

INFORMAL QUARTERLY REPORT
July 15, 1942

to

**NATIONAL DEFENSE
RESEARCH COMMITTEE
of
OFFICE OF SCIENTIFIC
RESEARCH AND DEVELOPMENT**

on

**N.D.R.C. Research Project NRC 14
Contract No. OEM_{SR}-450**

**The Improvement of
Low-Alloy Armor Steels**

**S-633
BATTELLE
MEMORIAL INSTITUTE
505 King Avenue
COLUMBUS, OHIO**

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THE IMPROVEMENT OF LOW-ALLOY ARMOR STEELS

from

BATTELLE MEMORIAL INSTITUTE

July 15, 1942

INTRODUCTION

The tables in this report give the chemistry, hardenability, and mechanical properties of various groups of steels that were chosen for examination in line with the two problems of reducing the alloying elements in armor steel without sacrificing ballistic properties and of determining means by which better armor steel can be made with the present alloy composition. A considerable number of grain size determinations must be made on these steels before a final analysis of the data will be undertaken.

Among the problems not considered in this report, but which are in various stages of progress, are the following:

1. A study of boron-treated steels in which smaller boron additions are made than those selected for the preliminary series. The data of the preliminary series are included in this report. Results described in this report indicated

that the impact and hardenability of low alloy, homogeneous, armor steels are not impaired by substituting minute quantities of boron for all the molybdenum. On the other hand, boron in the same quantities added to steels containing 0.40 per cent molybdenum resulted, in the case of cast armor in particular, in a marked decrease in impact resistance. To check these findings and to determine the probable limit in molybdenum content at which the impact resistance of boron containing armor steels is affected adversely, work is in progress on a series of boron steels with molybdenum contents varying from 0 per cent to 0.40 per cent.

2. Attempts to lower the alloy content of face-hardened armor. A number of steels have been cast and rolled into 1/2-inch plate. Carburization of these plates is complete and heat treatments are to follow. Ballistic and mechanical properties will be determined.

3. Equipment is being assembled for isothermal quench tests on rolled 1/2-inch plate.

4. The addition of special deoxidizers to armor steels is being studied.

5. A determination of the effect of homogeneizing time and temperature on hardenability and impact properties of cast armor plate is to be made. Plates for these tests are to be furnished by various foundries making armor plate.

6. An attempt to carburize plate during the rolling operation was only partially successful. A detailed report on this problem will be made when final tests have been completed.

The wrought steels listed in the tables on mechanical properties were all drawn to a hardness range of 350 to 370 Brinell to correspond to the commercial practice for 1/2-inch armor plate, whereas the cast steel specimens were drawn to 270 to 290 Brinell to simulate the practice on 1-1/2-inch cast armor plate. All cast steels were homogenized at 1900°F. for two hours before quenching and drawing.

EXPERIMENTAL WORKWrought Boron-Treated SteelsChemistry and Hardenability - Table 1.

Hardenability data were obtained with the Jominy-type test specimen on wrought boron-treated plain carbon, nickel-chromium-molybdenum, and manganese-molybdenum steels. The hardenability of each steel is indicated by the length along the bar at which the Rockwell "C" hardness drops 5 and 10 points, respectively, below the quenched end hardness.

Additions of boron were made to each heat to obtain ingots having a desired residual analyses of 0, 0.005, and 0.010 per cent boron. In most cases the residual boron exceeded these amounts.

With the plain carbon steel, boron additions increased the hardenability slightly. The same effect can be observed for those alloy steels which were not deoxidized with aluminum (Heats 8221 and 8224), but when aluminum was used as a deoxidizer the results are not consistent. The boron-free alloy steel heats made with 0.10 per cent Al as a deoxidizer have exceptionally high hardenabilities which were lowered by boron additions, yet a later heat, No. 8478, which is a duplicate of the aluminum-treated, manganese-molybdenum steel, has a hardenability much similar to that of the aluminum-free heat, No. 8224. It would appear from these data and the results of check boron determinations on the hardenability test specimens that the boron-free, aluminum-deoxidized alloy Heats 8222 and 8225 exhibit an unusual hardenability behavior which cannot be accounted for by our present information. A further study is to be made of this problem.

The apparent ineffectiveness of the boron additions is at variance with the reported results of other investigators. This difference may be caused by the larger amounts of boron used in the present series of steels. Additional heats are now being processed in which the boron additions have been held to 0.005 per cent or less.

Mechanical Properties - Table 2.

