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AD-A953 682

W.A. 710/390

PROGRESS REPORT

August 27, 1941

to

WATERTOWN ARSENAL,
UNITED STATES ARMY

Research Investigation
of Armor Plate Steels.

S-547

BATTELLE
MEMORIAL INSTITUTE
505 King Avenue
COLUMBUS, O[illegible]

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CONTRACT
Ordnance Department

CONTRACTOR: The Battelle Memorial Institute
Columbus, Ohio

CONTRACT FOR: Sponsored Research Project AMOUNT: Approximately $15,000.00

PLACE: Watertown Arsenal, Watertown, Mass.

Payments to be made by the Finance Officer, Watertown Arsenal, Watertown, Mass.

The supplies and services to be obtained by this instrument are authorized by, are for the purpose set forth in, and are chargeable to Procurement Authority.

ORD 9670

the available balances of which are sufficient to cover the cost thereof.

This contract is authorized by the Act of July 2, 1940 (Public No. 703, 76th Congress)

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THIS CONTRACT, entered into this 23rd day of May, 1941, by THE United STATES OF AMERICA, hereinafter called the Government, represented by the Contracting Officer executing this contract and THE BATTELLE MEMORIAL INSTITUTE, a corporation organized and existing under the laws of the State of Ohio of the city of Columbus, in the State of Ohio, hereinafter called the Contractor, witnesseth that the parties hereto do mutually agree as follows:

Article I. Scope. The Contractor shall conduct research investigations to systematically study the effects of certain alloying elements on the ballistic properties of properly heat treated rolled homogeneous armor. A foremost consideration will be given to the substitution of nonstrategic alloying elements for nickel and chromium, elements which are respectively difficult to provide in sufficient quantities and of a highly strategic character. Primarily, the elements which will be studied in their effect upon the ballistic qualities of armor will be manganese, molybdenum, copper, silicon and vanadium.

Article II. Statement of Work. The work under the contract performed in close cooperation with Watertown Arsenal will involve:

a. The melting and refining of small experimental heats of steel in sizes up to approximately 350 pounds containing varying percentages and proportions of the elements manganese, molybdenum, copper, silicon and vanadium.

b. The rolling of these heats of steel into plate of a suitable size and thickness for ballistic testing.

c. The proper heat treatment of these steels to a specified proper range of hardness so that the effect of the alloying elements in varying percentages will be discernible in the results obtained. The determination of the most suitable heat treatment for each analysis will form an important part of the investigation.

d. The ballistic testing of the experimental plates according to the latest specifications at the Watertown Arsenal.

e. The metallurgical examination of the ballistically tested plates by the Contractor in full cooperation with the Watertown Arsenal.

f. The preparation and submission of a detailed report covering completely the procedures followed, the results obtained and indicating the following:

1. A homogeneous rolled armor analysis containing a minimum amount of strategic elements as well as a minimum total alloy content which meets the specified ballistic requirements for armor of this type and thickness.

2. An analysis meeting the ballistic requirements which can be melted and refined in open hearth furnaces and rolled on mills utilized in the production of tonnage plate steel.

3. The most practicable and effective heat treatment which can be adapted to production methods.

4. The determination of the microstructural constitution of the steel which produces the highest ballistic properties.

Article III. Method of Payment.

a. All research costs, miscellaneous supplies and expenses, except necessary special equipment and patent expenses, hereinafter set forth, shall be paid for by the consideration of two thousand dollars ($2000.00) per month for a period of six (6) months, this period to begin on date of approval of Contract by Chief of Ordnance.

b. The Contractor will be reimbursed for all necessary special equipment, for which prior approval by the Contracting Officer in writing has been secured, upon submission of properly certified invoices showing payments by the Contractor. The cost of such special equipment will not exceed two thousand dollars ($2000.00).

c. All expenses for the filing or assignment of applications for Letters Patent or any expenses in connection with the prosecution of said applications or the recording of such assignments and any expenses such as charges for staff time, travel, and other expenses incurred in connection with preparation or prosecution for Letters Patent, will be paid by the Contracting Officer, and does not constitute a part of the amount payable under this agreement, as specified in Article III-a hereof.

The Contracor further agrees that the reasonableness of all expenses incurred in connection with the prosecution of Letters Patent shall be determined by the Contracting Officer and that any dispute in connection herewith shall be governed by the Procedure outlined in Article VIII.

d. All payments will be made by the Finance Officer, Watertown Arsenal, Watertown, Massachusetts.

Article IV. Availability of Information. The Contractor agrees that all relevant information obtained through the work on the project specifically defined above shall be made available to the Contracting Officer or his designated assistants at any reasonable time during the Contractor's working hours, subject to the terms and conditions of the contract, and that he will communicate promptly without request, to the Contracting Officer, all important information which is pertinent to the project as it progresses. The Contractor further agrees to submit in writing to the Contracting Officer monthly reports, in quadruplicate, on the work herein contracted for.

Article V. Assignments of Patents. The Contractor agrees that employees assigned to the experimental work under this contract, who, during the period of this agreement, make a discovery or invention relating directly to the specifically defined subject of this project, shall promptly make such discovery known to the Contracting Officer, and upon the request and at the expense of the Contracting Officer, and through attorneys named by the Contracting Officer, make application for Letters Patent and the Contractor will assign such Letters Patent and any and all rights to such invention to the United States Government under the conditions of this agreement.

Article VI. Safeguarding Information.

a. The Contractor agrees that he will take all reasonable precautions that the results of this research project shall be, both during the progress of work and upon its completion, kept strictly confidential and that only American citizens will at any time have access to any reports, unless exception is granted by the Secretary of War.

b. The Contractor further agrees not to disclose the results of this research investigation without the permission of the Chief of Ordnance, U. S. Army, Washington, D. C.

Article VII. Termination

a. It is agreed that the Contracting Officer may terminate this agreement at any time after four (4) months from the date of the contract, by giving the Contractor sixty (60) days' notice in writing of his intention to cancel.

b. Upon such termination the Contractor shall forthwith deliver to the Government, F.O.B. Contractor's plant, all articles and equipment purchased and paid for under the terms of this Contract, and all information which has been developed or discovered up to the time of termination of this Contract.

c. There shall be determined by an audit conducted by or for the Contracting Officer, the total net amount of expenditures made and/or incurred by the Contractor in accordance with the terms of this Contract, and for which he has not been reimbursed; and also the cost of cancelling any commitments for the purchase of materials or special equipment under the terms of this Contract.

d. The Contractor shall be reimbursed to the extent of the amount determined under Paragraph c. of this Article, and upon the making of said payments, all obligations of the Government to make further payments or to carry out other undertakings hereunder shall cease.

Article VIII. Disputes. All disputes concerning questions of fact arising under this Contract shall be decided by the Contracting Officer, subject to written appeal by the Contractor within thirty (30) days from the decision of the Contracting Officer to the Chief of Ordnance, U. S. Army, whose decision shall be final and conclusive upon the parties hereto. In the meantime, the Contractor shall diligently proceed with performance.

Article IX. Approval Required. This Contract shall not become a binding and valid instrument until approved by the Chief of Ordnance, U. S. Army, or his duly authorized representative.

Article X. Officials not to Benefit. No member of or delegate to Congress or resident commissioner shall be admitted to any share or part of this Contract or to any benefit that may arise therefrom, but this provision shall not be construed to extend to this Contract if made with a corporation for its general benefit.

Article XI. Covenant against Contingent Fees. The Contractor warrants that he has not employed any person to solicit or secure this contract upon any agreement for a commission, percentage, brokerage, or contingent fee.

Breach of this warranty shall give the Government the right to annul the Contract, or, in its discretion, to deduct from the Contract price or consideration, the amount of such commission, percentage, brokerage, or contingent fees. This warranty shall not apply to commission payable by Contractors upon Contracts of sales secu.ed or made through bonna fide established commerical or selling agencies maintained by the Contractor for the purpose of securing business.

Article XII. Title to equipment. The Title to all equipment purchased in connection with this research and paid for by the United States Government in accordance with the terms of Article III-b shall vest in the United States Government, and after completion of this Contract, all such equipment purchased by the Contractor shall be delivered f. o. b. Contractor's plant in the same condition as when purchased, ordinary wear and tear, or destruction by an Act of God or public enemy excepted.

Article XIII. Assignment of Contractor's Claims. (a) Claims for moneys due or to become due to the Contractor from the Government arising out of this contract may be assigned to any bank, trust company or other financing institution, including any Federal lending agency; and any such assignment may cover all or any part of any claim or claims arising or to arise out of this contract and may be made to any one or more such institutions or to any one party as agent or trustee for two or more such institutions participating in the financing of this contract. Any claims so assigned may be subject to further assignment; and any bond, promissory note or other evidence of indebtedness secured by any such assignment may be rediscounted, hypothecated as collateral for a loan or credit, or sold with or without recourse. In the event of the assignment or reassignment of any claim for moneys due or to become due under this contract the assignee thereof shall file in quadruplicate, written notice of the assignment, together with one true copy of the instrument of assignment with (a) the General Accounting Office of the Government, (b) the Contracting Officer or the Secretary of War (c) the surety or sureties upon the bond or bonds, if any, in connection with such contract, and (d) with the Finance Officer of the U. S. Army at Watertown Arsenal, Watertown, Mass., who is hereby designated to make all payments under this contract. In no event shall copies of any plans, specifications or other similar documents marked "SECRET", "CONFIDENTIAL", or "RESTRICTED", be furnished to any assignee of any claim arising under this contract or to any other person not otherwise entitled to receive the same.

(b) Payments to any assignee of any claim assigned pursuant to the provisions of paragraph (a) above shall not be subject to reduction or set-off, nor shall any of such payments be subject to reduction or set-off for any indebtedness of the assignor to the United States arising independently of this contract.

Article XIV. Eight Hour Law - No laborer or mechanic doing any part of the work contemplated by this contract, in the employ of the contractor or any subcontractor contracting for any part of said work contemplated, shall be required or permitted to work more than eight hours in any one calendar day upon such work at the site thereof, except upon the condition that compensation is paid to such laborer or mechanic in accordance with the provisions of this article. The wages of every laborer and mechanic employed by the contractor or any subcontractor engaged in the performance of this contract shall be computed on a basic day rate of eight hours per day and work in excess of eight hours per day is permitted only upon the condition that every such laborer and mechanic shall be compensated for all hours worked in excess of eight hours per day at not less than one and one-half times the basic rate of pay. For each violation of the requirements of this article a penalty of five dollars shall be imposed upon the contractor for each laborer or mechanic for every calendar day in which such employee is required or permitted to labor more than eight hours upon said work without receiving compensation computed in accordance with this article, and all penalties thus imposed shall be withheld for the use and benefit of the Government: Provided: that this stipulation shall be subject in all respects to the exceptions and provisions of U. S. Code, title 40, sections 321, 324, 325, and 326, relating to hours of labor, as in part modified by the provisions of Section 5 (b) of Public Act No. 671, 76th Congress, approved June 28, 1940, and Section 303 of Public Act No. 781, 76th Congress, approved September 9, 1940, relating to compensation for overtime.

Article XV. Property Records. The Property Officer, Watertown Arsenal, Watertown, Mass., is designated as the officer to maintain the necessary property records in connection with this contract as contemplated by Army Regulation 35-6520.

IN WITNESS WHEREOF, the parties hereto have executed this Contract as of the day and year first above written.

THE UNITED STATES OF AMERICA

BY (Sgd.) R. W. CASE
R. W. CASE
Brigadier General, U. S. Army,
Contracting

Two Witnesses:

(Sgd.) B. D. THOMAS

(Sgd.) E. E. SLOWTER

THE BATTELLE MEMORIAL INSTITUTE

BY (Sgd.) CLYDE E. WILLIAMS
Director

RESTRICTED

Certificate as to Corporate Principal

I, (Signed) G. S. FENTON , certify that I am Secretary of the corporation named as contractor herein; that CLYDE E. WILLIAMS who signed this contract on behalf of the contractor, was then DIRECTOR of said corporation; that said contract was duly signed for and in behalf of said corporation by authority of its governing body, and is within the scope of its corporate powers.

(Signed) G. S. FENTON (Corporate)
(Seal)

(Seal)
BATTELLE
MEMORIAL
INSTITUTE
COLUMBUS, OHIO

BATTELLE MEMORIAL INSTITUTE

INDUSTRIAL AND SCIENTIFIC RESEARCH

COLUMBUS, OHIO

Sept. 19, 1941

Colonel S. B. Ritchie
Watertown Arsenal
Watertown, Massachusetts

Dear Colonel Ritchie:

Three copies of the report on the investigation of armor plate steels are enclosed.

Experimental work so far completed includes the making of 20 heats from the list of 40 prepared at Watertown. The steels have been rolled into 1/2 inch plates and coupons have been put through a variety of tests as follows:

1. Critical points for each steel have been determined and these have been correlated with compositions.

2. An examination for undissolved carbides has been made on the steels in the quenched condition.

3. All of the steels have been rated for cleanliness by both the S.A.E. and Chevrolet methods.

4. Preliminary drawing treatments have been given to find what temperatures and times are required to bring all of the steels within the specified hardness range.

5. Tests have been made to determine grain growth characteristics.

The preliminary work has been completed and the large plates are being quenched and drawn. When this work is finished, the plates will be shipped to you for testing and we shall start the melting on the second series.

Any comments on the work described in this report which you may care to make will be appreciated.

Yours very truly,

C. H. Lorig

C. H. Lorig.

CHL:DW
Enc. (3)

PROGRESS REPORT

on

RESEARCH INVESTIGATION OF ARMOR PLATE STEELS

to

WATERTOWN ARSENAL, UNITED STATES ARMY

by

M. L. Samuels and C. H. Lorig

BATTELLE MEMORIAL INSTITUTE

August 27, 1941

TABLE OF CONTENTS

	Page
FOREWORD	1
SUMMARY OF RESULTS	3
EXPERIMENTAL WORK	6
Preparation of Plates	6
Dilatometric Critical Point Determinations	11
Preliminary Heat Treatment	13
Construction of Quenching Fixture	13
Microscopic Examination of Finished Plates	17
A. Inspection for Undissolved Carbides	17
B. Inspection for Cleanliness	17
C. Austenitic Grain Size Inspection	19
DISCUSSION OF RESULTS	19
FUTURE WORK	21

PROGRESS REPORT

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RESEARCH INVESTIGATION OF ARMOR PLATE STEELS

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WATERTOWN ARSENAL, UNITED STATES ARMY

from

BATTELLE MEMORIAL INSTITUTE

by

M. L. Samuels and C. H. Lorig

August 27, 1941

FOREWORD

An outline for a research investigation of armor plate steels was drawn up by Dr. Hoyt, of Battelle Memorial Institute, and Messrs. Ritchie, Reed, and Mathews of Watertown Arsenal.

