hypothesis. Referring to Table 5, it is seen that with the 70-30, the 70-29-1, the 85-15, and the 77-22-1 alloys appreciable stresses were withstood at 400°F. with no continuous measurable flow, at least within the sensitivity of the apparatus employed, while

Table 5

Long-Time Creep Characteristics of Non-Ferrous Alloys at Elevated Temperatures

Material	Temperature of Recrystallization °F.	Temperature °F.	Proportional limit lb./sq. in.	No Measurable Flow	Creep Characteristics, Per Cent Flow per 1000 Hours		
					0.01	0.10	1.00
70-30	Over 400	400	13,000	10,000	12,700	18,000	27,000
	Under 500	600	6,750	*	290	850	2,150
		800	4,000	*	*	*	*
70-29-1	Over 400	400	21,000	10,000	13,000	19,000	27,000
	Under 500	600	15,000	*	1,000	1,950	3,800
		800	8,000	*	54	160	500
85-15	Over 500	400	7,000	7,500	8,800	12,000	17,000
	Under 600	600	5,500	*	1,000	2,600	6,800
60-40	Over 300	300	7,500	7,500	9,000	12,000	17,000
	Under 400	400	5,000	*	2,000	4,750	11,500
77-22-1	Over 500	400	8,000	7,500	10,500	13,000	16,500
	Under 600	600	4,000	*	1,200	2,500	5,300
59-40-1	Over 300	300	14,000	10,000	12,000	15,000	21,500
	Under 400	400	6,000	*	3,500	5,700	9,400
Monel	Over 800	600	28,000	22,000	26,000	36,000	46,000
	Under 1000	800	20,000	18,780	19,000	23,500	27,000
		1000	13,500	*	1,650	4,300	11,500
		1200		*	210	590	1,700

* Known to be very small and believed to approach zero.

at 600°F., continuous flow was obtained with each of these alloys with the smallest stresses employed.

Likewise, with the 60-40 and the 59-40-1 alloys continuous measurable flow was not obtained at 300°F. with certain of the stresses used, but was obtained in all cases for all of the stresses used at 400°F.

With the Monel metal, continuous measurable flow was not obtained with all the stresses until a temperature of 800°F. had been passed.

If the limiting temperatures for each alloy, below which a definite stress is required to produce continuous creep and above which continuous creep is obtained with the smallest stresses employed, be compared with the respective lowest recrystallization temperatures as given in Table 3, good agreement will be seen to exist.

These results, therefore, do lend support to the hypothesis that continuous flow occurs under any stress, whatsoever, at temperatures above the lowest-recrystallization temperature, while at those below, stressses of definite magnitude are required to produce continuous measurable creep.

Some may question whether flow actually comes to a stop or whether it is occurring at such a small rate that the measuring apparatus is not sufficiently sensitive to detect it. Such a question is, of course, difficult, if not impossible, to answer. Our present measuring system is sensitive to 2.8 millionths of an inch, and even if it were capable of reading to one-hundredth or even one-thousandth of this value, a similar question could still be raised. On the basis of the results obtained, and from theoretical considerations, however, it is felt that the above conclusions regarding the influence of lowest recrystallization temperature on creep characteristics are valid.

It is interesting to consider further the stress necessary to produce continuous deformation at temperatures just below the lowest recrystallization temperature. Again referring to Table 5, it is observed that in every case except one this stress is related to the carefully determined proportional-limit value at the corresponding temperature. The one exception is the cold-worked 70-29-1 alloy. With this latter alloy the proportional-limit value is considerably above the apparent limiting creep value. This is probably due to the proportional-limit value having been increased by the cold-working to which this material was initially subjected.

It therefore appears that at temperatures just below the recrystallization temperature, carefully determined proportional-limit values may be a measure of a metal's resistance to continuous creep, if it is not in a cold-worked condition.

GRAIN SIZE

Many conflicting statements have been made regarding the effect of grain size upon a metal's high-temperature strength characteristics, and very little experimental data have been offered to support these statements.