The lower impact values obtained with the higher boron steels are in agreement with the known embrittling effect of excessive boron contents. In the case of the plain carbon steel not treated with aluminum, a boron content of 0.007 per cent has produced a steel with better ductility and toughness than the base composition without boron. This effect is not found with the aluminum-deoxidized plain carbon steel, however.

The mechanical properties for Heat 8478, which is listed in Table 1, have not yet been determined.

TABLE 1. CHEMISTRY AND HARDENABILITY DATA
ON WROUGHT BORON-TREATED PLAIN CARBON,
NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-
MOLYBDENUM STEELS. BORON RANGE: 0.004-0.021%

Heat No.	Ingot No.	C	Mn	Si	Ni	Cr	Mo	B	Al	End Hardness Rc	Jominy Hardenability		
											Number of 16ths of an inch to Obtain a Drop of:	5 Rc	10 Rc
PLAIN CARBON COMPARISON STEEL:													
8226	1	0.30	1.16	0.29	-	-	-	-	-	48.0	3.0	4.0	
	2					0.007				50.5	5.5	6.5	
	3					.020				49.0	6.0	7.0	
8227	1	0.28	1.19	0.32	-	-	-	-	0.10 added	49.5	4.5	5.5	
	2 (4)					.006			"	50.0	5.0	6.0	
	3					.019			"	-	-	-	
NICKEL - CHROMIUM - MOLYBDENUM STEEL:													
8221	1	0.26	0.86	0.29	.40/.60	.40/.60	.30/.40	.000	-	48.0	6.0	8.0	
	2							.004	-	47.5	8.0	13.0	
	3							.014	-	47.0	8.0	10.5	
8222	1	0.25	0.88	0.29	.40/.60	.40/.60	.30/.40	.000	0.10 added	48.0	13.0	19.5	
	2 (4)							.009	"	47.0	9.0	12.0	
	3							.020	"	-	-	-	
MANGANESE - MOLYBDENUM STEEL:													
8224	1	0.31	1.54	0.28	-	-	.30/.40	.000	-	50.0	5.5	7.0	
	2							.008	-	50.0	10.5	14.0	

TABLE 1. CHEMISTRY AND HARDENABILITY DATA
ON WROUGHT BORON-TREATED PLAIN CARBON,
NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-
MOLYBDENUM STEELS. BORON RANGE: 0.004-0.021%

Heat No.	Ingot No.	Chemistry, %							Jominy Hardenability				
		C	Mn	Si	Ni	Cr	Mo	B	Al	End Hardness 30	End of an inch to Obtain a Drop of: 5 Rc	10 Rc	
MANGANESE - MOLYBDENUM STEEL:													
8224	3												
8225	1	.30	1.54	0.31	-	-	.30/.40	.019	-	51.0	19.5	30.0	
	2							.011	0.10 added	51.0	10.0	13.0	
	3							.021	"	-	-	-	
8478	1	.15/.30	1.0/1.6	.15/30	-	-	.30/.40	.000	0.10 added	53.0	4.5	6.0	
	2							.004	"	53.0	11.0	17.0	
	3							.015	"	53.0	13.0	17.0	

6A.

- (1) Sulfur and phosphorus are less than 0.04%.
- (2) Boron added.
- (3) Duplicate of heat 8225 except for boron addition.
- (4) These ingots cracked during forging.

TABLE 2. MECHANICAL PROPERTIES OF WROUGHT BORON-TREATED PLAIN CARBON, NICKEL-CHROMIUM-MOLYBDENUM, AND MANGANESE-MOLYBDENUM STEELS. BORON RANGE: 0.004-0.021%

