AN INVESTIGATION OF THE EFFECT OF
GRAIN SIZE ON DEEP DRAWING

THESIS FOR THE DEGREE OF M. S.

STUART E. SINCLAIR

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Shock - Testing

AN INVESTIGATION of the EFFECT

OF

GRAIN SIZE on DEEP DRAWING

An Investigation of Effect of Grain Size on Deep Drawing

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INTRODUCTION

An Investigation of the Effect of Grain Size on Deep Drawing.

The phase of cold working of steel that is encountered in deep drawing is a subject upon which there has not been a great deal of research. It seemed that it might be possible to find some quality in steel whereby a beginning might be had towards standardization. It would then be possible for a company buying steel to specify what physical properties as well as chemical analysis the steel should have in order to give definite properties on being cold worked.

The amount of investigation that would be necessary to obtain data for such a standardization would be greater than could be accomplished in this work, due to lack of time and equipment. The phase that has been chosen as a beginning is to determine the effect that is produced by different grain sizes in deep drawing steel.

This is of course only a step towards the goal, but it seems entirely possible that companies should be able to determine easily the properties which are inherent in that steel and to know how far it may be cold worked with safety. If, therefore this work is continued where time and equipment allow, the result should be gratifying.

The experimental work consists mainly of a series of heat treatments on a number of low carbon steel samples having the same composition. The samples were tested and observed after treatment and the observations correlated to determine what qualities had been produced and what their use would be in actual operation.

Another experiment included the investigation of a sample that had failed in practice. The author endeavored to correct the fault and in so doing determine what had caused the failure.

Experimental Work I

The object of the experiment was to determine if possible the effect of grain size on the deep drawing properties of a low carbon steel.

If the effect of grain size is to be considered it is then logical that an attempt be made to produce as large a grain as possible and also as small as possible. To do this twelve samples of steel having the composition of carbon 0.22% and manganese 0.31% were placed in a muffle furnace in a neutral atmosphere and heated to 1900° F. for one hour. It was known from a previous work (Bull. No. 9, M.S.C. Engineering Experiment Station) that this would produce a grain of nearly maximum size in the "as received" pieces. Another group of "as received" pieces were heated to 1650° F. for one hour, quenched in water and drawned for one hour at 1590° F. This treatment produced an unsatisfactory result as far as reducing the grain size was concerned, however, on testing the physical properties were improved. Due to the fact that grain growth had occurred it appeared that the drawing temperature had been too high. The pieces heat treated with some "as received" samples were tested for Rockwell hardness and for ductility on an Emerson Southworth Hydralic Ductility Machine.

The result of the ductility test is not a true indication of the deep drawing qualities of the metal.

This is evident in comparing the manner in which the metal is distorted in the testing machine with that of the presses used in the plant. The shape of the metal that is cold worked is controlled by dies both above and below the stock so that the operation is not one in which the metal undergoes a great tensile strain, but the metal must have the property of distortion without breaking. With the ductility testing machine there is no die above the steel being tested, but the ball below is pushed upwards distorting the test sample and acts as a die Fig. 11 shows a diagram of a test piece in the ductility machine. The difference that would prevail between the testing and the actual cold working on the press is caused by there being no die above the piece so that the metal receives a different type of distortion than would be evident in actual practice due to the pressure being increased until the test sample is broken.

The observations that were taken in recording the test were as follows: load at .250 inches deflection; deflection at maximum load; maximum deflection and maximum load. The load at .250 inches deflection is a rough measure of the hardness, but it cannot be depended upon to give accurate results each time. The deflection at maximum load is the most important property to consider for through that value it is possible to judge how much depth of draw a certain piece may be expected to withstand in practice without

Diagram of a Portion of the Ductility Machine

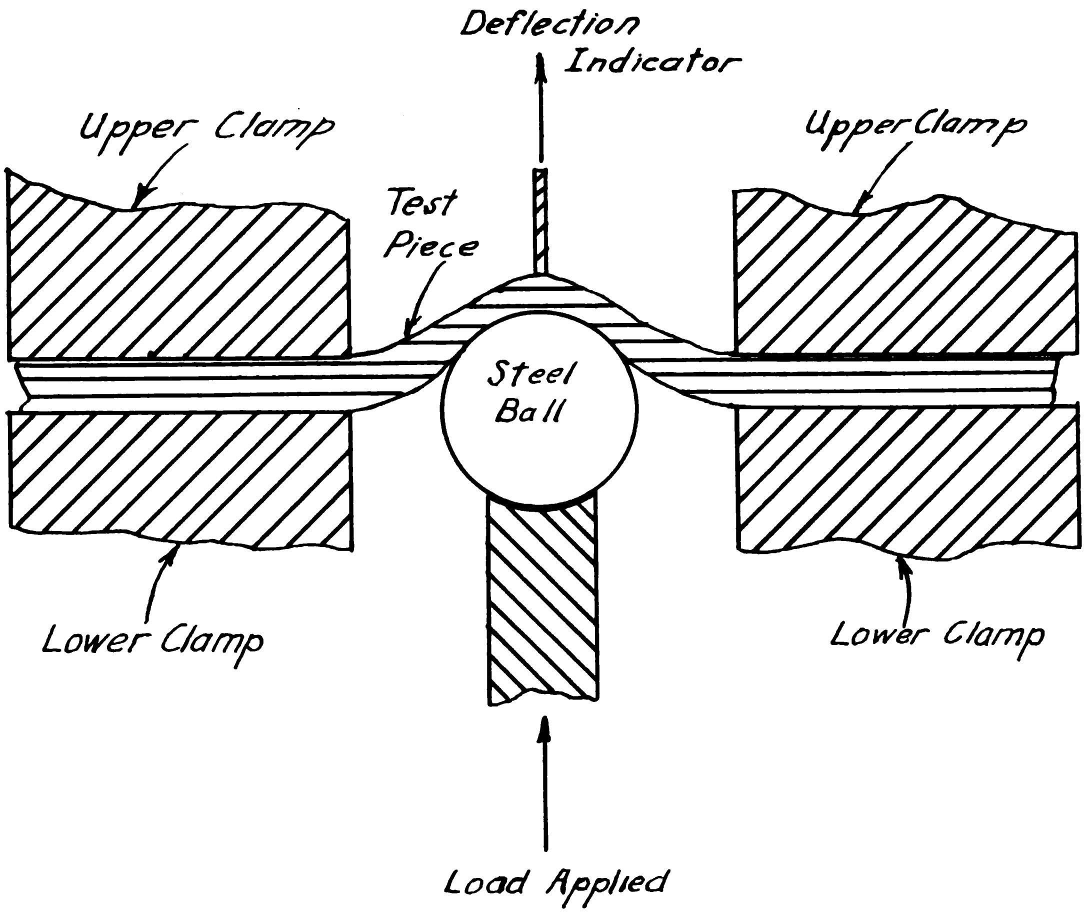


Fig. 11

failure.

The type of fracture which occurs in using the ductility tester is also an indication as to its cold drawing properties. It is a desirable quality for the distorted portion of the test piece to have a smooth, fine texture on the exterior and that the fracture may extend around the extended portion parallel with the base of the piece. The break should not, however, be too near the top and extend entirely around that portion as that would probably indicate brittleness. The hot rolled "as received" stock produced a different appearance after testing than any of the heat treated pieces. The break did not occur alike each time, sometimes being around as found in the heat treated pieces and sometimes across the top, but in all cases the material became exceedingly thin throughout the upper portion of the stock.

Figure 1 shows the type of break occurring in the heat treated specimens. It is noticeable that the upper portion has not become very thin and that in the region of the break the material has what might be considered a "small neck". Figure 2 shows a typical "as received" test sample. In this case the sample failed around the distorted portion, but the break occurred as the heat treated sample. As far as location is concerned the upper portion has become uniformly thin throughout the whole upper surface. With the heat treated stock the break usually appeared as desired, parallel to the base, but the appearance varied according to the grain size and the condition of the grains.

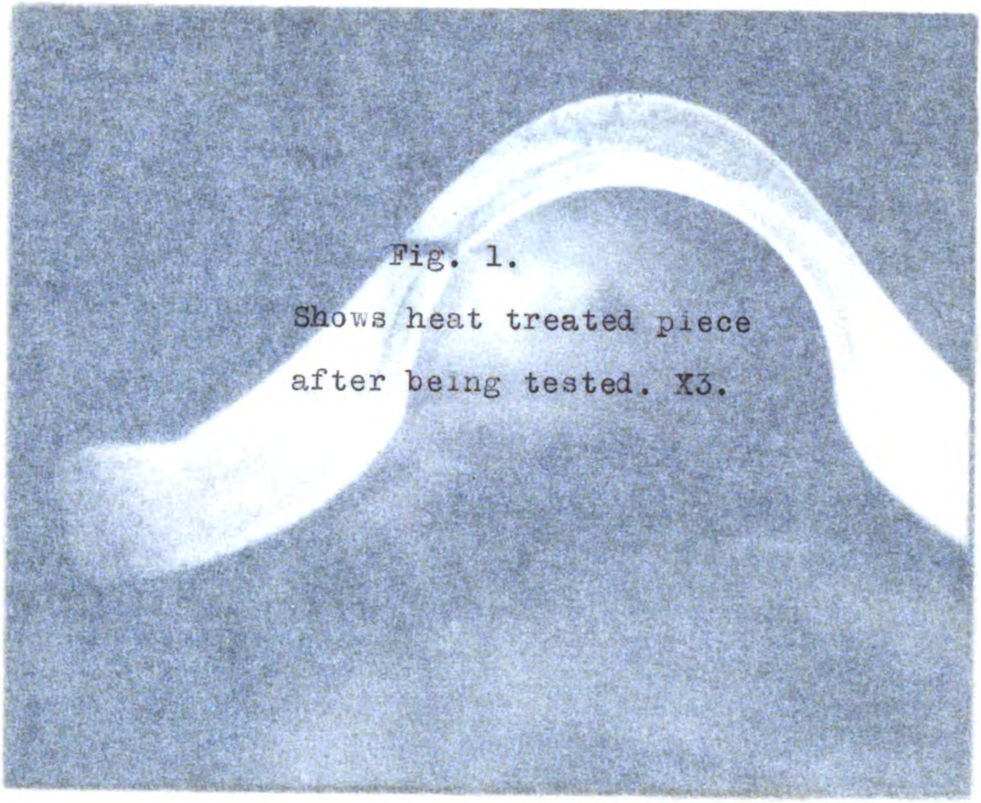


Fig. 1.

Shows heat treated piece after being tested. X3.

