



109
177
THS

AN INVESTIGATION OF THE EFFECT OF
ANNEALING TEMPERATURES ON
COLD-DRAWN STEEL

THESIS FOR THE DEGREE OF M. S.

Roy A. Gezelius
1930

THESIS

Steel

AN INVESTIGATION OF THE EFFECT
OF
ANNEALING TEMPERATURES
ON
COLD-DRAWN STEEL

An Investigation of the Effect of Annealing
Temperatures on Cold-Drawn Steel

Thesis
Submitted to the Faculty
of
Michigan State College

In Partial Fulfillment
of the
Requirements for a Degree
of

Master of Science

Roy A. Gezelius

August 1, 1930

THESIS

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Prof. H. E. Publow, under whose direction this investigation was carried out, for his assistance and suggestions.

He also wishes to express his appreciation to Albert Schweizes and Milton H. Grams of the Motor Wheel Corporation for their assistance in obtaining material and physical tests.

Introduction

Standardization of steel for cold working, deep-drawing, is a field which has as yet received very little attention from the research workers. It is a field which, if properly investigated, could do a great deal toward cheaper and better production of cold-drawn articles.

There are at present no specifications for steels used for deep-drawing purposes with the exception of chemical analyses within certain limits. It appears that specifications of this kind are not sufficient to insure a uniform product or a steel which will withstand the severe strains to which cold drawn steels are subjected. It has been found by commercial concerns that cold-drawing steels of very nearly identical chemical analyses have, under the same drawing conditions, reacted quite differently. As this is the case, it is logical to assume that the treatment given to the steel before drawing has a marked effect upon the results obtained.

Working upon this assumption, the writer has endeavored to conduct a series of experiments upon cold-drawn steel and upon hot-rolled cold-drawing stock to determine the effect of annealing temperatures upon the reaction of such steels to cold work.

As this investigation was approached from two angles, the change in hardness and the change in ductility, it would be best to review a few of the theories presented to account for hardening.

Jeffries and Archer present the following theory: "Hardness

is resistance to permanent deformation. Metals fail under stresses much below their ultimate strength because they are built up of crystals. Decreasing the size of these crystals will increase the hardness."

Katora Honda attributes hardness to two factors; first, "forces acting between molecules of the substance" and second, "the crystalline structure of the metal". He then goes on to add that "for a given substance having a definite molecular force its hardness increases with the fineness and strained state of the structure."

W. Geiss and Van Liempt declare that there are "two theories as to the mechanism of transformation of metals worked in the cold:

1st (Due to Tamman) That crystals glide over each other in certain characteristic gliding planes.

2nd (Due to Czochralski) That the actual shape of the lattice is distorted.

Lately these theories have merged to a great extent".

In the J. Inst. Metals (1925) H. J. Angus and P. F. Summers tell of an experiment on annealing pieces cold-rolled copper and bronze. "These were annealed at various temperatures up to 1000°In coarse grained copper and bronze a large decrease in hardness results from annealing at 300°, a small increase is obtained after annealing at 150° - 200°."

The work which the writer has conducted will in some instances bear out and in others contradict the theory given above. It has been impossible, in the time allowed, to complete an in-

vestigation of this type. The writer therefore sets forth the results obtained and the conclusions made therefrom as mere hypotheses which may, upon further investigation, prove to be erroneous. It is hoped, however, that a more intensive study of the subject will bear out these experiments and lead to some concrete specifications for cold-drawing steels.

Experimental Work I

A cold-drawn brake-drum, which had fractured upon drawing, was obtained and a microscopical investigation made to determine the cause of breakage. It appeared that the fracture was due to poor stock, as slug inclusions were found. (Figs. 1 and 2) Pieces of this same drum were then annealed for one-half hour at different temperatures, slow-cooled in the furnace and tested upon an Emerson-Southworth Hydraulic Ductility Machine. A marked increase in the amount of deflection at the maximum load shown by the heat-treated pieces as compared with the "as received" pieces led to further investigation along this line.

Four cold-drawn brake drums were selected at random from commercial stock at intervals of approximately two weeks. The braking surface of each drum, which had hardened during the cold-drawing, was removed. This was straightened slowly in a vice to eliminate as much further straining as possible and then cut into test pieces. The Rockwell hardness of each piece was noted and the pieces then annealed at temperatures varying from 1000°F. to 1950°F. being slow cooled in the furnace. The same furnace, automatically controlled, was used throughout all of the experimental work to insure a uniform treatment.

After the annealing process the Rockwell hardness was again noted and the pieces then tested for ductility in the Emerson - Southworth machine. In all tests on this machine readings were taken of the maximum load and the deflection, in inches at the maximum load.

FIG. 1

Fracture showing slag inclusions

X 100

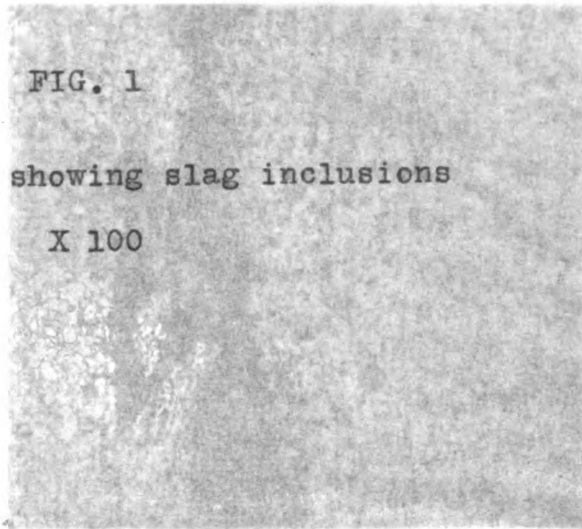


FIG. 2

Same fracture as above.

X 500

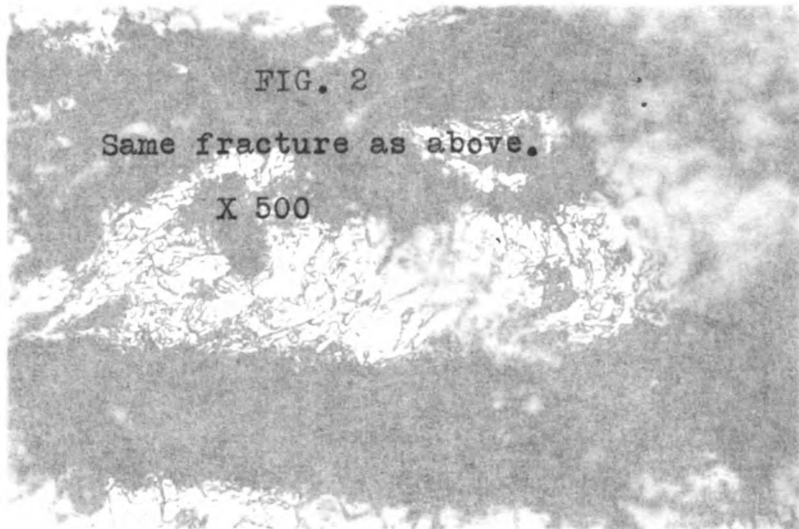


FIG. 1

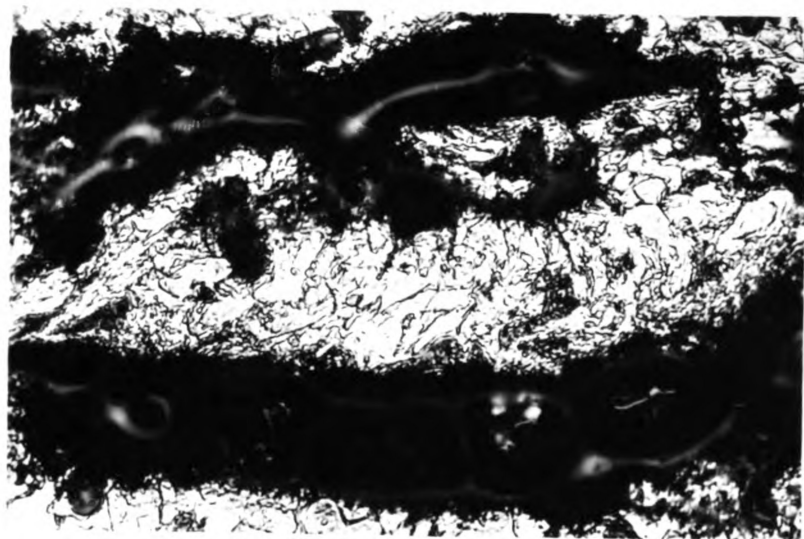
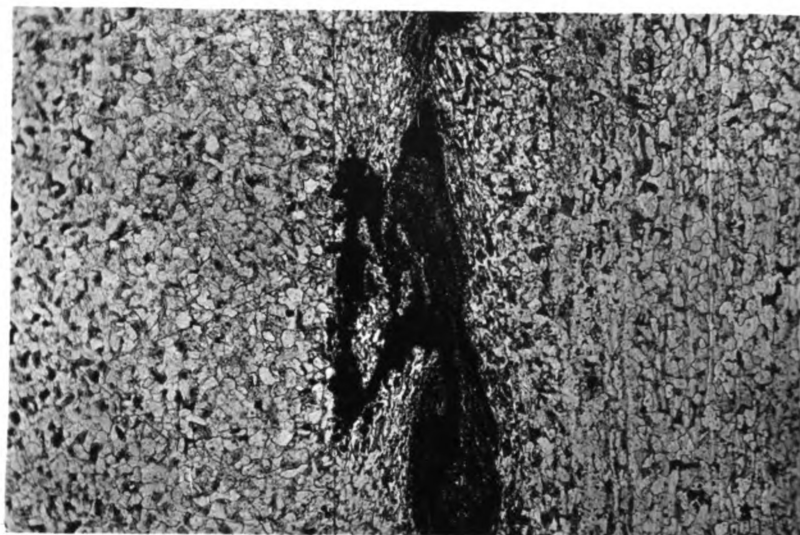
Tractate showing clay incisions

X 100

FIG. 2

Same fracture as above.

X 500



The data obtained by the ductility tests can only be used as an indication of what would happen in actual practice, as the drawing conditions are not the same. In commercial drawing, the steel is pressed between two steel dies to insure the desired shape. In the ductility machine the steel is forced thru a circular hole by a steel ball. There is no die above the steel to hold it to any specified shape. A diagram of the drawing conditions found is shown in Fig.3.

A microscopical investigation was made of the unstrained portions of each piece to determine if there was any relation between the grain size and the hardness or ductility. There appeared to be no difference in micro-structure with the exception of some grain growth at the higher temperatures. (Fig. 4) There was, however, no correlation between the grain size and the hardness or ductility.

An investigation of the condition of the pearlite was then made at higher magnifications. Some small differences in coarseness were found but nothing that could be correlated with the change in hardness or ductility. (Figs. 5 - 16).

Macrographs taken of the pieces, after drawing, show a comparison as to the depth of draw before breakage at different annealing temperatures. (Figs. 17 - 24) It should be noticed that the portions under strain, above the ball, show black strain-lines upon etching with sulphuric acid. A Rockwell test of this portion showed an increase in hardness back to the original hardness.

FIG. 3

Diagram showing a portion of the
Emerson- Southworth Ductility Machine
used in obtaining data for the deflection

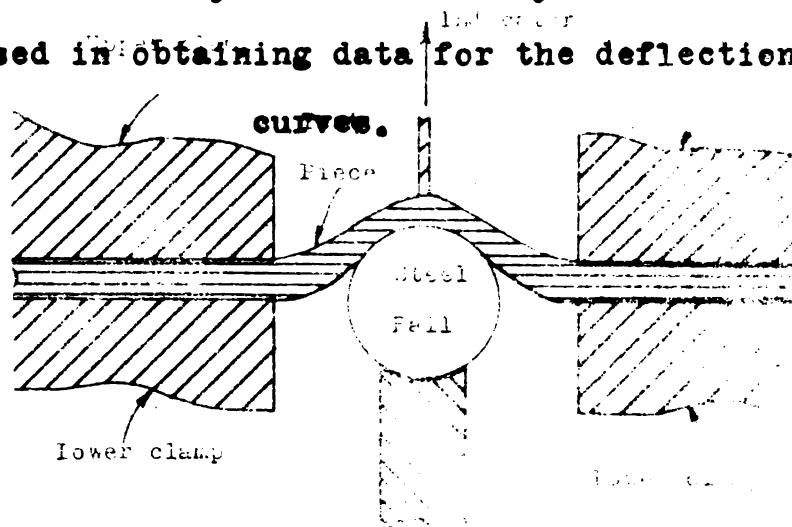
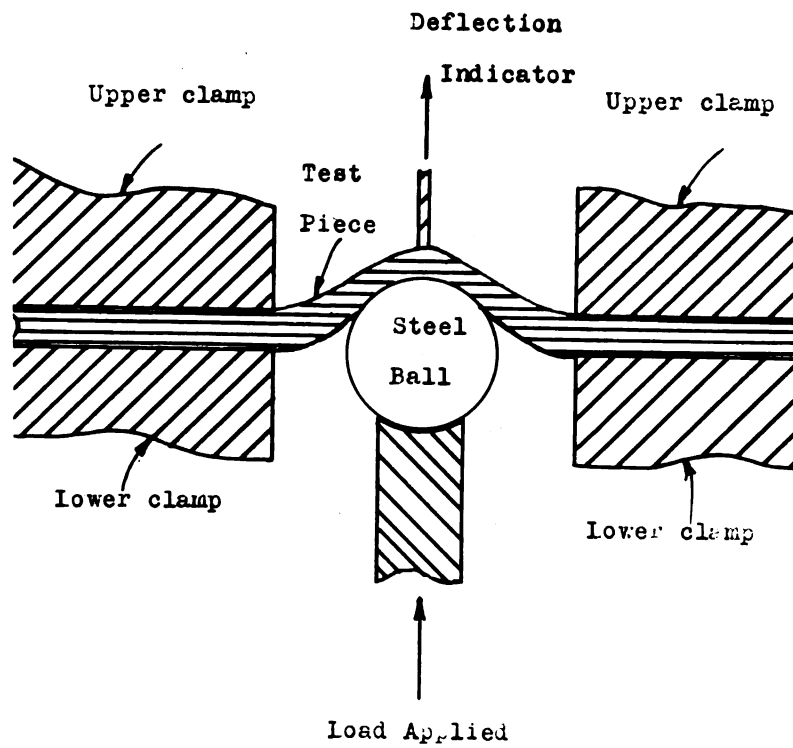
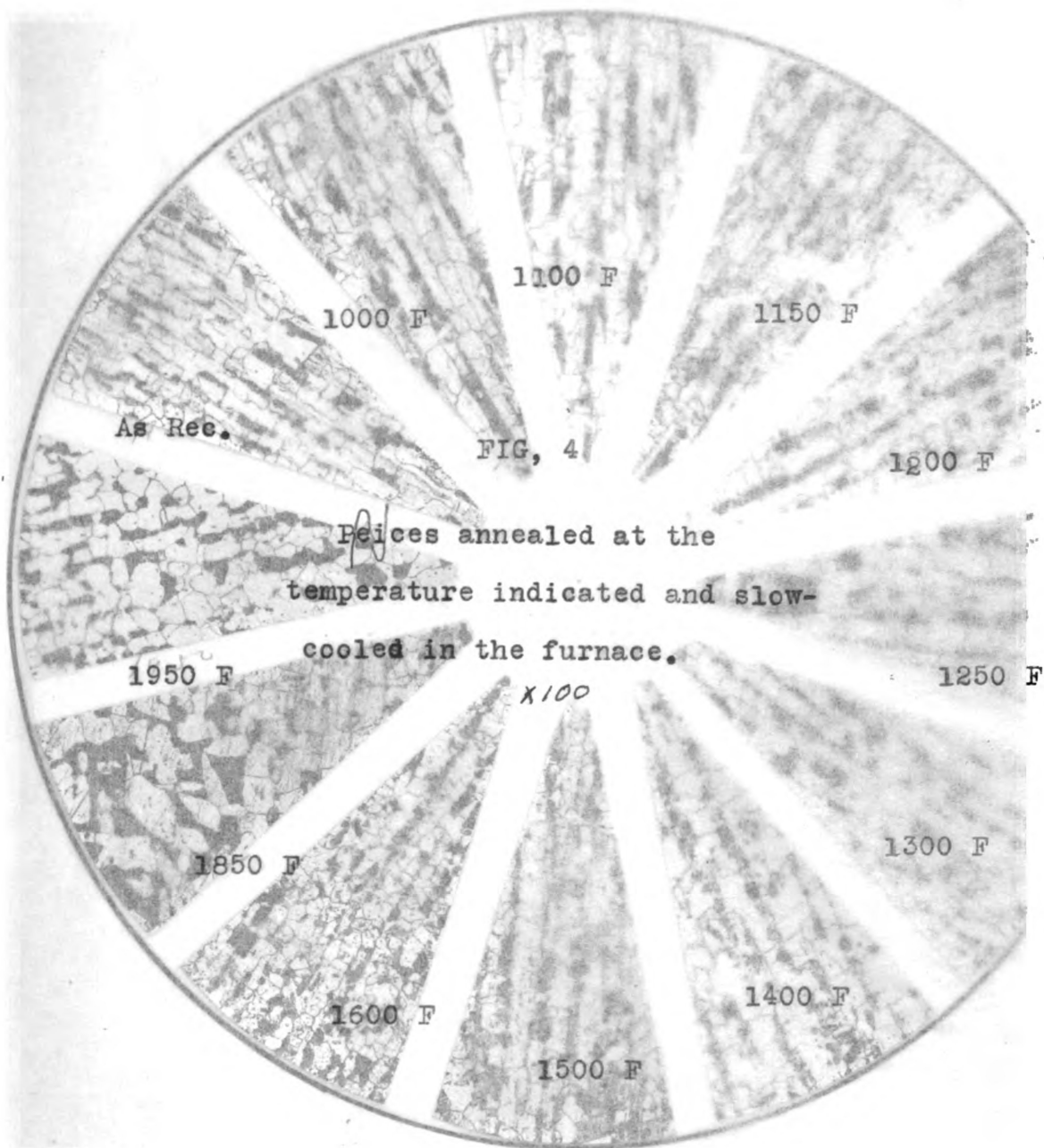