Heat No.	Ingot No.	Chemistry, (1) %		Mechanical Properties (2)							
		B	Al	Ultimate Tensile Strength, Lbs./Sq.In.	Yield Strength, Lbs./Sq.In.	%El.	Ductility R. of A.	Impact Ft. - Lbs.			
								Charpy	Double Charpy Izod		
PLAIN CARBON COMPARISON STEEL:											
8226	1	0.000	--	176,500	159,700	11.5	48.3	23.5	39.5	30.0	
	2	0.007	--	173,500	157,600	15.0	61.1	31.0	53.0	40.5	
	3	0.020	--	172,600	157,500	15.0	57.2	26.0	38.5	28.0	
8227	1	0.000	0.10 added	178,300	166,200	15.0	59.7	30.0	57.5	43.0	
	2	0.006	"	175,800	162,500	15.0	59.5	29.0	48.5	35.0	
	3	0.019	"	--	--	--	--	--	--	--	
NICKEL - CHROMIUM - MOLYBDENUM STEEL:											
8221	1	0.000	--	176,600	163,000	15.2	59.2	24.5	44.5	34.0	
	2	0.004	--	171,600	165,800	14.5	61.3	26.5	44.0	33.5	
	3	0.014	--	174,300	165,500	14.7	56.1	23.5	29.0	20.5	
8222	1	0.000	0.10 added	177,500	162,100	14.2	56.7	31.0	52.0	45.5	
	2	0.009	"	173,200	166,100	14.7	57.7	26.5	30.5	24.5	
	3(3)	0.020	"	--	--	--	--	--	--	--	
MANGANESE - MOLYBDENUM STEEL:											
8224	1	0.000	--	174,500	159,000 (4)	16.0	(4) 59.2	25.0	44.5	34.0	
	2	0.008	--	169,300	160,800	15.5	58.5	24.5	41.5	(5) 40.0	
	3(3)	0.019	--	--	--	--	--	--	--	--	
8225	1	0.000	0.10 added	176,100	163,750	15.0	55.1	27.5	49.0	41.0	
	2	0.011	"	173,100	159,800	14.5	55.3	24.0	31.5	27.0	
	3	0.021	"	--	--	--	--	--	--	--	

- (1) Sulfur and phosphorus are less than 0.04%. See Table 1. for complete analyses.
(2) All values are an average of two tests, except the Izod results which are an average of six tests made on two triple-Izod specimens.
(3) Ingot broke up on forging.
(4) One specimen only
(5) Longitudinal crack in both Izod specimens.

Cast Boron-Treated SteelsChemistry and Hardenability - Table 3.

Unlike the results obtained with boron-treated wrought steels (Table 1), the hardenability of cast steels of the same composition increased as the boron content increased. The maximum increase due to boron developed with the first addition of 0.005 per cent (desired residual). Boron was only slightly beneficial to the plain carbon comparison steel. Chemical analyses of these steels are now being made and the results will be submitted in a later report.

Mechanical Properties - Table 4.

The embrittlement encountered in most of the boron-treated steels is undoubtedly caused by the use of an excessive amount of this element. Tests now in progress will indicate whether smaller additions are equally as bad.

TABLE 3. CHEMISTRY AND HARDENABILITY DATA ON CAST BORON-TREATED PLAIN CARBON, NICKEL-CHROMIUM-MOLYBDENUM, AND MANGANESE-MOLYBDENUM STEELS. BORON RANGE: 0.000 - 0.010% (INTENDED)

Heat No.	Casting No.	Chemistry (1), %							Jominy Hardenability			
		C	Mn	Li	Ni	Cr	Mo	B	Al	End Hardness Rc	5 Rc	10 Rc
PLAIN CARBON COMPARISON STEELS:												
8305	1	.25/.30	0.9/1.1	.35/.45	-	-	-	.000	None	50.5	3.0	3.5
	2							.005	None	51.0	5.5	6.0
	3							.010	None	50.0	5.0	6.0
8306	1	.25/.30	0.9/1.1	.35/.45	-	-	-	.000	0.10 added	50.5	3.5	4.0
	2							.005	0.10 added	49.5	5.5	6.5
	3							.010	0.10 added	50.5	5.0	6.0
NICKEL-CHROMIUM-MOLYBDENUM STEELS:												
8301	1	.15/.25	.60/.90	.35/.45	.40/.60	.40/.60	.30/.40	.000	None	47.5	6.0	7.5
	2							.005	None	48.5	11.5	16.0
	3							.010	None	47.0	10.5	14.0
8302	1	.15/.25	.60/.90	.35/.45	.40/.60	.40/.60	.30/.40	.000	0.10 added	50.0	9.5	15.0
	2							.005	0.10 added	47.5	12.0	16.5
	3							.010	0.10 added	48.5	10.0	15.5
MANGANESE-MOLYBDENUM STEELS:												
8303	1	.15/.30	1.0/1.6	.35/.45	-	-	.30/.40	.000	None	50.5	6.0	7.5
	2							.005	None	50.0	10.5	15.5
	3							.010	None	51.0	10.0	13.0
8304	1	.15/.30	1.0/1.6	.35/.45	-	-	.30/.40	.000	0.10 added	50.5	10.5	14.5
	2							.005	0.10 added	51.0	10.5	15.5
	3							.010	0.10 added	50.5	11.0	16.5

(1) Intended analyses.