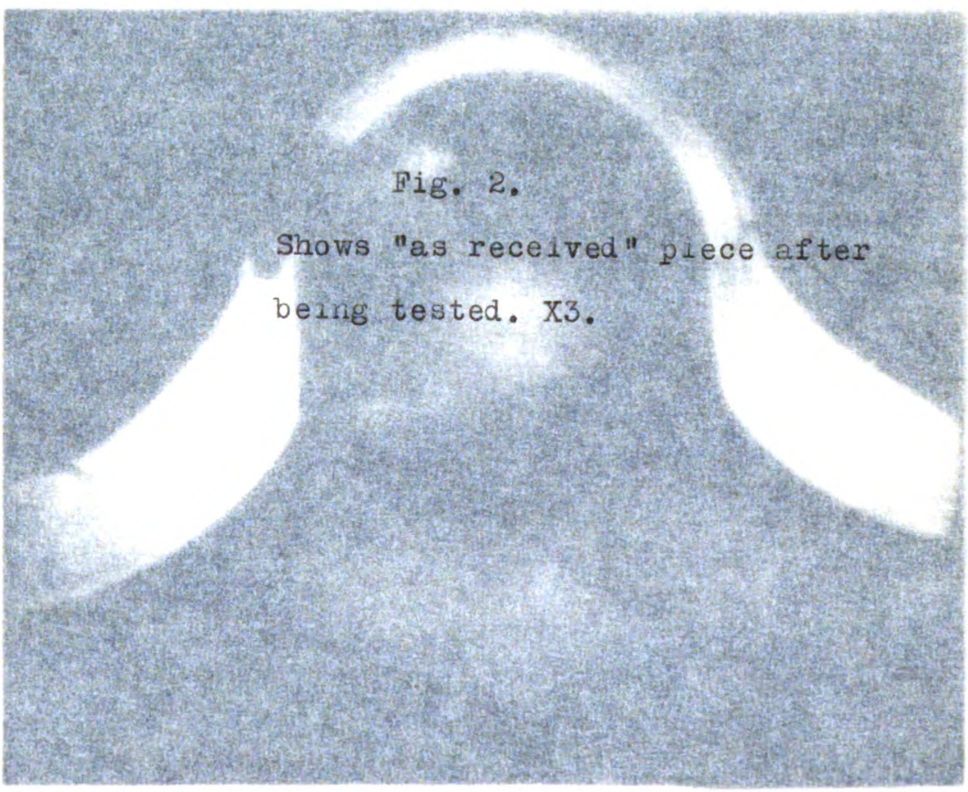


Fig. 2.

Shows "as received" piece after being tested. X3.

The data taken on the various pieces tested as follows:

Piece No.	Heat Treat.	Load @ .25 in. Deflec.	Max. Defl.	Def.@ Max. Load	Max. Load	Rockwell B Hardness
As Rec.	Hot rolled	10,000#	.447	.315	11,900#	61
1-12	1900° 1 hr. S.C.	10,300#	.375	.345	12,000#	56
23-32	1620° W.Q. D.1590°	9,800#	.400	.360	11,700#	61
35-42	1600° B.Q. 1600° B.Q. D.1310°	12,000#	.435	.335	14,000#	75
51-53	1610° B.Q. D.1300°	11,200#	.425	.370	13,600#	70
54-56	1610° B.Q. D.1360°	11,000#	.415	.346	13,000#	68
63-65	1610° ½ hr. S.C.	10,600#	.370	.342	12,500#	62
66-68	1620° B.Q. D.1460°	10,400#	.420	.345	11,800#	55
78-80	1850° S.C. D.1420°	10,000#	.405	.370	11,500#	61
81-83	1650° ½ H.S.C.	10,000#	.420	.345	11,700#	61
84-85	1890° S.C. R.H.1590°	10,100#	.405	.332	11,300#	40
88-89	1890° S.C. R.H.1500°	9,700#	.400	.345	11,500#	48

Nomeclature: S.C. - slow cool, D. - drawn, H. - hour
R.H. ¾ reheat, W.Q. - water quench, B.Q. - brine quench

Fig. 3.

"As received" hot rolled stock. X100.

Fig. 6.

Heated to 1900°F. for one hour. Slow colled.X100.

Fig. 8.

Water quenched from 1650°F. Drawn at 1590°F. X100.

Fig. 15.

Brine quenched from 1600°F. Drawn at 1310°F. X100.

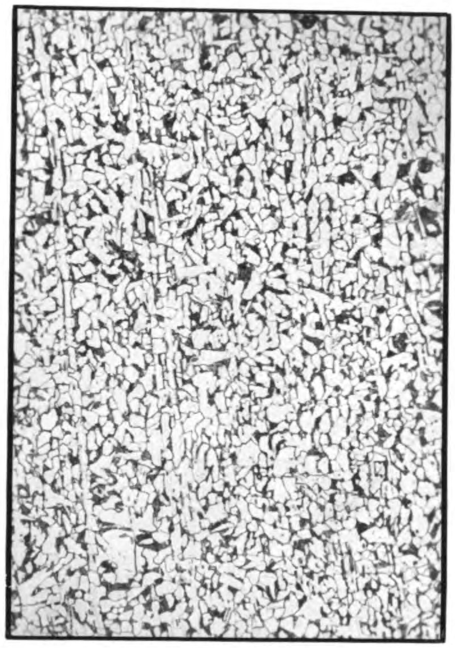
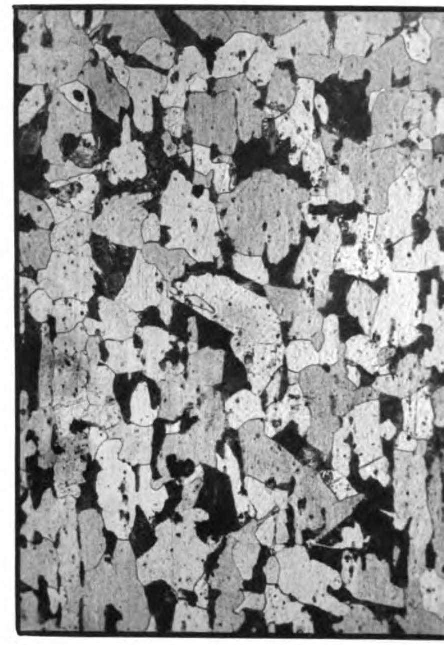
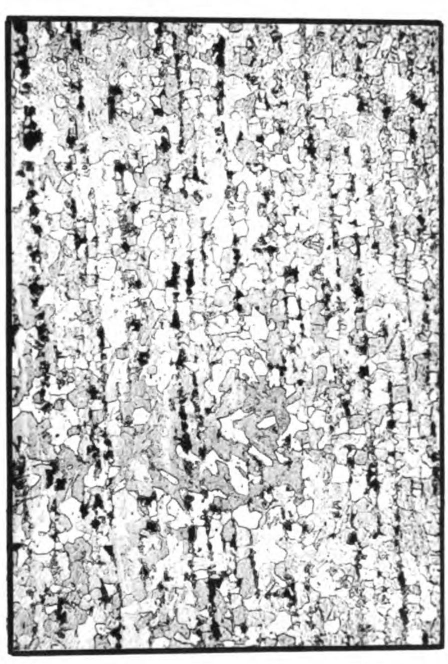
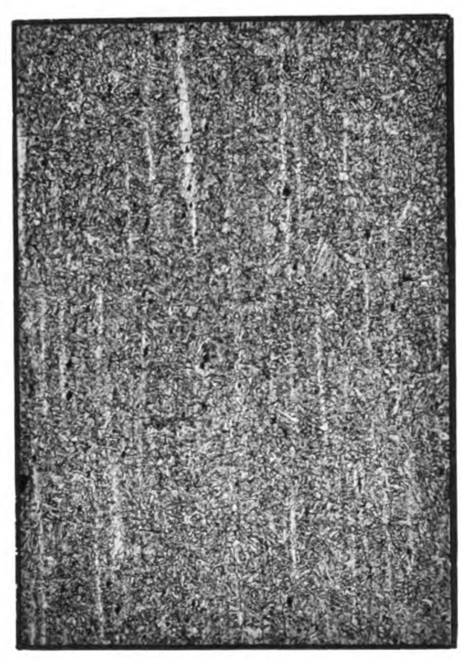





Fig. 4.

"As received" piece.

X500.

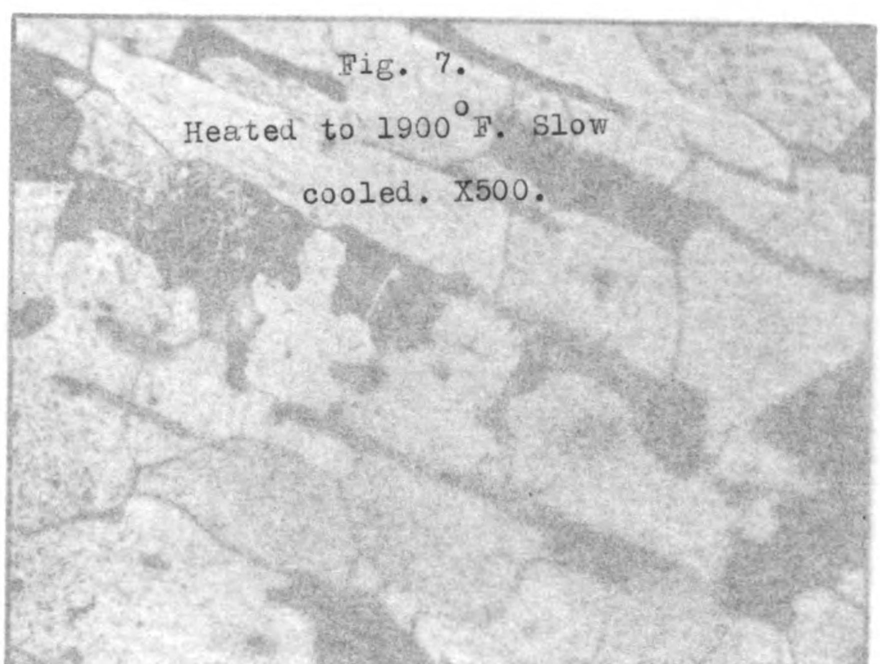
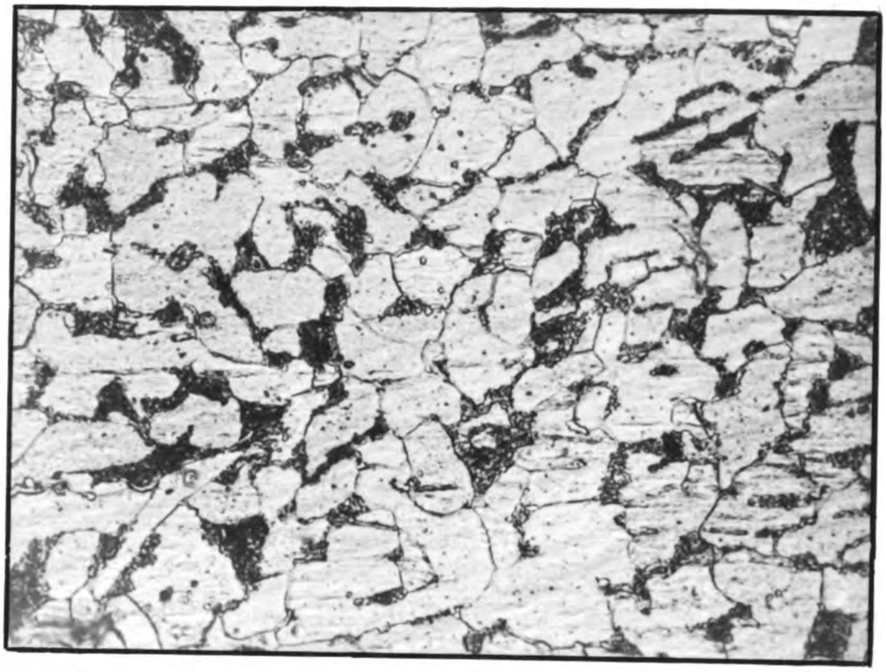
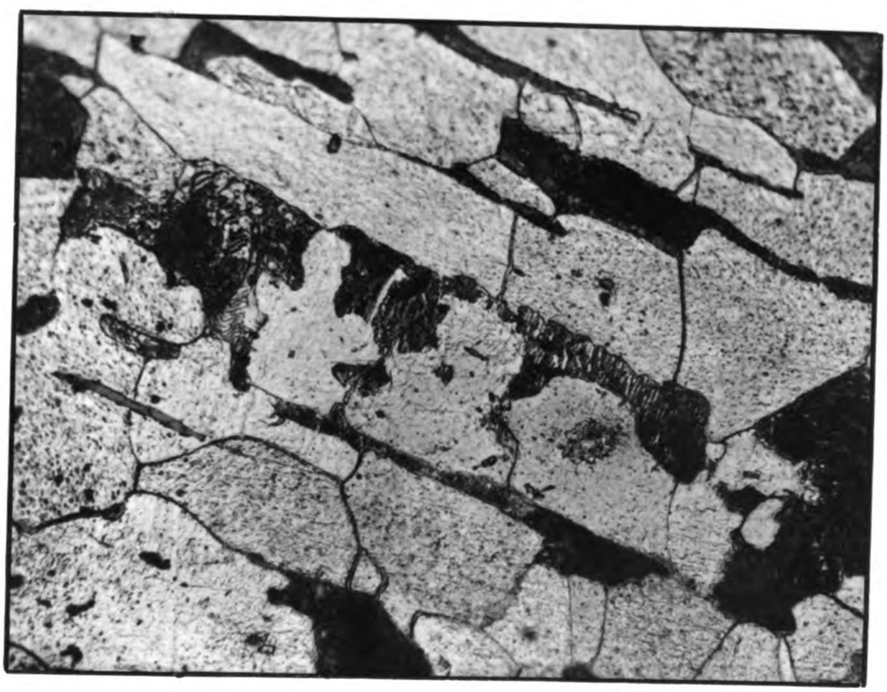
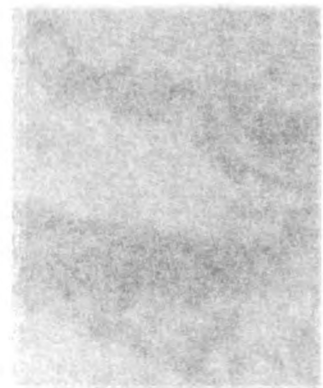


Fig. 7.