A primary purpose of this investigation is to develop a light armor plate that can be made in the open hearth furnace and rolled on a high production mill and which can be processed in less time than is now consumed. Another primary object is the substitution of less strategic metals, in whole or in part, for more strategic metals in armor plate steel.

The program for accomplishing these objectives consists in making up experimental heats of steel by methods which approximate open hearth heats in quality rather than electric furnace heats and by processing them to bring out their best ballistic properties for the specified hardness level. The compositions of the experimental heats will include, in varying amounts, the more conventional alloying elements -

nickel, chromium, vanadium and molybdenum, as well as the less strategic elements - manganese, silicon, copper, etc.

If the standard armor plate steel of this series of experimental heats meets present ballistic specifications, it may reasonably be expected that open hearth steel is of adequate quality since considerable experience has been accumulated in correlating laboratory or experimental heats with commercial steel. It must be kept in mind, however, that these correlations have never before included ballistic behavior. The ballistic tests of these steels should also indicate the possibilities of substituting one element for another without sacrifice of quality. If one or more of the "substitute" compositions is found to meet the ballistic specifications, that will be evidence that less strategic metals can be substituted for the more strategic alloy elements that are now used. The present report covers that portion of this work that was completed in August.

Upon the completion of the preliminary program, the most promising compositions will be studied for the most suitable heat treatment for homogeneous plate and flame hardening will be studied as a possible substitute for the present method of case hardening. During this stage of the work, larger heats will be made and tested ballistically at different thicknesses and in different conditions of heat treatment.

As another objective, this work should provide a better conception of the metallurgical requirements of armor plate. Upon this basis it may be hoped that information leading to the development of a plate with better ballistic properties will be obtained, or at least that plate of satisfactory ballistic properties will be more readily and uniformly obtained in the production.

To review briefly, the first or preliminary stage of this experimental program consists in making, heat treating, and testing about forty different steel compositions. The first twenty plates have been made and studied in the laboratory and will be heat treated and ready for testing at Watertown Arsenal very soon. The remainder of the preliminary heats will be started at once for the completion of this part of the program. The second, or final stage will be started as soon as the implications of the preliminary survey are clear.

An extended discussion of the selection of steel compositions and of the theory of substituting one element for another may best be deferred until the ballistic tests have been completed. However, it may be assumed that a major requirement of the alloy addition is that of slowing down the transformation on cooling so that full as-quenched hardness can be secured in the heavier sections and with more moderate quenching. This principle is illustrated by Fig. 1. The higher the nickel, the slower the cooling rate to produce full hardness. Less strategic metals which accomplish this effect are included in the present program.

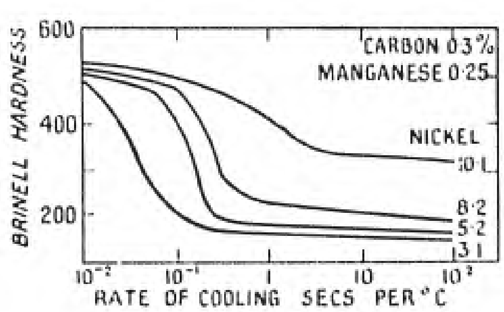

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Figure 1. Effect of Nickel upon the Critical Cooling Rates.

Jones, J. A. Jr. Iron and Steel Institute, 1928. Volume 117, page 295.

SUMMARY OF RESULTS

Twenty heats have been made from the list of 40 compositions compiled at Watertown Arsenal. Melting data, together with intended and actual analyses, are summarized in Table 1.

The ingots have been forged and rolled into 1/2-inch plates, from the ends of which coupons were removed for preliminary tests.

Critical points, including Ac1, Ac3, Ar3, and Ar1, were determined for each steel by the dilatometric method. The mass of data collected in making these determinations is entered in our notebook but only the curves, shown along with corresponding microstructures as Figures 4 to 23, are given in this report. Since the temperature at which the various transformations occur is influenced, especially upon cooling, by the rate of temperature change, time-temperature curves are given in Figure 24. The relation between composition and the temperature at which the transformations occur is shown in Table II. These data were used to determine optimum quenching temperatures and they also were of some help in determining whether a given steel should be quenched in oil or in water.

Coupons from each of the plates were put through preliminary heat treatments for the purpose of determining as quenched hardness values and approximate drawing temperature-time combinations necessary to bring the final hardness within the specified range of 350 to 370 Brinell. This work on the coupons was thought worthwhile because it will make possible the proper heat treatment of the large plates with a minimum of errors. The data showing quenching and drawing results are summarized in Table III.

Microscopical examinations were made for undissolved carbides with the steels in the as quenched condition. Some small spherical carbides were found after etching with Murakami's reagent but no chain-like or grain boundary structures were observed. Dr. Reed examined a few of the specimens and concurred with our opinion that little trouble would be experienced from this source.

Cleanliness ratings were made according to both the S.A.E. and the Chevrolet methods and the results are shown in Table IV. Specimens from Heats 7091, 7092, 7099, 7101 and 7103 showed long alumina stringers and should be watched for the possible effect of such inclusions on the ballistic properties. Analyses corresponding to the above heats will be repeated in order that the relation between cleanliness and ballistic properties may be determined.

Samples from Heats 7105 to 7110 inclusive were definitely cleaner than most of the other heats, possibly due to the addition of V, Ti or Grainal. It is apparent from the tables, however, that cleanliness is not very definitely related to the compositions produced. This leads to the conclusion that furnace practice may be the determining factor and future melts will be made with this in mind.

Microstructures from the as rolled plates indicated that most of the steels were fine grained but a few showed abnormal grain growth. See Figures 5, 6, 8, and 9. Coupon samples from all of the steels were heated to the respective temperatures selected for quenching the large plates, held for ½ hour and cooled in air. A ferrite network around the original austenite grains showed what grain size might be expected in the quenched material. Five of the steels showed some evidence of a duplex structure but this condition is not thought to be serious.

The above summary covers all the preliminary work and, at this time, the plates are being put through the quenching and drawing treatments in preparation for ballistic tests.

EXPERIMENTAL WORK

Preparation of Plates.

The preparation of the twenty steels which are described in this report followed the practice outlined by Dr. Hoyt on his visit to the Watertown Arsenal. The steels were melted in a 16 pound high frequency induction furnace with standard ferro alloys and Armco punchings being used to make up the charges. All heats were deoxidized with an aluminum addition unless otherwise specified, and were cast into a 16 pound circular ingot mold.

Tabulated melting data on this group of steels are given in Table I.

One half-inch by six-inch plates approximately 13 inches in length were cross forged and rolled from the ingots in the following manner. The hot tops were removed from all ingots before forging. On the first heating the ingots were squared up to give a length of 7 to 8 inches. Following the squaring up operation the ingots were reheated and upset to a length of approximately 6 inches. Forging, upsetting, and reheating was continued until a section 6 inches wide, 1½ to 2 inches thick, and 3 to 4 inches in length was obtained. Approximately 5 reheatings were used for this operation with a temperature of 2080° F. to 2150° F. being maintained.

The rolling procedure used in the preparation of these plates was as follows. The forged blanks were sandblasted in preparation for rolling and were reduced to 7/8 inch plates in six passes. Two reheatings were required for this operation at a temperature of 1850° F. to 1900° F. The 7/8 inch plates were sandblasted in preparation for finishing and were then reheated to 1750° F. and finished to approximately .515 inch in four passes. After hot rolling was completed the plates were given

TABLE I. MELTING DATA FOR THE SERIES OF TWENTY HEATS.
Made in 15-lb. Induction Furnace.

Heat No.	Charges and Additions			Analysis							
	Material	Wt.-Lb.	Time of Addition	C	Mn	Si	Ni	Cr	Mo	V	Ti
			Power on								
7091	Armco	15.75	8:55	.42/.48	.30/.40	.20/.30	- Intended				
	C	.075	9:56½	.45	.34	.20	- Actual				
	FeMn	.034	9:59½								
	SiMn	.069	9:58								
	FeSi	.053	10:00½								
	Al	.016	10:02								
			Tapped 10:03								
			Power on								
7092	Armco	15.67	10:20	.42/.48	.60/.90	.20/.30	- Intended				
	SiMn	.069	11:07	.46	.85	.24	- Actual				
	C	.068	11:07½								
	FeSi	.053	11:07½;11:09								
	FeMn	.133	11:08¼								
	Al	.015	11:10½								
			Tapped 11:11½								
			Power on								
7093	Armco	15.60	10:22	.42/.48	1.0/1.30	.20/.30	- Intended				
	SiMn	.069	11:10	.46	1.17	.21	- Actual				
	C	.062	11:11								
	FeSi	.051	11:11;11:14								
	FeMn	.206	11:13								
	Al	.016	11:16								
			Tapped 11:17								

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	Al	.015	11:10½						
			Tapped						
			11:11½						
			Power on						
7093	Armco	15.60	10:22	.42/.48	1.0/1.30	.20/.30		- Intended	20.4
	SiMn	.069	11:10	.46	1.17	.21		- Actual	
	C	.062	11:11						
	FeSi	.051	11:11; 11:14						
	FeMn	.206	11:13						
	Al	.016	11:16						
			Tapped						
			11:17						
			Power on						
7094	Armco	15.50	2:05	.42/.48	1.50/1.80	.20/.30		- Intended	2024
	SiMn	.069	2:49	.46	1.82	.26		- Actual	
	C	.056	2:49½						
	FeSi	.050	2:49½; 2:51½						
	FeMn	.326	2:50½						
	Al	.016	2:54						
			Tapped						
			2:55						
			Power on						
7095	Armco	15.40	2:59	.32/.38	.50/.80	.20/.30	1.80/2.00	- Intended	[illegible]
	SiMn	.069	3:49	.36	.71	.19	1.93	- Actual	
	C	.054	3:49½						
	FeSi	.053	3:49½; 3:52						
	FeMn	.109	3:51						
	Al	.016	3:54						
	Ni	.304	3:16						
			Tapped						
			3:55						
			Power on						
7096	Armco	15.150	3:58	.32/.38	.50/.80	.20/.30	3.30/3.70	- Intended	[illegible]
	Ni	.360	4:10	.37	.75	.25	3.41	- Actual	
	SiMn	.069	4:39						
	C	.054	4:39½						
	FeSi	.053	4:39½; 4:41						
	FeMn	.109	4:40½						
	Al	.016	4:43						
			Tapped						
			4:44						

- Continued, page 8

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Table I - Continued. Melting Data for the Series of Twenty Heats

Heat No.	Charges and Additions			Analysis								
	Material	Wt.-Lb.	Time of Addition	C	Mn	Si	Ni	Cr	Mo	V	Ti	
			Power on									
7097	Armco	14.90	1:50	.32/.38	.50/.80	.20/.30	4.80/5.20	-				Intended
	Ni	.800	2:10	.36	.73	--	4.96	-				Actual
	SiMn	.069	2:42									
	C	.053	2:42½									
	FeSi	.050	2:42½; 2:45									
	FeMn	.109	2:44									
	Al	.016	2:55									
			Tapped 2:56									
			Power on									
7098	Armco	15.305	2:55	.32/.38	1.00/1.30	.20/.30	1.80/2.00	-				Intended
	Ni	.304	3:20	.37	1.18	.23	1.99	-				Actual
	SiMn	.069	3:37									
	C	.046	3:39									
	FeSi	.051	3:39;3:41½									
	FeMn	.206	3:40½									
	Al	.016	3:43									
			Tapped 3:44									
			Power on									
7099	Armco	15.26	3:47	.32/.38	.60/.90	.20/.30	1.30/1.60	.70/.90	-			Intended
	Ni	.232	4:15	.37	.84		1.52	.87	-			Actual
	SiMn	.069	4:28									
	FeCr	.206	4:30									
	C	.040	4:30									
	FeSi	.045	4:30;4:32½									
	FeMn	.127	4:31½									
	Al	.016	4:34½									
			Tapped 4:35½									

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	FeSi	[illegible]	[illegible]								
	FeMn	.206	3:40½								
	Al	.016	3:43								
			Tapped 3:44								
			Power on								
7099	Armco	15.26	3:47	.32/.38	.60/.90	.20/.30	1.30/1.60	.70/.90		-	Intended
	Ni	.232	4:15	.37	.84		1.52	.87		-	Actual
	SiMn	.069	4:28								
	FeCr	.206	4:30								
	C	.040	4:30								
	FeSi	.045	4:30;4:32½								
	FeMn	.127	4:31½								
	Al	.016	4:34½								
			Tapped 4:35½								
7100	Armco	14.51	Power on 8:52	.32/.38	.60/.90	.20/.30	3.60/3.90	2.40/2.60		-	Intended
	Ni	.600	9:05	--	.81	--	3.75	2.60		-	Actual (No analysis made; specimen unmachinable)
	SiMn	.069	10:45								
	FeCr	.620	10:47								
	C	.021	10:47								
	FeSi	.035	10:55								
	FeMn	.127	10:55								
	Al	.016	10:57								
			Tapped 10:58								
			Power on								
7101	Armco	15.20	10:04	.32/.38	.60/.90	.20/.30	1.30/1.60	.70/.90	.20/.30	..	Intended
	Ni	.232	10:20	.36	.85	.25	1.52	.89	.39	..	Actual
	FeMo	.063	10:45								
	SiMn	.069	10:46								
	FeCr	.206	10:48								
	C	.040	10:48								
	FeMn	.127	10:49								
	FeSi	.047	10:50								
	Al	.016	10:52½								
			Tapped 10:54								

- Continued, page 9

2

Table I - Continued. Melting Data for the Series of Twenty Heats

Heat No.	Charges and Additions: Material	Wt.-Lb.	Time of Addition	Analysis: C	Mn	Si	Ni	Cr	Mo	V	Ti	
			Power on									
7102	Armco	14.78	11:00	.32/.38	.60/.90	.20/.30	3.30/3.70	.90/1.10	.35/.45	-		Intended
	Ni	.560	11:15	.38	.87	--	3.50	1.09	.60	-		Actual
	FeMo	.101	11:36									
	SiMn	.069	11:39									
	FeCr	.252	11:41									
	C	.038	11:41									
	FeMn	.129	11:43									
	FeSi	.047	11:44									
	Al	.016	11:46									
			Tapped 11:47									
			Power on									
7103	Armco	15.05	11:22	.32/.38	1.40/1.60	.20/.30	1.30/1.60	.75/.90	.25/.35	-		Intended
	Ni	.232	11:36	.36	1.53	.25	--	--	--	-		Actual
	FeMo	.076	11:59									
	SiMn	.0695	12:02									
	FeCr	.206	12:04									
	C	.032	12:04									
	FeMn	.276	12:06									
	FeSi	.043	12:07									
	Al	.016	12:09									
			Tapped 12:10									
			Power on									
7104	Armco	15.40	12:12	.32/.38	.60/.90	.20/.30	1.30/1.60			.10/.15		-Intended
	Ni	.232	12:26	.33	.83	--	1.52			.14		-Actual
	SiMn	.0695	12:58									
	C	.051	1:00									
	FeSi	.047	1:00;1:03									
	FeMn	.127	1:02									
	Al	.016	1:05½									