Fig. 3

Diagram showing a portion of the
Emerson-Southworth Rectifying Machine
used in obtaining data for the deflection
curves.

Diagram of a Portion of
the Ductility Machine.





1000 F

1000 F

1000 F

As Rec.

FIG. 4

1000 F

pieces annealed at the
temperature indicated and slow-

cooled in the furnace.

1000 F

1000 F

1000 F

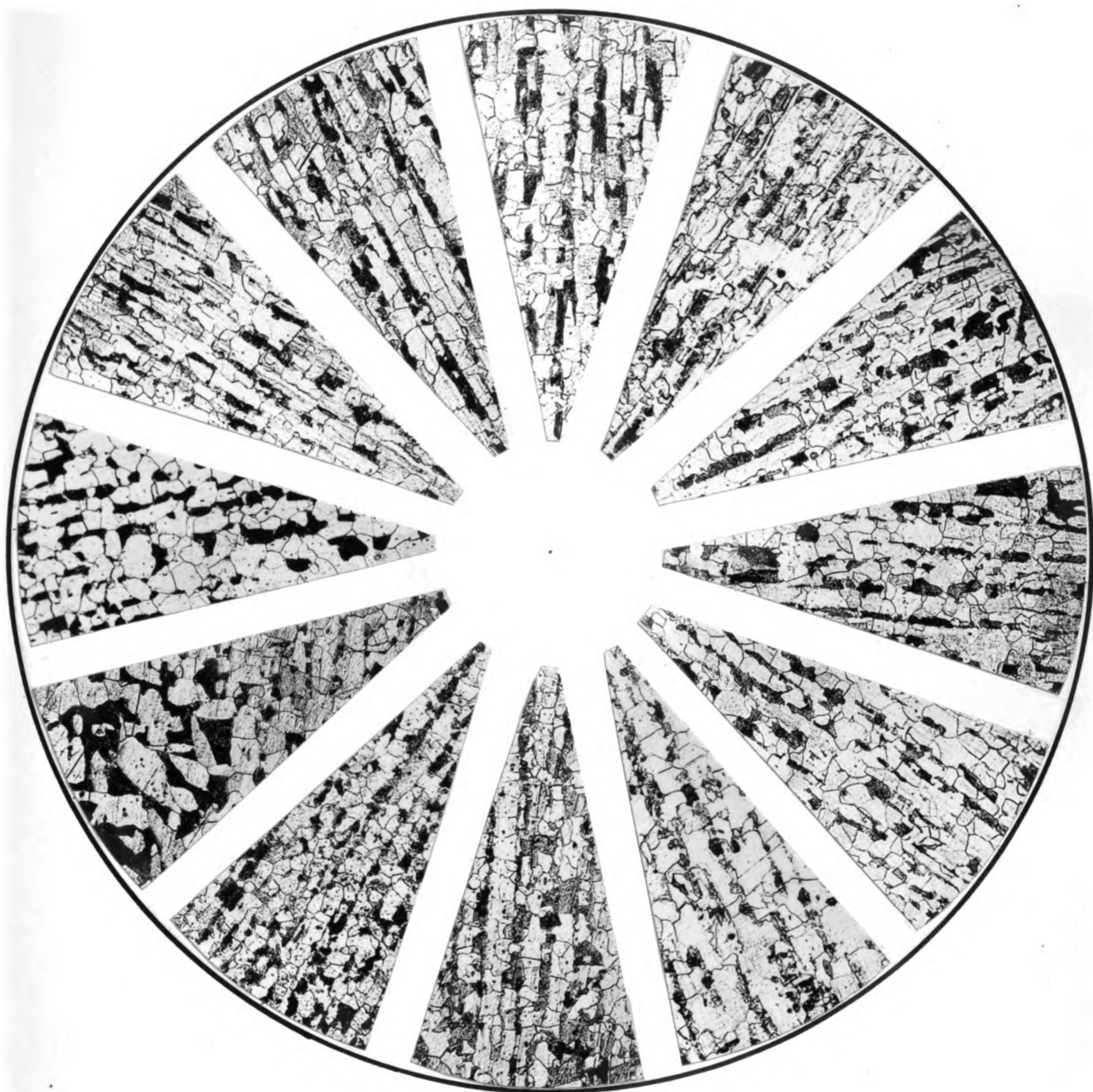
1000 F

1000 F

1000 F

1000 F

1000 F



1000 F

As Rec.

1100 F

FIG. 5

Peices of brake drum annealed at temperature indicated for one-half hour and furnace cooled. X100

1250 F

1150 F

1200 F

1000 F

1100 F

As Rec.