TABLE 4. MECHANICAL PROPERTIES OF CAST BORON - TREATED PLAIN CARBON, NICKEL - CHROMIUM - MOLYBDENUM, AND MANGANESE - MOLYBDENUM STEELS. BORON RANGE: 0.000 - 0.010% (INTENDED)

Heat No.	Casting No.	Chemistry, %		Ultimate Tensile Strength, Lbs./sq.in.	Yield Strength Lbs./sq.in.	Ductility % El. R.of A.	Impact Ft - Lb.		
		B	Al				Charpy	Double Charpy Izod	
PLAIN CARBON COPRIMISON STEELS:									
8305	1	0.000	None	140,300	126,300	16.0	51.5	--	43.5
	2	.005	"	133,600	120,800	17.2	50.8	--	40.0
	3	.010	"	(3) 102,700	(3) ---	(3) --	(3) --	--	20.0
8306	1	.000	0.10 added	136,600	128,800	14.0	44.0	--	37.0
	2	.005	"	134,000	122,250	13.0	38.5	--	38.0
	3	.010	"	131,000	121,250	3.7	7.3	--	16.5
NICKEL - CHROMIUM - MOLYBDENUM STEELS:									
8301	1	.000	None	143,100	126,700	19.5	59.4	--	52.0
	2	.005	"	138,100	126,600	14.5	35.1	--	19.5
	3	.010	"	131,300	(4) 129,000	(4) 2.5	(4) 1.9	--	7.5
8302	1	.000	0.10 added	139,100	129,600	16.5	46.4	--	42.5
	2	.005	"	140,000	128,300	10.7	24.6	--	17.0
	3	.010	"	134,300	129,000	2.5	3.9	--	10.0
MANGANESE - MOLYBDENUM STEELS:									
8303	1	.000	None	138,500	124,700	18.2	57.2	--	51.0
	2	.005	"	137,800	126,250	14.7	38.5	--	20.0
	3	.010	"	130,000	124,600	3.0	4.3	--	10.0
8304	1	.000	0.10 added	138,000	127,600	14.5	39.3	--	42.0
	2	.005	"	138,600	127,500	12.2	25.2	--	11.0
	3	.010	"	129,250	(4) 129,500	2.0	3.3	--	6.5

(1) - See Table 3. for complete (intended) analysis.

(2) - All results are an average of two tests, except the Izod values which are an average of six tests on two triple-notch specimens.

(3) - Poor specimens.

(4) - One value only.

Wrought Alloy Steels Containing Supernormal
Amounts of Aluminum and Silicon

Chemistry and Hardenability - Table 5.

A U.S. patent issued to Talbot and Mearns (U.S. Patent No. 2,279,079) claims that the co-presence of silicon and aluminum in amounts larger than normal permits a closer control of grain size and produces a finer grained steel than when either one of these elements is present alone. It is also claimed that in steels of intermediate alloy content, these additions also effect a pronounced improvement in hardenability. The steels of this series were selected to test these premises and also to examine the possibilities of using combinations of aluminum, silicon, and boron as advocated by Craft and co-workers (U.S. Patents Nos. 2,280,283;- 2,280,286) for increased hardenability.

The straight aluminum-silicon combination does not offer any outstanding advantage as far as these tests indicate, but combined with boron, the hardenabilities are markedly increased. Whether or not this increase would be less if aluminum and silicon were present in normal amounts may be determined by heats that are now being processed. With both the nickel-chromium-molybdenum and manganese-molybdenum types of steels, the addition of boron permitted the complete removal of molybdenum without a consequent deterioration of the hardenability characteristics. The possibility of substituting boron for part or all of the molybdenum in armor constituted part of the program.