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	Al	.016	12:09					
			Tapped					
			12:10					
			Power on					
7104	Armco	15.40	12:12	.32/.38	.60/.90	.20/.30	1.30/1.60	.10/.15-Intended
	Ni	.232	12:26	.33	.93	--	1.52	.14 -Actual
	SiMn	.0695	12:58					
	C	.051	1:00					
	FeSi	.047	1:00;1:03					
	FeMn	.127	1:02					
	Al	.016	1:05½					
	FeV	.062	1:03					
			Tapped					
			1:06½					
			Power on					
7105	Armco	15.50	1:12	.42/.48	1.4/1.6	.20/.30		Intended - .10/.20
	SiMn	.069	1:51	.48	1.58	.26		Actual - .18
	C	.057	1:53					
	FeMn	.276	1:54					
	Si-Ti	.0965	1:57					
			Tapped					
			1:53					
			Power on					
7106	Armco	15.51	2:03	.42/.48	1.4/1.6	.20/.30	(Grainal - 5[illegible]/Ton)	
	SiMn	.069	2:45	.48	1.62			
	C	.057	2:47					
	FeMn	.276	2:49					
	Grainal	.040	2:52					
			Tapped					
			2:53					

- Concluded, page 10

REPRODUCED AT GOVERNMENT EXPENSE

2

Table I - Concluded.   Melting Data for the Series of Twenty Heats

Heat No.	Charges and Additions: Material	Wt.-Lb.	Time of Addition	Analysis: C	Mn	Si	Ni	Cr	Mo	V	Ti
			Power on								
7107	Armco	15.13	2:59	.42/.48	1.4/1.6	.60/.80		.90/1.10		.10/.20	
	SiMn	.069	3:44	.47	1.70	.68		1.13		.13	
	C	.045	3:46								
	FeCr	.252	3:46								
	FeMn	.276	3:48								
	FeSi	.140	3:49								
	FeV	.071	3:49								
	Al	.016	3:53								
			Tapped 3:54								
			Power on								
7108	Armco	15.17	1:20	.42/.48	1.4/1.6	.60/.80		.90/1.10	(Grainal - 5#/Ton)		
	SiMn	.069	2:18	.50	1.62	.69		1.13		.08	
	FeCr	.252	2:20								
	C	.045	2:20								
	FeMn	.276	2:21½								
	FeSi	.142	2:22½								
	Grainal	.040	2:26½								
			Tapped 2:27½								
			Power on								
7109	Armco	15.18	2:31	.42/.48	1.4/1.6	.35/.50		.90/1.10	.25/.35		
	FeMo	.076	3:11	.48	1.62			1.10	.50		
	SiMn	.069	3:12								
	FeCr	.252	3:14								
	C	.045	3:14								
	FeMn	.276	3:15								
	FeSi	.082	3:16½								
	Al	.016	3:18½								
			Tapped 3:19½								

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			Tapped						
			2:27½						
			Power on	.42/.48	1.4/1.6	.35/.50		.90/1.10	.25/.35
7109	Armco	15.18	2:31	.48	1.52			1.10	.50
	FeMo	.076	3:11						
	SiMn	.069	3:12						
	FeCr	.252	3:14						
	C	.045	3:14						
	FeMn	.276	3:15						
	FeSi	.082	3:16½						
	Al	.016	3:18½						
			Tapped						
			3:19½						
			Power on	.42/.48	1.4/1.6	.20/.30			.35/.45
7110	Armco	15.43	3:25	.48	1.57	.24			.53
	FeMo	.102	4:00						
	SiMn	.069	4:03						
	FeSi	.047	4:05;4:07						
	C	.057	4:05						
	FeMn	.276	4:06						
	Al	.016	4:09						
			Tapped						
			4:10						

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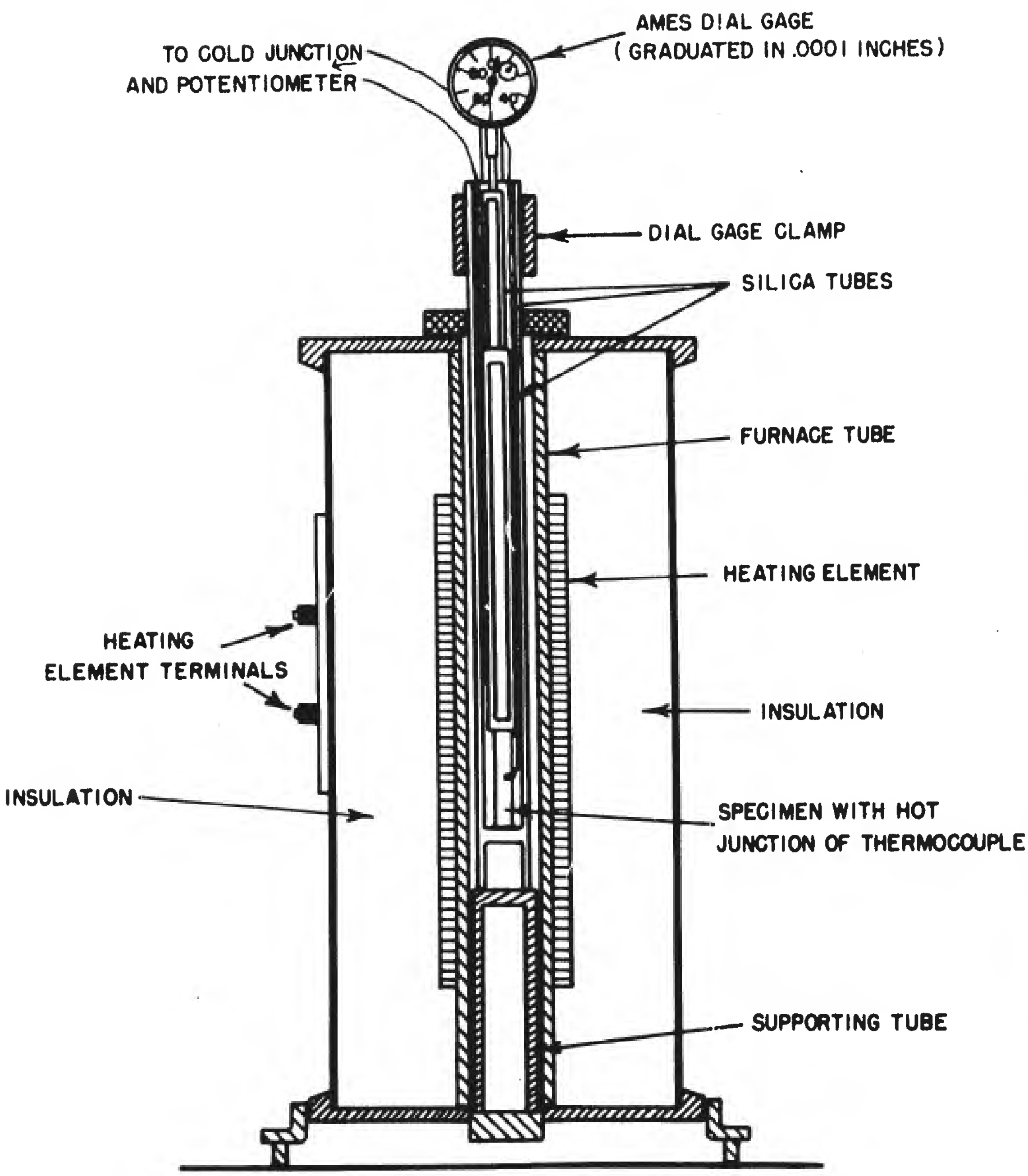
a light skin pass through the cold rolls to reduce them to the final thickness. The finished plates ranged in thickness from .503 inch to .513 inch, with a length and width of approximately 13-1/4 inches and 6-1/8 inches respectively.

Dilatometric Critical Point Determinations.

Critical points for all of the twenty steels were determined by the dilatometric method. Check runs on the apparatus were made with specimens of SAE 4130 steel and gave values which were in agreement with the published data on this type of material.

Specimens 3 inches in length and ½ inch in diameter were machined from test coupons cup from the ends of the finished plates. A 22-gauge chromel-alumel thermocouple was placed in the side of each specimen. Temperature measurements were obtained with a Brown portable potentiometer, and deflections were measured with an Ames dial gauge graduated in 1/10,000 of an inch. An electrically heated vertical tube furnace, constructed especially for this type of work, was used for these tests. Quartz tubes were used for specimen holders and thrust bars throughout the tests. The current supply used was a 110 volt service line passed through a Variac transformer with resistance to give approximately 5 amperes. A cross-section view of the apparatus is shown on page 11a.

Dilatometric curves for each steel are shown in Figures 4 to 23 inclusive along with the as-rolled microstructure for each plate. Cooling rates for each determination are shown as time-temperature curves in Figure 24. The rate of heating was very nearly identical for all specimens so only one heating curve was plotted. This time-temperature curve is also shown in Figure 24. The effect of the various alloying elements upon the location of the critical points - heating and cooling rates being very nearly the same for all specimens-is shown by data summarized in Table II.



12174

Fig. 2. Schematic drawing showing a cross-section view of the furnace set-up for obtaining dilatometer readings.

TABLE II. RELATION BETWEEN COMPOSITION AND CRITICAL POINTS FOR HEATS 7091 TO 7110 INCLUSIVE.

Series	Heat No.	Composition								Critical Points, °F.			
		C	Mn	Si	Ni	Cr	Mo	V	Ti	Ac1	Ac3	Ar3	Ar1
Manganese	7091	.45	.34	.20	--	--	--	--	--	1355	1455	1390	1285
	7092	.46	.85	.24	--	--	--	--	--	1345	1450	1330	1250
	7093	.46	1.17	.21	--	--	--	--	--	1350	1435	1310	1215
	7094	.48	1.82	.26	--	--	--	--	--	1340	1450	1190	1180
Nickel	7095	.36	.71	.19	1.93	--	--	--	--	1310	1415	1270	1160
	7096	.37	.75	.25	3.41	--	--	--	--	1275	1370	1175	1040
	7097	.36	.73	--	4.96	--	--	--	--	1240	1340	1060	910
Mn-Ni	7098	.37	1.18	.23	1.99	--	--	--	--	1355	1425	980	840
Cr-Ni	7099	.37	.84	--	1.52	.87	--	--	--	1325	1410	1235	1185
	7100	--	.81	--	3.75	2.60	--	--	--	1250	1460	660	500
Cr-Ni-Mo	7101	.36	.85	.25	1.52	.89	.39	--	--	1330	1445	935	685
	7102	.38	.87	--	3.50	1.09	.60	--	--	1245	1430	655	500
Mn-Cr-Ni-Mo	7103	.36	1.53	.25	1.3/1.6	.75/.90	.25/.35	--	--	1270	1460	790	590
Ni-V	7104	.33	.83	--	1.52	--	--	.14	--	1320	1440	1300	1160
TiMn	7105	.48	1.58	.26	--	--	--	--	.18	1330	1425	1260	1180
Mn-Grainal	7106	.48	1.62	--	--	--	--	--	--	1345	1425	1225	1180
Si-Mn-Cr-V	7107	.47	1.70	.68	--	1.13	--	.18	--	1385	1515	1275	1245
Si-Mn-Cr-Grainal	7108	.50	1.62	.69	--	1.13	--	.08	--	1375	1495	1280	1250
Mn-Cr-Mo	7109	.48	1.62	--	--	1.10	.50	--	--	1370	1505	860	625
Mn-Mo	7110	.48	1.57	.24	--	--	.53	--	--	1350	1455	1000	840

Preliminary Heat Treatment.

Following the completion of the critical point determinations, preliminary heat treating data were obtained on coupons cut from the finished plates. Proper hardening temperatures and quenching media were determined by the trial and error method and approximate drawing temperatures were determined by elimination.

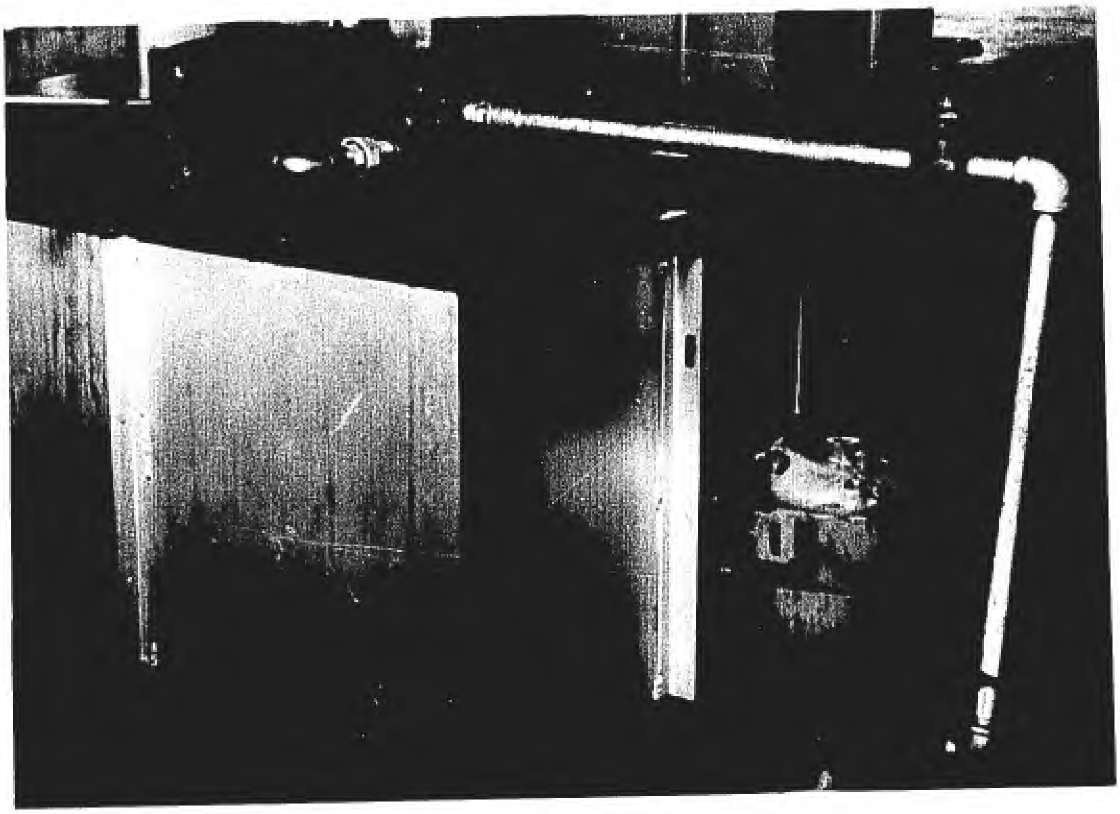
Tabulated data on the results of these tests are given in Table III.