Heated to 1900°F. Slow cooled. X500.







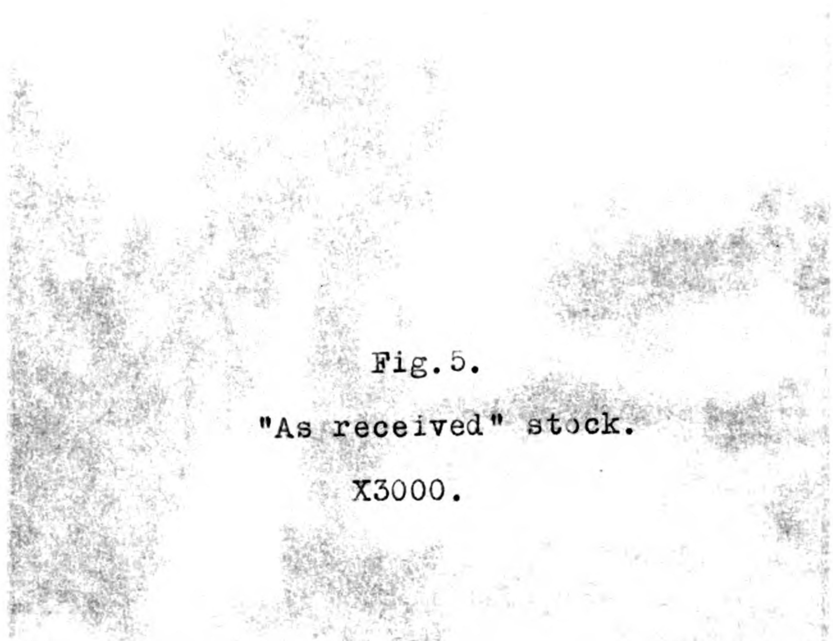
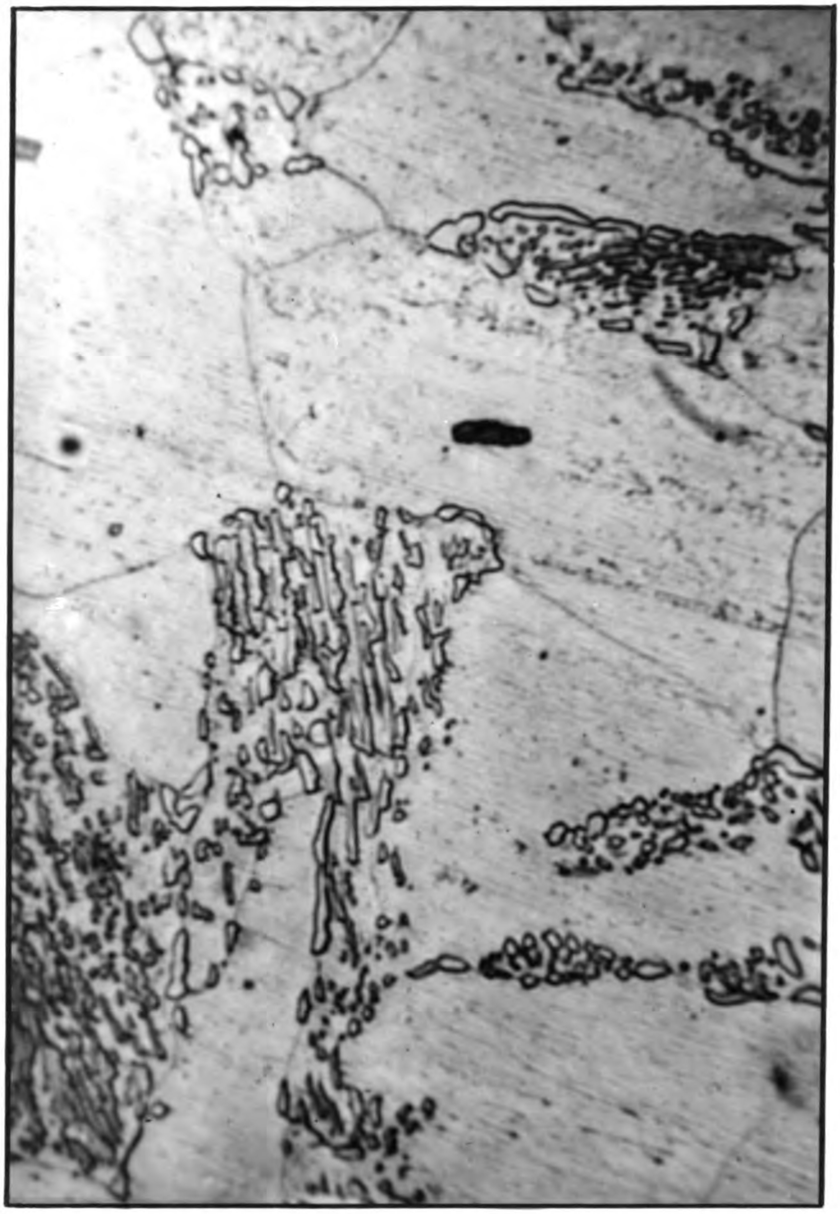


Fig. 5.

"As received" stock.

X3000.



The resulting comparison of properties occurring in the first three sets tested including the "as received" pieces gave quite widely varying results, a condition which is entirely an expected circumstance. As will be noted, the maximum elongation of the "as received" pieces is far greater than the heat treated samples. This is a result of excessive stretching causing a thin portion throughout the top. The greater elongation is caused by the thinning of the piece at the top, a condition which would be very undesirable in actual practice on account of the loss in strength that would be evident in a finished piece. The main difference between the coarse and finer grained heat treated test pieces is their exterior appearance. The coarser grained pieces are inclined to cause a rough surface which could not be tolerated in practice. The differences in deflection at maximum load and hardness is not great enough to be considered important so the reason for rejecting the coarse grain will rest with its rough exterior after cold working. In Figures3, 4, and 5 are shown the "as received" stock at different magnifications. Figure 3 shows the steel to be banded to some extent, Figures4 and 5 show the condition of the pearlite and Figure 6 shows the large grained sample at 100X, while figure shows the same specimen at 500x.

The test pieces were cut through the portion projecting caused by the ball in the testing machine. These pieces were polished, etched, and photographed to

show several characteristics. In the "as received" pieces figure 10 shows the result of cold working. The elongation of grains is very apparent and in comparing with figure 4 there seem to be but minor changes in the appearance of the ferrite and pearlite other than the elongation of both. The band of ferrite does not appear to have changed and that may be an answer to the question as to why the thin portion appears across the top on the "as received" stock and not on the heat treated pieces. Figure 8 and figure 9 showing the stock which washeated to 1620^{o} F, quenched in water and drawn at 1590^{o} F does not have the banded ferrite, however, the pearlite seems in this instance to have precipitated in bands and the ferrite is fairly free of banded structure. This condition, in my opinion, would promote the possibility of a thin portion occurring across the top asthe ferrite is more ductile and has less strength than the pearlite, therefore if these types of metals are deformed it would be expected that the piece having portions that were reasonably ductile extending throughout the piece would for the same maximum load give much more elongation. The pearlite in the banded condition seems to act as a reinforcment and when the break occurs there is not the extending and reducing of area as is present in preceeding sample, but the break occurs nearly simultaneous around the piece accompanied by less reduction in thickness of the test sample

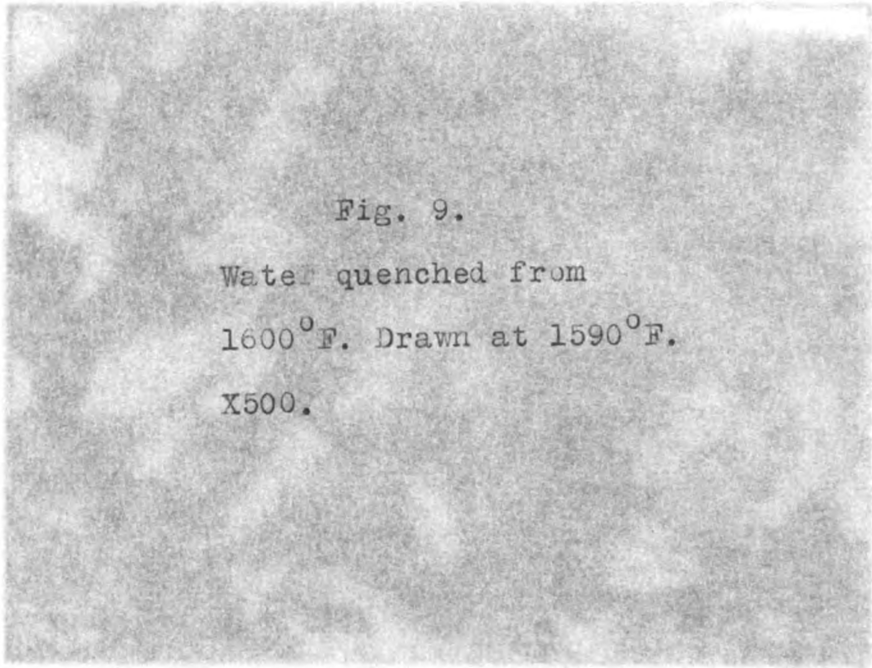


Fig. 9.
Water quenched from 1600°F. Drawn at 1590°F. X500.

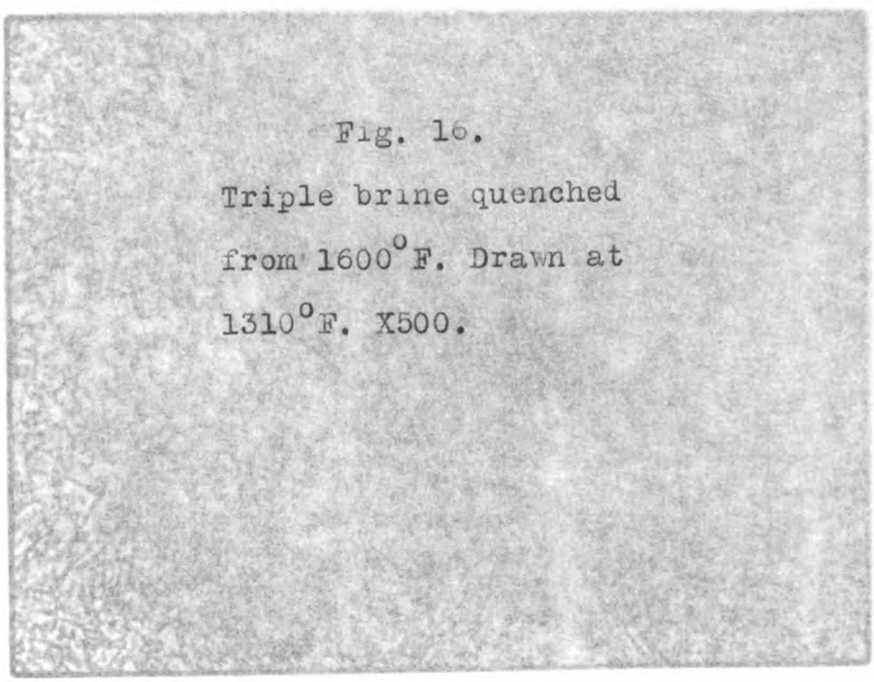


Fig. 16.
Triple brine quenched from 1600°F. Drawn at 1310°F. X500.