TABLE 5. CHEMISTRY AND HARDENABILITY DATA ON BORON-TREATED
WROUGHT ALLOY STEELS CONTAINING SUPERNORMAL AMOUNTS
OF ALUMINUM AND SILICON

Heat No.	(1) Chemistry, %							Jominy Hardenability			
	C	Mn	Si	Ni	Cr	Mo	B	End Hardness Ro	Number of 16ths of an Inch to Obtain a Drop of 5 Ro	10 Ro	
NICKEL-CHROMIUM STEEL											
8373	0.23	0.88	0.45	0.54	0.54	-	-	-	47.5	3.0	3.5
8377	0.25	0.89	0.46	0.54	0.53	-	-	0.003	46.5	8.0	9.5
NICKEL-CHROMIUM-MOLYBDENUM STEEL											
8374	0.17	0.86	0.44	0.53	0.53	0.34	-	-	48.5	5.0	6.5
8378	0.23	0.85	0.44	0.54	0.53	0.35	0.005	-	47.5	11.0	15.5
MANGANESE STEEL											
8375	0.30	1.49	0.44	-	-	-	-	-	50.5	3.0	3.5
8379	0.28	1.43	0.47	-	-	-	-	0.004	50.5	8.0	10.0
MANGANESE-MOLYBDENUM STEEL											
8376	0.27	1.46	0.46	-	-	-	0.35	-	51.0	5.0	7.0
8380	0.28	1.45	0.47	-	-	-	0.34	0.004	51.5	16.0	22.0

(1) 0.20 per cent Al added to all heats.

Mechanical Properties - Table 6.

Mechanical properties of these steels fall within the normally expected limits. It is of interest to note that wherever molybdenum and boron occur together, the Izod values are lowered. Boron alone in either of these two base steels gave properties that are the equivalent of those found in the steels containing molybdenum. In view of the extremely tight situation regarding molybdenum these findings, if they can be substantiated by further tests, may be extremely important from the standpoint of molybdenum conservation. A more exhaustive investigation of the probable interrelation between molybdenum and boron in low alloy, homogeneous armor type steel is now in progress.

TABLE 6. MECHANICAL PROPERTIES OF BORON-TREATED WROUGHT STEELS
CONTAINING SUPERNORMAL AMOUNTS OF ALUMINUM AND SILICON

Heat No.	(1) Chemistry, % B	Mechanical Properties ⁽²⁾				Impact, Ft. Lbs. Izod
		Ultimate Tensile Strength, lbs./sq.in.	Yield Strength lbs./sq.in.	Ductility % Elong. R.A.%		
NICKEL-CHROMIUM STEEL						
8373	- -	180,000	168,500	15.5	61.0	41.0
8377	0.003	179,000	161,000	15.0	60.6	38.0
NICKEL-CHROMIUM-MOLYBDENUM STEEL						
8374	- -	178,200	165,300	(3) 15.0	(3) 58.3	44.0
8378	0.005	174,500	158,100	14.7	60.2	35.0
MANGANESE STEEL						
8375	- -	175,600	165,500	15.2	58.3	32.5
8379	0.004	175,100	157,300	14.7	58.8	31.5
MANGANESE-MOLYBDENUM STEEL						
8376	- -	176,500	164,100	(4) -	(4) -	41.0
8380	0.004	172,600	157,600	15.5	57.8	32.0

(1) See Table 5. for complete analysis.

(2) All results are an average of two tests, except the Izod results which are an average of six tests on two triple-notch specimens.

(3) One bar cracked.

(4) Both bars cracked.

Cast Alloy Steels Containing Supernormal
Amounts of Aluminum and Silicon

Chemistry and Hardenability - Table 7.

The discussion of the wrought steels of the same composition (Table 6) will apply for these cast steels as well.

Mechanical Properties - Table 8.

The ultimate tensile and yield strengths of these cast steels are lower than the corresponding wrought steels because they were drawn to a lower Brinell hardness (270-290). In these cast steels, as well as in the wrought, Izod values are lowered when boron and molybdenum occur together, but boron alone gives results that are the equivalent of those obtained with normal amounts of molybdenum when boron is absent .

TABLE 7. CHEMISTRY AND HARDENABILITY DATA ON CAST BORDON - TREATED ALLOY STEELS CONTAINING SUPERNORMAL AMOUNTS OF ALUMINUM AND SILICON.

Heat No.	(1) Chemistry, %								Jominy Hardenability			
	C	Mn	Li	Ni	Cr	Mo	B	End Hardness Rc	Number of 16ths of an inch to obtain a drop of:			
									5 Rc	10 Rc	10 Rc	
	NICKEL - CHROMIUM STEEL:-											
8373	0.23	0.88	0.45	0.54	0.54	--	--	46.5	3.0	4.0		
8377	0.25	0.89	0.46	0.54	0.53	--	0.003	47.5	7.0	9.5		
	NICKEL - CHROMIUM - MOLYBDENUM STEEL:-											
8374	0.17	0.86	0.44	0.53	0.53	0.34	--	47.5	5.5	7.5		
8378	0.23	0.85	0.44	0.54	0.53	0.35	0.005	47.5	7.5	10.0		
	MANGANESE STEEL:-											
8375	0.30	1.49	0.44	--	--	--	--	51.0	3.0	4.0		
8379	0.28	1.43	0.47	--	--	--	0.004	51.0	7.0	9.0		
	MANGANESE - MOLYBDENUM STEEL:-											
8376	0.27	1.46	0.46	--	--	0.35	--	51.5	5.5	8.0		
8380	0.28	1.45	0.47	--	--	0.34	0.004	51.5	9.0	13.5		

(1) 0.20 % Al added to all heats.