Purely from a theoretical viewpoint, grain size should play an important part in a metal's creep characteristics. It is well known that at room temperature, fracture resulting from tension, and thus the greatest share of deformation occurs through the grains.[5] In other words, at these temperatures the material surrounding the grains, or the grain boundaries, is stronger and more able to withstand deformation than the grains themselves, and therefore, a fine-grained material will possess the greater strength because of the greater relative amount of grain boundaries present.

As the temperature is increased, however, the material surrounding the grains, or the grain boundaries, weakens at a more rapid rate than the crystals, and a temperature is soon reached at which fracture proceeds around, rather than through, the grains.[6] At these temperatures, a coarse-grained material will possess the greatest strength because of the presence of a larger amount of the stronger phase, the crystalline.

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[5] A.E. White and R. Schneidewind: "Fractures in Boiler Metal", Fuels and Steam Power, Trans., A.S.M.E., Vol. 53, No. 8, pp. 193-214. 1931.

[6] W. Rosenhain: "The Plastic Deformation and Fracture of Metals", The Engineer, Oct. 14, pp. 422-3, 1927.

There is still considerable question as to the location of this apparently critical temperature. The authors believe that this temperature is the lowest-temperature of recrystallization, or the equicohesive temperature. They also advance the suggestion that the following two conditions exist, depending on what temperatures are under consideration.

1. That at temperatures below the lowest temperature of recrystallization, a fine-grained material possesses the greater creep resistance.

2. That at temperatures above the lowest recrystallization temperature, a coarse-grained material possesses the greater creep resistance.

Materials and Procedure.

Two non-ferrous alloys of the copper-zinc-tin series, each of which had been treated to produce two different grain sizes, were used for this investigation. Their chemical composition and grain size are given in Table 6. Their metallographic structures are also shown in Photomicrographs 16 through 19.

The non-ferrous alloys were used because of the ease with which it was possible to obtain a relatively great variation in grain size. The results obtained, however, are believed to be applicable to any metal or alloy.

Table 6

Chemical Composition of Non-Ferrous Alloys with Varying Grain Size

Designation	Type of Material	Chemical Composition			Grain Size
		Cu	Zn	Sn	
E-2	77-22-1	77.26	21.61	1.18	0.020
E-20	77-22-1	77.24	21.77	1.02	0.045
E-3	59-40-1	58.79	40.43	0.88	0.025
E-24	59-40-1	60.08	38.72	0.83	0.045

The tests conducted on these materials were long-time creep tests at temperatures both below and above their lowest recrystallization temperature. The procedure used in these tests is the same as that mentioned previously in this paper.

Results.

The results of the creep tests are given in Figure 4. As before, the logarithmic system of plotting is used, that is, the logarithm of the rate of creep is plotted against the stress producing it.

At 400°F., the fine-grained 77-22-1 material is more resistant to continuous creep than the coarse-grained material, and at 600°F., the coarse-grained alloy offers the greater resistance. Since the lowest temperature of recrystallization of this material has been found to be between 500 and 600°F., Table 3, the hypothesis just advanced appears to be supported.

Likewise, with the 59-40-1 alloy, the fine-grained material is the more resistant at 300°F., while the coarse-grained material is superior at 400°F. Again, from Table 3, this change is closely related to the lowest temperature of recrystallization.

On the basis of the results obtained from both of these alloys, it may be said that at temperatures below the lowest temperature of recrystallization, fine-grained materials possess the greater creep resistance, while at temperatures above, the coarse-grained material has the greater resistance to creep.

CONCLUSIONS

Creep tests conducted on alloys of the copper-zinc, copper-zinc-tin, and nickel-copper series at temperatures both above and below their lowest temperature of recrystallization, and in certain cases in which a considerable variation in grain size existed, allow the following general conclusions:

1. At temperatures below the lowest temperature of recrystallization, metals are capable of withstanding stresses of appreciable magnitude without continuous deformation or creep, at least within the sensitivity of the apparatus employed; and for those temperatures in the immediate neighborhood of the lowest temperature of recrystallization, the limiting stress below which continuous creep is not obtained, may in the case of metals which have a stable structure under the given testing conditions, be the carefully determined proportional-limit value at the corresponding temperature.

