A STUDY OF THE STRUCTURE AND PROPERTIES OF CERTAIN "STAINLESS" STEELS

BY

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THESIS

FOR THE

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IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

SAUL SOLKIND CALLNER

ENTITLED A STUDY OF THE STRUCTURE AND PROPERTIES OF CERTAIN "STAINLESS" STEELS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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C O N T E N T S

****INTRODUCTION****

Although but twenty years old, the science of metallography, as a method of testing and investigating, has produced extensive development in the steel and iron industry. When the science was unknown, the chemist had to be consulted with in order to obtain any information regarding steel. His report consisted of an ultimate composition of the steel, which did not bear much relation to the physical properties. However, when the metallographist came forward with his results of proximate composition, the steel industry had a very valuable means of investigation for their products.

For example, the analytical chemist tells us that a certain specimen of steel contains .7 carbon without our being able to discern whether the sample may have a tensile strength of 2000 lbs. per square inch or 10000 lbs. per square inch, or what ductility or elongation it may have. While on the other hand when the metallographist reports 40% ferrite and 60% pearlite, we know that the steel is fairly soft and ductile, or when he reports 100% martensite, we know that we have an extremely hard specimen with but very little ductility.

It is without doubt that the metallographist gives the most practical report. We also come across the same proposition with metals that we met with in organic chemistry; i.e. different groupings, and association of the ultimate constituents. And with these different combinations of metals we are able to obtain a series of alloys which can only be investigated

thoroughly by a metallographist.

Theoretically an unlimited field of alloys of steel is available. We have chromium, tungsten, nickel, manganese, etc. as elements which imporve the proppcerties of steel in one way or another. Any one, or two, or three, or four of these elements can be grouped with some alloy steel and give a desirable product for some use. They form compounds with iron and with each other and can only be studied under the microscope efficiently.

This combination of elements and the pure element itself form structures which are the source of the investigation for the metallographist. These structures are subjected to the effect of thermal treatments which create a further enlargement of the field of research. Along these lines of study much work has been done - alloys have been developed and to-day there are innumerable alloys that are in use in every mode of life.

****HISTORICAL****

In the extensive work on investigation, a steel alloy with non-corroding properties was developed in the last few years. Due to its far reaching usage in the home, the steel was called "Stainless" on account of its special property of resisting the action of acids found in foods.

The steel was discovered almost simultaneously in England and America in 1913 and 1914. Similar to all other inventions the discovery was largely a matter of accident and has played a large part in war work. It was by Mr. Elwood Haynes, that "Stainless" steel was developed in America, and H. Brearly a little later was given credit for his work on "Stainless" steel in England. Since then patents have been secured for it in the United States, Argentine, Brazil, Canada, France, Italy, Japan, and Spain.*

"Stainless" steel was primarily manufactured for cutlery purposes. However further investigation showed very valuble usage in the production of tool steel. It came to the immediate attention of manufacturers, especially those of automobiles and aeroplanes. Dur-

*Iron Age, 294-294, 1919.

ing the period of the war its use was restricted for government purposes due to the restriction on the output of steel in which chromium was used. At that time it demonstrated its fitness as a material from which engine and aeroplane valves of superior quality could be made.

Since the ending of the war, the restrictions have been removed and the production of the steel has been enormously developed. In this country, the American Stainless Steel Co. control the patents and issues licenses to those companies that wish to produce the steel. In England, the Firth-Brearley Stainless Steel Sydicate Ltd. have control of the patent.*

Although the manufacturing of this alloy steel has been for a comparatively short time, innumerable uses have been found for it. The non-corrosive and heat resisting of the "Stainless" steel along with the strength and toughness found in the best grades of heat treated alloy steels make the product available for the following uses:- Cutlery, saddlery, sporting goods, valves for internal combustion motors, ship machinery, furnace parts, and acid resisting machiner, tools, dies, etc.

*Report from American Stainless Steel Co.

****THEORY****
****

Stainless steel is a high chromium alloy steel analyzing approximately .30% carbon and 13% chromium. The following chemical analysis is general for a stainless steel:

Carbon------------------------	.30%	-	.40%
Manganese (Not to exceed)----	.50%		
Silicon (Not to exceed)------	.30%		
Sulphur and phosporous as low as possible but not over-----	.035%		
Chromium-------------------	.125%	-	14%**

By referring to above analysis, we notice that a range is given for carbon and chromium, and limits are made for manganese, silicon, sulphur, and phosphorous. These may be discussed spearately regarding their effects when present in steel.