1100 F

pieces of brake drum annealed at temp-

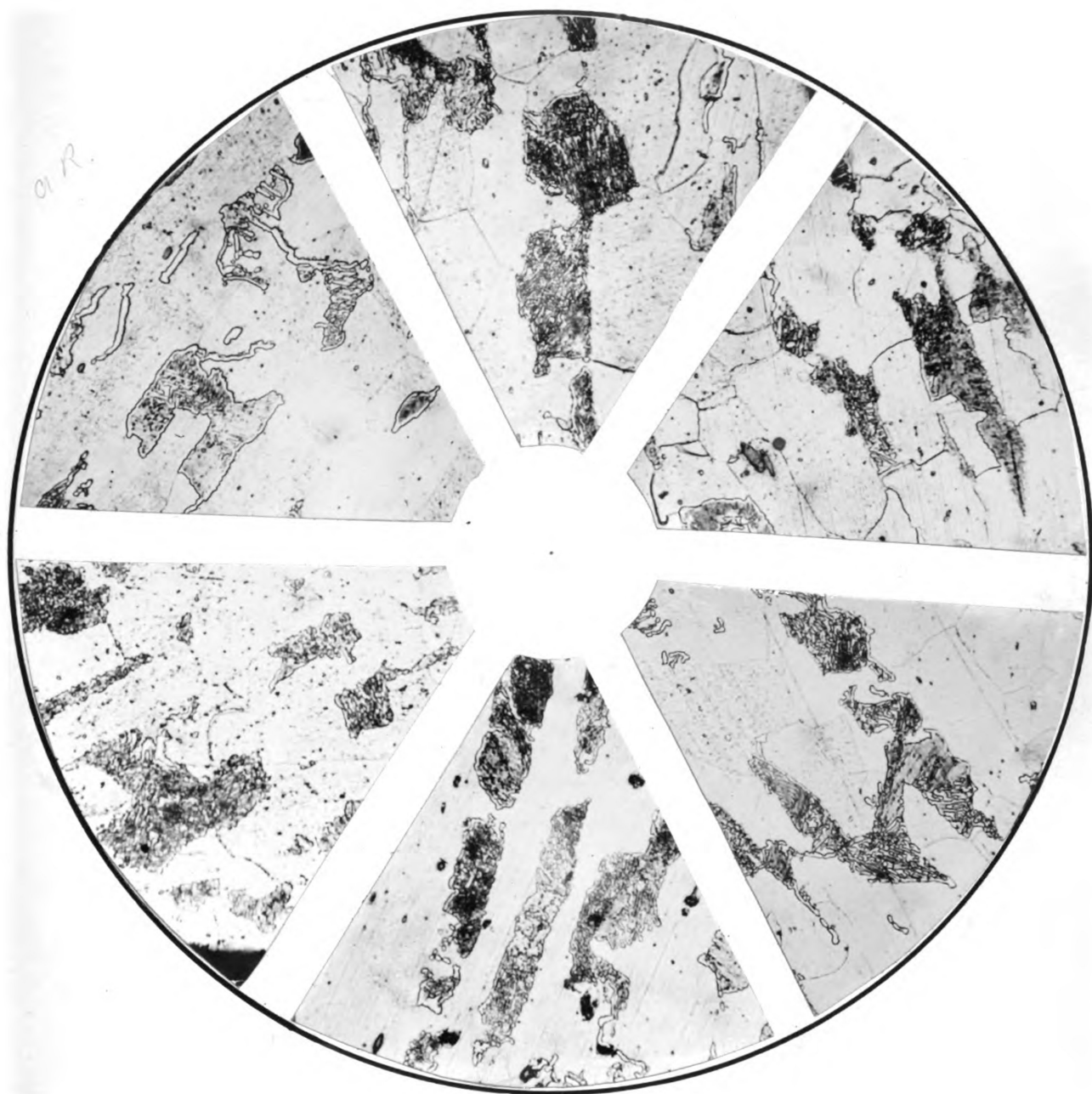
erature indicated for one-half hour and

furnace cooled. 1100

1100 F

1250 F

1300 F



1400 F

1300 F

1500 F

FIG. 6

Continuation of Fig. 5

1950 F

1600 F

1350 F

1880 E

1880 E

1880 E

1880 E

Continuation of 1880 E

1880 E

1880 E

1880 E

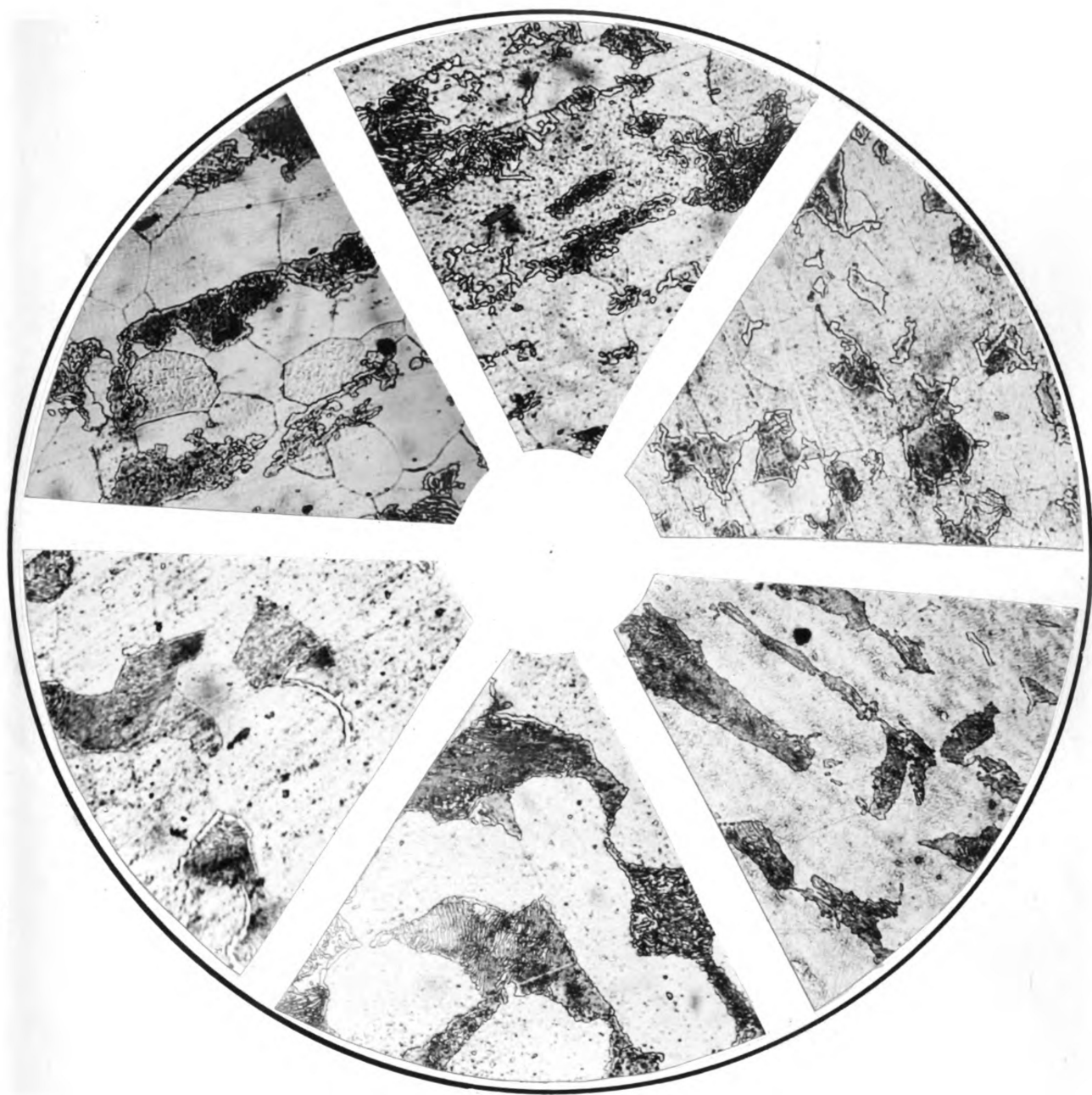


FIG. 7

As Recieved

X 2000

FIG. 8

Annealed at 1000 F

Slow-cooled

X 2000

FIG. 9

Annealed at 1100 F

Slow-cooled

X 2000

FIG. 10

Annealed at 1150 F

Slow-cooled

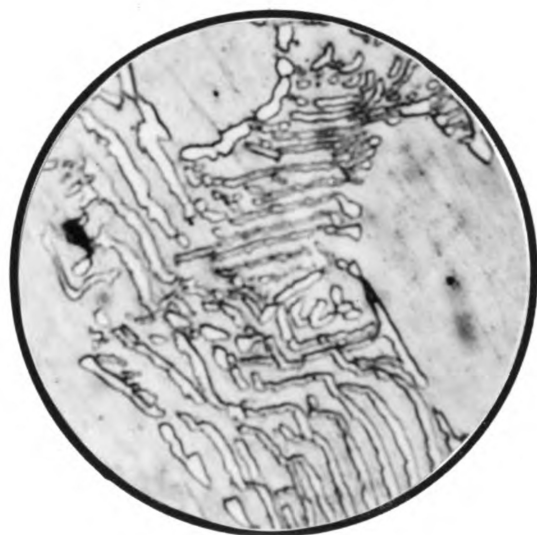
X 2000

FIG. 8
Annealed at 1000 °C
Slow-cooled
X 2000

FIG. 7
As Received
X 2000

FIG. 10
Annealed at 1150 °C
Slow-cooled
X 2000

FIG. 9
Annealed at 1100 °C
Slow-cooled
X 2000



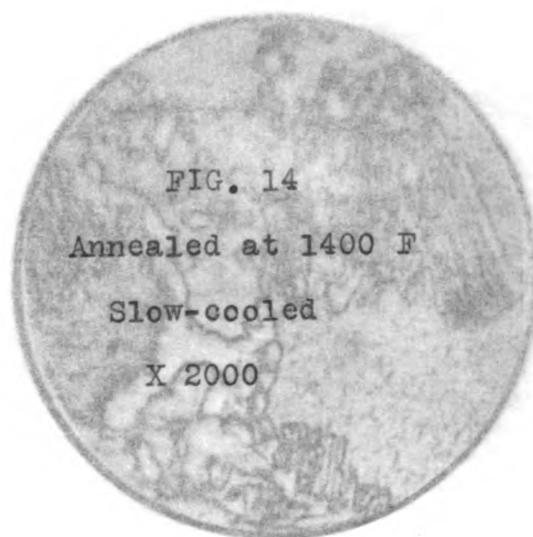
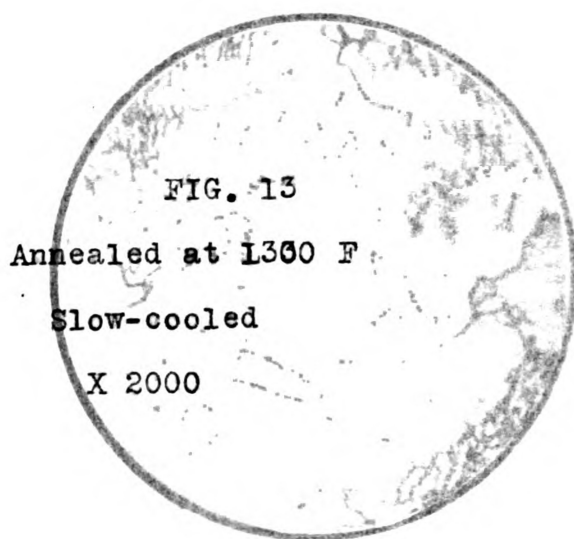


FIG. 11

Annihilated at 1200 E

Slow-cooled

X 2000

FIG. 12

Annihilated at 1200 E

Slow-cooled

X 2000

FIG. 13

Annihilated at 1300 E

Slow-cooled

X 2000

FIG. 14

Annihilated at 1400 E

Slow-cooled

X 2000

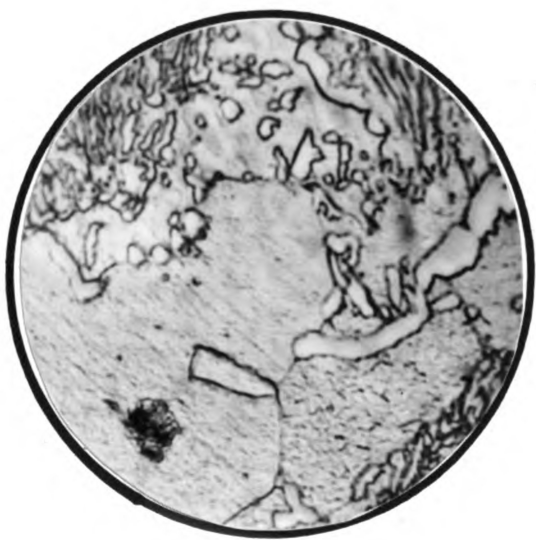
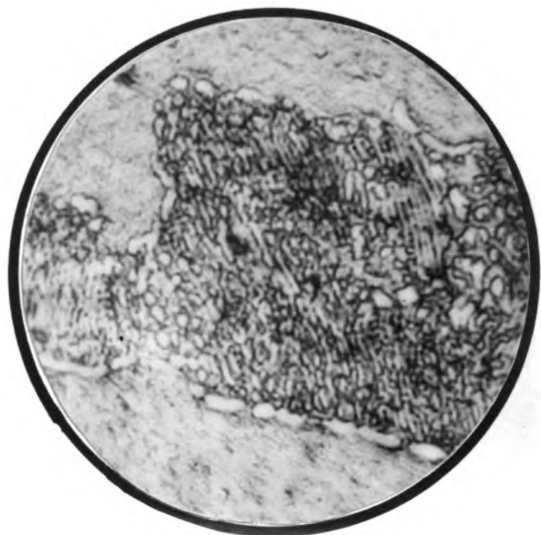


FIG. 15

Annealed at 1500 F

Slow-cooled

X 2000

FIG. 16

Annealed at 1950 F

Slow-cooled

X 2000

85 .517

Annexed at 1830 E

Blow-coiled

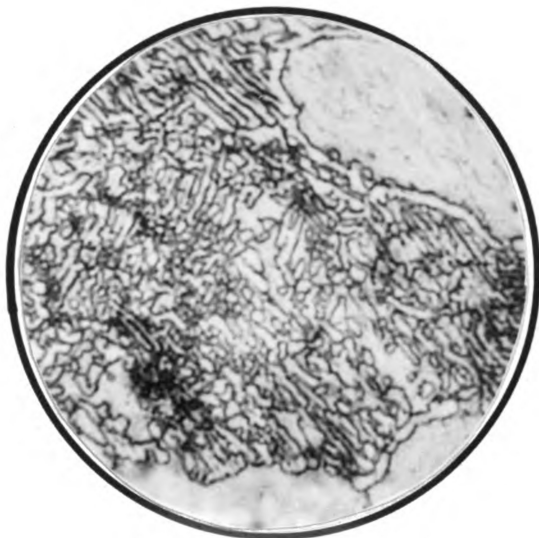
X 2000

85 .517

Annexed at 1830 E

Blow-coiled

X 2000



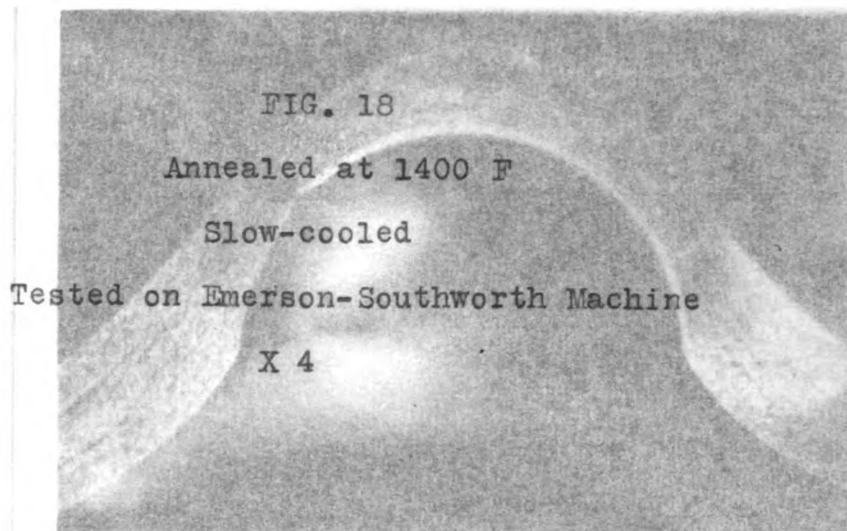
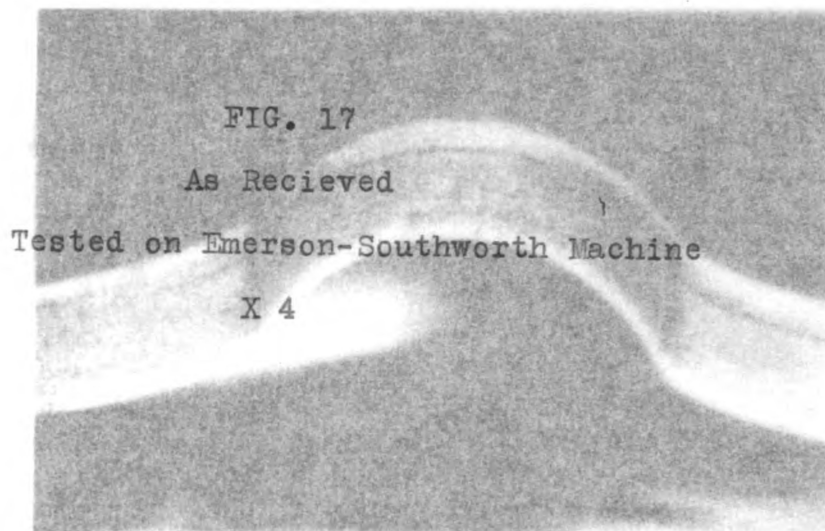


FIG. 17

As Received

Tested on Emerson-Southworth Machine

X 4

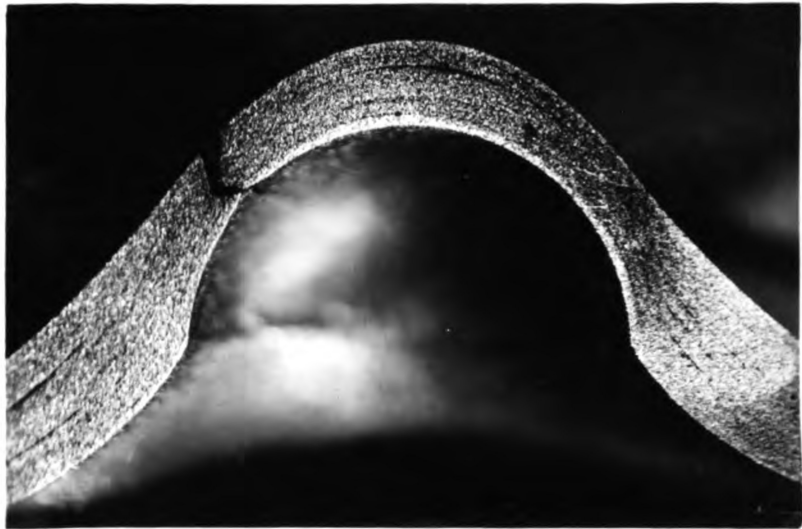
FIG. 18

Annealed at 1400 F

Slow-cooled

Tested on Emerson-Southworth Machine

X 4



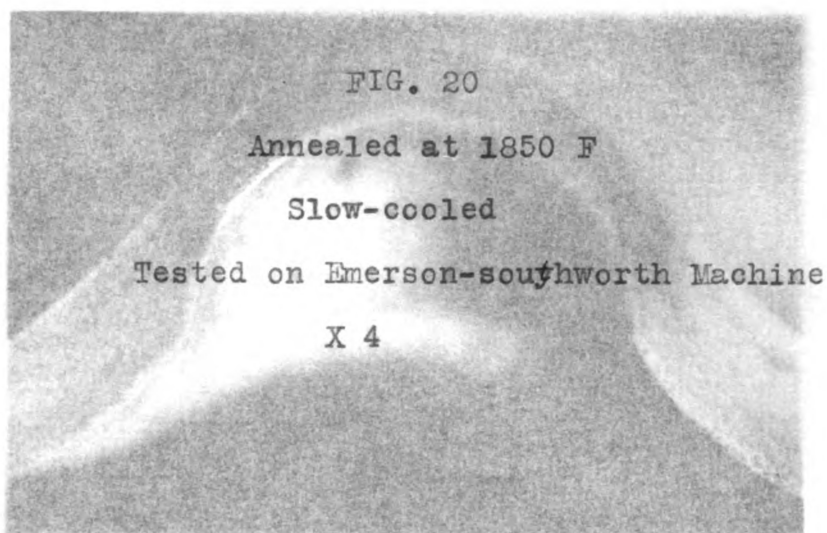
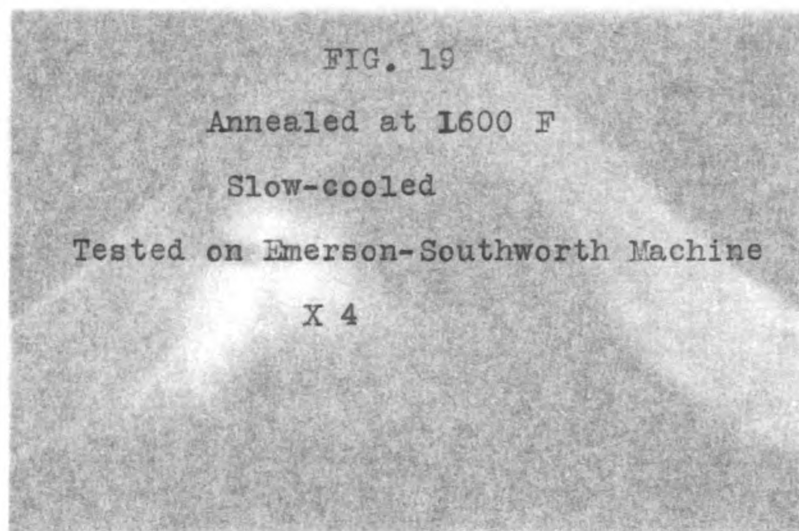