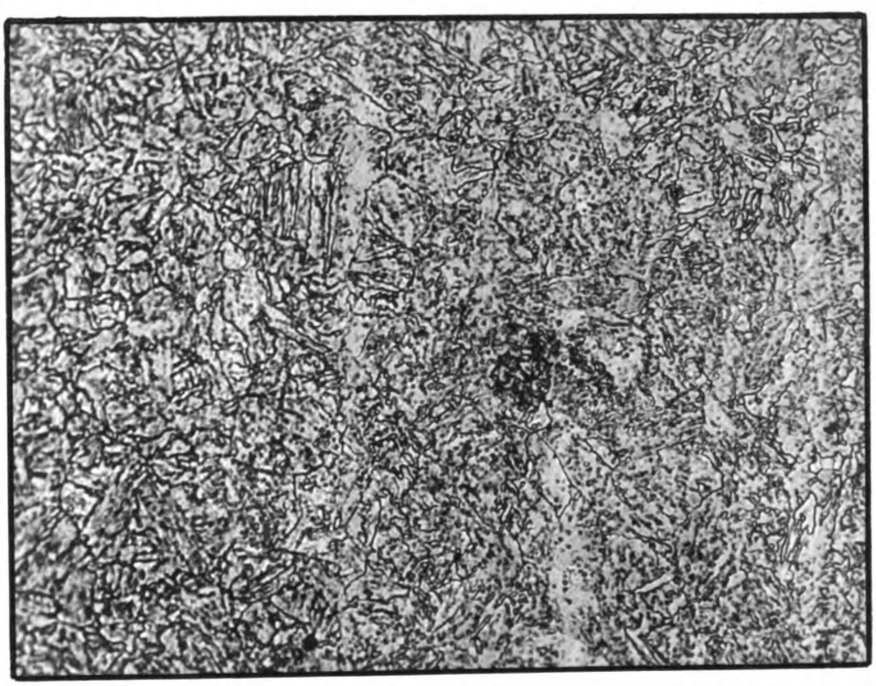


Figure 12 shows the large grains in the strained portion. In figures 13 and 14 are shown the beginning of fractures. Figure 13 shows the fracture in the coarse grain in which the ferrite seems to flow into the cracking portion. The pearlite located directly in the crack has somewhat the same appearance as the ferrite in the neighboring regions, but the pearlite that is just removed from the disturbed region has no sign of distortion in evidence. In figure 14 another fracture is shown of a finer grained piece. The statement that was made regarding the previous coarse grained piece seems to apply in thisone also as what pearlite there is, even though it does not appear in the normal condition, is not distorted and the ferrite grains have been extended greatly flowing into and towards the fracture.

It was evident after counting the grains that to obtain small grains of minimum size a different heat treatment was necessary. To obtain a smaller grain a faster quench would tend to assist such a condition providing the correct temperature was used to draw back to the normal state. Pieces 33 to 43 were heated to 1600° F. quenched in brine, reheated to 1600° F. and again brine quenched. Some experimental draws were then made to attempt to get the desirable grain size characteristics along with a hardness that would be practical to consider. This proved difficult to accomplish. The remaining pieces were drawn at 1310°F. for $1\frac{1}{2}$ hours and furnace cooled producing a hardness

Fig. 10.

Showing distorted grain in

an "as received" piece.

X500.

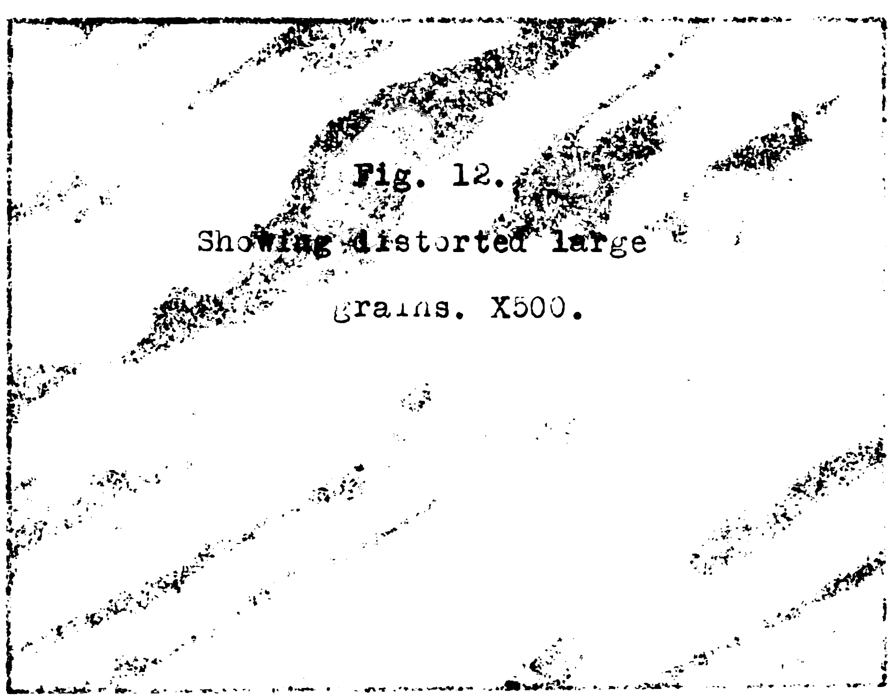
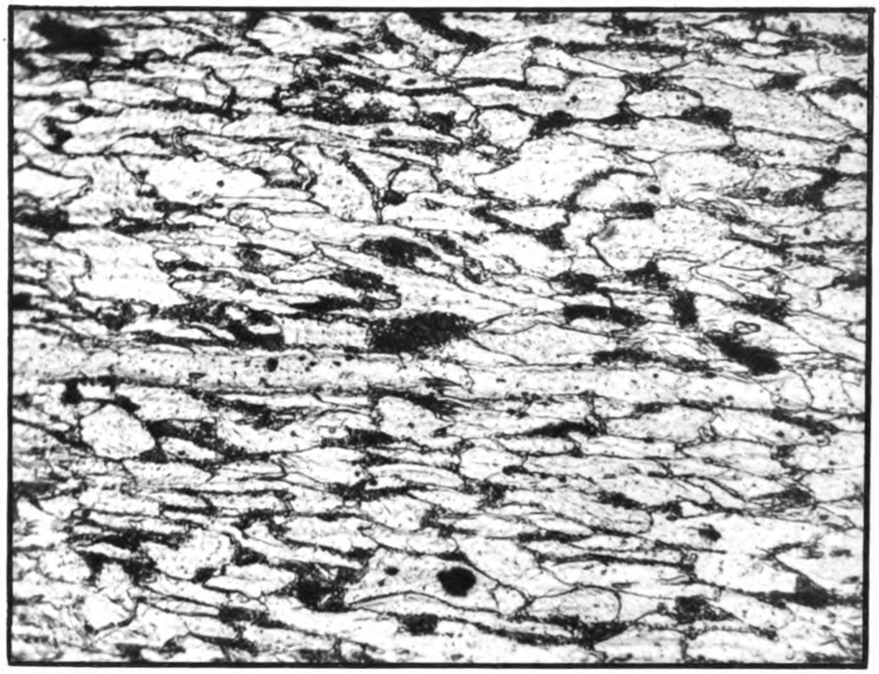


Fig. 12.

Showing distorted large

grains. X500.



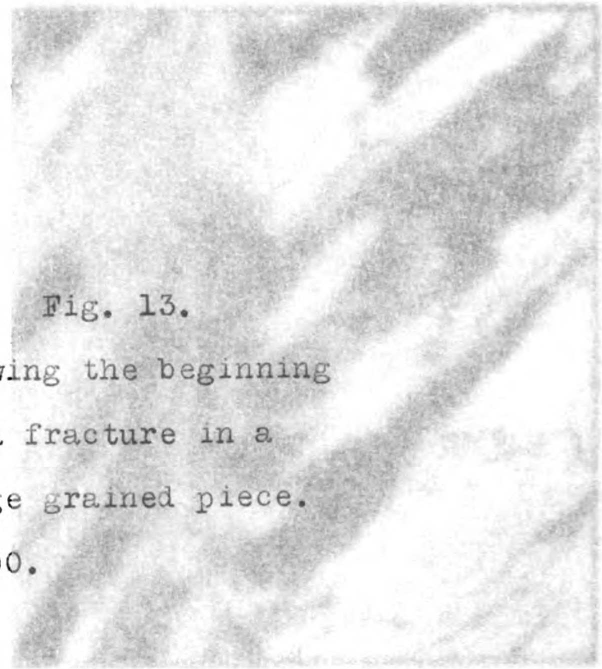


Fig. 13.

Showing the beginning of a fracture in a large grained piece. X 500.

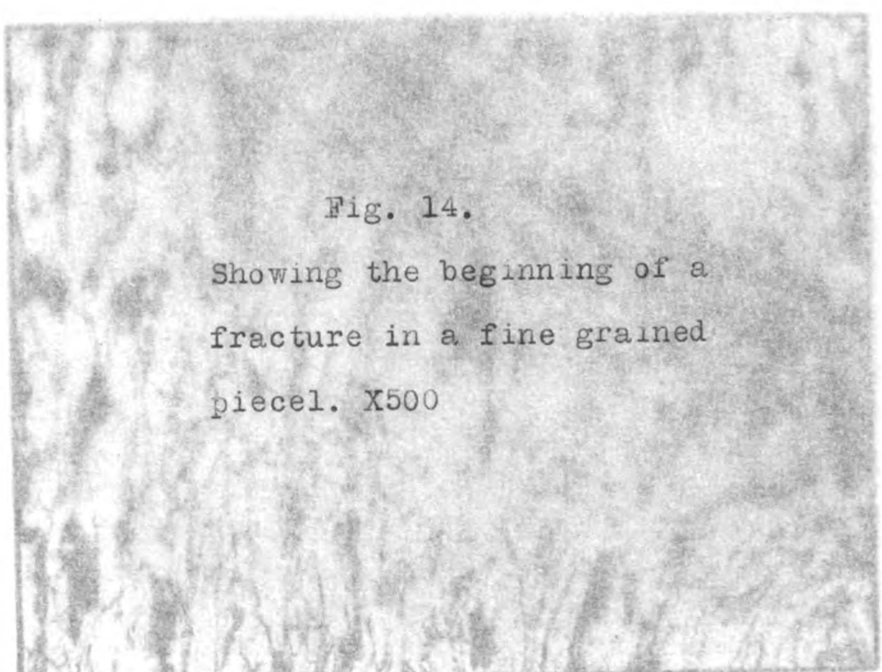


Fig. 14.

Showing the beginning of a fracture in a fine grained piecel. X500

Fig. 13.

Showing the beginning of a fracture in a large grained piece.

X 500.

Fig. 14.