CARBON

CARBON: Carbon is present in all steels and is the most important of all elements in reference to its effects on the final product. The variation of the percentage of carbon content is as follows:-

The amount of ductility varies inversely with the carbon content while the toughness and tensile strength varies directly with the amount of carbon. For example a low carbon steel will be fairly soft and ductile while a high carbon steel will be tough

**Report of American Stainless Steel Co.

and of great tensile strength but will be low in ductility. Pure iron has a ductility corresponding to an elongation of at least 40% and a tensile strength of some 50000 lbs. per square inch. Low carbon steel is magnetic and has a high electric donductivity. Carbon is present in three different forms in steel, ferrite, pearlite, and cementite. They are summarized as follows:

Name	Ductility	Hardness	Hardening Power
Ferrite	Very Ductile	Soft	None
Pearlite	Medium	Hard	Maximum
Cementite	None	Very Hard	None

The effect of the percentage of carbon on the thermal critical points is considerable. Pure iron exists in three forms, Alpha, Beta, and Gamma iron. The addition of more carbon tends to reduce the existence of these different forms to one. Pure iron up to .4% carbon has three critical ranges. Up to .83% carbon, there are two ranges or two forms, Alpha and Beta and after that there is but one form. The effect of carbon on the critical range is too lengthly a subject to discuss here, but up to .5% carbon content in which we are interested, the critical rangge is approximately constant.

CHROMIUM: The presence of chromium in steel opposes the disentegration and reconstitution of cementite. The effect of chromium on the critical range is very slight in the amount used in "Stainless" steel and therefore the range is considered the same as a plain carbon steel from .3 to .5% carbon content. Chrome steels are very hard, the decomposition of austenite being prevented. The hardness of chrome steels is also due to the presense of double carbides of chrome and iron in the steel in the hardened or slightly tempered condition, which indicates that the degree of hardness depends upon the chromium and carbon content both. As chromium produces fine structures, chrome steels are expected to be very tough.

With the properties of hardness and toughness, one naturally infers that chrome steel is resistant to wear (abrasive action.) This property is the underlying principle of the manufacture of "Stainless" steel.

As chromium opposes the disintegration of austenite, we deduce that chrome steels are very little affected by heating and will not scale or form a coating of iron oxide. This fact is also made use of in "Stainless" steel. The additional hardness obtained by the presence of chromium does not raise the degree of brittleness as carbon does.

MANGANESE: Manganese adds to the tensile strength of steel, but is very susceptible to high temperature and prolonged heat treatment. This fact make the prescence of manganese in "Stainless" steel undesirable as it would reduce the non-corroding property of the product.

SILICON: Silicon has a tendency to cause the formation of graphitic carbon which is undesirable in "Stainless" steel. It also causes the deformation of the iron carbon eutectic which would reduce the degree of hardness. It adds, however, to the non-corroding property of a steel alloy, and a rustless steel of chromium and silicon is now being manufactured. This alloy can be clas ified with "Stainless" steel.

SULPHUR & PHOSPHOROUS: Sulphur forms undesirable sulphides with the various constituents of alloy steels while phosphorus causes the steel to be very brittle. Both of these elements are therefore reduced to a minimum.

In practice, the carbon content is usually from .20% to .40%, but it can be used up to .45 - .5% for structural purposes and will resist corrosion, but it is not quite so stainless. When the carbon content is raised and the chromium percentage is lowered, the stainless and non-corroding properties of the steel are narroweddown.**

**Report from American Stainless Steel Co.

****INVESTIGATION****
****

Being a comparatively new field, there has not been much work done on "Stainless" steels as there has been done on other alloy steels. Its characteristics and treatments are briefly summarized as follows.

HEAT TREATMENT: "Stainless" steel is very hard while hot and therefore is difficult to forge. In this respect it is to be compared with high speed tool steel rather than ordinary carbon steels. It may be forged between the temperatures of 1000 and 1200 degrees centigrade. The steel will harden on cooling after being forged.**

ANNEALING: The steel may be annealed by heating to 775 to 820 degrees and allowed to cool very slowly. This will give a Brinell hardness of about 700.**

HARDENING: To harden stainless steel it is necessary to obtain the proper quenching medium and the proper quenching temperature. Water, oil, and air may be used according to the degree of hardness desired. The hardening range of temperatures is from 900 to 1050 degrees centigrade. Oil is usually used, water quenching producing distortion in the structure.**

**Recommended byLudlum Steel Co.

ETCHING: "Stainless" steel is not attacked by HNO_3, so for an etching agent, a solution of one per-cent of ferric chlroide in one to one hydrochloric acid is used.