Construction of Quenching Fixture.

In order to obtain uniformity of quench and sufficiently high hardness a quenching fixture was designed for use in the heat treatment of the finished plates. The fixture consists of 2 spray heads, approximately 13 inches in length and 6-1/2 inches in width, attached to a coolant supply line by means of a swing joint and the necessary pipe fittings. Each spray head contained fifty two-1/8 inch holes spaced at equal distances over the area of the spray head face. A Crane three-way, stop-cock is installed in the coolant supply line so as to by pass the coolant during the time necessary to insert the heated plate into the holder on the quenching fixture. After the plate is in position the entire fixture is dropped into the quenching bath and the stop-cock is automatically opened to permit the quenching medium to flow over the surface of the plate.

The coolant is delivered to the fixture, by means of a centrifugal pump mounted on the side of the quenching tank, at a rate of approximately 210 gallons per minute.

A photograph of the quenching tank and fixture is shown in Figure 3.



12224

Fig. 3. Quenching Tank and Fixture.

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TABLE III. RESPONSE OF THE STEELS TO P
Specimens Represent Coupons Cut fro

Heat No.	Preliminary Quenching Treatment * Water Quench 1750°F	Oil Quench 1550°F	Brinell Hardness After First Quenching and Drawing T. Oil Quench °F	Water Quench °F	Draw 800°F $\frac{1}{2}$ hr	Draw No.2	Draw No.3	Draw No.4	Draw No.5	Draw No.6	Draw No.7	Draw No.8	Draw No.9	Draw No.
7091	--	--	1500° (181)**	1500° (302)	235									
7092	(567)	(415)	1475° (207)	1600° (411)	331									
7093	(601)	(514)	1475° (269)	1475° (404)	293									
7094	(640)	(555)	1475° (477)	--	408	500° $\frac{1}{2}$hr 429	600° $\frac{1}{2}$hr 444	600° $1\frac{1}{2}$hr 441	675° 2hr 444	750° 2hr 368				
7095	(539)	(505)	1450° (429)	--	331									
7096	(534)	(514)	1400° (495)	--	358									
7097	(550)	(534)	1400° (477)	--	331									
7098	(561)	(514)	1475° (411)	--	321									
7099	(567)	(534)	1450° (453)	--	401	500° $\frac{1}{2}$ hr 415	600° $\frac{1}{2}$ hr 415	600° $1\frac{1}{2}$hr 409	650° $1\frac{1}{4}$hr 415	675° 2hr 401	700° 2hr 412	750° 2hr 398	800° 1 hr 383	800° 1 hr 380
7100	(555)	(534)	1500° (453)	--	408	500° $\frac{1}{2}$hr	600° $\frac{1}{2}$hr	600° $1\frac{1}{2}$hr	650° $1\frac{3}{4}$hr	700° 4hr	750° 2hr	850° 2hr	900° 2hr	
7101	(555)	(514)	1500° (404)	--	381	500° $\frac{1}{4}$hr 385	600° $\frac{1}{2}$hr 398	600° $1\frac{1}{4}$hr 368						
7102	(567)	(555)	1475° (514)	--	415	600° $\frac{1}{4}$hr 401	600° $\frac{1}{2}$hr 423	600° $1\frac{1}{2}$hr 420	650° $1\frac{1}{2}$hr 420	675° 2hr 420	750° 2 hr 417	800° $1\frac{1}{2}$hr 423	850° 2hr 413	900° 2hr 393
7103	(590)	--	1500° (453)	--	364	500° [illegible] 415	600° [illegible] 415	600° [illegible] [illegible]	650° [illegible] [illegible]	675° 2hr 415	750° 2hr [illegible]	800° 1 hr 404	800° 1 hr 401	850° $1\frac{3}{4}$hr 388
7104	(539)	(495)	1550° (363)	1550° (429)	363									
7105	(627)	(555)	1475° (316)	1475° (429)	316									

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THE STEELS TO PRELIMINARY HEAT TREATMENTS.
Coupons Cut from the Half-Inch Plates.

...g and Drawing Treatment								Brinell Hardness After Second Treatment							
...w Draw ...7	Draw No.8	Draw No.9	Draw No.10	Draw No.11	Draw No.12	Draw No.13	Oil Quench °F	Water Quench °F	Draw No.1	Draw No.2	Draw No.3	Draw No.4	Draw No.5	Draw No.6	
								1650° 614	600° ½hr 454	600° 1½hr 448	650° 1¾hr 412	675° 2 hr 388	700° 2 hr 378	750° ½hr 359	
								1550° 555	600° ½hr 448	600° 1½hr 444	675° 2hr 395	700° 2hr 388	750° 1½hr 347		
							1475 495		600° ½hr 38[illegible]	600° ¾hr 373	600° ¼hr 366				
							1400 534		600° ½hr 420	600° 1½hr 420	650° 2hr 375	675° ½hr 373	675° 1½hr 363		
							1400 555		600° ½hr 423	600° 1½hr 415	650° 2hr 368				
								1475 544	600° ½hr 429	600° 1½hr 417	650° 1½hr 415	675° 2hr 417	750° 2hr 313		See 3rd treatment below
°	750° 2hr 398	800° 1 hr 383	800° 1 hr 380	850° ½hr 378	850° 1½hr 366										
°	850° 2hr	900° 2hr													
							1550 489		600° 1 hr 426	650° 1 hr 417	700° 2hr 398	750° 1 hr --			
° r	800° 1½hr 423	850° 2hr 412	900° 2hr 393	950° 1½hr 393	1000° 1½hr 363										
°	800° 1 hr 404	800° 1 hr 401	850° 1¾hr 388	900° 1 hr 388	950° 1 hr 366										
								1575 543	850° 1¼hr 317						See 3rd treatment below
							1600 578		600° ½hr 467	600° 1½hr 461	675° 2hr 409	700° 2hr 393	750° 2hr 363		

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REPRODUCED AT GOVERNMENT EXPENSE

Table III - Continued.

Heat No.	Preliminary Quenching Treatment: Water Quench 1750°F	Preliminary Quenching Treatment: Oil Quench 1550°F	Oil Quench °F	Water Quench °F	Draw 800°F ½ hr	Draw No.2	Draw No.3	Draw No.4	Draw No.5	Draw No.6	Draw No.7	Draw No.8	Draw No.9	Dra[w] No.
					Brinell Hardness AFTER First Quenching and Drawing T									
7106	(627)	(567)	1475° (411)	--	375	600° ½hr 438	600° 1½hr 444	650° 2hr 441	750° 2hr 385	800° 1 hr 363				
7107	(627)	(510)	1550 (422)	--	394	500° ¼hr 438	600° ½hr 448	600° 1½hr 451	650° 1¾hr 448	700° 2hr 415	750° 2hr 415	800° 2hr 393	850° 1 hr 383	850 1 h 390
7108	(627)	(614)	1550 (415)	--	401	500° ½hr 444	600° ½hr 448	600° 1½hr 451	650° 1¾hr 444	700° 2hr 415	750° 2hr 420	800° 2hr 420	850° 2hr 398	900 2hr 361
7109	(601)	(614)	1550° (514)	--	461	600° ½hr 495	600° ½hr 485	600° 1½hr 495	650° 1¾hr 485	700° 2hr 477	800° 2hr 432	850° 2hr 420	900° 2hr 412	950 ½hr 398
7110	(627)	(567)	1500 (465)	--	394	500° 1/6hr 415	600° ½hr 415	600° 1½hr 404	650° 1¼hr 429	675° 2hr 406	700° 2hr 395	750° 2hr 401	800° 2hr 388	850 ½hr 390
7104 3rd Treatment														
7106 3rd Treatment														
7098 3rd Treatment														

* Hardness values in parentheses are converted Rockwell C readings.

** Compositions:

Heat No.	C	Mn	Ni	Cr	Mo	V	Ti	Heat No.
	Chemical Analysis							
7091	.45	.34						7101
7092	.46	.85						7102
7093	.46	1.17						7103
7094	.48	1.82						7104
7095	.36	.71	1.93					7105
7096	.37	.75	3.41					7106
7097	.36	.73	4.96					7107
7098	.37	1.18	1.99					7108
7099	.37	.84	1.52	.87				7109
7100	.32/.48	.81	3.75	2.60				7110

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Response of the Steels to Preliminary Heat Treatments.

and Drawing Treatment						Brinell Hardness After Second Treatment									
Draw No.8	Draw No.9	Draw No.10	Draw No.11	Draw No.12	Draw No.13	Oil Quench	Water Quench	Draw No.1	Draw No.2	Draw No.3	Draw No.4	Draw No.5	Draw No.6		
						1550 547		850° $1\frac{1}{4}$hr 329						See 3rd treatment below	
800° 2hr 393	850° 1 hr 383	850° 1 hr 390	900° 1 hr 390	950° 1 hr 388	1000° $1\frac{1}{8}$hr 366	1600° 653	-- --	1000° $1\frac{3}{4}$hr 373							
800° 2hr 420	850° 2hr 398	900° 2hr 361				1600° 637	--	825° 2hr 409	875° 1 hr 398	900° 1 hr 388	925° 1 hr 393	950° 1 hr 370			
850° 2hr 420	900° 2hr 412	950° $\frac{1}{2}$hr 398	950° $1\frac{1}{2}$hr 388	1000° $1\frac{1}{8}$hr 361											
750° 2hr 401	800° 2hr 388	850° $\frac{1}{2}$hr 390	850° $1\frac{1}{2}$hr 395	900° 2hr 368											
							1575 554	700° 2hr 354							
						1550° 555	--	700° 2hr 393	775° 2hr 370						
							1500 530	700° 2hr 354							

;s.

Chemical Analysis

Ti	Heat No.	C	Mn	Ni	Cr	Mo	V	Ti
	7101	.36	.85	1.52	.89	.39		
	7102	.38	.87	3.50	1.09	.60		
	7103	.36	1.53	1.3/1.6				
	7104	.33	.83	1.52			.14	.10/.20
	7105	.48	1.58					
	7106	.48	1.62		Grainal			
	7107	.47	1.70		1.13		.18	
	7108	.50	1.62		1.13	Grainal		
	7109	.48	1.62		1.10	.50		
	7110	.48	1.57			.53		

2

Microscopic Examination of Finished Plates.

A. Inspection for Undissolved Carbides:

Coupons from each plate in the quenched condition were examined microscopically for free carbide. Murakami's etch was used for purpose of identification and, in order to be sure that the reagent was working satisfactorily, two specimens of other steels which were known to contain carbide chains were etched in the same dish with the armor plate steels.

Several specimens showed tiny spherical carbides randomly distributed but not one of the twenty contained grain boundary chains. Two specimens which exhibited the worst condition found were examined by Dr. Reed and it was his opinion that no trouble would be experienced from this source.

B. Inspection for Cleanliness:

The series of specimens previously prepared for the examination of carbides was rated for inclusion content according to the system adopted as standard by the S.A.E., Iron and Steel Division, on February 6, 1940. Each sample was also given a general rating designated by a small letter to represent the average rating of the specimen as a whole based on the frequency and width of inclusions over 1 unit in length and also the quality of the background. (Here e is excellent, g-good, f-fair, p-poor, according to a standard series of photomicrographs.)

The ratings of this first series of specimens are listed in Table IV a.

Due to the small size of the above specimens, another series of samples approximately 1/2" X 1" in size were examined. Results on this second series are listed in Table IV b.

TABLE IV. CLEANLINESS

a.

Series	Heat No.	S.A.E. Rating (1) Length of Longest	Average Length of Long Inclusions	Back-ground	General (2)	Chevrolet Rating (3)	S.A.E. Length of Longest	A L o In
Manganese	7091	Not rated					28^{vdgh}	
	7092	25^{vdgh}	6	B+	g+(pipe)	S_3O_7	6^{vdg}	
	7093	13^{vdg}	4	C+	g	S_3O_5	13^{vdg}	
	7094	7^{vdg}	3	B	g	S_2O_5	6^{vdg}	
Nickel	7095	20^{vdgh}	8	B-	f-	S_3O_7	7^{vdg}	
	7096	8^{vdg}	3	A-	g (pipe)	S_2O_4	8^{vdg}	
	7097	26^{vdg}	6	B+	p+(pipe)	S_2O_7	13^{vdg}	
Mn-Ni	7098	8^{vdg}	3	B	g-	S_3O_4	26^{vdgh}	
Cr-Ni	7099	37^{vdg}	9	B+	p+	S_2O_8	17^{vdg}	
	7100	24^{vdg}	5	B-	p+	S_3O_7	9^{vdg}	
Cr-Ni-Mo	7101	36^{vdgh}	10	B-	p (pipe)	S_3O_7	10^{vdg}	
	7102	10^{vdg}	4	B	f+	S_2O_5	7^{vdg}	
Mn-Cr-Ni-Mo	7103	42^{vdg}	7½	B-	p (pipe)	S_3O_8	35^{vdgh}	
Ni-V	7104	19^{vdg}	2½	B	f	S_2O_6	27^{vdgh}	
Mn-Ti	7105	12^{vd}	2	A-	g	S_2O_4	10^{vd}	
Mn-Grainal	7106	4^{vdg}	2	B-	g-	S_2O_3	7^{vd}	
Si-Mn-Cr-V	7107	8^{vdg}	3½	B+	g	S_2O_4	10^{vdg}	
Si-Mn-Cr-Grainal	7108	5^{vd}	2	B	g+	S_2O_3	10^{vdg}	
Mn-Cr-Mo	7109	12^{vdg}	4	B	g-	S_2O_5	5^{vd}	
Mn-Mo	7110	10^{vd}	4	B+	g-	S_2O_4	5^{vdg}	

(1) vd - very divided
g - group
h - very wide and heavy

(2) e - excellent
g - good
f - fair
p - poor

A, B, C, D rates background from good to bad.