Fig. 1

Amesbury at 1830 E

Slow-cooled

Tested on Amesbury-southwest Machine

X 4

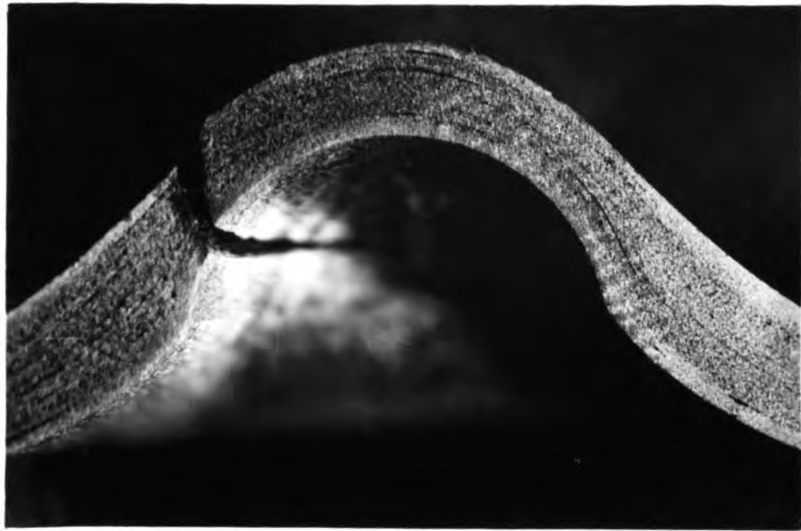
Fig. 2

Amesbury at 1830 E

Slow-cooled

Tested on Amesbury-southwest Machine

X 4



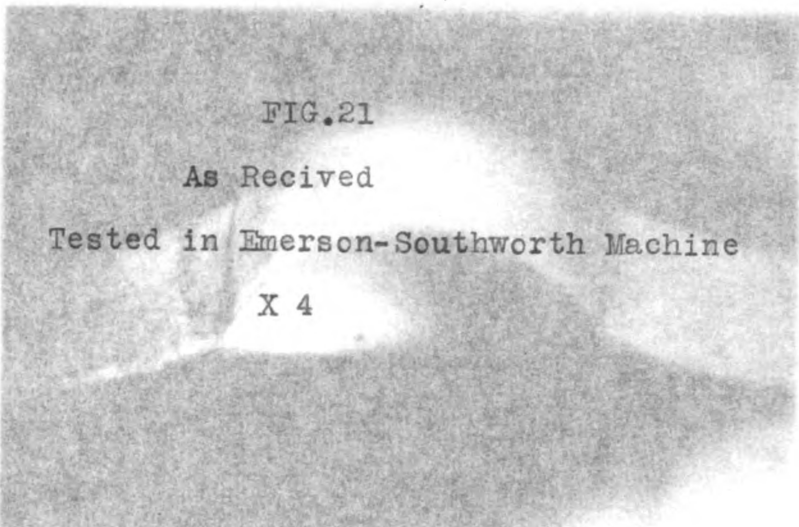


FIG.21

As Recived

Tested in Emerson-Southworth Machine

X 4

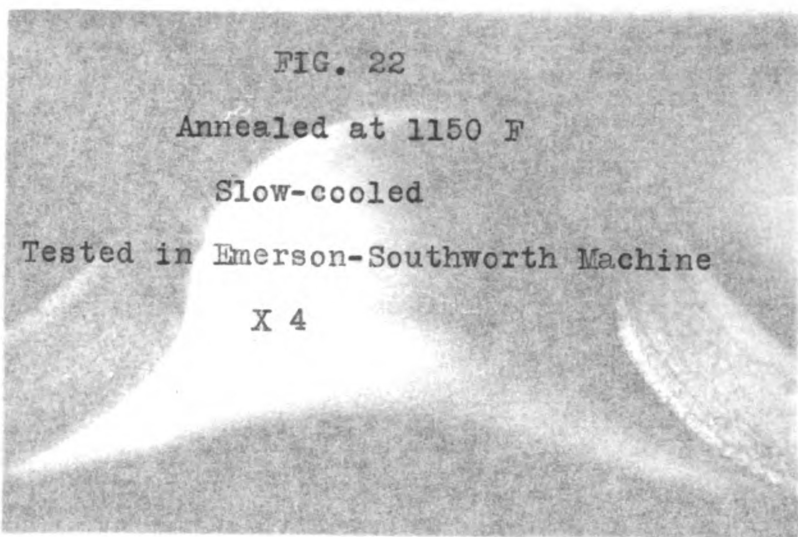


FIG. 22

Annealed at 1150 F

Slow-cooled

Tested in Emerson-Southworth Machine

X 4

EX. 111

As received

Tested in Emerson-Boniforth Machine

X 4

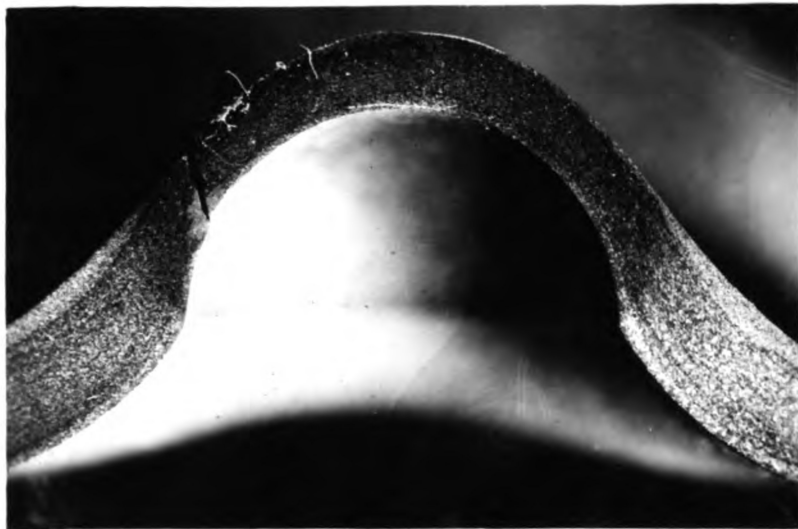
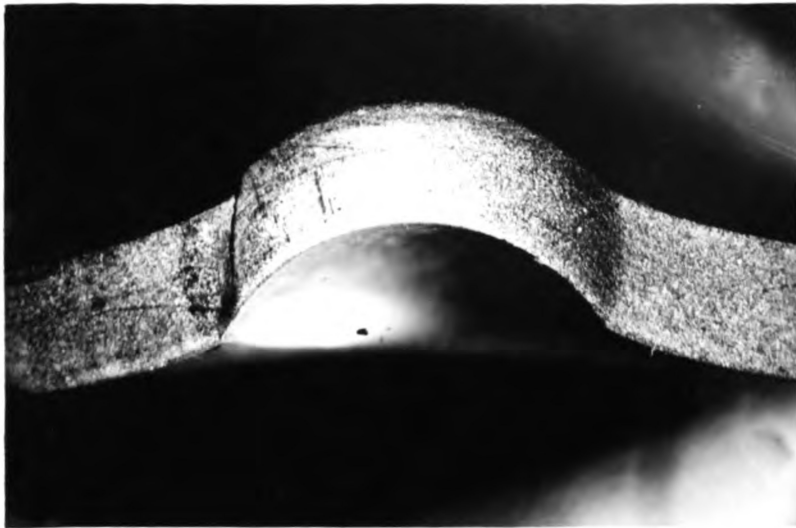
EX. 112

Annealed at 1150 F

Glow-cooled

Tested in Emerson-Boniforth Machine

X 4



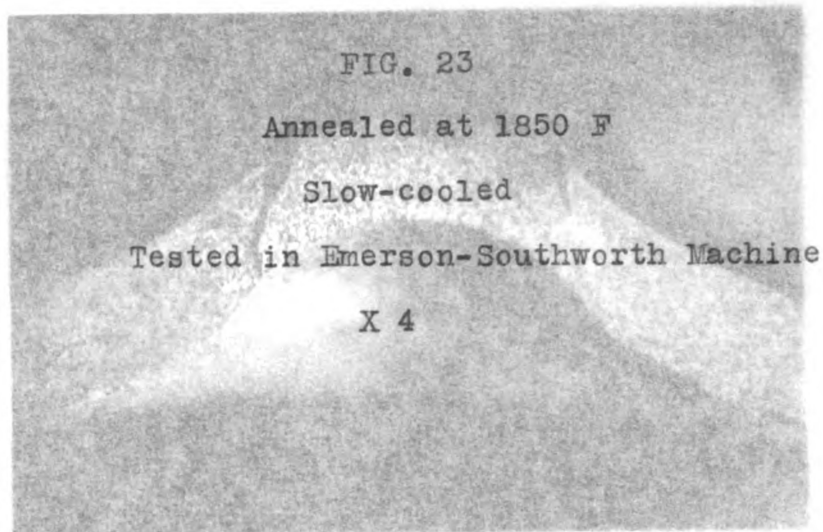


FIG. 24

Comprison of ductility tests
made on Emerson-Southworth Machine

As Rec.	1150 F	1850 F
---------	--------	--------

.....		
-------	-------	-------

Fig. 11

Annealed at 1800 F

Slow-cooled

Tested in Emerson-Southworth Machine

X 4

Fig. 12

Comparison of ductility tests
made on Emerson-Southworth Machine

As Rec. 1150 F 1800 F



There was, however, no correlation between the grain size and the hardness or ductility.

Data

Brake Drum #1

<u>Sample</u>	<u>Rockwell Hardness</u>	<u>Defl. @ Max. Load</u> <u>in inches</u>	<u>Max. Load</u> <u>#/ sq. in.</u>
A. R.	90	.190	8,250
1000	89	.196	8,300
1100	69	---	---
1150	70	---	---
1200	71	.405	10,900
1250	67	---	---
1300	63	.387	11,000
1350	62	---	---
1400	65	---	---

Brake Drum #2

A. R.	63	.342	11,500
1000	63	.352	11,700
1100	63	.385	11,950
1150	60	.383	12,400
1200	58	.372	12,400
1250	54	.365	11,900
1300	60	.385	12,000
1400	63	.372	11,700
1650	65	.366	11,300

Brake Drum #3

<u>Sample</u>	<u>Rockwell Hardness</u>	<u>Defl. @ Max. in inches</u>	<u>Max. Load #/ sq. in.</u>
A. R.	91	.240	7,600
1000	90	.240	8,350
1100	67	.360	10,700
1150	62	.310	11,200
1200	63	.320	11,100
1250	64	.369	12,600
1300	59	.355	12,000
1400	59	.368	10,800
1500	65	.360	11,700
1600	69	.340	11,950
1850	62	.365	12,100
1950	65	.205	4,900

Brake Drum #4

A. R.	90	.180	9,200
1000	89	.180	9,300
1100	72	.323	11,100
1150	67	.329	12,300
1200	60	.380	11,900
1250	59	.395	12,300
1300	58	.370	10,800
1400	58	.370	11,600
1500	62	.360	11,600
1600	62	.325	10,900
1850	65	.360	11,300
1950	68	.230	12,100

Brake Drum #5

<u>Sample</u>	<u>Rockwell Hardness</u>	<u>Defl.@ Max.Load</u>	<u>Max. Load</u>
A. R.	85	.170	9,000
1000	82	.180	10,000
1100	65	.210	8,500
1150	59	.360	11,400
1200	60	.230	8,000
1250	57	.365	11,250
1300	55	.240	7,900
1400	60	.230	7,500
1500	62	.235	7,300
1600	66	.170	5,600
1850	68	.200	7,000
1950	65	.205	5,500

Experimental Work II

A study of the effect of annealing temperatures upon the cold-drawing properties of hot-rolled stock was also made. The Rockwell hardness of several pieces was noted and the pieces annealed for one-half hour at temperatures varying from 1000°F. to 1950°F. and slow-cooled in the furnace. The Rockwell hardness was then again noted. Considerable difficulty was encountered in getting comparable Rockwell readings in this experiment, due to irregularities in the stock used. This difficulty was overcome in the following manner. Two pieces were run in each heat and the change in hardness of each noted. An average "original hardness" was computed and the average change in hardness for each heat added, or subtracted, to this to obtain a value which could be plotted.

The same care was exercised in obtaining deflection readings, the average deflection for each heat being used.

In this case, as well as in the previous one, care was taken that the heating-rate, cooling rate and all other conditions should be identical for each run.

The shape of the draw obtained in the ductility machine seemed to depend a great deal upon the annealing temperature. The "as received" pieces drew out very thin and became balloon-shaped. This continued until an annealing temperature of 500°F. -600°F. was reached when a smooth draw with very little decrease in thickness was obtained. This type of draw continued thru the remainder of the range of annealing temperature.