****EXPERIMENTAL DATA****

LUDLUM STAINLESS STEEL: The sample was first annealed at 800 degrees centigrade for three hours and was allowed to cool very slowly in the furnace. The treatment had no effect on the specimen, e.i. no scaling. The structure of the steel was photographed and was found to be martensite. The presence of carbides of chromium and carbon was noticed to a slight degree.

It wasthen hardened from 950 degrees centigrade by quickly heating and holding it to that temperature for ten minutes to insure the complete solution of the constituents and then quenched in oil. The specimen was again untouched by thermal treatment. The structure developed wastotally martensenic. The specimen was then tempered at 400 degrees centigrade, but no change was effected in the structure, it being very fine martensite.

The sample was again annealed and hardened from a temperature of 1030 degrees centigrade. Austenitic structure was obtained.

The same treatments were given to the Firth Sterling specimen and approximately the same results were obtained; In the annealed condition, the carbides

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

of chromium and carbon were present to a slightly higher degree than in the Ludlum sample. The same resistance to high temperatures were obtained with the Firth Sterling sample.

ATLAS: The Atlas sample gave the same results as the Ludlum specimen. A very good austenitic structure was obtained from 1050 degrees centigrade.

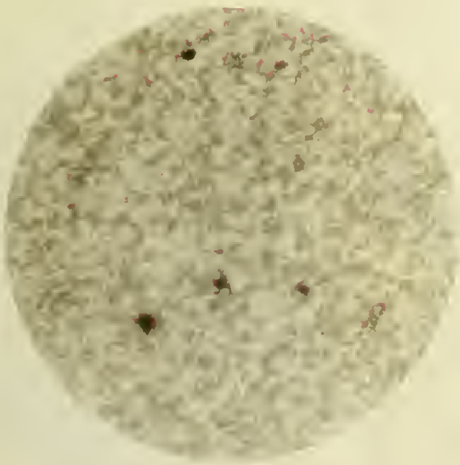
CORRODING TESTS: The three samples were treated identically as follows: First in the annealed state, the samples were polished and a photographic plate of the structure was made. Each sample was then immersed in a 25% solution of Nitric Acid for thirty seconds and was rephotographed. This was again repeated. The effect was that after one minute in 25% Nitric Acid the sample appeared over etched. The series of photographs illustrate the effect of HNO_3 in the structure in Figure One.

Secondly, the three samples were hardened and were then immersed into the acid again. Pictures were taken at intervals and the time in the acid was two hours before the structure appeared fully etched.

The series of photographs illustrate the effect of the acid on the structure in Figure Two. The results of this test illustrated the fact that the steel is more resistant to corrosion in the hardened state than in the annealed state.

P H O T O G R A P H S
Fig. No. I

X 350 Annealed
Polished



X 350 Etched in
25% HNO_3 for 30 sec.

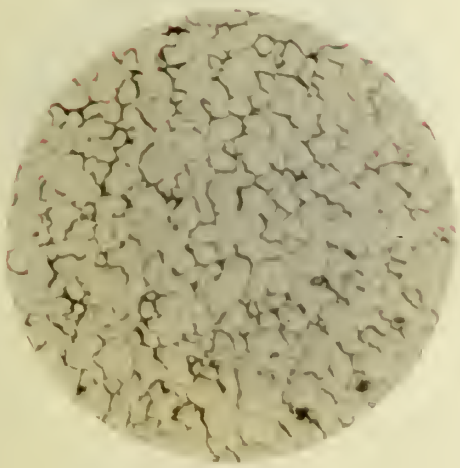
X 350 Etched in
25% HNO_3 for one minute.