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TABLE IV. CLEANLINESS RATINGS.

b.

al	Chevrolet Rating (3)	S.A.E. Rating(1) Length of Longest	Average Length of Long Inclusions	Back-ground	General (2)	Chevrolet Rating (3)	Remarks
		28^{vdgh}	9	B+	p+	S_2O_8	
e)	S_3O_7	6^{vdg}	2	A-	g+	S_2O_5	Very clean
	S_3O_5	13^{vdg}	4½	B+	f	S_2O_5	
	S_2O_5	6^{vdg}	2	A-	g	S_2O_4	
	S_3O_7	7^{vdg}	3½	B+	g-	S_2O_5	
e)	S_2O_4	8^{vdg}	4	B	f+(pipe)	S_8O_5	
e)	S_2O_7	13^{vdg}	3	A-	f	S_2O_5	
	S_3O_4	26^{vdgh}	5	B	p+	S_2O_8	Many large inclusions.
	S_2O_8	17^{vdg}	5	A-	f-	S_2O_6	
	S_3O_7	9^{vdg}	3	B+	f+	S_2O_5	
e)	S_3O_7	10^{vdg}	3	B+	f+	S_2O_5	
	S_2O_5	7^{vdg}	3	C	g-	S_2O_5	
e)	S_3O_8	35^{vdgh}	5½	B+	p	S_2O_8	Several large inclusions
	S_2O_6	27^{vdgh}	6½	C+	p	S_3O_8	Many large inclusions
	S_2O_4	10^{vd}	3	A-	g+	S_2O_4	Very clean; 2 inclusions
	S_2O_3	7^{vd}	3	C+	f	S_3O_4	
	S_2O_4	10^{vdg}	2	C+	f-	S_2O_5	Bad oxide spots in background
	S_2O_3	10^{vdg}	3	B+	f+	S_2O_4	Fairly clean
	S_2O_5	5^{vd}	2	A-	g	S_2O_3	16 Short inclusions
	S_2O_4	5^{vdg}	3	B+	g	S_2O_3	13 short inclusions

excellent
good
fair
poor

(3) S - sulphides and inclusions elongated on rolling.
O - oxides and inclusions not elongated on rolling.

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Both sets of specimens were rated by the Chevrolet Method and the results are listed in the corresponding tables.

C. Austenitic Grain Size Inspection:

An examination of the microstructures from the as rolled plates indicated that some of the steels were not particularly fine grained.

Specimens from all melts were then heated to the respective quenching temperatures which had been determined for each particular steel, held for 1/2 hour and cooled in air. Examination of the etched samples clearly revealed the grain size due to the formation of a ferrite network around the original austenite grains. The following steels showed a duplex structure with some grains being abnormally large.

Heat No.	C	Mn	Ni
7091	.45	.34	---
7092	.46	.85	---
7093	.46	1.17	---
7095	.36	.71	1.93
7104	.48	1.58	---

DISCUSSION OF RESULTS

Complete analyses were not run on all heats but results which were run show that most of the steels are within specifications, or are so little out as to cause no concern. Results on the molybdenum steels showed the greatest variation from the specified range. The following tabulation shows those heats which were out of the specification range, how much they are off, and what elements are out of line.

Chemical Analysis

Heat Number		%C	%Mn	%Si	%Cr	%Mo
	Intended		1.5/1.8			
7094	Actual		1.82			
	Intended			.20/.30		
7095	Actual			.19		
	Intended					.20/.30
7101	Actual					.39
	Intended					.35/.45
7102	Actual					.60
	Intended		1.4/1.6			
7106	Actual		1.62			
	Intended		1.4/1.6		.90/1.10	
7107	Actual		1.70		1.13	
	Intended	.42/.48	1.4/1.6		.90/1.10	
7108	Actual	.50	1.62		1.13	
	Intended		1.4/1.6			.25/.35
7109	Actual		1.62			.50
	Intended					.35/.45
7110	Actual					.53

The occurrence of an excessive amount of alumina inclusions in some melts, and a tendency toward abnormal grain growth at 1600° F., and below, in others, raises a question as to melting practice. Since no slag was used it is possible that the FeO content of the melts was not uniform from one heat to another and, hence, the addition of aluminum could fail to produce grain size control in some melts and form alumina inclusions of microscopic size in others. Some of these heats are to be repeated and more thought will be given to the melting practice. It may be found advisable in making the larger heats proposed for the second series to pour off a 5 pound ingot separately from the first few heats, roll this into plate and test the steel for cleanliness and grain growth characteristics before the larger ingots are forged.

In the course of other microscopical examinations, some surface decarburization was noticed. This condition was traced back to the as rolled material and subsequent reheating, even in a lead bath, did not cause enough diffusion to completely eliminate the low carbon layer. A new lot of neutral heat treating salt has been obtained and the large plates will be cleaned by sandblasting and heated for the quenching operation in the neutral salt bath.

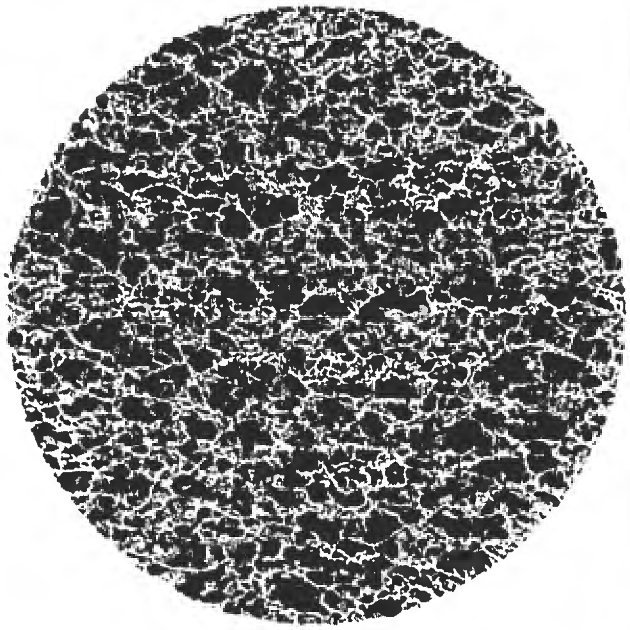
FUTURE WORK

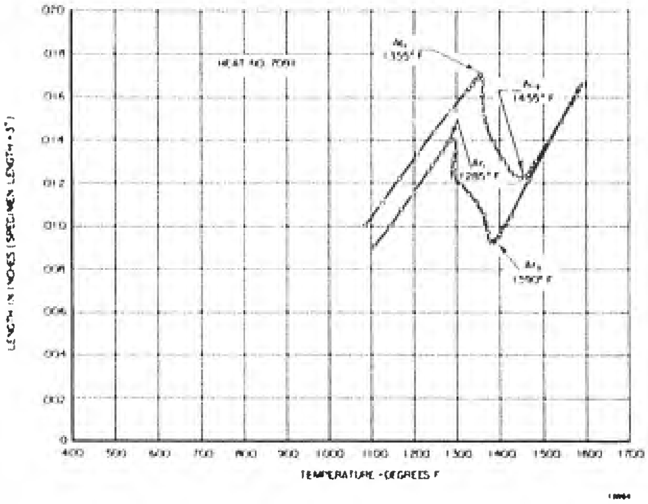
The large plates representing the heats listed in this report are being quenched and drawn at present. After those plates have been brought within specified hardness range, they will be shipped to Watertown for ballistic testing and the new melting series will be started. Large ingots are to be made so that more coupon material will be available for the necessary preliminary testing. It is also proposed that the plates be finished thick enough to permit machining both surfaces before the final quenching treatment so as to completely eliminate decarburization.

Definite plans for the changes in the melting practice have not yet been made but the matter will be discussed before the next series of melts is started.

Data from which this report was written are recorded in B.M.I. notebook number 799, pages 3 to 55, inclusive.

MLS-CHL:DW
9/18/41



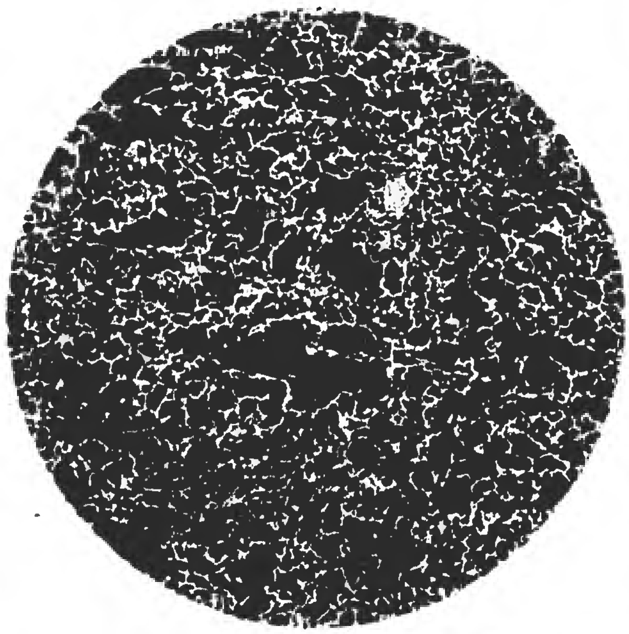


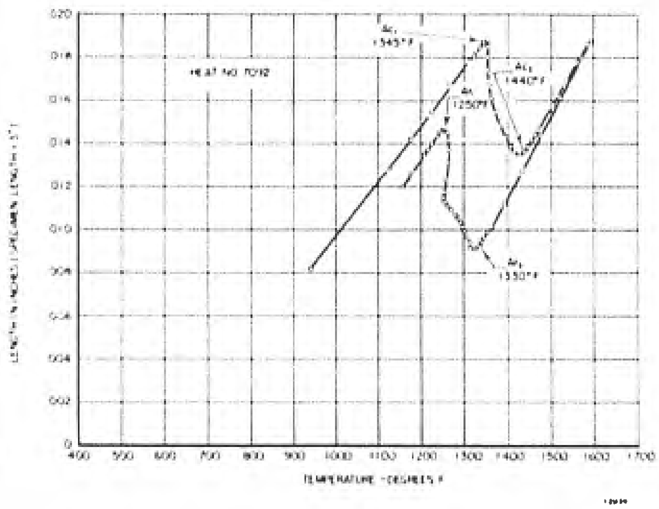
11975

Fig. 4. Heat No. 7091 - Microstructure of the as-rolled plate. X100

Carbon ---------- .45%
Silicon --------- .20
Manganese ------- .34

Dilatometric curve is shown at right.

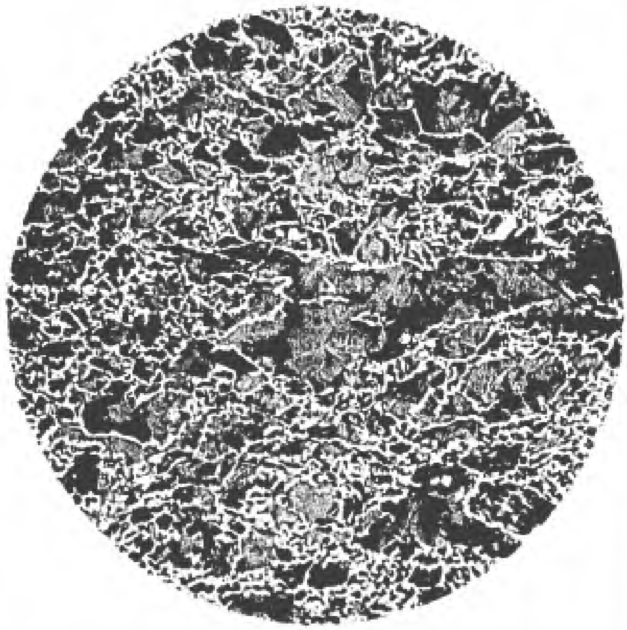


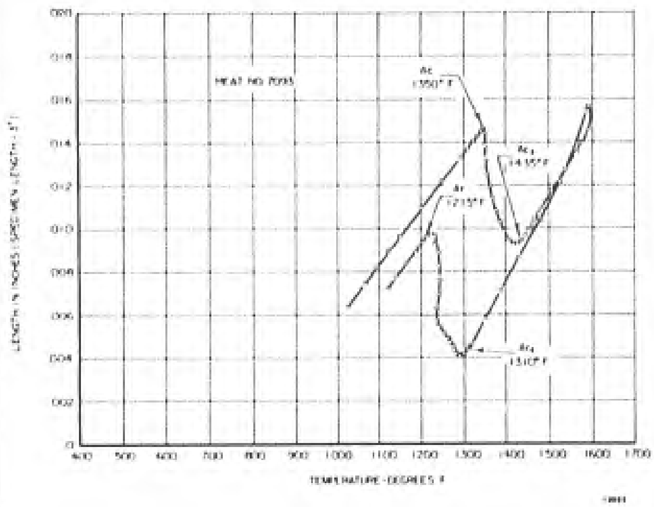


11976

Fig. 5. Heat No. 7092 - Microstructure of the as-rolled plate. X100

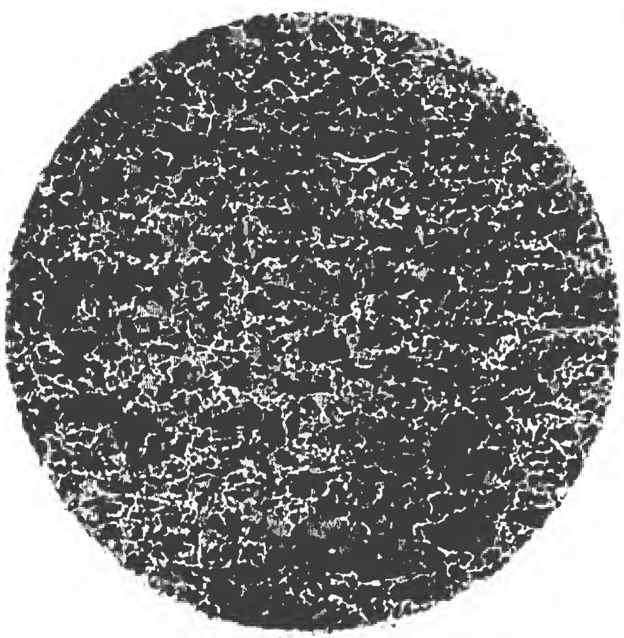
Carbon ---------- .46%
Silicon --------- .24
Manganese ------- .85