TABLE 8. MECHANICAL PROPERTIES OF CAST
BORON-TREATED ALLOY STEELS CONTAINING
SUPERNORMAL AMOUNTS OF ALUMINUM AND SILICON

Heat No.	Chemistry ⁽¹⁾ B	Mechanical Properties ⁽²⁾				
		Ultimate Tensile Strength, lbs./sq.in.	Yield Strength, lbs./sq. in.	Ductility		Impact, Ft. Lbs. Izod
				% El.	R.of A	
NICKEL - CHROMIUM STEEL						
8373	-	138,600	130,800	14.5	41.3	33.0
8377	0.003	137,250	126,250	15.0	43.5	44.0
NICKEL-CHROMIUM-MOLYBDENUM STEEL						
8374	-	140,200	131,300	17.0	51.1	44.5
8378	0.005	139,600	127,100	11.0	23.0	26.5
MANGANESE STEEL						
8375	-	141,700	133,300	10.7	27.4	26.5
8379	0.004	136,000	123,800	14.7	37.5	39.5
MANGANESE-MOLYBDENUM STEEL						
8376	-	140,000	132,000	15.7	42.5	39.5
8380	0.004	139,500	127,250	14.0	35.5	20.5

(1) See Table 7 for complete analysis.

(2) All results are an average of two tests except the Izod values which are an average of six tests on two triple notch specimens.

Wrought Alloy Steels Treated with Special AdditionsChemistry and Hardenability - Table 9.

Advantageous effects are claimed for nitrogen additions to steels by Smith and Motok (U. S. Patent No. 2,229,140). The nitrogen-bearing steels in this group were prepared to test this claim. The nitrogen did not seem to have much effect on the hardenability in any case.

Mechanical Properties - Table 10.

The data would indicate a trend towards higher strengths in the nitrogen-bearing steels and those treated with special deoxidizers. Other special addition agents are in the process of being tested.

TABLE 9. CHEMISTRY AND HARDENABILITY DATA ON WROUGHT NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-MOLYBDENUM STEELS MADE WITH SPECIAL ADDITIONS

Heat No.	Chemistry (1), %							Remarks.	Jominy Hardenability		
	C	Mn	Ni	Cr	Mo	N	End Hardness Rc		Number of 16ths of an inch to obtain a drop of:	5 Rc	10 Rc
	NITROGEN-BEARING NICKEL-CHROMIUM-MOLYBDENUM STEELS:										
8381	.18	.88	.44	.53	.52	.34	.014	Added as high Ni. ferrochromium	47.5	4.5	6.0
8382	.22	.89	.45	.53	.53	.34	.010	Added as calcium cyanamid	47.0	5.0	6.0
8383	.13	.89	.44	.53	.53	.33	.015	Calcium cyanamid slag	40.1	3.0	4.0
	NITROGEN-BEARING MANGANESE-MOLYBDENUM STEELS:										
8384	.25	1.47	.44	-	.34	.34	.010	Added as calcium cyanamid	48.5	5.5	6.5
8385	.15	1.51	.44	-	.35	.35	.015	Added as calcium cyanamid slag	42.5	3.0	4.0
	SPECIAL DEOXIDIZERS ADDED TO NICKEL-CHROMIUM-MOLYBDENUM STEELS:										
8386	.24	.81	.42	.53	.35	.35	-	V-5 alloy (2)	49.0	6.5	8.0
8387	.25	.82	.41	.50	.35	.35	-	V-7 alloy (2)	48.5	6.0	7.5

(1) 0.10% Al added to nitrogen-bearing heats only

(2) Enough V-5 and V-7 alloy was used to furnish the required chromium.