Results of corroding test on annealed sample

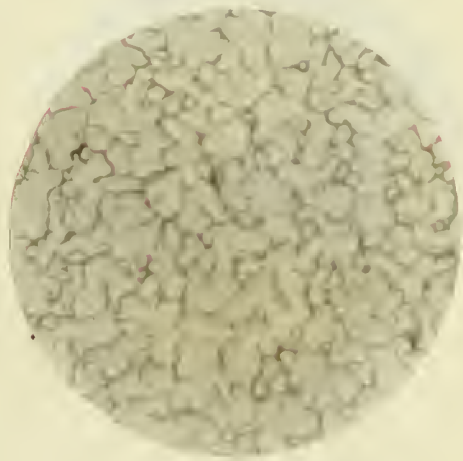
P H O T O G R A P H S Fig. II

X 350
Polished

X350
Etched 30 seconds
In 25% HNO3.



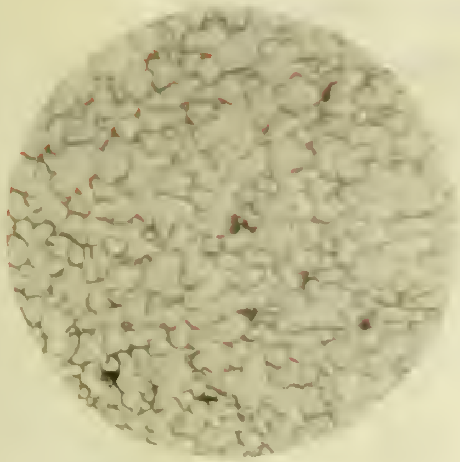
X 350
Etched two
minutes in HNO3



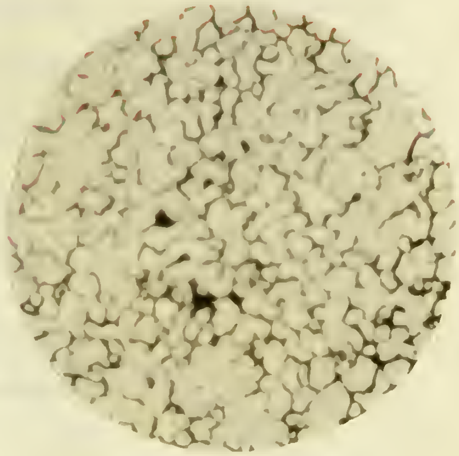
X 350
Etched five
minutes in HNO3

Results of corroding test on hardened sample.

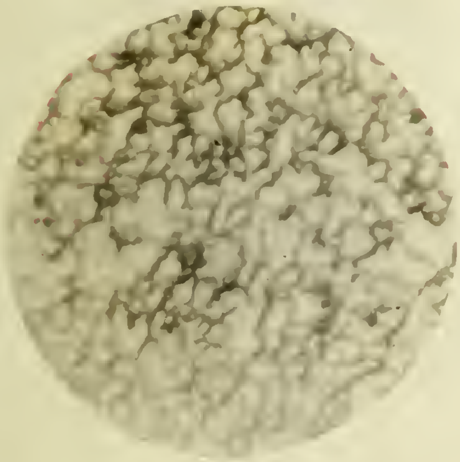
P H O T O G R A P H S
Fig II cont.



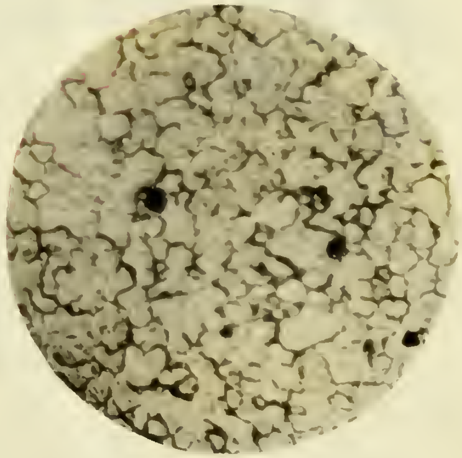
X 350 etched
10 minutes in
25% HNO3



X 350 etched
30 minutes in
25% HNO3



X 350 etched
60 minutes in
25% HNO3



X 350 etched
120 minutes in
25% HNO3

Results of corroding test on hardened sample.

Another test was of suspending the samples in a solution of 25% HNO_3 for a certain length of time and calculating the solubility rate per square inch of surface. This was done both for the annealed and the hardened sample. Results were as follows:

Name of Sample	Hardened*	Annealed*
Atlas	.00012	.105
Ludlum	.00009	.182
Firth-Sterling	.00007	.080
.6 Carbon Steel		2.23

*Figures indicate loss per square centimeter in gms.

(The above data is given for a period of 18 hrs. 15 min. e.i. Atlas loss .00012 gm represents gm. loss in a period of 18 hours and 15 minutes.)