2. At temperatures above the lowest temperature of recrystallization, continuous creep appears to be obtained with any stress, regardless of its magnitude.

3. At temperatures below the lowest temperature of recrystallization, a fine-grained material possesses the greater

creep resistance, while at temperatures above, the coarse-grained material offers the greater resistance to creep.

4. A change in the slope of the lines, resulting from the logarithmic plotting of stress versus rate of creep produced by that stress, appears to occur as the lowest temperature of recrystallization is passed. For the metals tested all the lines expressing results obtained below this temperature are approximately parallel, but their slope is not as great as that of the lines obtained above the lowest recrystallization temperature. At temperatures above this apparently critical temperature, the corresponding lines are not necessarily parallel.

Photomicrographs

No. 1 77-22-1 Alloy
Severely Cold-
Worked.
X75D

No. 2 77-22-1 Alloy
Severely Cold-
Worked.
X500D

No. 3 77-22-1 Alloy
Severely Cold-
Worked. Drawn
100 hours at 400°F.
X75D
No Recrystallization

No. 4 77-22-1 Alloy
Severely Cold-
Worked. Drawn
100 hours at 400°F.
X500D
No Recrystallization

No. 5 77-22-1 Alloy
Severely Cold-
Worked. Drawn
100 hours at 500°F.
X75D
No Recrystallization.

No. 6 77-22-1 Alloy
Severely Cold-
Worked. Drawn
100 hours at 500°F.
X500D
No Recrystallization

No. 7 77-22-1 Alloy
Severely Cold-
Worked. Drawn
100 hours at 600°F.
X75 D
Recrystallization

No. 8 70-30 Alloy
As Received
Condition
X75D

No. 9 70-30 Alloy
Creep specimen
at 400°F. Tested
for 2000 hours.
X75D

No. 10 70-30 Alloy
Creep specimen
at 600°F. Tested
for 1600 hours.
X75D

No. 11 70-30 Alloy
Creep specimen
at 800°F. Tested
for 500 hours.
X75D

No. 12 70-29-1 Alloy
As Received
Condition.
X75D

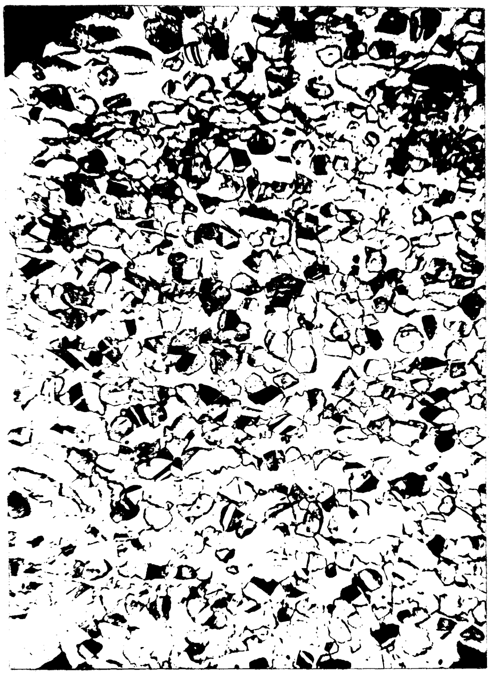
No. 13 70-29-1 Alloy
Creep specimen
at 400°F. Tested
for 2000 hours.
X75D

No. 14 70-29-1 Alloy
Creep specimen
at 600°F. Tested
for 1600 hours.
X75D

No. 15 70-29-1 Alloy
Creep specimen
at 800°F. Tested
for 1600 hours.
X75D

No. 16 77-22-1 Alloy As Received Condition. Coarse grained. X75D

No. 17 77-22-1 Alloy As Received Condition. Fine grained. X75D



No. 18 59-40-1 Alloy As Received Condition. Coarse grained. X75D

No. 19 59-40-1 Alloy As Received Condition. Fine grained. X75D