Data

<u>Sample</u>	<u>A. R.</u> <u>Hardness</u>	<u>H. T.</u> <u>Hardness</u>	<u>Diff. in</u> <u>Hardness</u>	<u>Average</u> <u>Difference</u>	<u>Plotted</u> <u>Value</u>
A. R.	60	--	--	---	
	61	--	--	--	60
200	64.25	64.625	+ .375		
	63.0	63.5	+ .5	+ .4275	60.4
300	63.0	63.875	+ .875		
	62.75	64.375	+1.625	+1.25	61.25
400	62.1	61.5	- .6		
	60.0	62.5	+2.5	+ .95	60.95
500	60.0	62.125	+2.125		
	57.0	60.875	+3.875	+3.0	63
600	62.0	64.0	+2.0		
	60.5	65.75	+5.25	+3.625	63.625
700	61.0	63.0	+2.0		
	55.0	63.0	+8.0	+5.0	65
800	63.0	69.0	+6.0		
	58.0	63.625	+5.6	+5.8	65.8
900	63.0	67.25	+4.25		
	46.0	61.5	+5.5	+4.875	64.875
10005	59.0	65.0	+6.0		
	59.0	63.0	+4.5	+5.0	65
1100	56.0	61.5	+5.5		
	55.0	62.0	+7.0	+6.25	66.25
1150	58.0	62.0	+4.0		
	58.0	62.0	+4.0	+4.0	64
1200	61.0	65.0	+7.0		
	62.0	66.0	+4.0	+4.0	64

<u>Sample</u>	<u>A. R. Hardness</u>	<u>H. T. Hardness</u>	<u>Diff. in Hardness</u>	<u>Average Difference</u>	<u>Plotted Value</u>
1250	59.0	62.0	+3.0		
	56.0	62.0	+6.0	+4.5	64.5
1300	56.0	59.5	+3.5		
	59.0	62.5	+3.5	+3.5	63.5
1400	57.0	60.8	+3.8		
	62.0	63.0	+1.0	+2.4	62.4
1500	62.0	62.5	+ .5		
	56.0	57.0	+1.0	- .75	60.75
1600	56.0	57.	+1.0		
	59.0	57.25	-1.75	-3.75	59.625
1850	60.0	62.0	+2		
	58.0	57.75	- .25	- .875	60.875
1950	59.9	56.0	-3.		
	54.0	57.25	+3.25	+1.25	61.25

Sample	Draw Tests Hot-Rolled Stock		Aver.
	Max.Load #/ sq.in.	Defl. @ Max.Load in inches	
A. R.	11,900	.327	
A. R.	11,950	.318	.321
200	11,650	.322	
	11,750	.315	.318
300	11,700	.318	
	11,650	.322	.320
400	11,850	.324	
	11,600	.315	.319
500	11,600	.320	
	11,900	.322	.321
600	11,900	.325	
	12,600	.365	.345
700	11,800	.340	
	11,800	.330	.335
800	12,400	.360	
	12,200	.340	.350
900	12,250	.360	
	13,700	.365	.362
1000	12,600	.345	
	12,200	.340	.342
1100	13,350	.360	
	13,200	.353	.356
1150	13,100	.360	
	12,600	.350	.355
1200	14,700	.383	
	14,400	.370	.376

<u>Sample</u>	<u>Max. Load #/ sq. in.</u>	<u>Defl. @ Max. Load In inches</u>	<u>Aver.</u>
1250	13,700	.365	
	13,000	.374	.369
1300	12,900	.365	
	12,400	.351	.353
1400	11,400	.346	
	11,800	.344	.345
1500	12,300	.358	
	11,500	.344	.351
1600	12,000	.357	
	11,700	.352	.354
1850	10,900	.329	
	11,800	.330	.329
1950	11,600	.358	
	10,400	.355	.356

Results

An examination of the hardness curves (Figs. 26-30) obtained shows that the reaction of all of the hardened steels to heat-treatment is apparently the same. All of the curves have about the same general shape.

The annealing temperatures for the first two drums were only carried to what was considered a full annealing temperature. It was only by experimenting that it was found that changes occurred above this point and that the temperatures should be carried higher.

The strains due to cold-working are, to all appearances, removed just above 1000°F. as there is a marked softening at this point. The steel continues to soften thru 1150°F. - 1200°F. and then hardens. A second softening reaction follows with a maximum softness being reached at 1300°F. and then a hardening effect again takes place.

The variation in hardness is not great, being about five points Rockwell, but is consistent and found in all pieces examined at about the same points.

The first change in hardness could not be due to transformation at the critical point but the rehardening effect began in the neighborhood of the AC point.

In the deflection curves (Figs. 31-34) the same trend is found with a marked increase in ductility above 1000°F. A maximum deflection is reached at 1150°F. - 1200°F. with a subsequent falling off and then an increase as in the hardness curves. The curves did not exactly coincide for temperature, but if the mean hardness and mean deflection curves are compared (Fig. 35) it will be noted that there is a great deal of correlation. The

FIGS. 26-30 inclusive

Curves showing the relation between
annealing temperatures and Rockwell hardness.

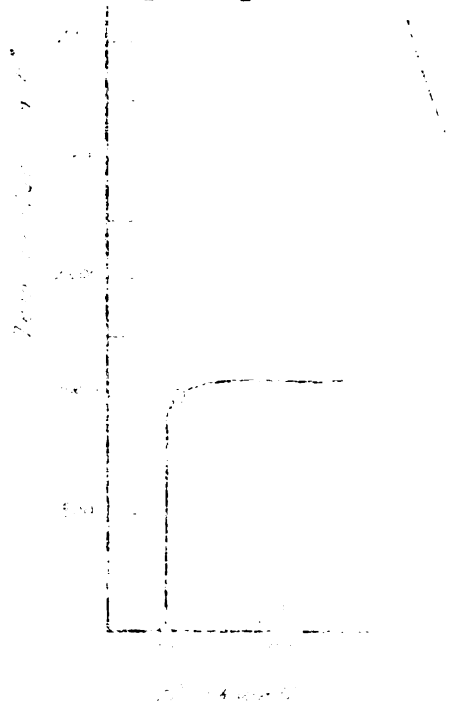
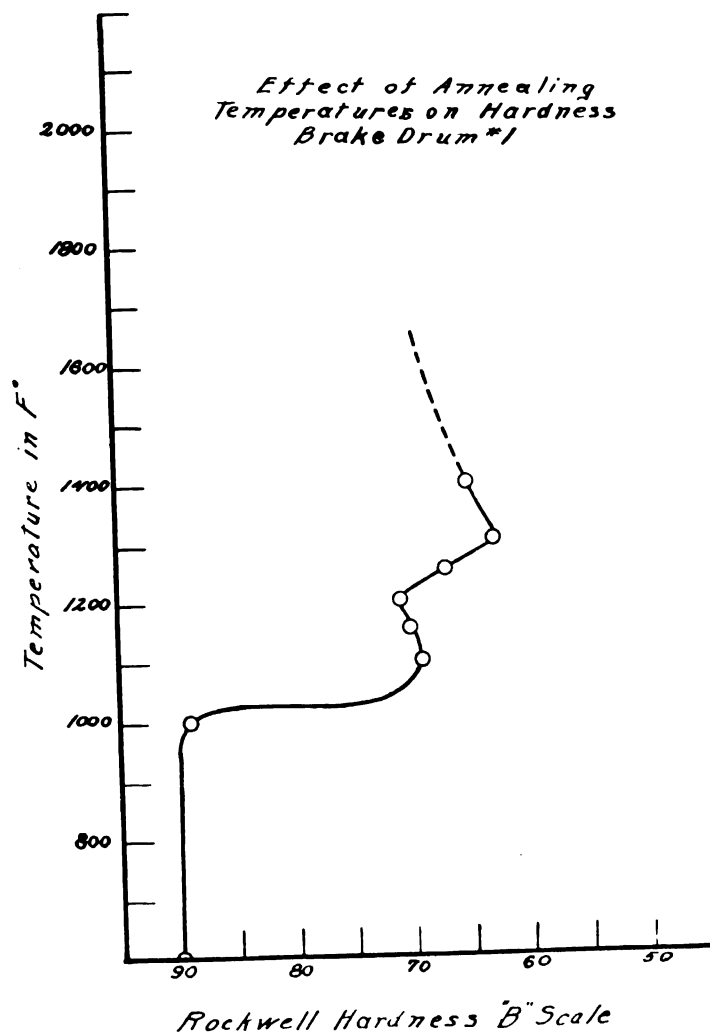
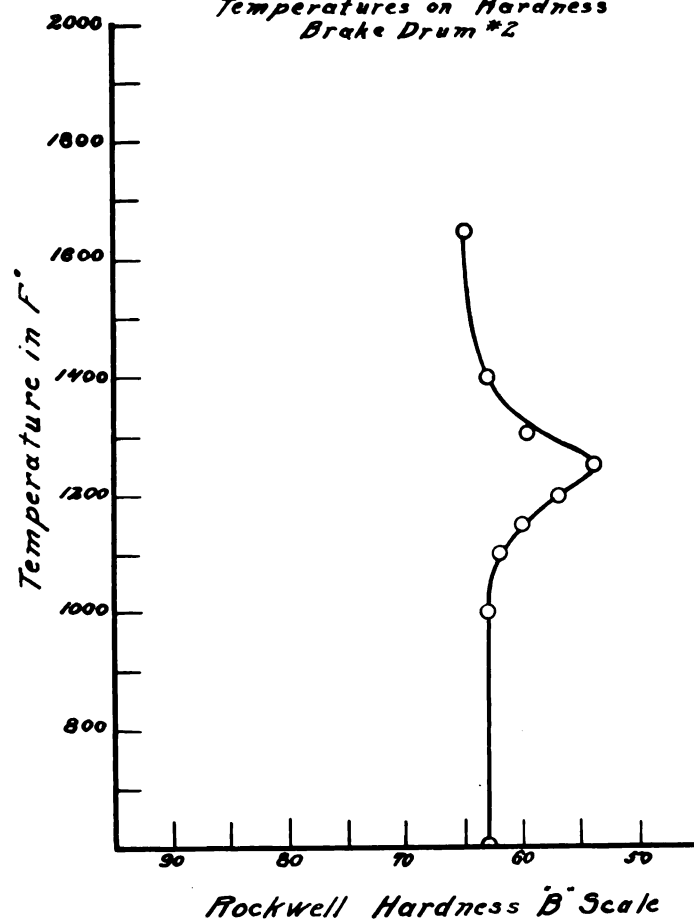


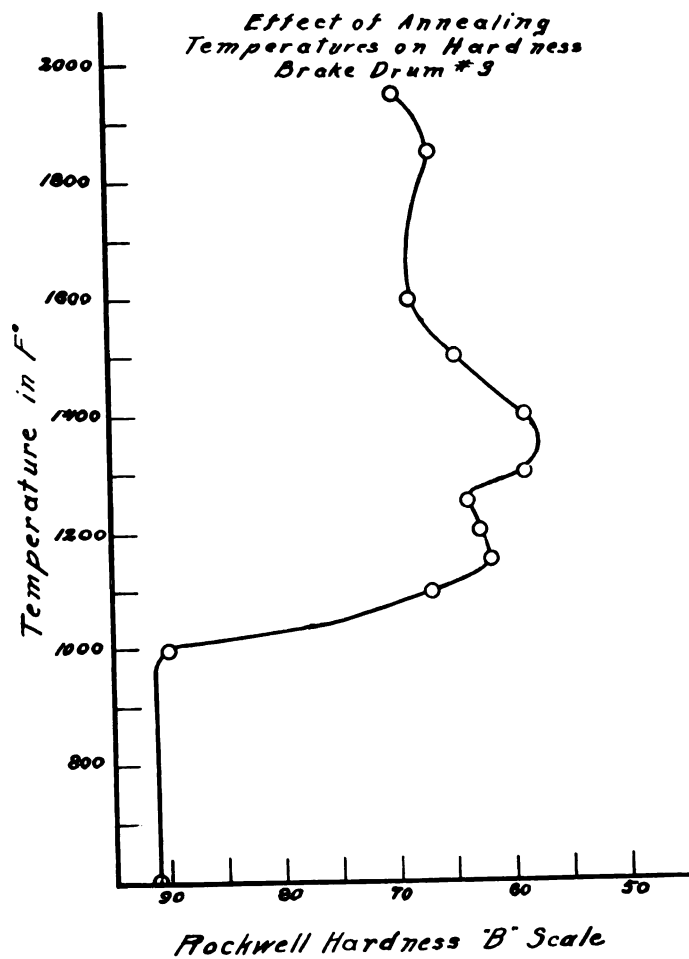
FIG. 26-30 inclusive

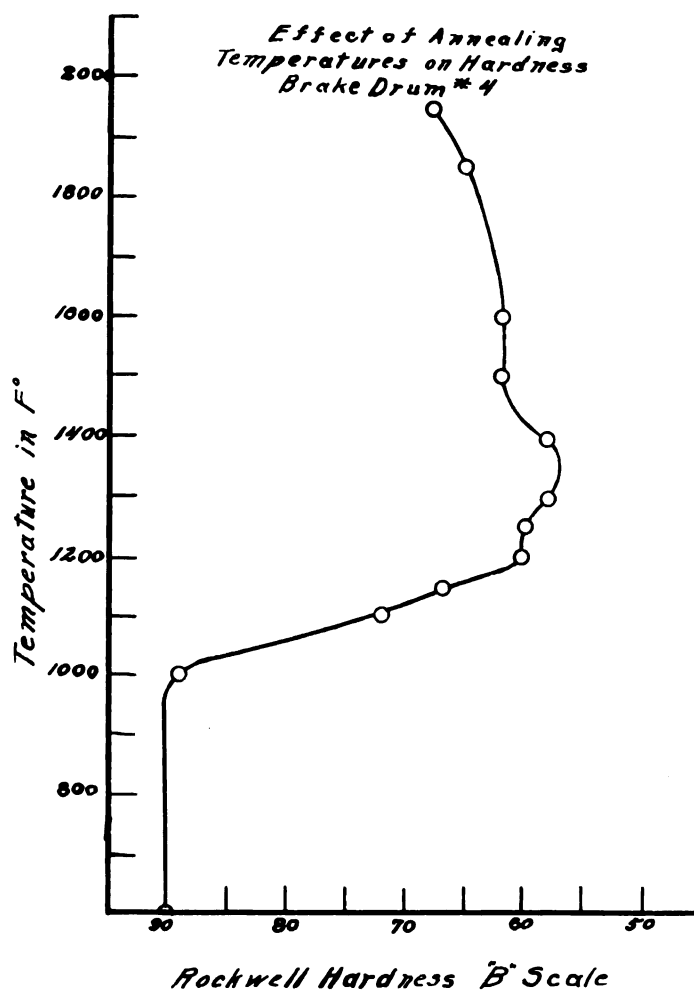
Curves showing the relation between
annealing temperature and Rockwell hardness.