This test illustrates even more the non-corroding property of stainless steel especially so in the hardened state.

Another "Stainless" test was to allow a specimen to be immersed in vinegar over night. The acid present in the vinegar had no effect on the specimen.

DELHI RUSTLESS: Delhi rustless steel is a chromium silicon steel used in the annealed, soft condition as the steel is not hardened by heating and quenching.

The sample was annealed and its structure was photographed, It gave martensitic strucute and carbides

[illegible]

of iron and chromium. The sample was then hardened from two different temperatures but it had no effect on the structure except to distort the carbides slightly.

The same corroding test was given to the Delhi Sample that was given to the "Stainless" steel. The test was given to the steel in the annealed condition. It was polished before suspending it in the acid and after being in the solution for 18 hours lost no weight. The surface was untouched and did not even show effects of the acid test under the microscope. To investigate its rustless property, it was allowed to stand in salt water over night. After two days there was no rust visible.

The steel was highly inactive to high temperatures treatment. A polished sample heat treated was practically untouched.

The uses of the steel are innumerable and is usually adapted for purposes where a rustless and non-corrosive material is required.

CONCLUSION

From the investigation on "Stainless" steels, the work may be summarized as follows:-

1. All "Stainless" steels have approximately the same chemical composition, .30% carbon and 14% chromium. They therefore give the same results when treated alike.
2. The heat treatment is as follows:-

   Annealing; 780° - 810° C. and slowly cooled either in the furnace or buried in lime. The latter produces the best results.

   Hardening; 950° - 1050° C. and quenched in oil. In order to obtain extremely hard structures, the higher temperatures must be used.
3. The steel has very good non-corrosive and "Stainless" properties which are best obtained in a hardened condition.
4. Delhi Rust-less steel is a chrome-silicon alloy used in the annealed state as hardening has no effect on its structure. It has excellent non-corrosive, acid resisting and non-scaleing properties.

B I B L I O G R A P H Y

1. Chemical & Metallurgical Engineering Vol.21, 10 Oct. 1 1919.

2. Iron Age Journal, Vol. 104, Feb. 1919.

3. Journal of American Steel Treater's Society, Sep. 1919.

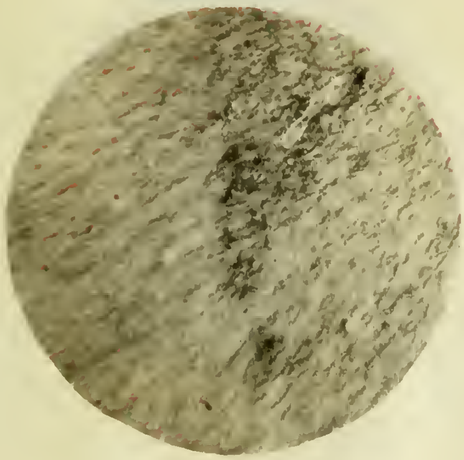
4. Heat Treatment of Steels, Bullens.

5. The heat treatment and metallography of Iron & Steel, Sauveur.

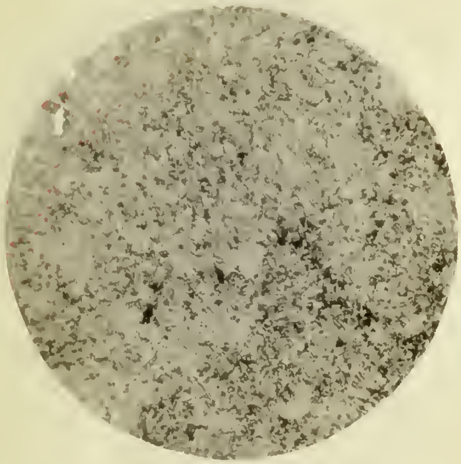
6. Report from American Stainless Steel Co.

7. Report from Ludlum, Atlas, and Firth Sterling Steel Cos.

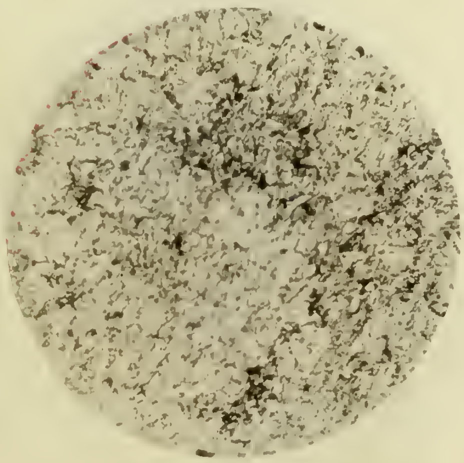
PHOTOGRAPHS
Annealed Structures



X 350 Ludlum Steel.
Heated to 800° C.
Held three hours.
Cooled in lime.