Showing the beginning of a fracture in a fine grained piece. X500.

of 73-75. The structure is shown in figures 15 and 16. The results were not desirable so a trial heat was made of heating to 1600^{o} F. for $\frac{1}{2}$ hour and quenching in oil. This produced a rockwell B. hardness of 81 plus which is too high to consider and the piece which is shown in figure 17 was not tested. A treatment then was tried of heating to 1570^{o} F. for 15 minutes, oil quenching to 1300^{o} F. where it was held for fifteen minutes and slow cooled. This produced a Rockwell B hardness of 54, but the grains were larger than those found in the "as received" pieces. Three pieces were then taken, heated to 1600^{o} F. for 10 minutes and brine quenched giving a Rockwell B hardness of 100 plus. Two of the pieces were then reheated to 1600 F. for ten minutes and brine quenched giving a Rockwell B hardness of 111. One of the remaining pieces was again reheated to 1600 for ten minutes and brine quenched, this however did not materially change the hardness. Figures18, 19 and 20 show the photographs of these pieces in the quenched state. Experimental draws were taken on the three pieces to determine again the treatment necessary to produce the desirable results. Small pieces were cut from each of the three quenched pieces which are numbered 48A, 49A, and 50A. These small pieces were all drawn at 1300^{o} F. for 15 minutes and slow cooled. The hardness on the single and triple quench wasthe same or Rockwell B 63-68, so the single quenched piece was used for the remainder of the experimental heats.

Fig. 17.

Oil quenched from 1600°F. X500.

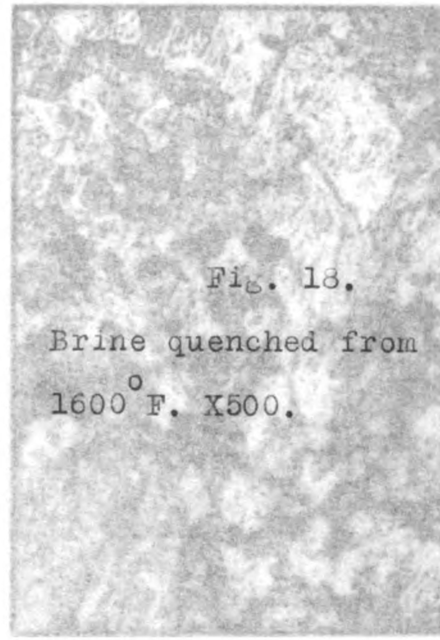


Fig. 18.

Brine quenched from 1600°F. X500.

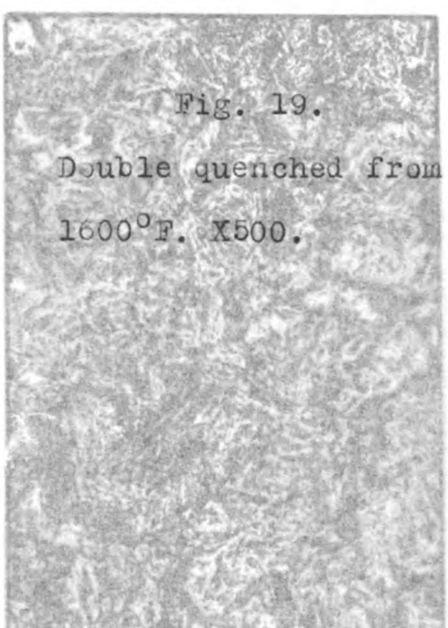


Fig. 19.

Double quenched from 1600°F. X500.

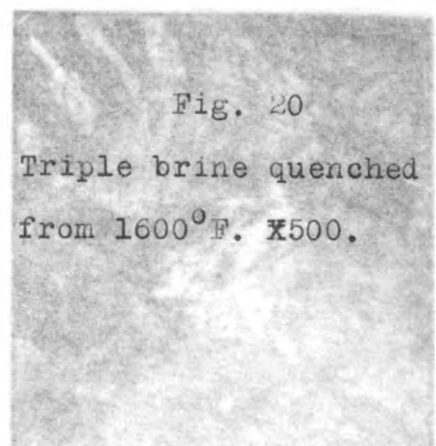


Fig. 20

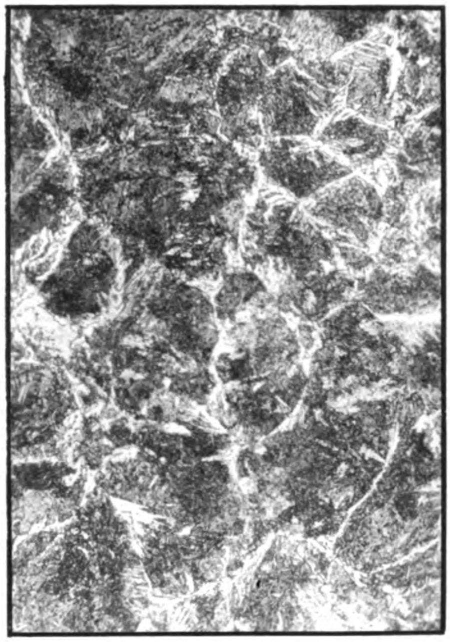
Triple brine quenched from 1600°F. X500.

Fig. 17.
Oil quenched from
1600°F. X500.

Fig. 18.
Brine quenched from
1600°F. X500.

Fig. 19.
Double quenched from
1600°F. X500.

Fig. 20.
Triple brine quenched
from 1600°F. X500.



Figures 21, 22, and 23 show pieces after this treatment.

The next draw or pieces 48B and 48C were rejected as the temperature recorded was questioned asto its accuracy. The next draw chosen or piece 48D was heated from 1350° F. to 1380° F. for 45 minutes and slow cooled. At thispoint a strange phenomena was observed in etching which nearly led to erroneous conclusions. It first appeared that by regulating the drawing temperature accurately that grainless steel might be produced as is shown in figures 24, 25, 28 and 29. Upon further investigation it was found to be an error in the etching technique for by using a light etch the cementite could be brought out without any indication of a grain boundry whatsoever. It can be observed that the cementite granules seem finer and more equally distributed in the pieces that are drawn at 1350° F. or above than in the pieces which are drawn at a lower temperature. Figures 26, 27, 30 and 31 show the same pieces referred to above only they are etched deeper.

Other experimental draws were made at 1350° F. on 48E., 1330-1340° F. on 48G, 1340-1350°F on 48G, 1330°F. on 48I, 1290°F. for 1¼ hours on 48J and 1240°F. for 1 hour on 48K. From the results of these draws the temperatures of 1300°F and 1360°F. were chosen. Pieces 51 to 54 were heated to 1600°F., brine quenched and drawn at 1300°F. for ½ hour and slow cooled. Figures 32 and 33 show the light and normal etch of these pieces.

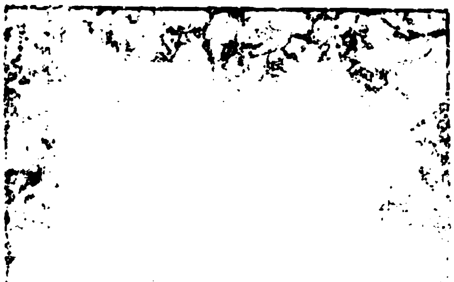


Fig. 21.

Brine quenched from 1600°F. Drawn at 1300°F. X500.

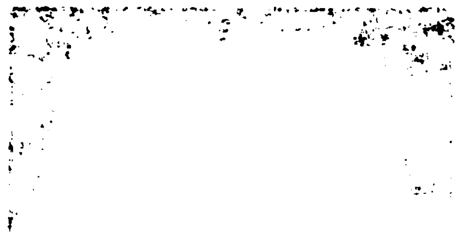


Fig. 22.

Double brine quenched from 1600°F. Drawn at 1300°F. X500

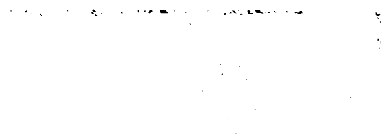


Fig. 23.

Triple brine quenched from 1600°F. Drawn at 1300°F. X500.

Fig. 24.

Brine quenched from 1600°F. Drawn at 1350°F. to 1380°F. Light etch. X100.

Fig. 21.

Brine quenched from 1600°F. Drawn at 1300°F. X500.

Fig. 22.

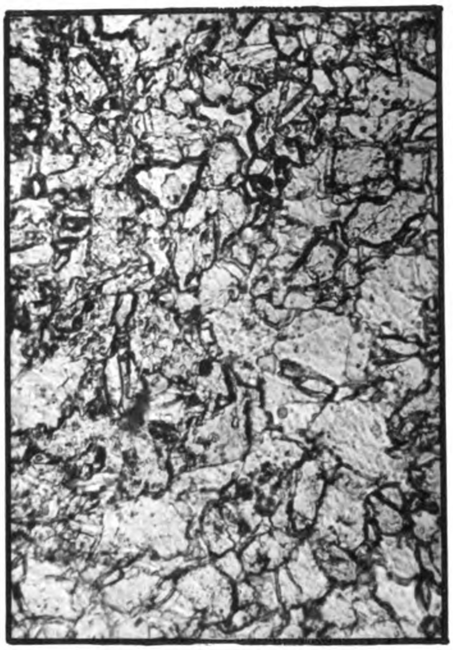
Small brine quenched from 1600°F. Drawn at 1300°F. X500.

Fig. 23.

Triple brine quenched from 1600°F. Drawn at 1300°F. X500.

Fig. 24.

Brine quenched from 1600°F. Drawn at 1300°F. to 1380°F. Light etch. X150.



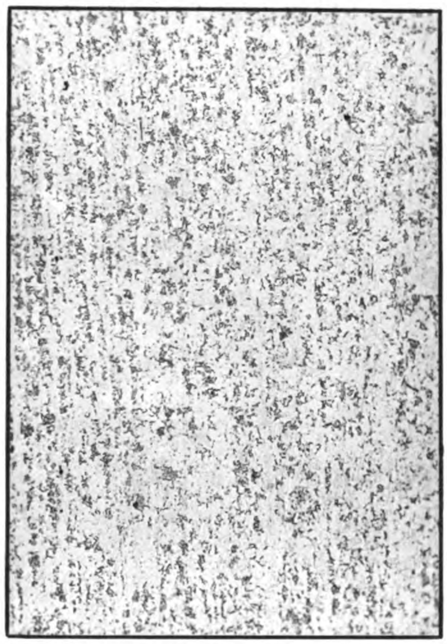


Fig. 25.

Brine quenched from $1600^{\circ}F$. Drawn at $1350^{\circ}F$. to $1380^{\circ}F$. Light etch. X500.

Fig. 26.

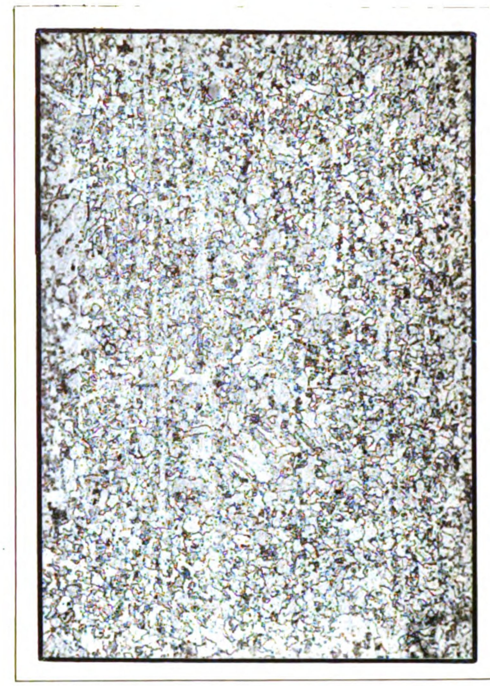
Brine quenched from $1600^{\circ}F$. Drawn at $1350^{\circ}F$. to $1380^{\circ}F$. Deep etch. X100.