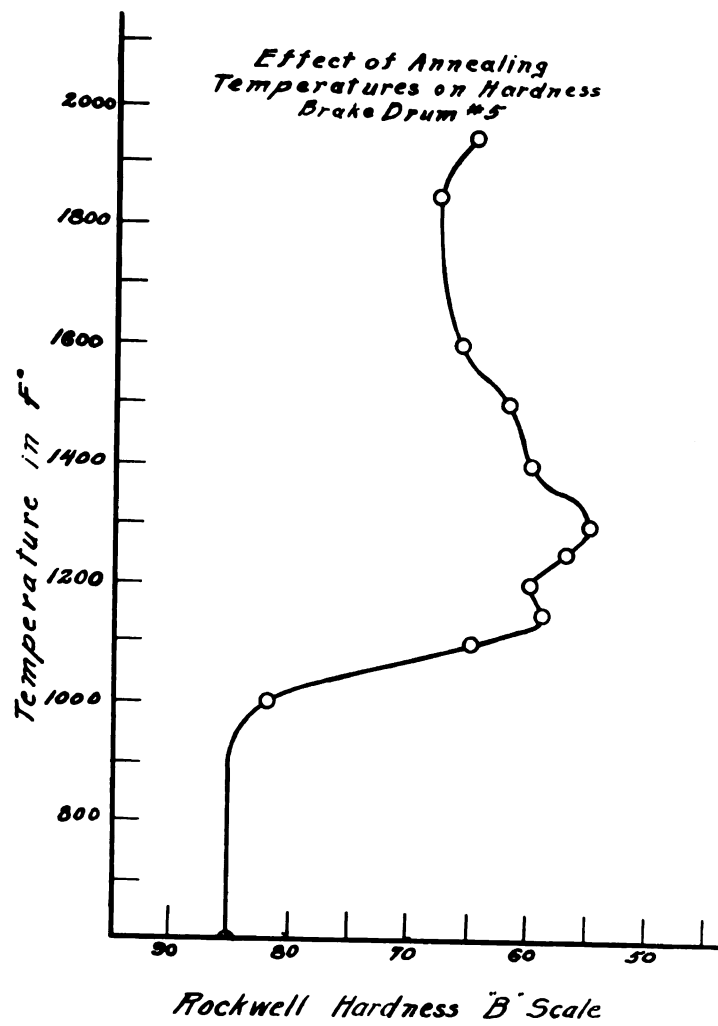


*Effect of Annealing
Temperatures on Hardness
Brake Drum #2*



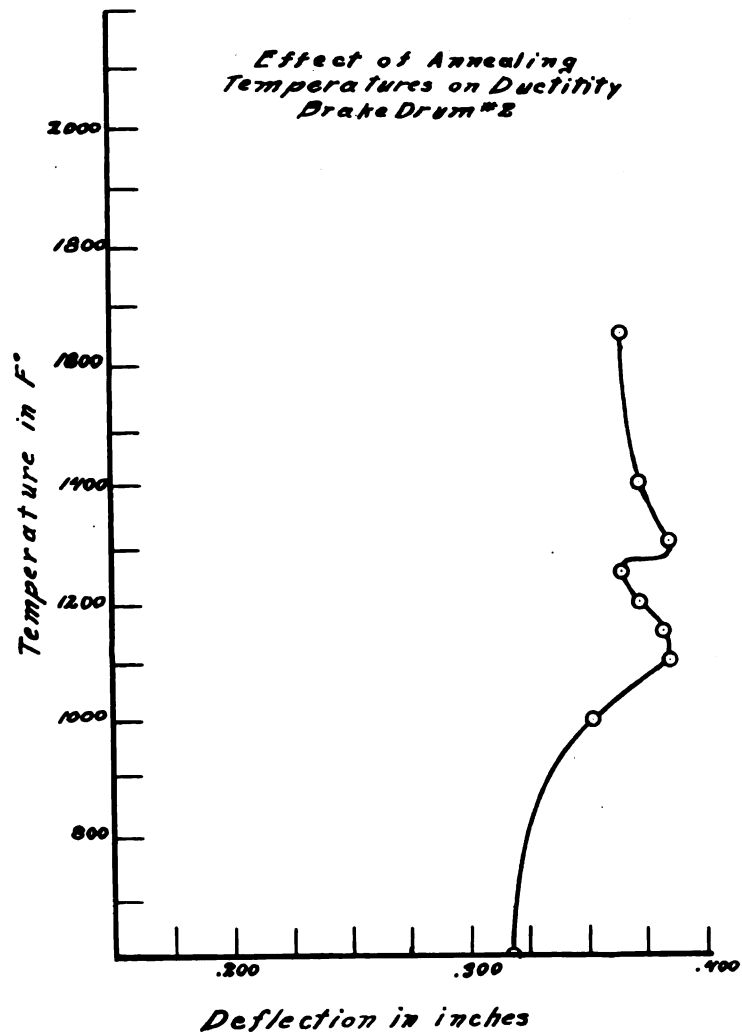


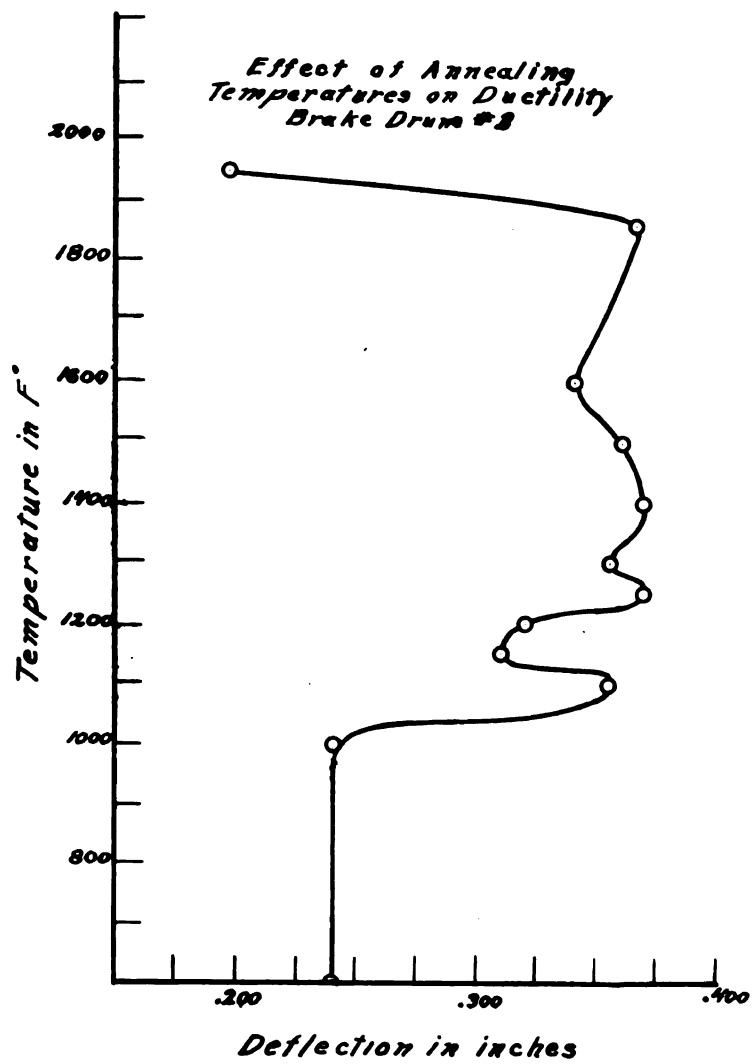


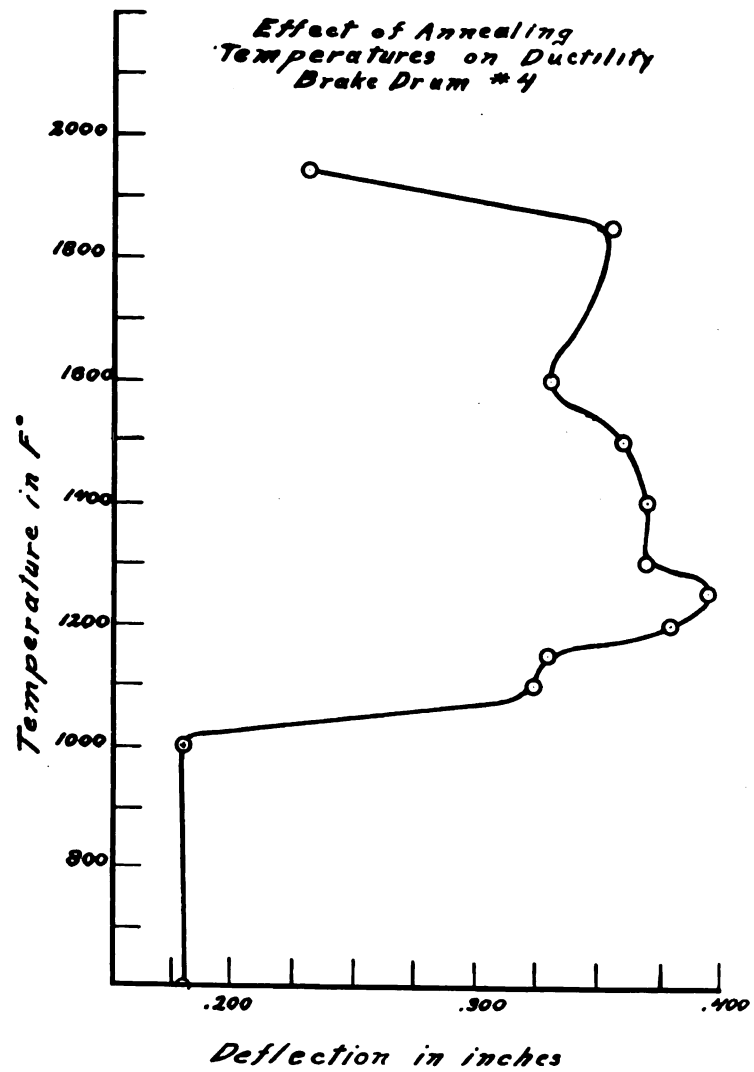


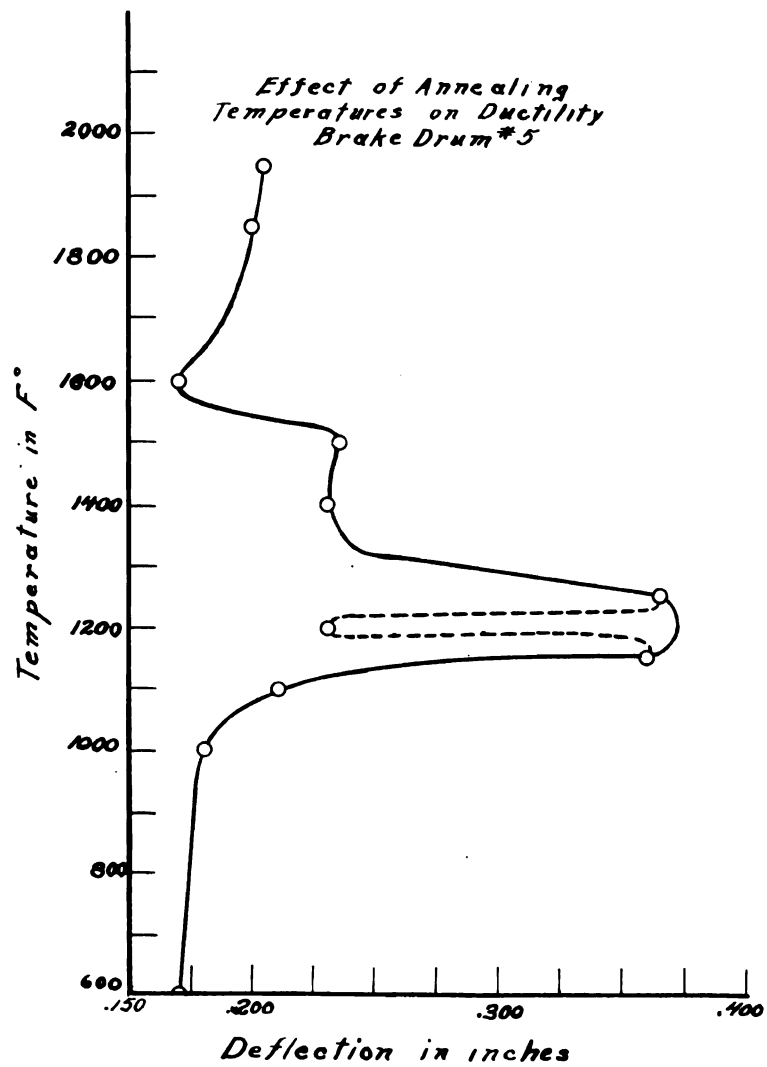
FIGS. 31-34 inclusive
Curves showing the relation between
annealing temperatures and the deflection
obtained on the Emerson-Southworth Deflection
Machine.

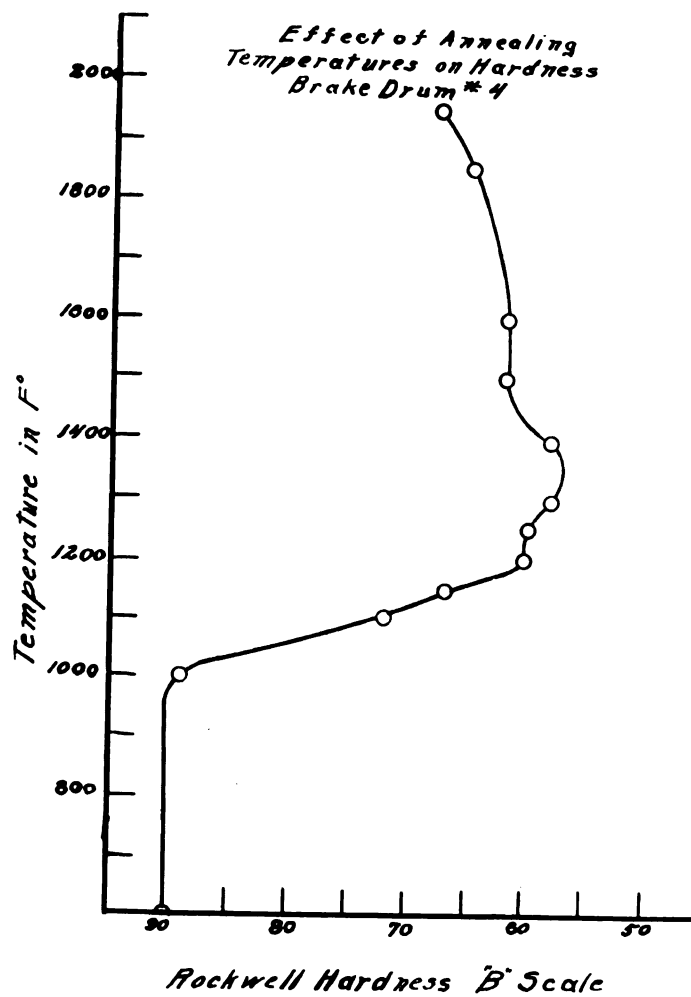
*Effect of Annealing
Temperatures on Ductility
Brake Drum #2*