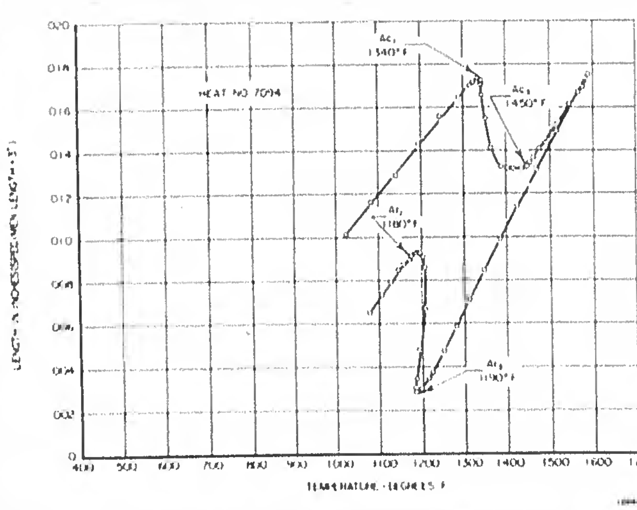




11977
Fig. 6. Heat No. 7093 - Microstructure of the as-rolled plate. X100

Carbon ----------- .46%
Silicon ---------- .21
Manganese --------1.17





11974

Fig. 7. Heat No. 7094 - Microstructure of the as-rolled plate. X100

Carbon ---------- .48%
Silicon---------- .26
Manganese-------- 1.82

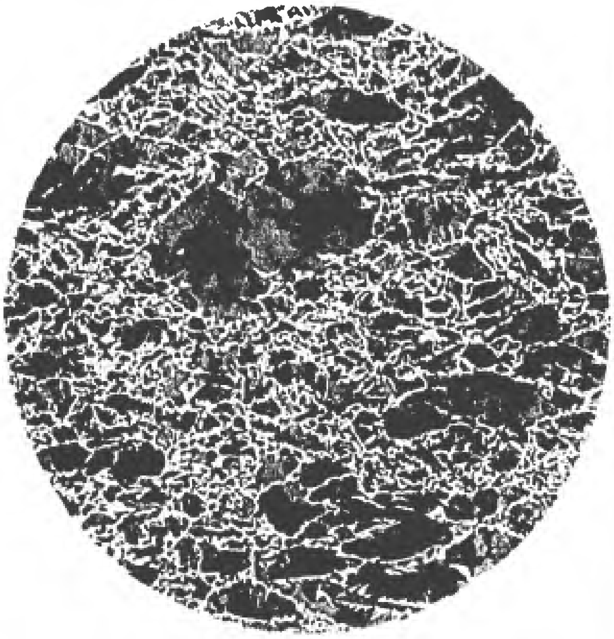


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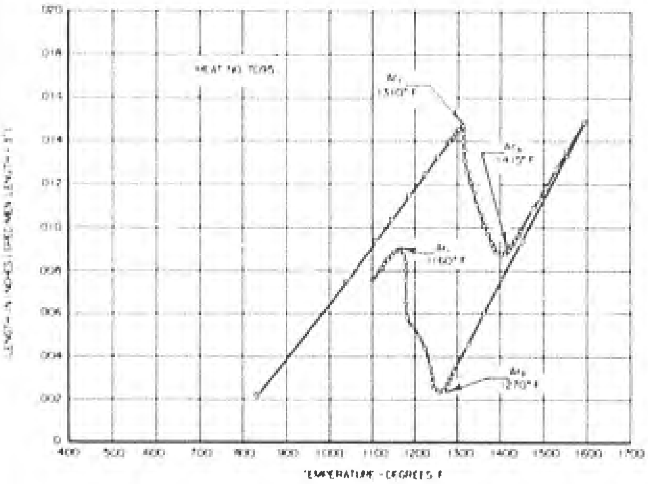
Fig. 8. Heat No. 7095 - Microstructure of the as-rolled plate. X100

Carbon --------- .36%
Silicon -------- .19
M..ganese ------ .71
Nickel --------- 1.93



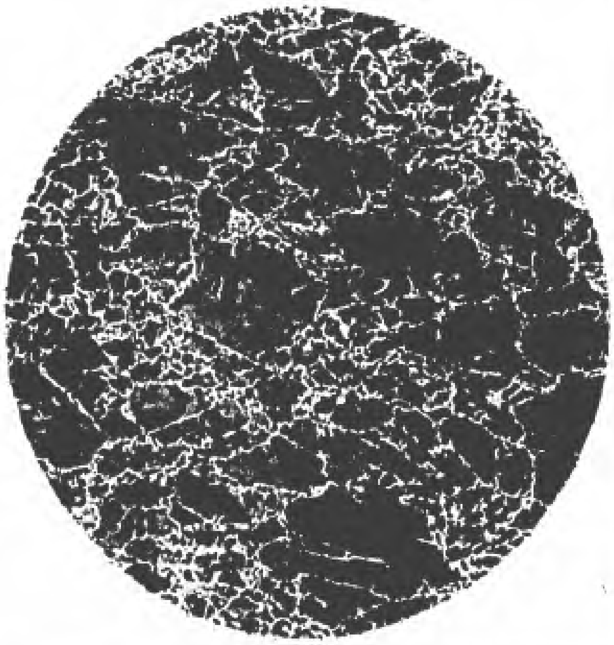


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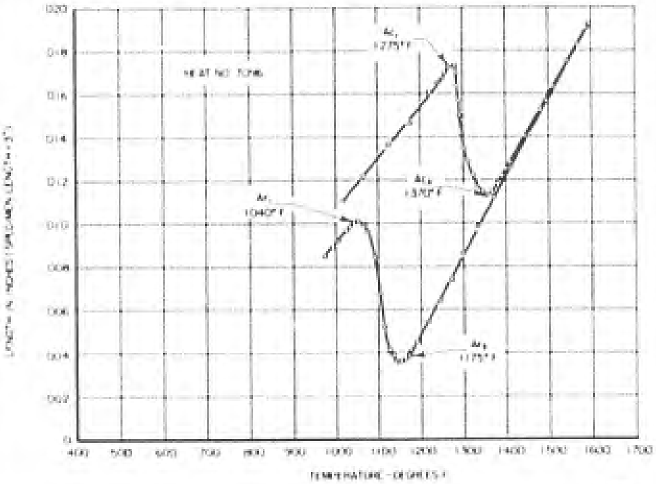
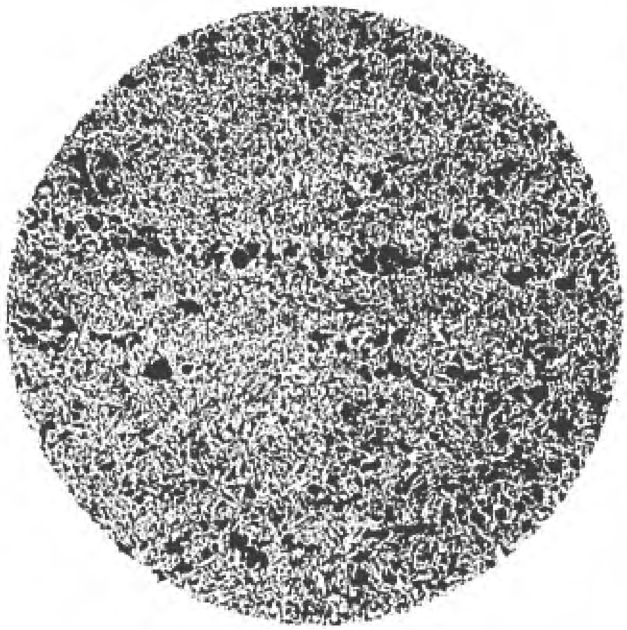
Fig. 9. Heat No. 7096 - Microstructure of the as-rolled plate. X100

Carbon ---------- .37%
Silicon --------- .25
Manganese ------- .75
Nickel ---------- 3.41





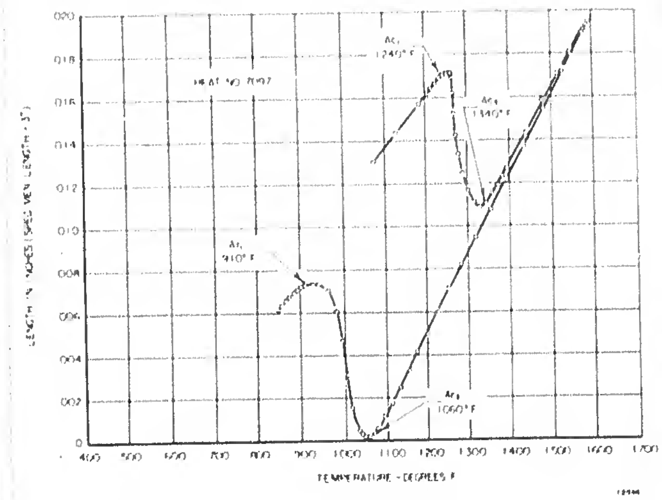


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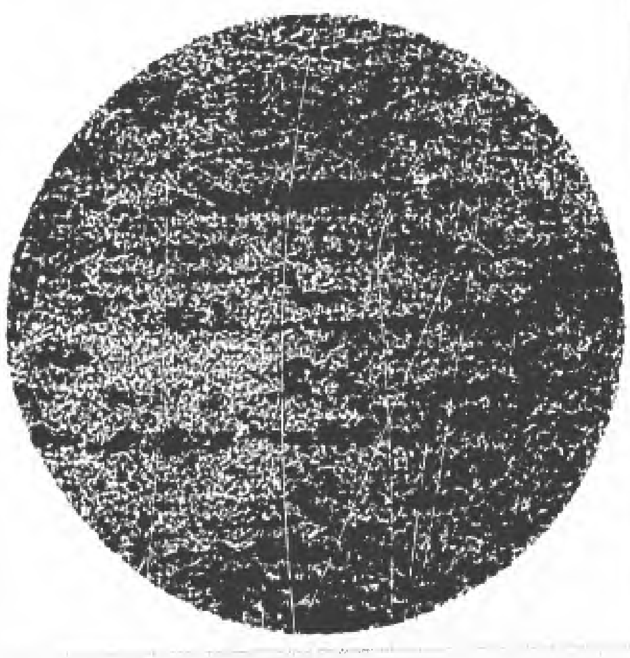
Fig. 10. Heat No. 7097 - Microstructure of the as-rolled plate. X100

Carbon -------	0.36%
Silicon ------	0.20-0.30
Manganese ----	0.73
Nickel -------	4.8 -5.2



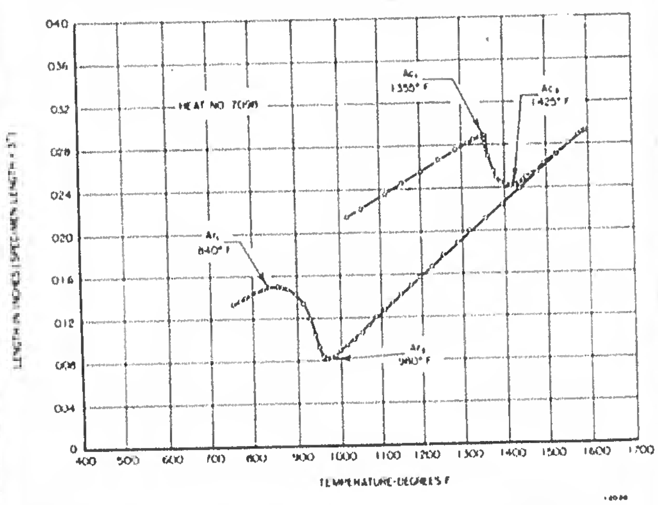


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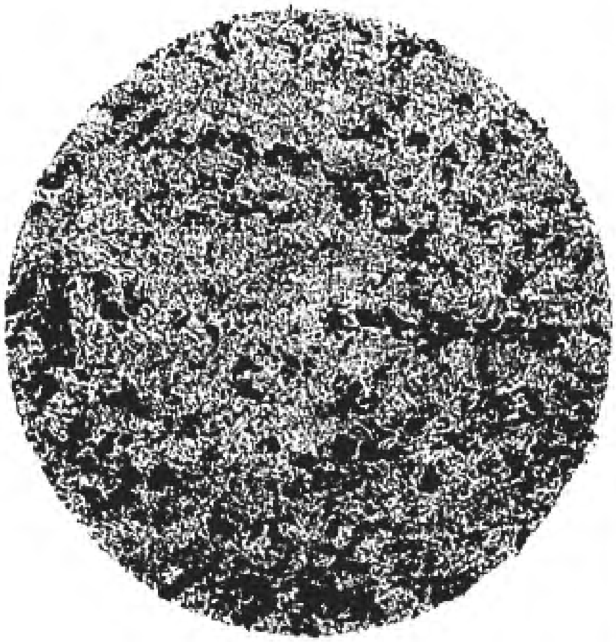
Fig. 11. Heat No. 7098 - Microstructure of the as-rolled plate. X100

Carbon -------	0.37%
Silicon ------	0.23
Manganese ----	1.18
Nickel -------	1.8-2.0



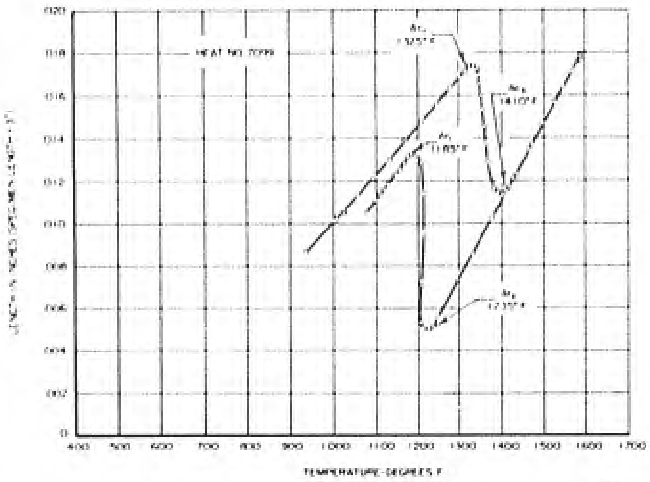


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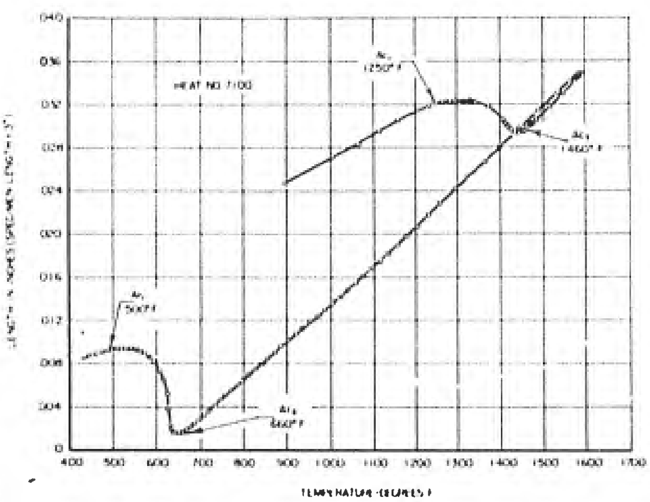
Fig. 12. Heat No. 7099 - Microstructure of the as-rolled plate. X100