Fig. 27.

Brine quenched from $1600^{\circ}F$. Drawn at $1350^{\circ}F$ to $1380^{\circ}F$. Deep etch. X500.

Fig. 28.

Brine quenched from $1600^{\circ}F$. Drawn at $1350^{\circ}F$. Light etch. X100.



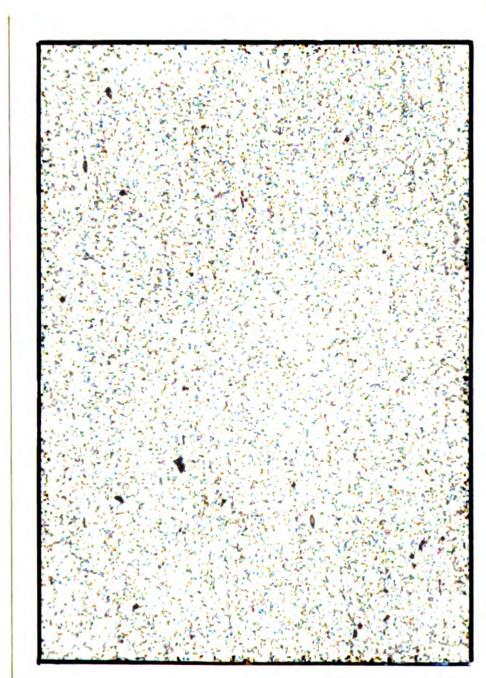


Fig. 29.

Brine quenched from 1600°F. Drawn at 1330°F. Light etch. X500.

Fig. 30.

Brine quenched from 1600°F. Drawn at 1330°F. Deep etch. X100.

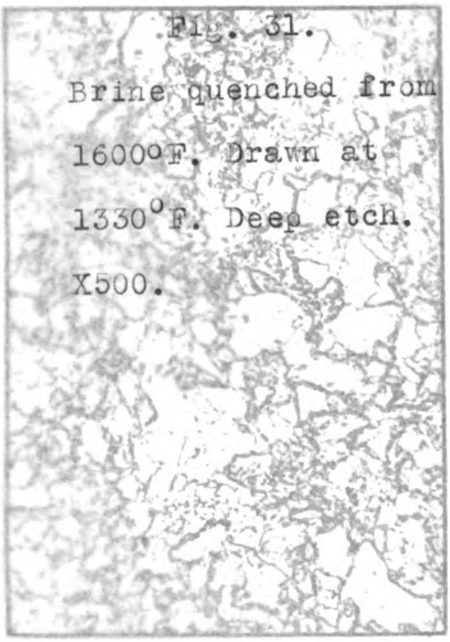


Fig. 31.

Brine quenched from 1600°F. Drawn at 1330°F. Deep etch. X500.

Fig. 32.

Brine quenched from 1600°F. Drawn at 1300°F. Light etch. X500.

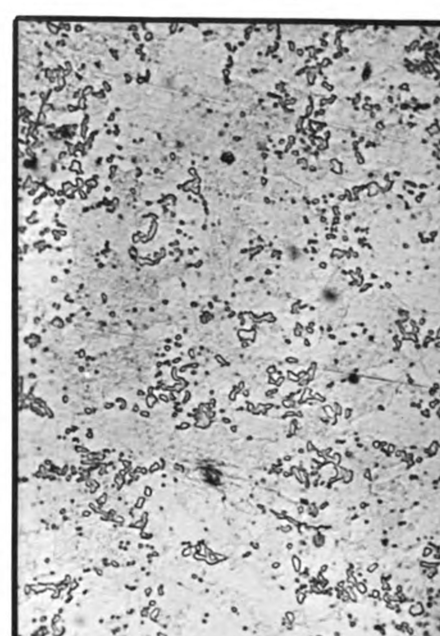


Fig. 33.

Brine quenched from 1600°F. Drawn at 1300°F. Deep etch. X500.

Fig. 36.

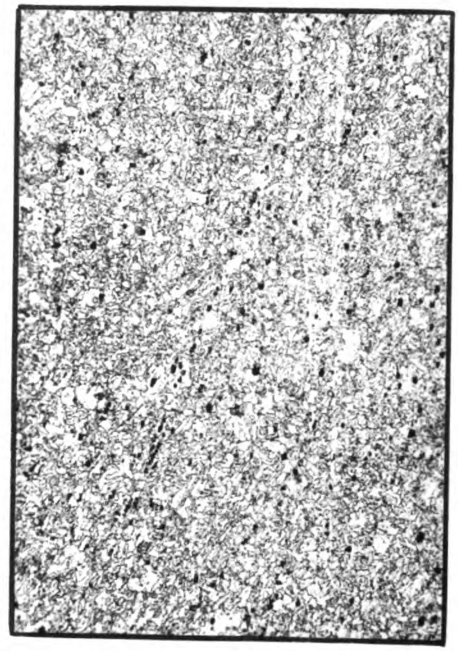
Brine quenched from 1600°F. Drawn at 1360°F. Light etch. X100.

Fig. 36.

Brine quenched from 1600°F. Drawnat 1360°F. Light etch. X500.

Fig. 37.

Brine quenched from 1600°F. Drawn at 1360°F. Deep etch. X500.



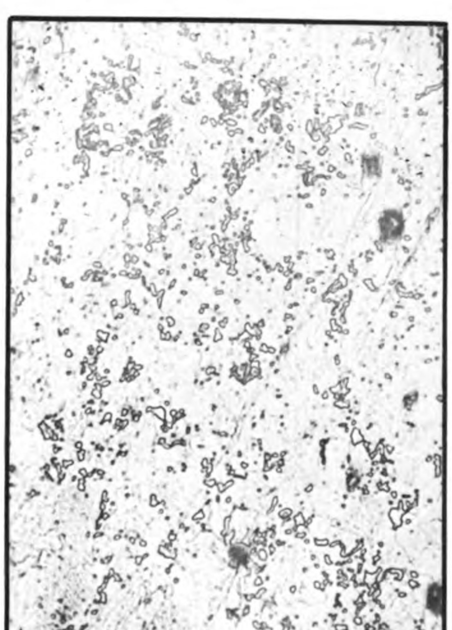


Figure 34 shows a portion which has been distorted. Pieces 54 to 56 were heated to 1600°F., brine quenched and drawn at 1360 for 45 minutes followed by a slow cool. From a study of the test results on page it can be seen that this treatment produced the most desirable results for cold drawing. The metal is harder in thisstate than it is in the "as received" state, but its drawing properties are better as far as ability to be distorted and other properties. It merely means that stronger presses might have to be used and the metal would be much harder on leaving the presses, a feature which is usually very desirable. Figures 35, 36 and 37 show this steel under various conditions.

The feature desired at this stage was to produce results of the above by one heat treatment alone. Pieces 63 to 66 were heated to 1610°F. for one-half hour and furnace cooled. This produced physical properties that were desirable, but grain growth has commenced as shown in figure 38, causing a grain size that isin excess of that desired.

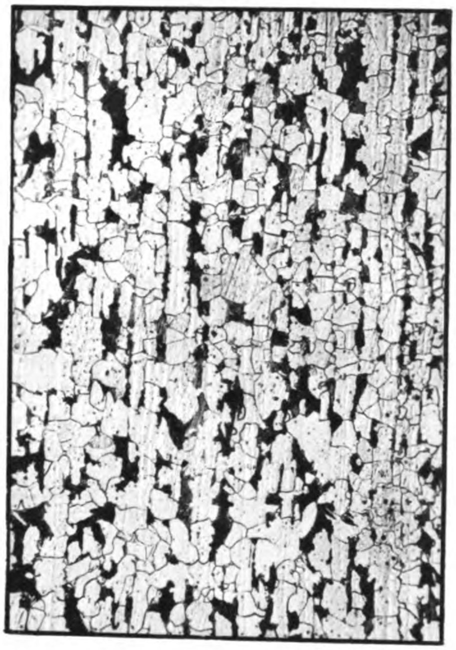
Three pieces 78 to 81 were then heated to 1850°F. for two hours. It was then slow cooled to 1190°F. or just below the Arl, held for 15 minutes and then reheated to 1430°F. for 15 minutes and slow cooled. Thisgrain size was too large as shown in figure 39, although the physical tests were desirable. The pieces 81 to 84 were then heated to 1650°F for ½ hour

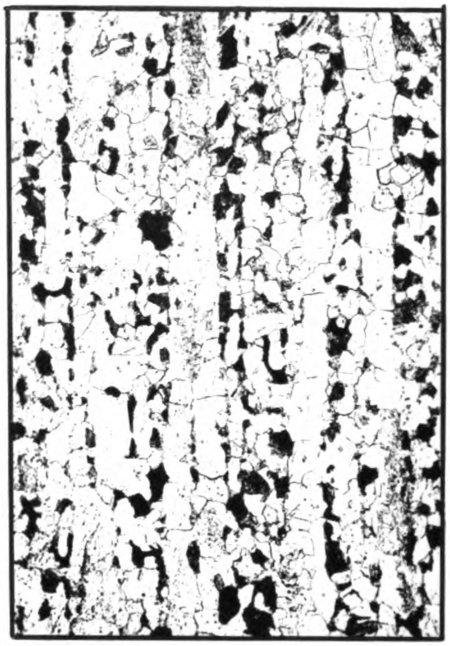
Fig. 38.
Heated to 1610°F.
$\frac{1}{2}$ hr. and slow
cooled. X100.

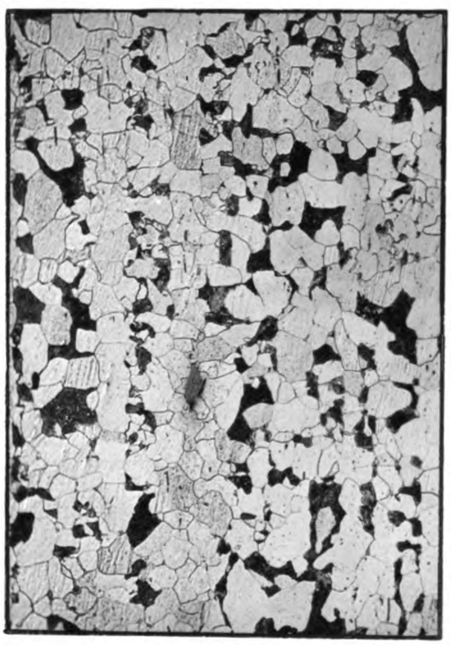
Fig. 39.
Heated to 1350°F. 2
hr. Slow cooled to 1190°
F. Reheated to 1420°F.
and slow cooled. X100.

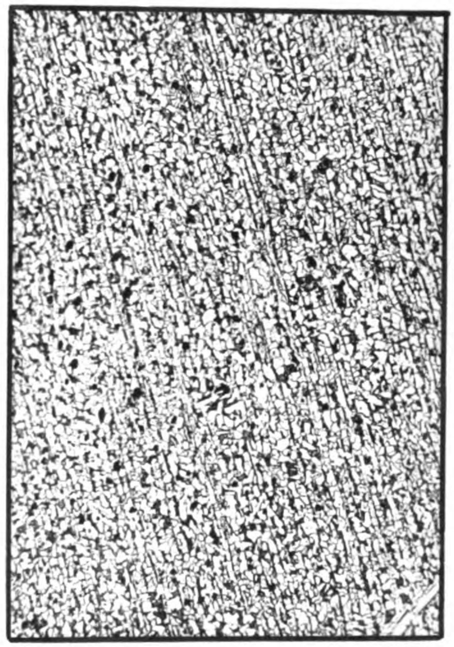
Fig. 40.
Heated to 1390°F
$2\frac{1}{2}$ hrs. and slow
cooled. X100.