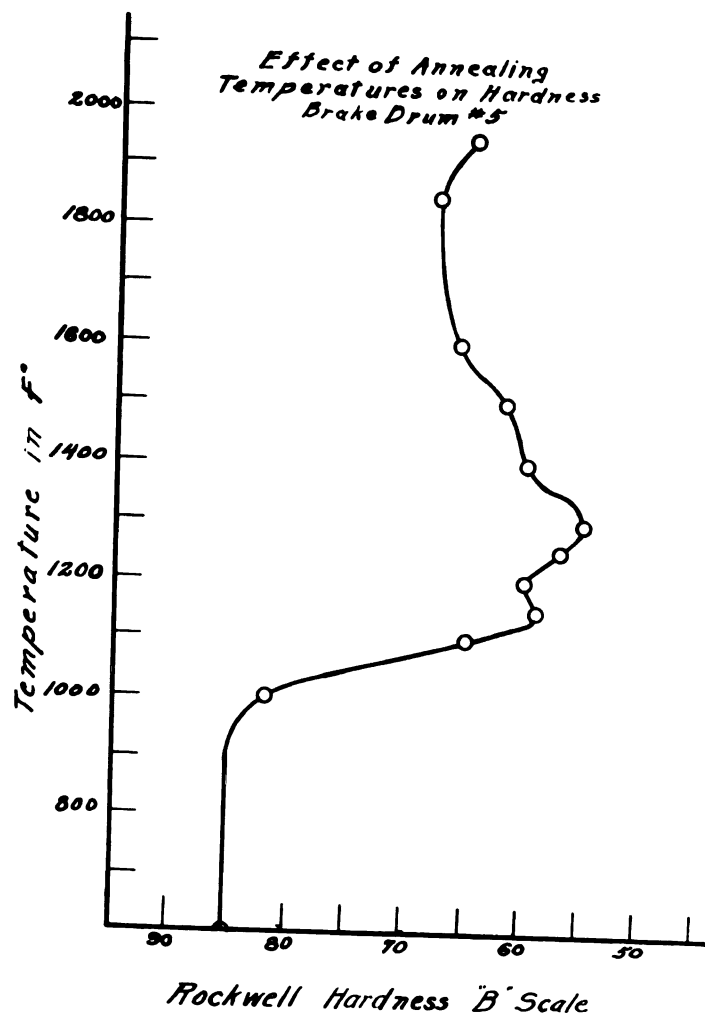








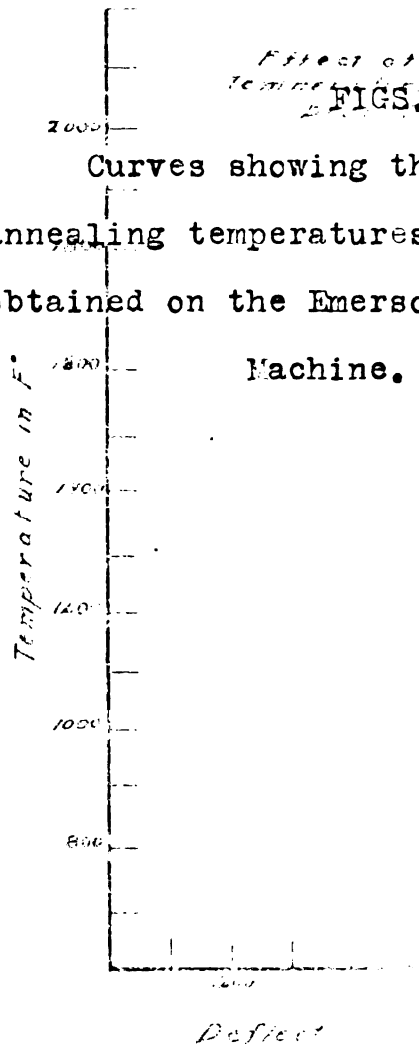




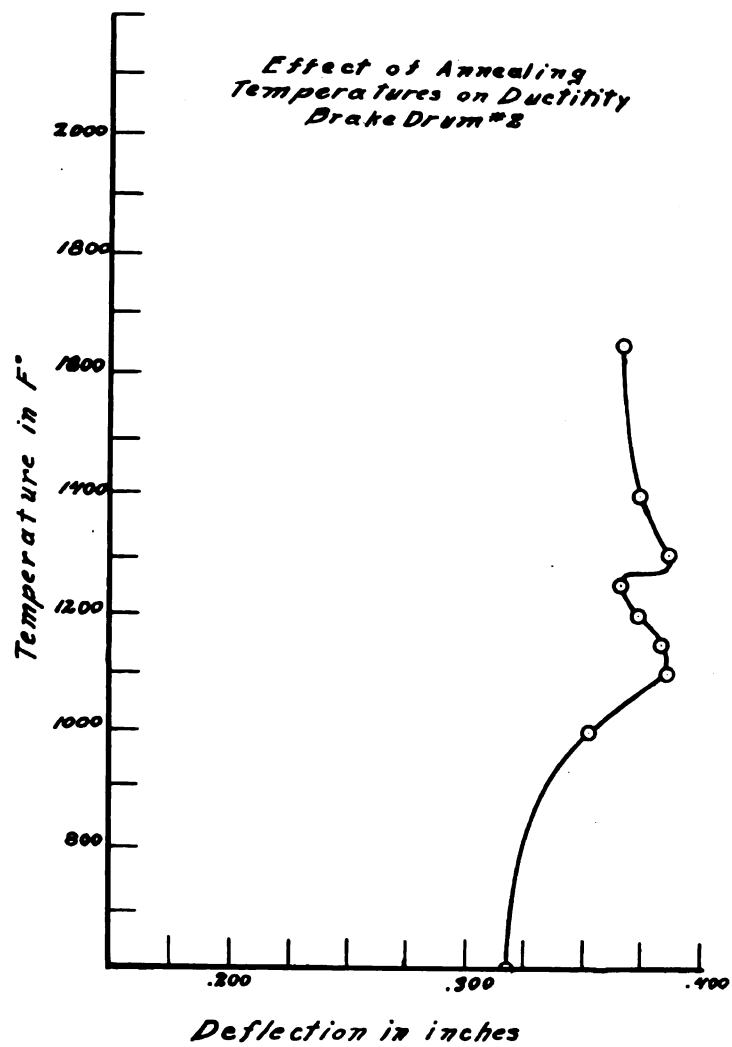
Effect of Annealing

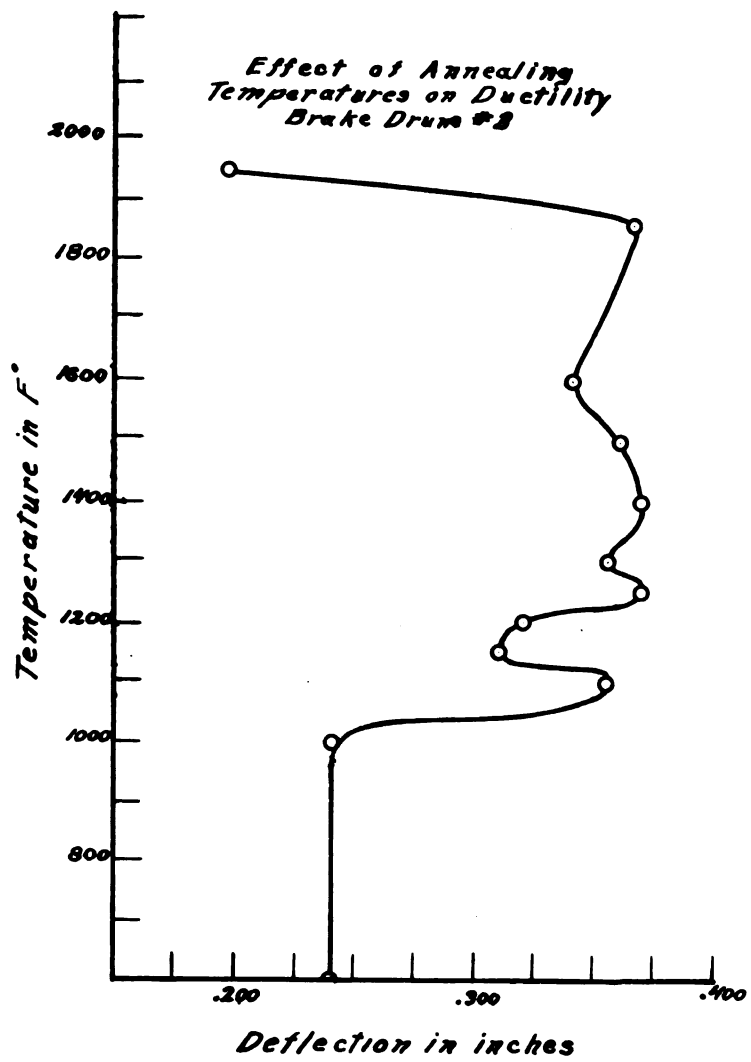
Temperature FIGS. 31-34 inclusive

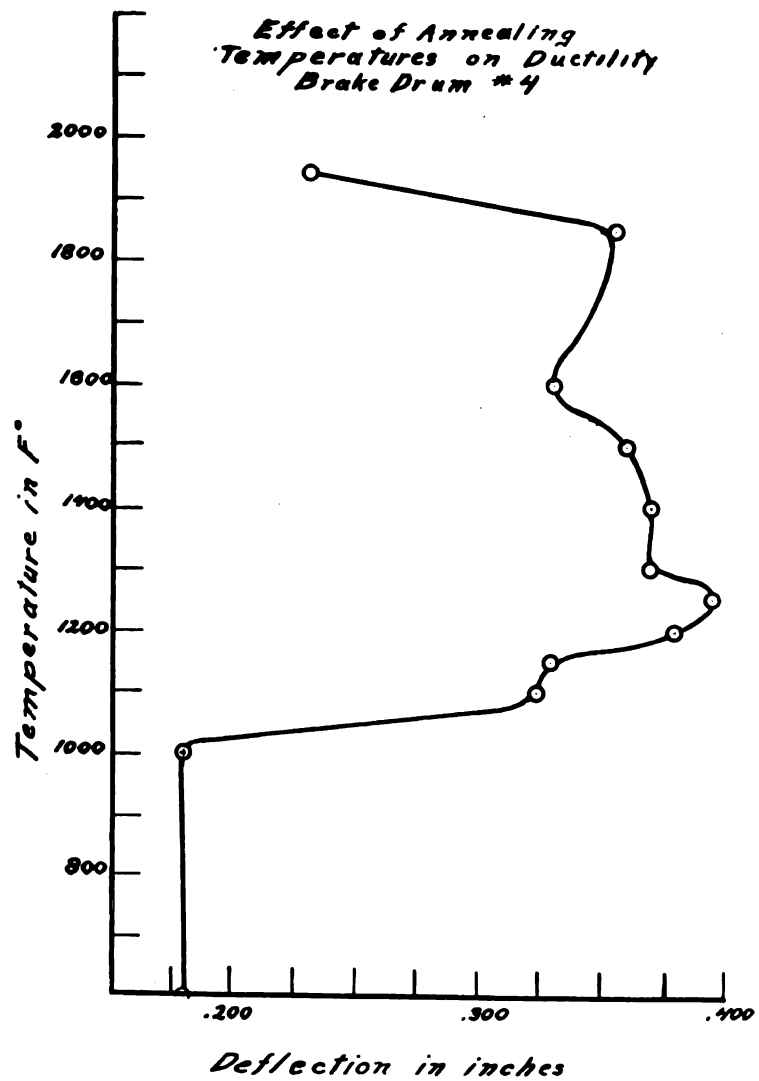
Curves showing the relation between
annealing temperatures and the deflection
obtained on the Emerson-Southworth Ductility
Machine.



FIGS. 31-34 inclusive
Curves showing the relation between
annealing temperatures and the deflection
obtained on the Emerson-Southworth Rectifier
Machine.







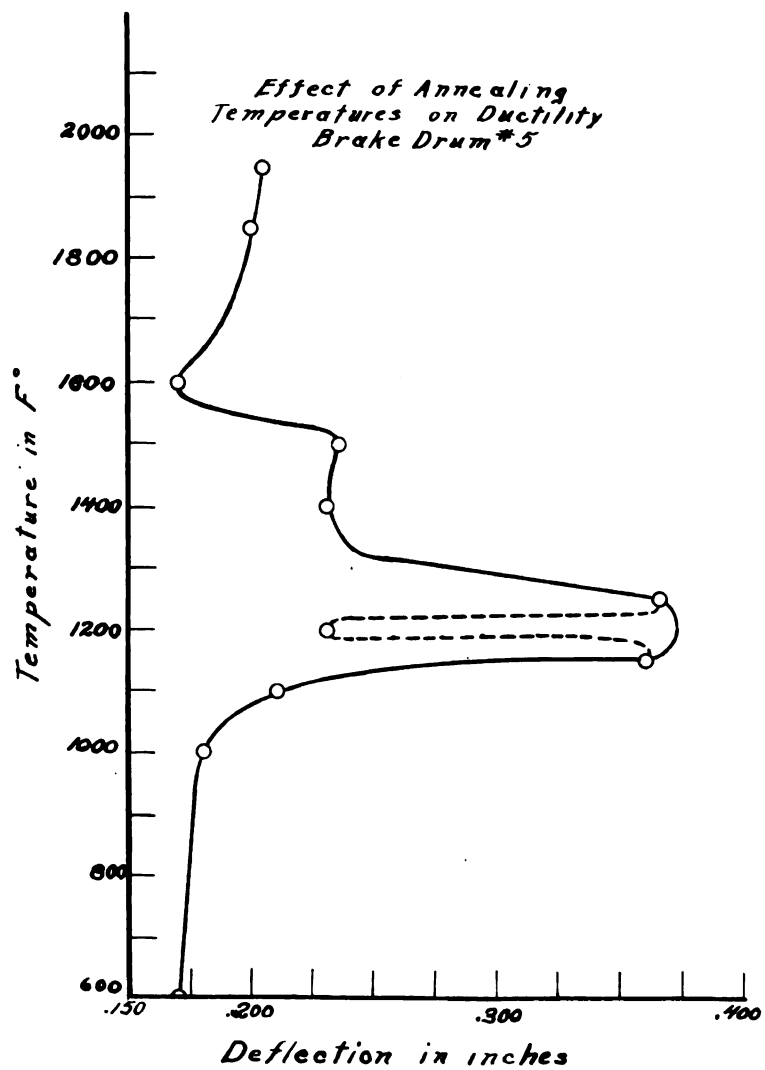


FIG.35

Curves showing the relation between
annealing temperatures and the mean values of
hardness and deflection.