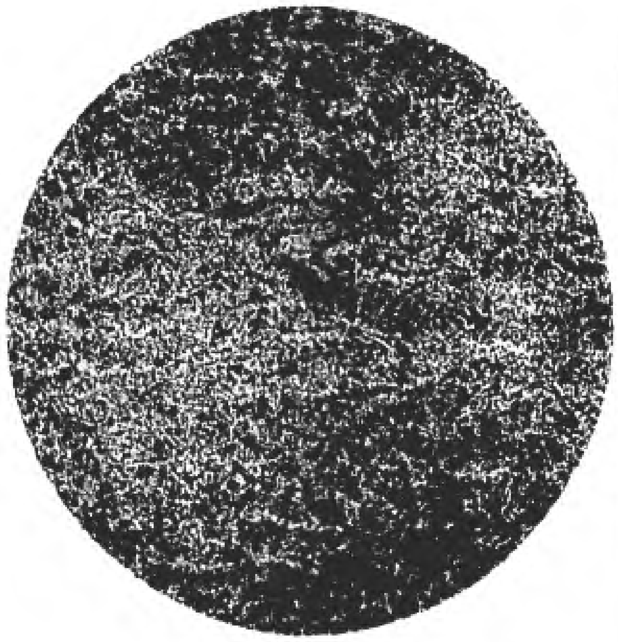
Carbon ---------	0.37%
Silicon --------	.20-.30
Manganese ------	0.84
Nickel ---------	1.3-1.6
Chromium -------	.70-.90

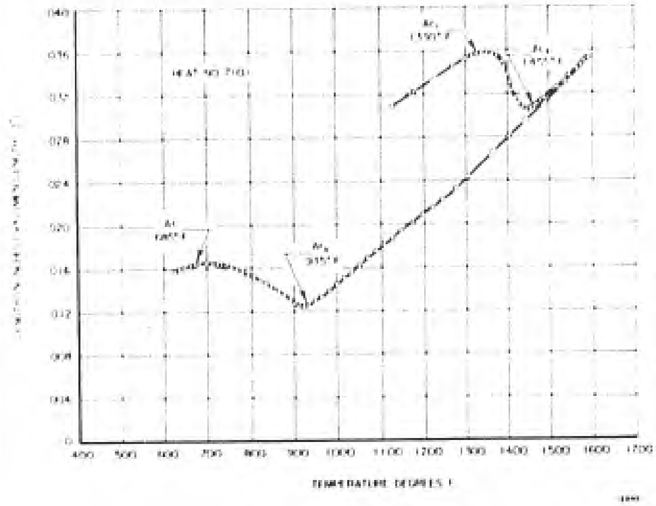


11981

Fig. 13. Heat No. 7100 - Microstructure of the as-rolled plate. X100

Carbon ---------	.32- .38%
Silicon --------	.20- .30
Manganese ------	.60- .90
Nickel ---------	3.6 - 3.9
Chromium -------	2.4 - 2.6

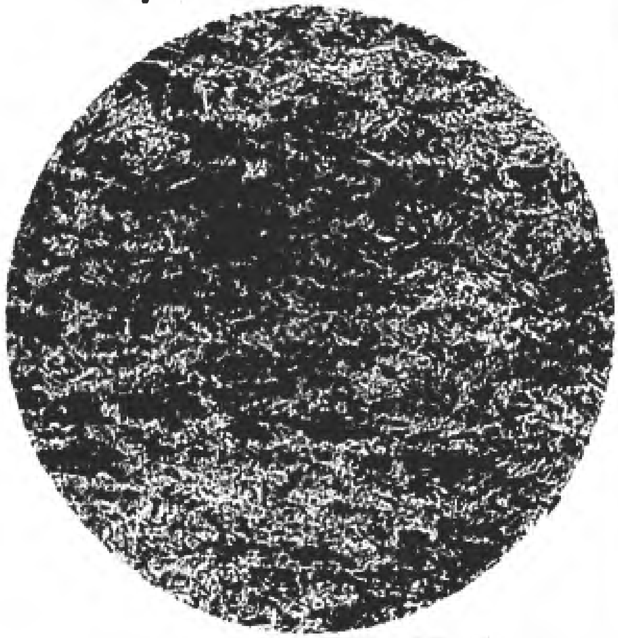


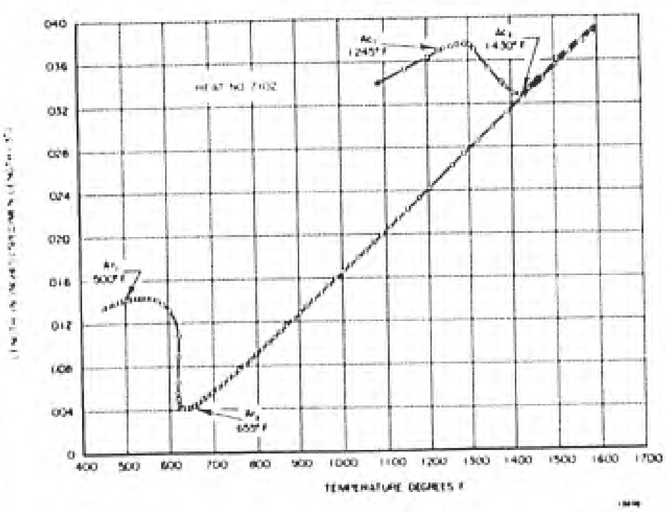


11982

Fig. 14. Heat No. 7101 - Microstructure of the as-rolled plate. X100

Carbon ---------	0.36%
Silicon --------	0.25
Manganese ------	0.85
Nickel ---------	1.3-1.6
Chromium -------	.70-.90
Molybdenum -----	.20-.30





11983

Fig. 15. Heat No. 7102 - Microstructure of the as-rolled plate. X100

Carbon ---------	0.38%
Silicon --------	.20- .30
Manganese ------	0.87
Nickel ---------	3.3 -3.7
Chromium -------	.90-1.10
Molybdenum -----	.35- .45

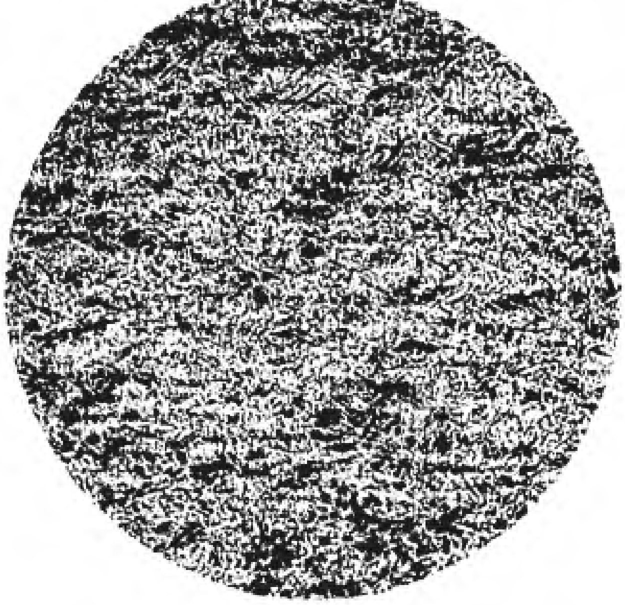


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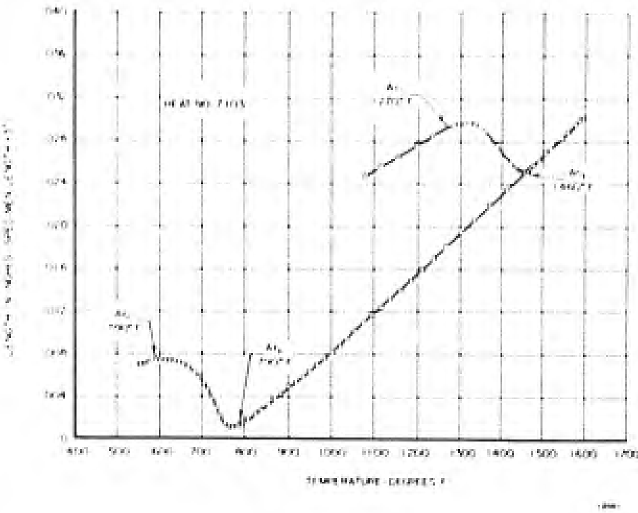
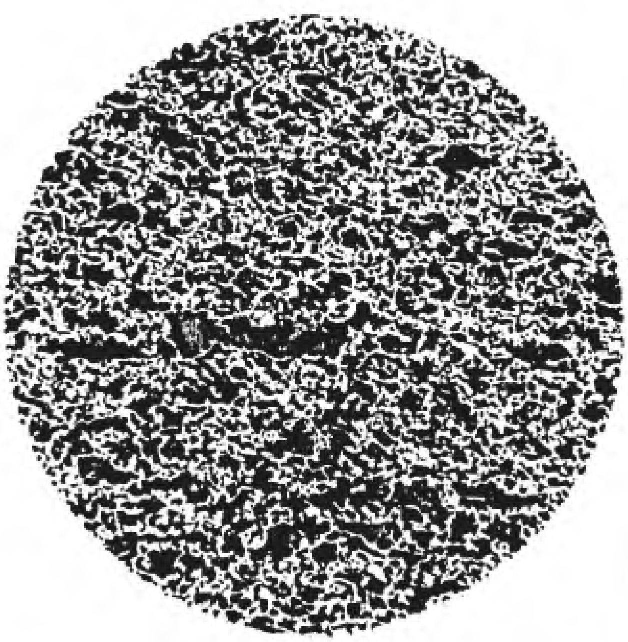
Fig. 16. Heat No. 7103 - Microstructure of the as-rolled plate. X100

Carbon ----------	0.36%
Silicon ---------	0.25
Manganese -------	1.53
Nickel ----------	1.3 -1.6
Chromium --------	.75- .90
Molybdenum ------	.25- .35

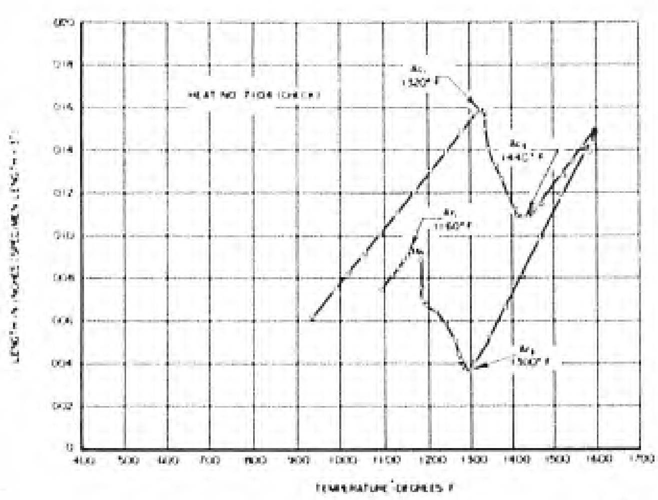


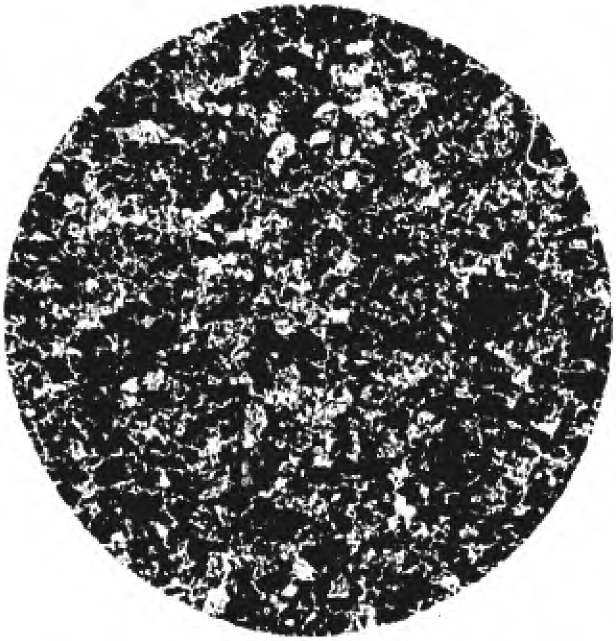


11985

Fig. 17. Heat No. 7104 - Microstructure of the as-rolled plate. X100

Carbon ----------	0.33%
Silicon ---------	.20 - .30
Manganese -------	0.83
Nickel ----------	1.3 - 1.6
Vanadium --------	.10 - .15

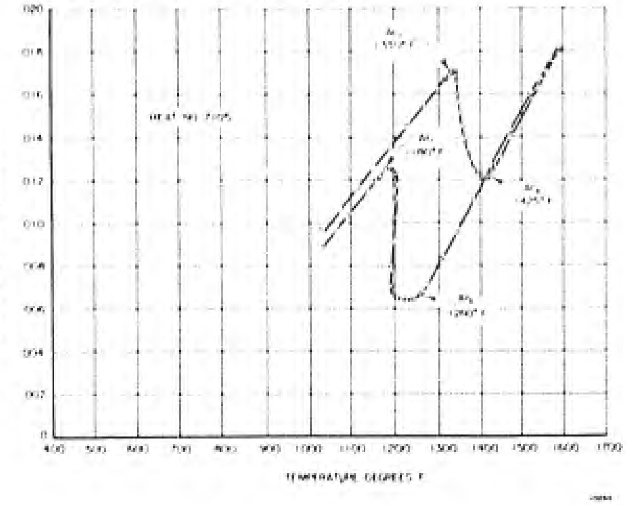




11986

Fig. 18. Heat No. 7105 - Microstructure of the as-rolled plate. X100

Carbon ------------	0.48%
Silicon -----------	0.26
Manganese ---------	1.58
Titanium ----------	.10-.20