C	3.80	2.42
Si	15.82	20.61
Mn	10.33	14.54
Ca	0.85	1.10
Ti	0.64	0.69
Cr	38.20	30.25

TABLE 10. MECHANICAL PROPERTIES OF WROUGHT NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-MOLYBDENUM STEELS MADE WITH SPECIAL ADDITIONS

Heat No.	N(1) Content, %	Remarks	Ultimate Tensile Strength Lbs./sq.in.	Yield Strength Lbs./sq.in.	Ductility		Impact, Ft.-Lbs.	
					% El.	R. of A.	Charpy	Double Charpy Izod
NITROGEN-BEARING NICKEL-CHROMIUM-MOLYBDENUM STEELS:								
8381	0.014	Added as high Al ferrochrome	188,500	168,600	14.2	52.4	20.5(3)	31.5 32.0
8382	.010	Added as calcium cyanamid	183,300	165,300	14.2	59.4	23.0	31.5 37.0
8383	.015	Added as calcium cyanamid slag	178,100	164,200	15.0	59.9	23.0	36.5 36.0
NITROGEN-BEARING MANGANESE-MOLYBDENUM STEELS:								
8384	0.010	Added as calcium cyanamid	185,200	166,000	14.5	59.1	20.0	30.5(3) 27.0
8385	.015	Added as calcium cyanamid slag	171,600	156,100	14.2	57.4	22.0	36.0 37.0
SPECIAL DE-OXIDIZERS ADDED TO NICKEL CHROMIUM MOLYBDENUM STEEL:								
8386	0	V-5 Alloy (4)	185,200	160,600	14.5	60.5	19.0	31.5 29.5
8387	0	V-7 Alloy (4)	184,500	159,000	14.2	58.4	19.5	31.5 28.5

(1) See Table 9. for complete analysis

(2) All values are the average of two tests except the Izod values which are the average of six tests on two triple notch specimens.

(3) One specimen only.

(4) Compositions of V-5 and V-7 are given in Table 9.

Cast Alloy Steels Treated with Special Additions

Chemistry and Hardenability - Table 11.

See remarks for the wrought steels.

Mechanical Properties - Table 12.

See remarks for wrought steels. The izod impact values of the cast steels treated with V-5 and V-7 alloys are higher than those for the wrought steels.

TABLE 11. CHEMISTRY AND HARDENABILITY DATA ON CAST NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE MOLYBDENUM STEELS MADE WITH SPECIAL ADDITIONS

Heat No.	Chemistry (1), %							Remarks	End Hardness RC	Jominy Hardenability	
	C	Mn	Si	Ni	Cr	Mo	N			Number of 16ths of an inch to obtain a drop of:	5 RC
	NITROGEN-BEARING NICKEL-CHROMIUM-MOLYBDENUM STEELS:										
8381	.18	.88	.44	.53	.52	.34	0.014	Added as high N Ferrochrome	48.0	6.0	8.5
8382	.22	.89	.45	.53	.53	.34	.010	Added as calcium cyanamid	45.0	4.5	7.0
8383	.13	.89	.44	.53	.53	.33	.015	Added as calcium cyanamid slag	38.0	3.5	4.5
	NITROGEN-BEARING MANGANESE-MOLYBDENUM STEELS:										
8384	.25	1.47	.44	-	-	.34	0.010	Added as calcium cyanamid	48.0	5.0	6.5
8385	.15	1.51	.44	-	-	.35	.015	Added as calcium cyanamid slag	40.5	3.5	4.5
	SPECIAL DE-OXIDIZERS ADDED TO NICKEL-CHROMIUM-MOLYBDENUM STEELS:										
8386	.24	.81	.42	.53	.53	.35	-	V-5 Alloy(2)	47.5	5.5	7.5
8387	.25	.82	.41	.50	.55	.35	-	V-7 Alloy(2)	48.0	5.5	7.5

(1) 0.10% Al added to nitrogen-bearing heats only.

(2) Enough V-5 and V-7 alloy was used to furnish the required chromium.