X 350 Atlas Steel.
Heatedto 800° C.
Held three hours,
Cooled in lime.

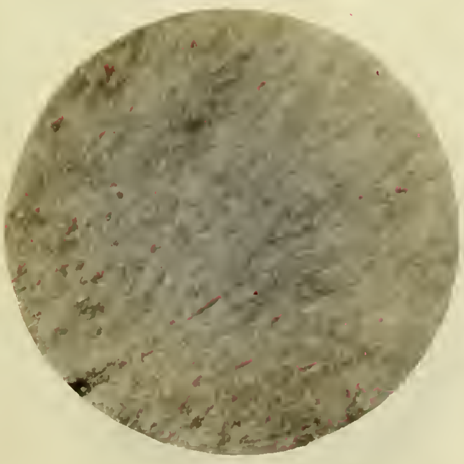


X 350 Firth Sterling
Heated to 800° C.
Held three hours,
Cooled in lime.

PHOTOGRAPHS
Annealed Structures

X 350 Ludlum Steel.
Heated to 800° C.
Held three hours.
Cooled in furnace.

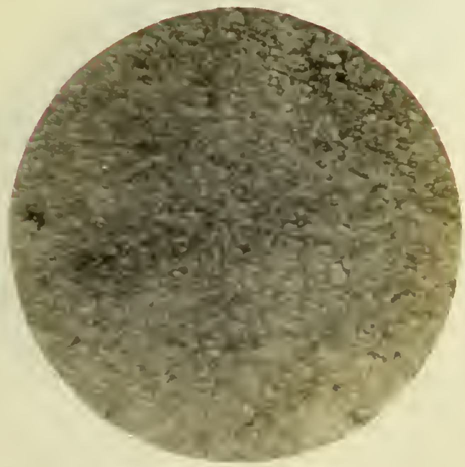
X 350 Atlas Steel.
Heated to 800° C.
Held three hours,
Cooled in furnace.



X 350 Firth Sterling
Heated to 800° C.
Held three hours.
Cooled in furnace.

P H O T O G R A P H S
Hardened Structure

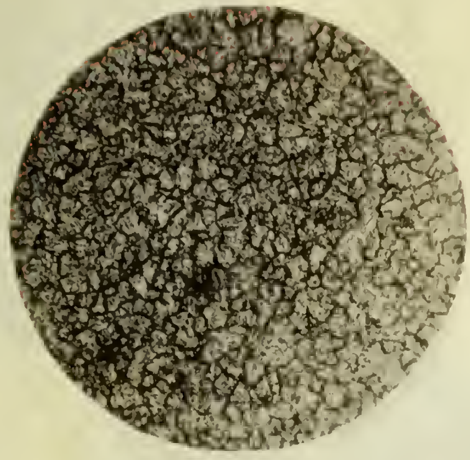
X 350 Ludlum
Heated to 950° quickly
Held for 10 minutes
Quenched in oil.



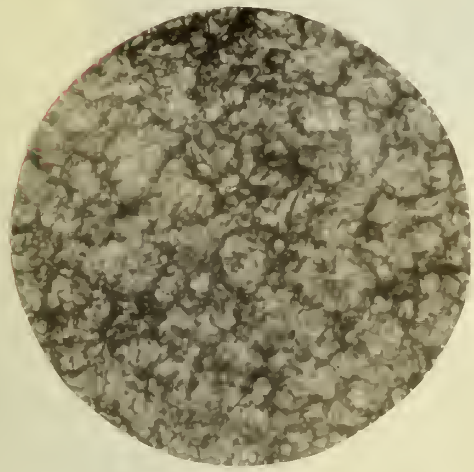
X 350 Atlas
Heated to 950° quickly
Held for 10 minutes
Quenched in oil.

X 350 Firth Sterling
Heated for 950° quickly
Held for ten minutes
Quenched in oil.