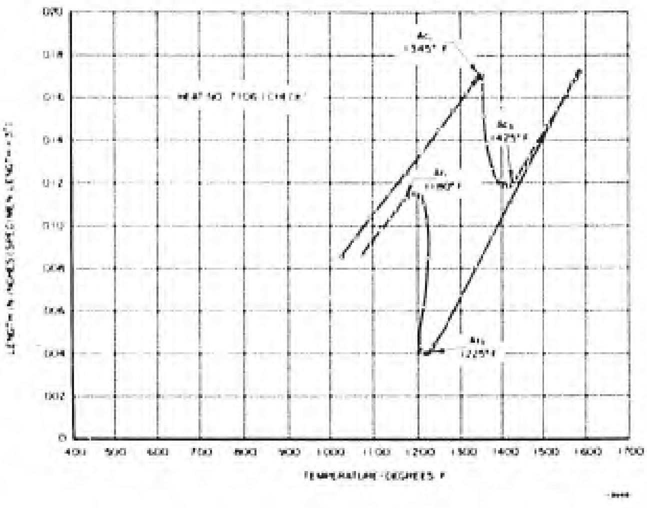


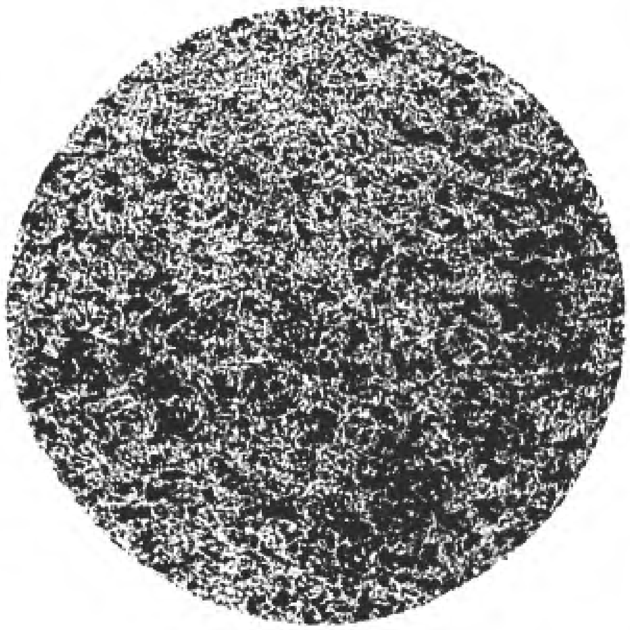
11987

Fig. 19. Heat No. 7106 - Microstructure of the as-rolled plate. X100

Carbon ------------	0.48%
Silicon -----------	.20-.30
Manganese ---------	1.62

Deoxidized with Grainal





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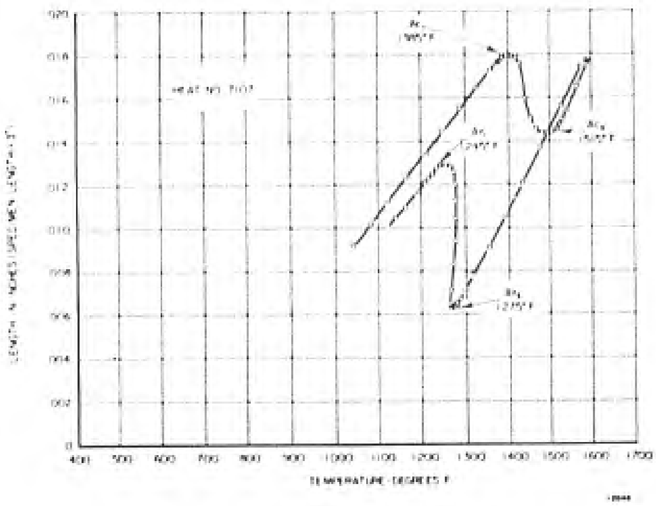
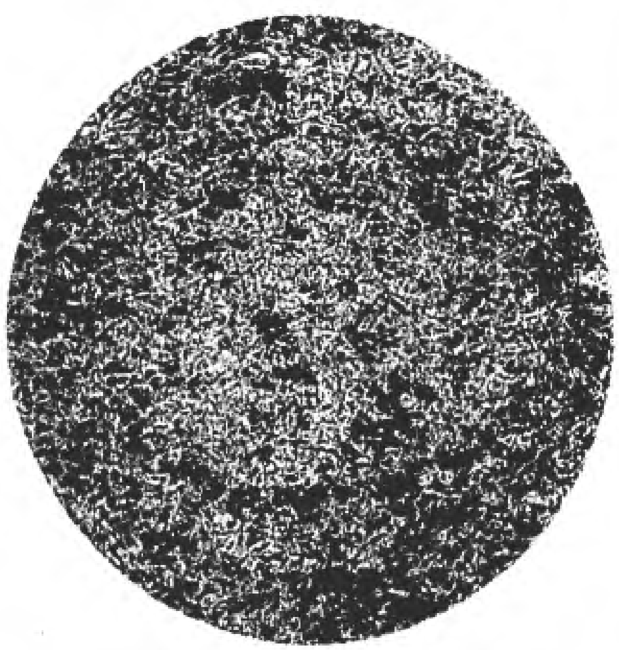


Fig. 20. Heat No. 7107 - Microstructure of the as-rolled plate. X100

Carbon ------------ 0.47%
Silicon ----------- 0.68
Manganese --------- 1.70
Chromium ---------- .90-1.10
Vanadium ---------- .10- .20



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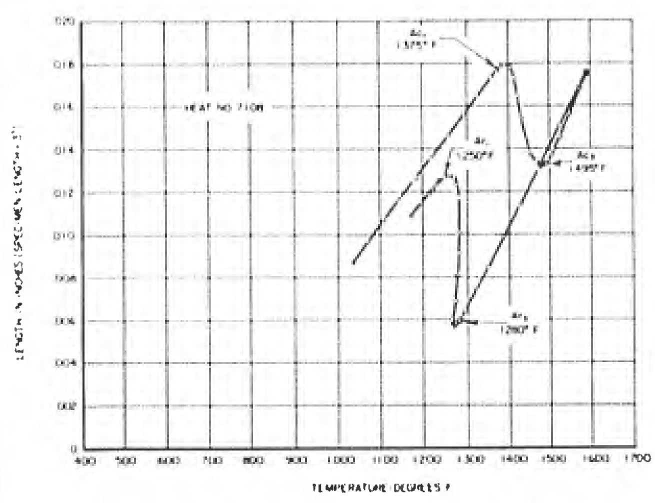
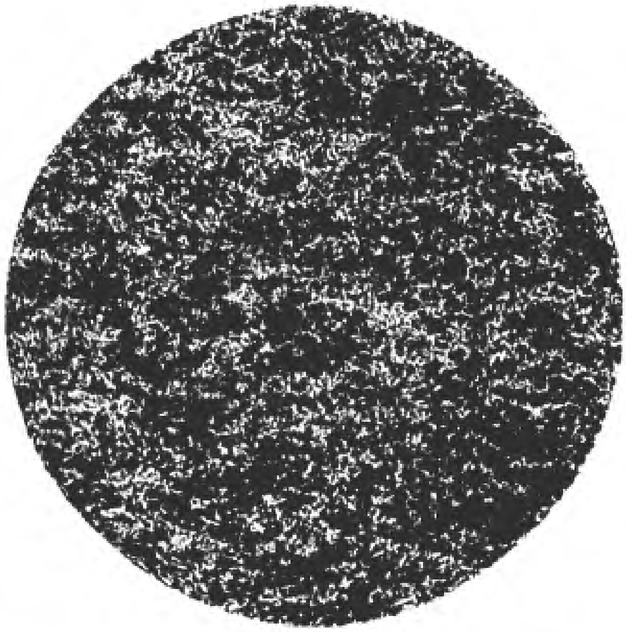
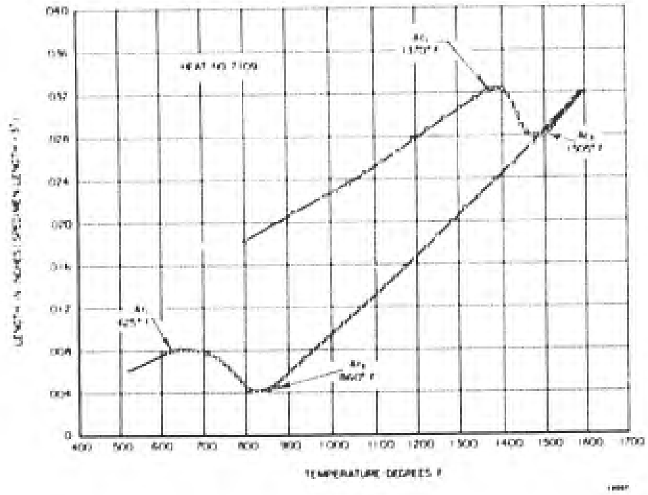


Fig. 21. Heat No. 7108 - Microstructure of the as-rolled plate. X100

Carbon ------------ 0.50%
Silicon ----------- 0.69
Manganese --------- 1.62
Chromium ---------- .90-1.10
Deoxidized with Grainal

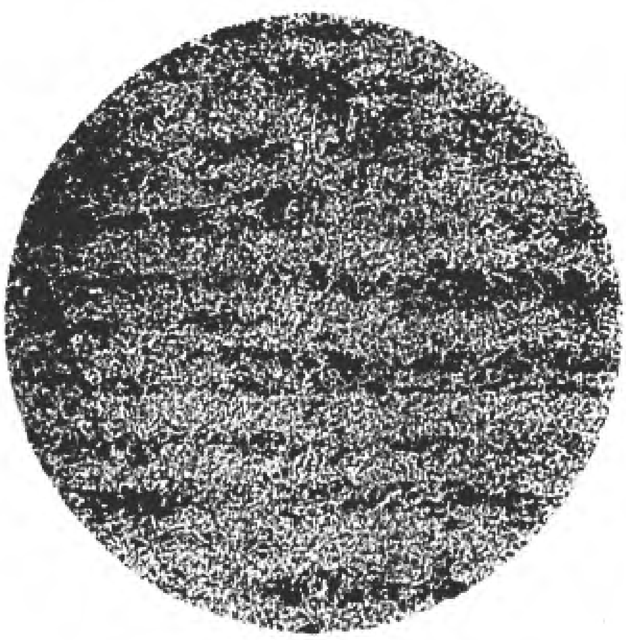




11990

Fig. 22. Heat No. 7109 - Microstructure of the as-rolled plate. X100

Carbon ------------	0.48%
Silicon -----------	.35-.50
Manganese ---------	1.62
Chromium ----------	.90-1.10
Molybdenum --------	.25- .35



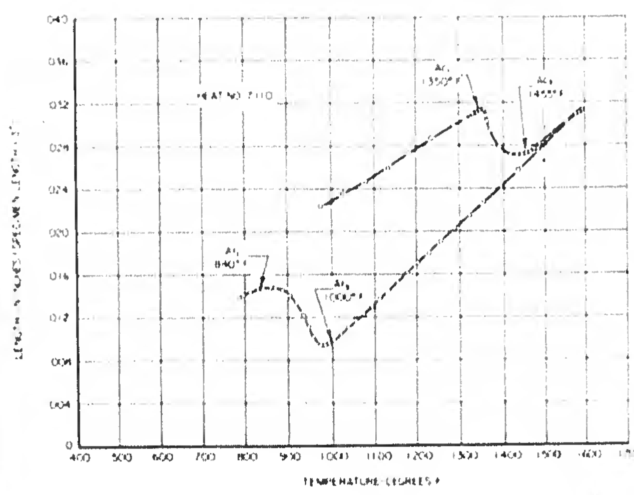


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Fig. 23. Heat No. 7110 - Microstructure of the as-rolled plate. X100

Carbon -----------	0.48%
Silicon ----------	0.24
Manganese --------	1.57
Molybdenum -------	.35-.45

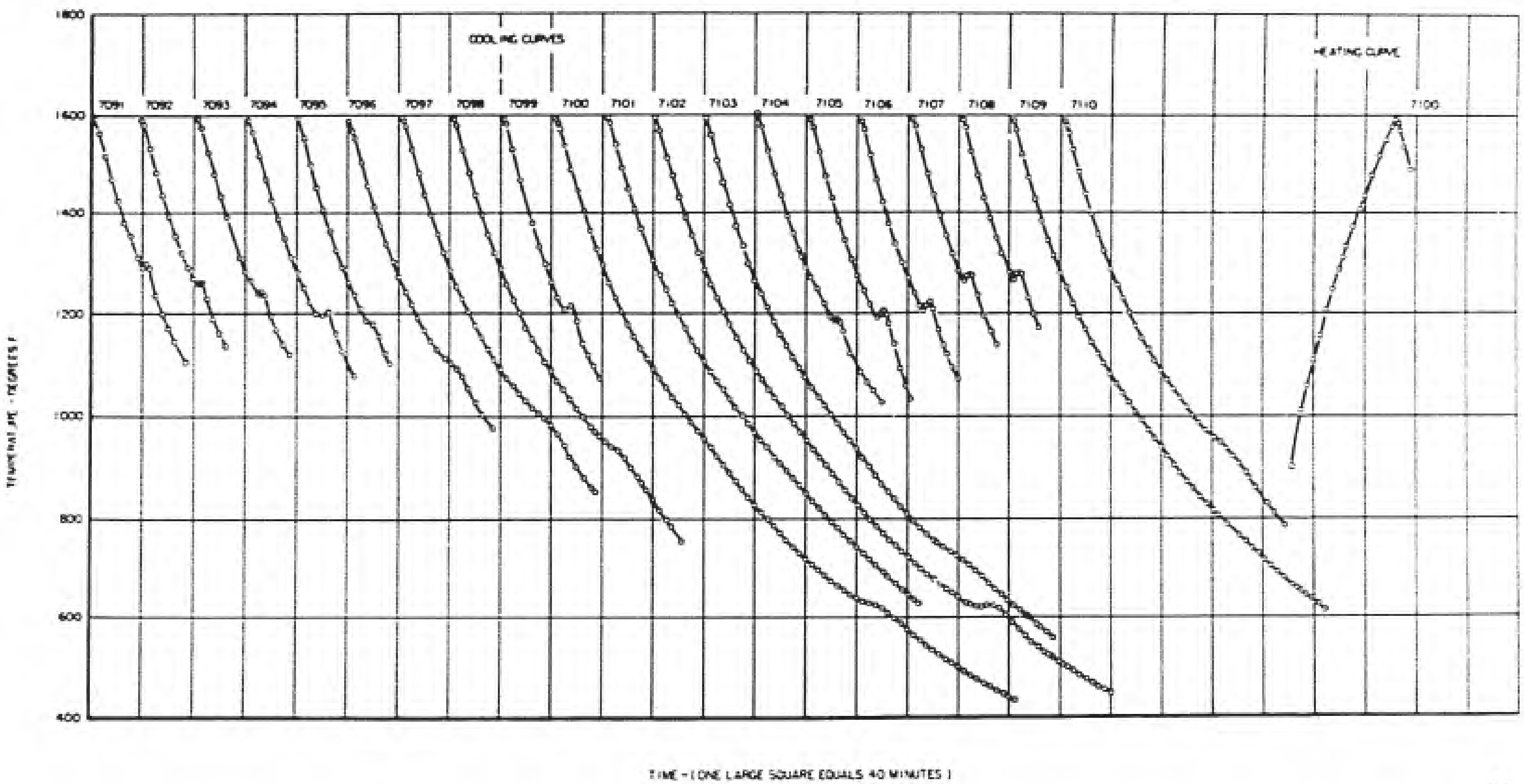

Fig. 24. Time-temperature curves for each dilatometric determination shown in Figures 4 to 23.