Fig. 44.
Original of the stock
which would not draw.
X100.









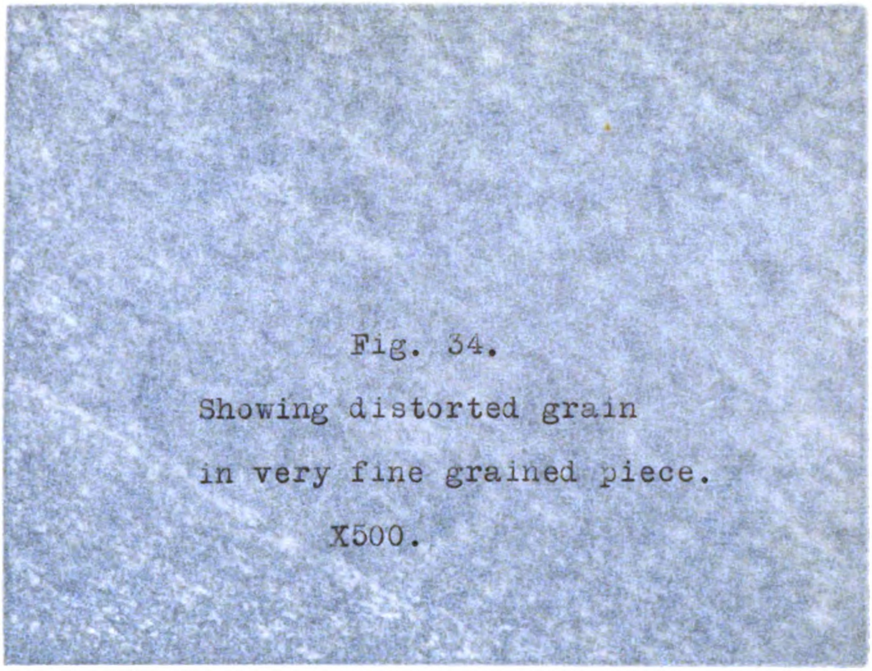
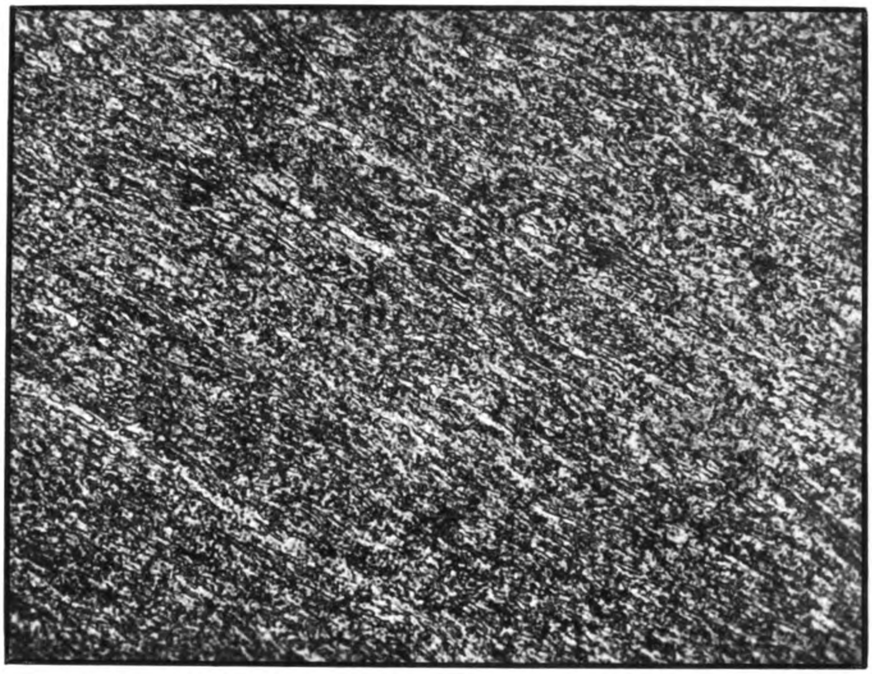
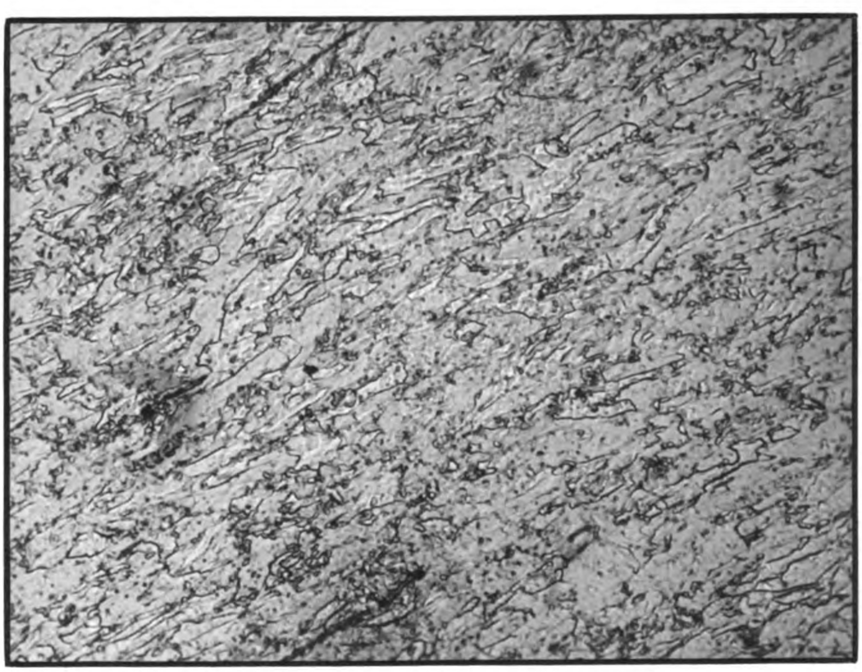


Fig. 34.
Showing distorted grain
in very fine grained piece.
X500.

Fig. 48.
Brine quenched from 1610°F.
Drawn at 1300°F. X500.





and slow cooled resulting in physical properties that were right, but a grain size again too large for a desirable.

The next heat was run endeavoring to obtain a smaller grain through heat treatment alone. Pieces 84 and 85 were heated to 1890°F. for $2\frac{1}{2}$ hours and slow cooled. The photograph is shown in figure 40. Pieces 88 and 89 received the same as 84 and 85 except that they were drawn at 1500°F. There isvery little difference in the physical tests and the grain size differed only slightly. It seemed that by heat treatment alone without quenching a smaller grain could not be obtained.

In the figures 41, 42 and 43 are the curves showing the relation between grain size and the various physical tests. The pieces are designated by the numbers on the curves as follow:

1 --	Piece No. 7	5 --	Piece No. 67
2 --	" " 81	6 --	" " 51
3 --	" " 24	7 --	" " 53
4 --	" " A.R.		

The curve shown in figure 42 showing the relation between depth of draw at maximum load and grain size illustrates that through heat treatment the characteristic of draw depth is improved over that of the hot rolled "as received" stock and with the heat treated pieces the smaller grain demonstrated qualities somewhat better than the larger.

Relation between Depth of Draw at Max. Load & Grain Size as Determined on an Emery Southworth Ductility Machine.

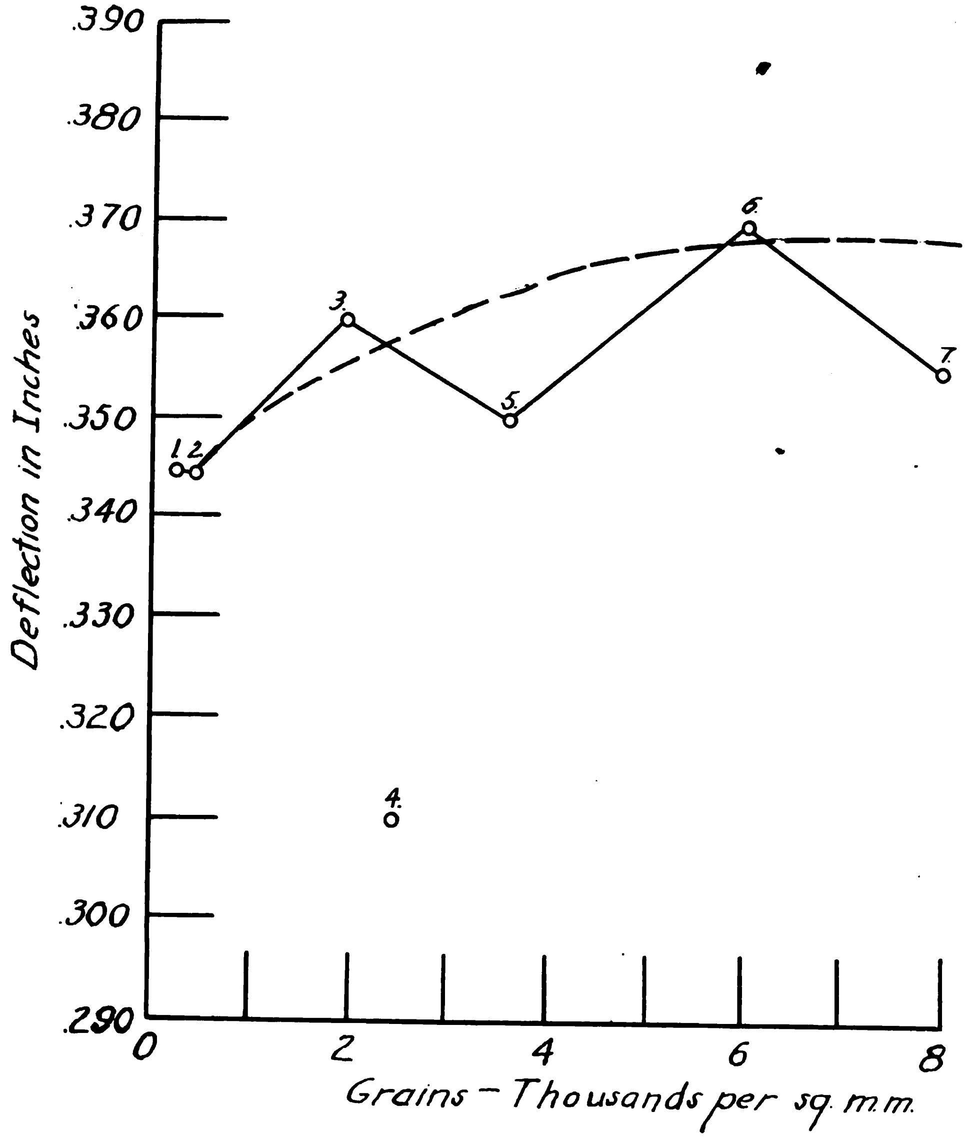


Fig. 41

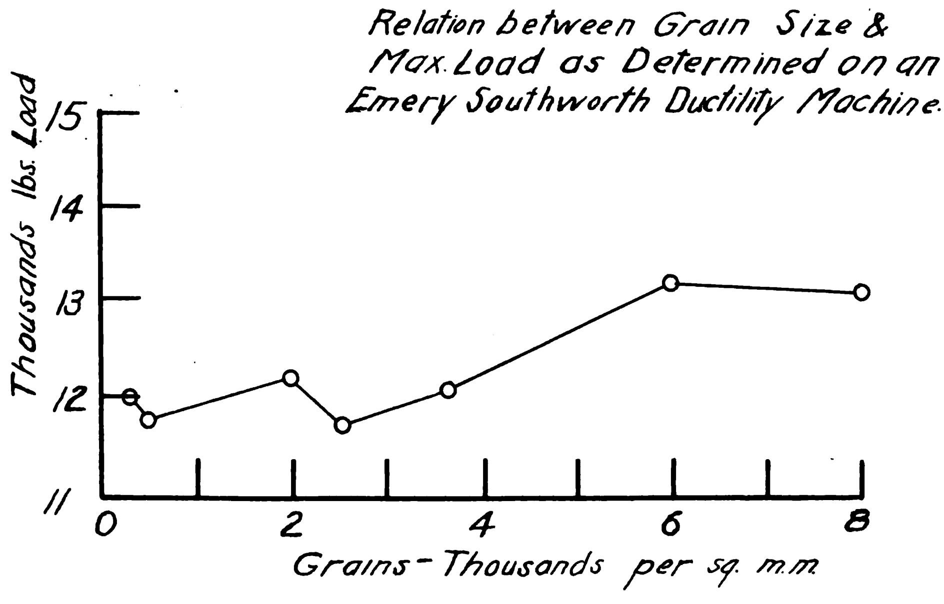

Relation between Grain Size & Max. Load as Determined on an Emery Southworth Ductility Machine.
Thousands lbs. Load
15
14
13
12
11
0
2
4
6
8
Grains - Thousands per sq. m.m.