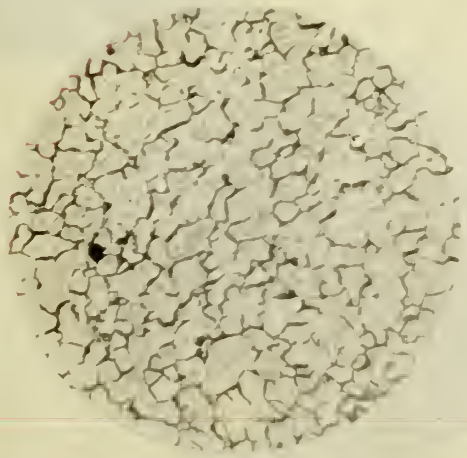
P H O T O G R A P H S
Hardened Structure



X 350 Atlas.
Heated to 1050° quickly.
Held for 10 minutes.
Austenite.
Quenched in oil.



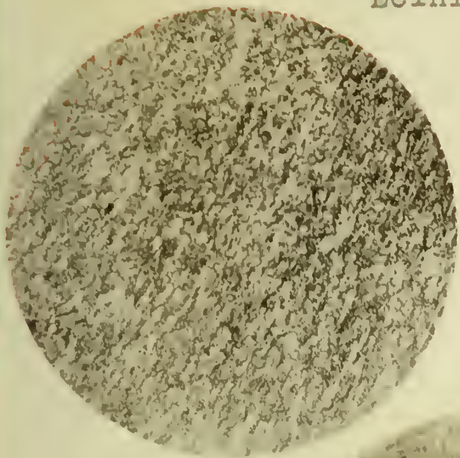
X 350 Ludlum
Heated to 1050° quickly.
Held for 10 minutes.
Quenched in oil.
Austenite.



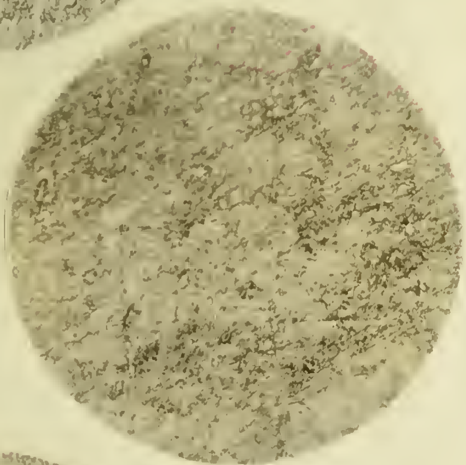
X 350 Firth Sterling
Heated to 1050° quickly.
Held for 10 minutes.
Quenched incoil.
Austenite.

P H O T O G R A P H S

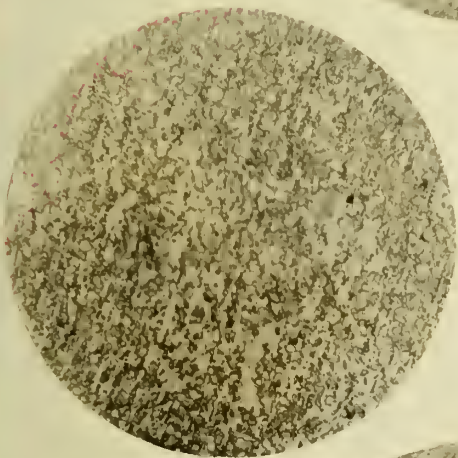
Delhi Rustless Steel



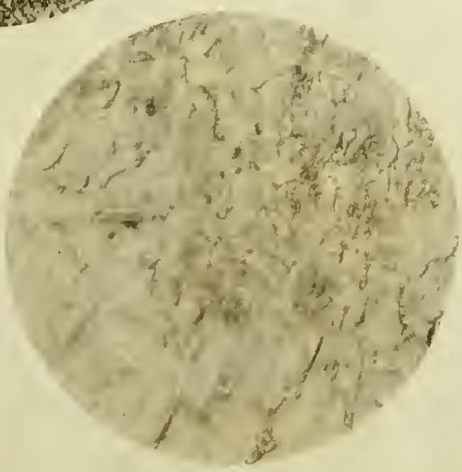
X 350 annealed.
Heated to 800° C.
Held for three hours.
Cooled in Furnace.



X 350 Hardened.
Heated to 950° quickly.
Held for ten minutes.
Quenched in oil.



X 350 Annealed
Heated to 800°C.
Held for three hours.
Cooled infurnace.



X 350 Hardened
Heated to 1050°C. quickly
Held for ten minutes.
Quenched in oil.