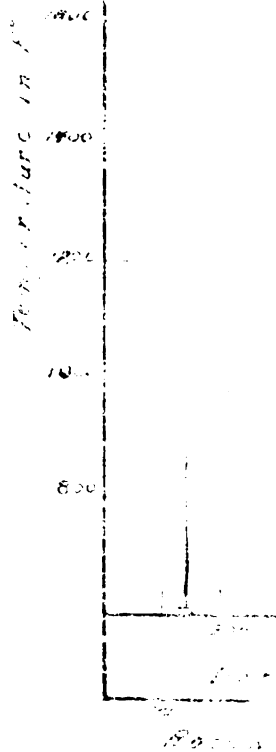
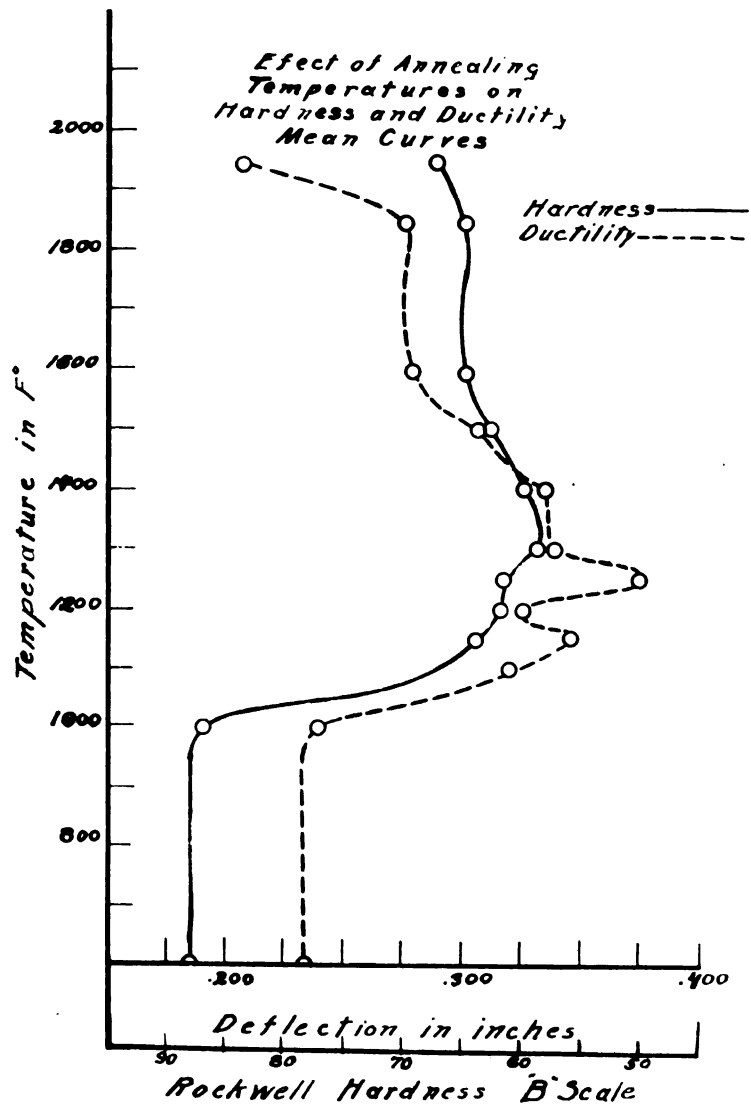


Fig. 35

Curves showing the relation between
annealing temperatures and the mean values of
hardness and deflection.



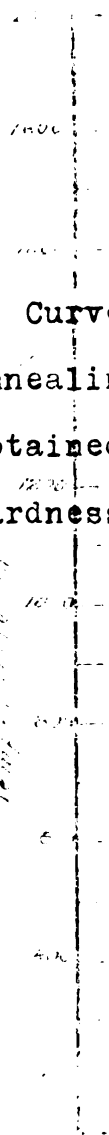


FIG. 36

Curve showing the relation between annealing temperatures and the deflection obtained in hot-rolled stock. The Rockwell hardness is given in the small circles.

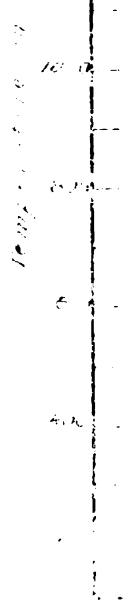
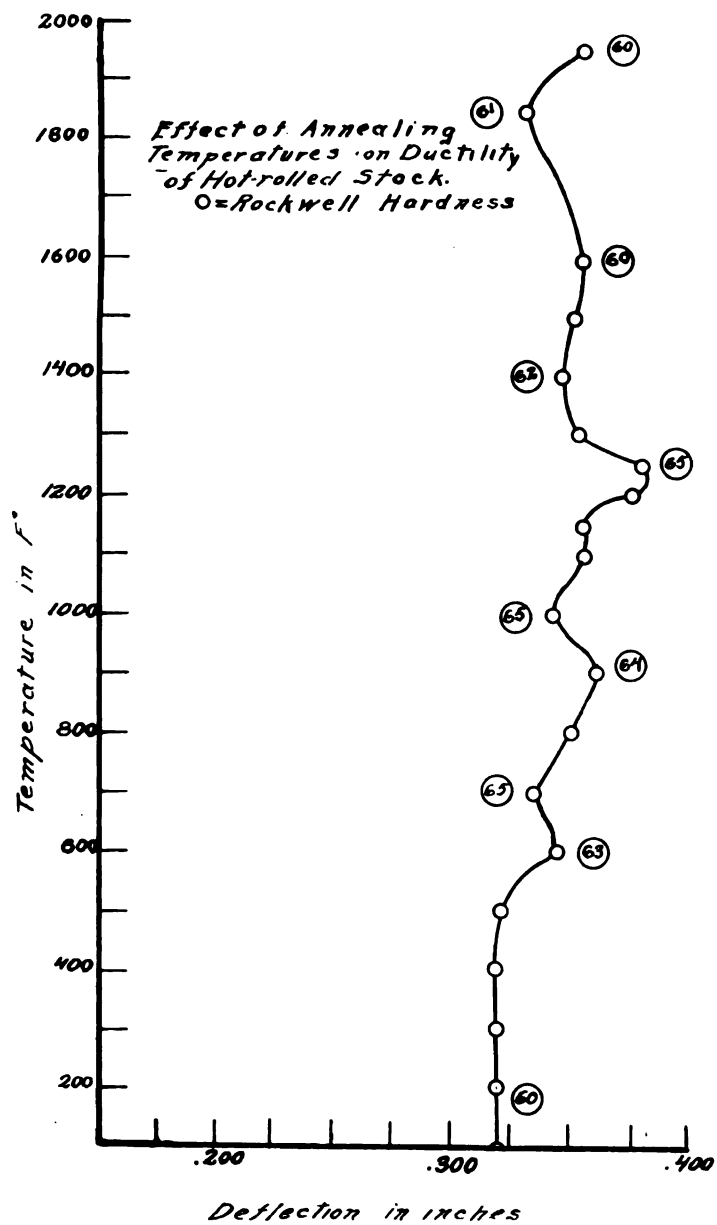


Fig. 36

Curve showing the relation between
annealing temperature and the deflection
obtained in hot-rolled stock. The Rockwell
hardness is given in the small circles.



only marked difference between the two curves is that the hardness curve lags behind the deflection curve. Taking these facts into consideration it appears that in annealing for a subsequent draw a temperature of 1150°F.- 1200°F. should give the best results.

The data collected from the experimental work on the hot-rolled stock does not show any correlation between hardness and ductility (Fig.36). In this case it appears that the ductility is much more sensitive to irregularities as it varies considerably when there is no variation in hardness. It should be noted that the deflection curve of both the cold-work steel and the hot-rolled stock show approximately the same variations.

It is ordinarily assumed that no change takes place in an unquenched steel until the critical point is reached. In this case hardening began about the time oxidation was noticed (400°F.) and reached its maximum value at 600° F. From this point the hardness remained at a constant value until the 1300°F. anneal was reached. At 1300°F. it began to drop back to the original hardness which was attained at 1600°F.

Although oxidation was noticed at about the same time that hardening started it cannot be used to account for it as all of the Rockwell readings were taken upon polished surfaces.

A peculiarity noticed was that a piece heated to 600°F. became hard. A similar piece heated to 1600°F., passing thru 600°F. upon heating and again upon cooling, remained at the original hardness. The hardening effect therefore must be due to changes in heating and not changes in cooling. A quenched piece hardened by rapid cooling from above the critical shows the fact microscopically as well as physically. In these samples the changes

are noticeable physically but no microscopic. . (Figs. 4-16)
change takes place even at high magnifications.

Another part noticed was that steel that drew well showed no microscopic deformation. Any steel examined that did show microscopic deformation had been deformed beyond the safe limit for cold-drawing. In Figs. 37-38 are shown examples of steel in which a fracture is beginning. The deformation on the grains can easily be seen.

In reviewing the theory given in the introduction we find the following statements which apply to this case.

Jeffries and Archer say "Hardness is resistance to permanent deformation. Metals fail under stresses below their ultimate strength because they are made up of crystals. Decreasing these crystals will increase the hardness".

In this case the metal did show microscopic deformation before the ultimate strength was reached. There was, however, no change in grain size or the cementite particles and yet there was a change in hardness from 60-90 Rockwell (figs. 4-16). The strain mentioned by Honda should be removed by the anneal. If his statement is true internal strains must be set up by the anneal itself as the annealing temperature is varied.

The statement of Geiss and Van Liempt that crystals glide over each other in cold drawing and that the actual shape of the lattice is distorted does seem to apply to this case. The metal must flow around the die during the drawing operation and as, in safe drawing, no deformation occurs it is logical to assume the crystals slip over each other. In this case the hardness could be accounted for by the distortion of the lattice

FIG. 37

Fracture just beginning in a peice
of fine grained stock.

X 500

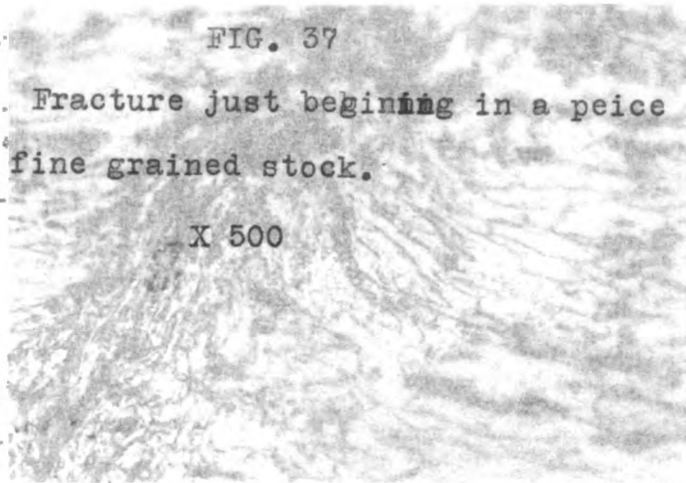


FIG.38

Fracture just begining in a peice
of coarse grained stock.

X 500

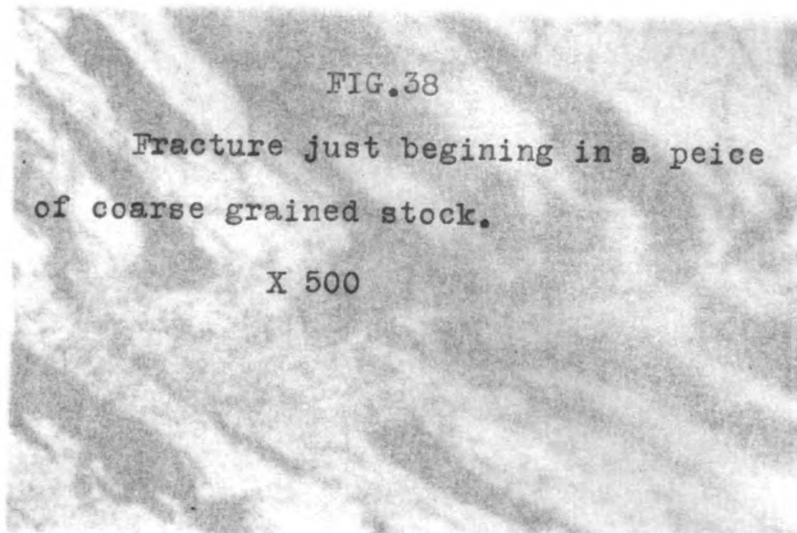


FIG. 27

Fracture just beginning in a piece

of fine grained stock.

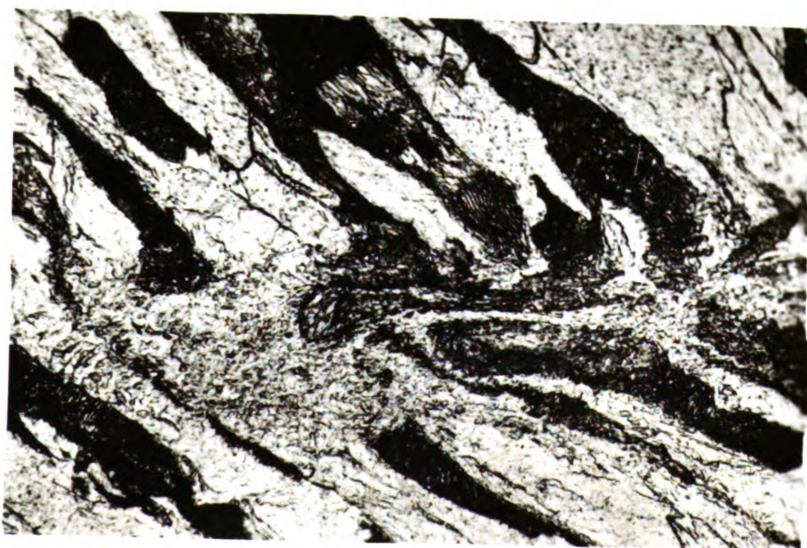
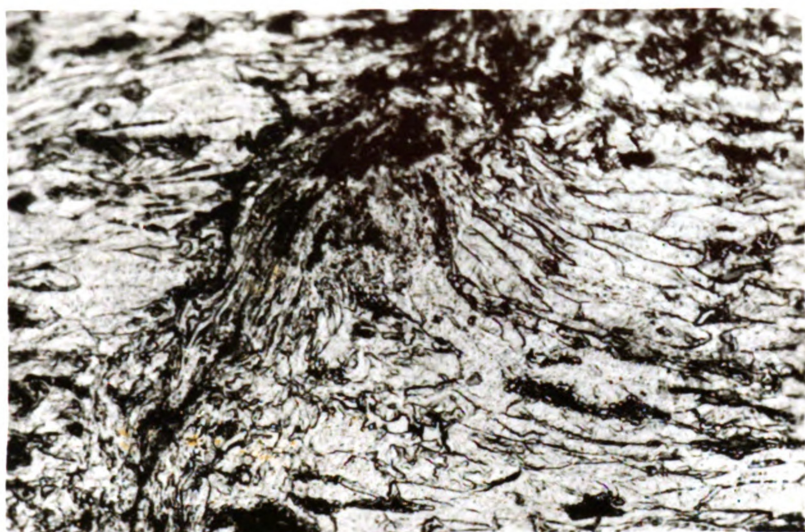
X 500

FIG. 28

Fracture just beginning in a piece

of coarse grained stock.

X 500



structure.

Angus and Summers show by their work on copper, and the bronzes that hardening and softening effects exist in those cases very similar to the ones found during this investigation.

ROOM USE ONLY

ROOM USE ONLY

MICHIGAN STATE UNIVERSITY LIBRARIES



3 1293 03061 2976