Fig. 42.

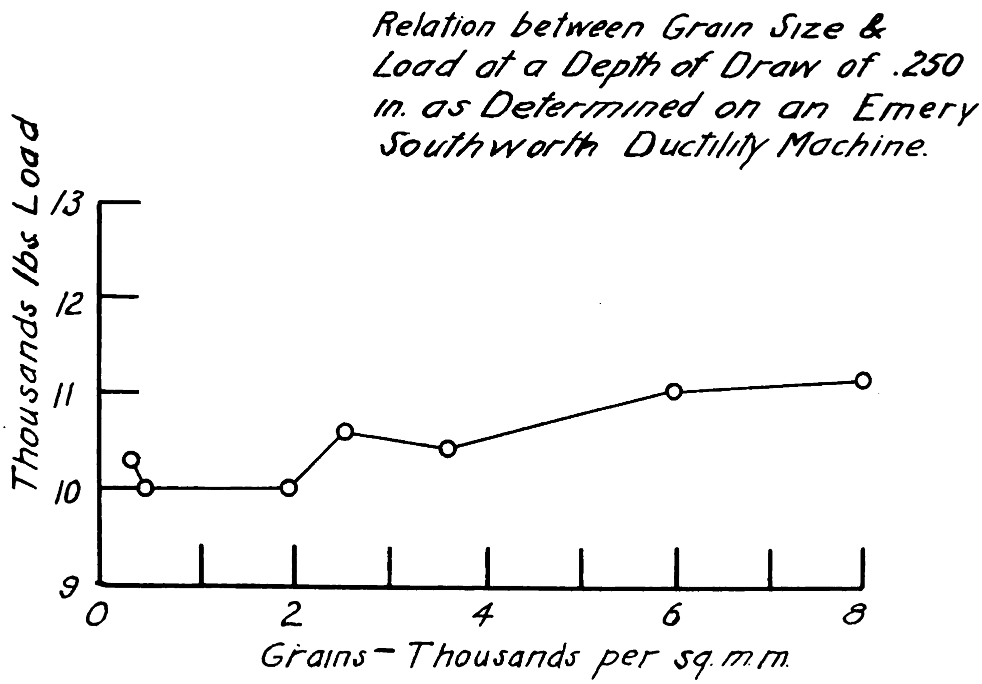

Relation between Grain Size & Load at a Depth of Draw of .250 in. as Determined on an Emery Southworth Ductility Machine.
Thousands lbs Load
13
12
11
10
9
0
2
4
6
8
Grains - Thousands per sq. m.m.

Fig. 43.

In figure 42 giving the relation between grain size and maximum load the grain size seems to be a direct indication of its properties regardless as to whether it is heat treated or not. There is a small gradual rise in the maximum load from the larger to the smaller grains.

Figure 43 shows a curve very similar to figure 42 except that the "as received" piece takes a slight change in position relative to the other points.

CONCLUSION

In drawing conclusions from the work done the curves in figures 41, 42 and 43 are the best indications of the results obtained.

The most important relation in consideration of the cold working properties isfound in figure 41. The maximum deflection is plotted in reference to the grain size and here is founda rather unexpected quality as there is comparatively little difference between the maximum deflection for the different grain sizes in the samples that were heat treated not considering the hot rolled "as received" stock as heat treated pieces. In first considering the pieces that were just heat treated without any quench it was found that the grains had all atained some growth over that of the hot rolled "as received" stock and all the grain sizes ranged at less than 1000 grains per square m. m. The deflection in all cases was found to be very similar, which is as should be considering the comparatively little difference in the heat treatment which they received.

The remaining pieces all received a quench in varying media and were then drawn to or near a normal condition and in these is found some varying results in the deflection at maximum load for the different grain sizes, but it isevident that there is a slight general rise as the grains become smaller.

The hot rolled "as received" stock has a value so far below the pieces referred to that it was not even placed on the curve. The ability of a piece to withstand cold working is evidently effected to a great extent by the condition of strain it is in. In the heat treated pieces the condition present would in all cases be less strained than would be found in the hot rolled state. This condition seems an explanation as to the reason for the very low value of the hot rolled stock shown in figure 41. It seems entirely reasonable not to expect steel in a strained condition to withstand the deformation that steel in an annealed state will.

It is found that the appearance of the draw does not change to a great extent after the grain size has reached approximately three thousand per square m.m. and it may have that smooth fine appearance somewhat b below this size.

The curve shown in figure 42 illustrates the relation between grain size and the load at a deformation of 0.250 inches. This curve showing a fairly regular rise in load as the grain diminishes can hardly be assumed to be an effect produced by grain size alone due to the smaller grains being produced through the quenching and drawing back towards the normal state. In considering the grains above four thousand per square m.m. there is a tendency for the pieces to still contain some indication of the quenching treatment. As has been stated previously these values are an approximate indication of the hardness in most cases and as would be expected, the hardness is higher on pieces which have had a lower draw.

The curve shown in figure 43 showing the relation between the maximum load and grain size is somewhat similar to the preceding curve, however, the rise is more gradual. It seems, nevertheless, another case where an increase in hardness has raised its resistance to deformation for it was found in the sample that the small grain gave a greater Rockwell B value.

The hardness on all the test pieces regardless of heat treatment gave a higher value after cold working. The pieces were ground off to form a slight flat portion at the top of the strained region and the hardness in all cases was found to ninety plus Rockwell B. This hardness is not a duplicate of what conditions would prevail in an actual deep drawing cold working operation as the piece has been strained to the point of fracture, but it is an indication that all the heat treated pieces will harden to some extent after receiving cold work.

It seems obvious from the curves that grain size is a factor in the improving of deep drawing qualities, but the heat treatment necessary to obtain the various grain sizes isalso a large factor in the improved qualities over that of the hot rolled state.

Experimental Work II

This experiment deals with a steel that would not draw and the object was to determine the cause of its condition and attempt to correct the fault.

The original stock, which had an analysis of carbon 0.24% and manganese 0.60% was tested on the ductility machine which indicated its deflection only 0.210 inches at maximum load, which was 14,000 pounds. The Rockwell B hardness was 81 so there appeared from the physical tests to be a number of corrections to be made.

Photographs shown in figure 44 and 45 were taken of the original stock. In figure 44 is shown the severely banded structure and in figure 45 is seen banded structure is pearlite which seems to be drawn out into threads.

The most desirable method of correcting this defective steel is of course by one heat alone. It was not possible to accomplish this as is shown by the following information.

The following data gives the heat treatment and the results of physical tests on the various pieces:

Piece No.	Heat Treatment	Load @ .250 in. Deflec.	Deflec. @ max. Load	Max. Defl.	Max Load	Rock. B.
Original			.210"	.255"	14,000#	81
NG_1	1380° ½H S.C.	15,000#	.250"	.290"	15,100#	79
NG_2	1600° ½H. S.C.	14,300#	.260"	.310"	15,850#	71
NG_3	1610° B.Q. 1460° S.C.	14,900#	.270"	.325"	15,800#	76
NG_4	1900° S.C. 1430° S.C.	13,800#	.320"	.360"	15,300#	61
NG_5	1900° S.C. 1300° S.C.	15,800#	.335"	.430"	17,650#	75

Nomeclature: H - hour, S.C.- slow cooled, B.Q - brine quenched.

From the above data it is evident that the defect must be of a serious nature when such varied and vigorous treatment was necessary to produce qualities that would cold draw. With the piece NG4 shown in figure 46 the qualities are very nearly what a piece should be except that the deflections are not as great as are in a normal piece and the strength seems extremely high. The strength might be desirable in the dies of a press, but the author is of the opinion that the high strength would cause great distortion to the stock due to the resistance that it would offer to being shaped. The piece NG_5 shown in figure 47 hasthe qualities of deflection greater than the preceding piece, but the same

Fig. 46.

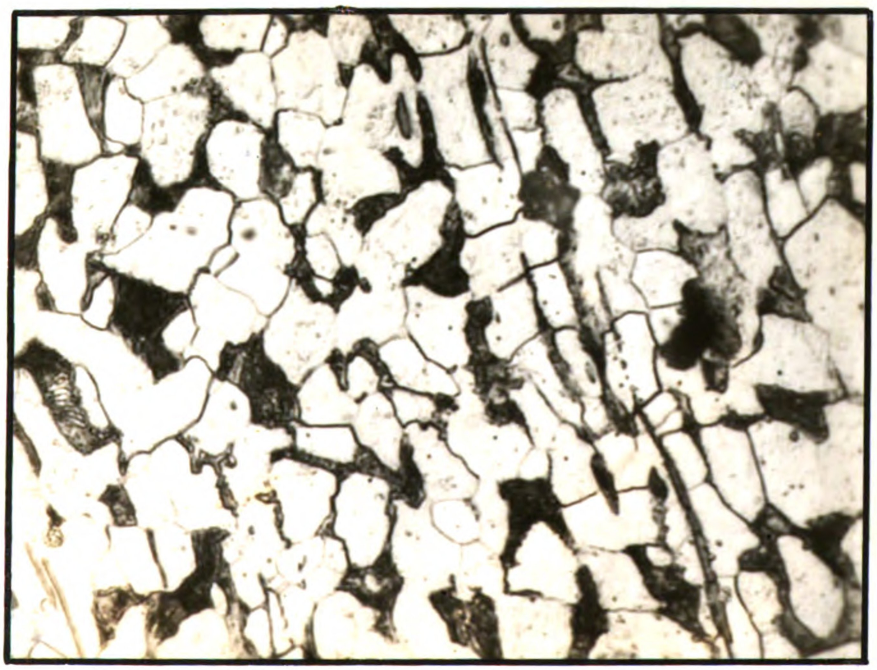
Heated to 1900°F. Slow cooled. Reheated to 1430°F. Slow cooled. X100.

Fig. 47.

Heated to 1900°F. Slow cooled. Reheated to 1300°F. Slow cooled. X100.

Fig. 48

"As received" stock that would not draw. X500.



question enters as to what effect the high strength, and in this case the high hardness, would have when placed between two dies instead of one as is found in the ductility machine.

There seems to be two, perhaps three factors, that might be the cause of the condition of this steel. The manganese content might have an effect in producing the hardness as it is on the upper limit allowed in cold drawing, but a more logical and probable reason is that during the hot rolling operation the temperature was allowed to fall too low. Another factor that had some bearing is the presence of slag. In figure 45 the portions that are drawn out thread-like are slag particles which would also be undesirable, especially when found in the condition shown in the photograph.

If the piece had been hot rolled under favorable conditions it is the author's opinion that the stock would have given fairly satisfactory results on cold regardless of the presence of an excess of slag and the manganese being on the upper limit, but in consideration of the experimental heats tried on the steel "as received" it seems evident that there is no treatment except hot rolling which may be given this steel that would be economically advisable.

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