	V-5	V-7
C	3.80	2.42
Si	15.82	20.61
Mn	10.33	14.54
Ca	0.85	1.10
Ti	0.64	0.69
Cr	38.20	30.25

TABLE 12. MECHANICAL PROPERTIES OF CAST NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-MOLYBDENUM STEELS MADE WITH SPECIAL ADDITIONS

Heat No.	N(1) Content %	Remarks	Mechanical Properties(2)				
			Ultimate Tensile Strength lbs./sq.in.	Yield Strength lbs./sq.in.	Ductility % Elong.	% R.A.	Impact, Ft.-Lbs. Izod
8381	0.014	NITROGEN BEARING NICKEL-CHROMIUM-MOLYBDENUM STEELS: Added as high nitrogen ferrochrome	147,750	139,800	13.2	34.1	30.0
8382(4)	0.010	Added as calcium cyanamid					
8383	0.015	Added as calcium cyanamid slag	142,500	129,700	13.7	40.0	27.0
8384(4)	0.010	NITROGEN BEARING MANGANESE-MOLYBDENUM STEELS: Added as calcium cyanamid					
8385	0.015	Added as calcium cyanamid slag	141,300	131,300	11.7	30.8	27.0
8386	0	SPECIAL DEOXIDIZERS ADDED TO NICKEL-CHROMIUM-MOLYBDENUM STEELS: V-5 Alloy(3)	143,800(3)	131,800	17.5(3)	54.8	45.5
8387	0	V-7 Alloy	146,000	133,100	18.2	55.0	46.5

(1) See Table 11 for complete analysis.

(2) All values are averages of two tests except the Izod values which are an average of six tests on a triple notch specimen.

(3) One specimen only.

(4) No data available.

Wrought Tellurium-Treated SteelsChemistry and Hardenability - Table 13.

The claim made for a tellurium treatment (U.S. Patent Reissue No. 22,021) such as given to the steels listed in Table 13 is that it produces a consistently fine grain size with an accompanying improvement of those mechanical properties associated with fine grained steels. A tellurium treatment therefore, cannot be expected to increase hardenability, but it is of interest to know how it does effect this important property. As the results indicate, tellurium additions have a slight tendency to reduce hardenability.

One of the claimed necessary conditions for obtaining grain refinement by adding tellurium is to have the sulfur content above a certain minimum value, consequently the sulfur content of all the steels in this series was adjusted to approximately 0.04 per cent.

Mechanical Properties - Table 14.

One would expect to find an increase in toughness after refining the grain size of a steel, yet, if anything, the toughness of these steels was reduced by a tellurium addition. The degree of refinement as determined by the austenitic grain size has not yet been determined.

TABLE 13. CHEMISTRY AND HARDENABILITY DATA ON WROUGHT TELLURIUM-TREATED NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-MOLYBDENUM STEELS.

Heat No.	Ingot No.	Chemistry, %								End Hardness RC	Jominy Hardenability		
		C	Mn	Si	S	Ni	Cr	Mo	Te (1)		Al (2)	Number of 16ths of an inch to obtain a drop of:	5 RC
NICKEL-CHROMIUM-MOLYBDENUM STEELS													
8323	1	.25	.84	.28	.030	.40/.60	.40/.60	.30/.40	.000	.0	48.0	4.0	5.5
	2								.022	0	45.0	4.5	5.5
	3								.033	0	46.5	3.5	4.5
	4								.045	0	46.0	3.0	4.0
8324	1	.25	.83	.30	.028	.40/.60	.40/.60	.30/.40	.000	0.10	48.0	4.0	5.0
	2								.022	0.10	47.5	3.5	4.5
	3								.033	0.10	48.0	3.5	4.0
	4								.045	0.10	46.5	3.5	4.0
MANGANESE-MOLYBDENUM STEELS:													
8325	1	.29	1.47	.26	.034	-	-	.30/.40	.000	0	51.0	5.0	6.0
	2								.022	0	50.0	4.0	5.0
	3								.033	0	50.0	4.0	5.0
	4								.045	0	49.5	4.5	5.0
8326	1	.29	1.47	.28	.036	-	-	.30/.40	.000	0.10	50.0	3.5	4.5
	2								.022	0.10	50.0	3.0	4.0
	3								.033	0.10	50.0	3.0	4.0
	4								.045	0.10	49.5	3.0	3.5

(1) These are added, not actual, amounts.
(2) 0.10 per cent Al added.

TABLE 14. MECHANICAL PROPERTIES OF WROUGHT TELLURIUM-TREATED
NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-MOLYBDENUM STEELS

Heat No.	Ingot No.	Chemistry ⁽¹⁾ , %		Mechanical Properties				Impact, Ft.-Lbs. Izod
		Te ⁽²⁾	Al ⁽³⁾	Ultimate Tensile Strength Lbs./Sq.In.	Yield Strength Lbs./Sq.In.	Ductility		
						% El.	R.of A.	
<u>NICKEL-CHROMIUM-MOLYBDENUM STEELS</u>								
8323	1	0.000	0	183,200	143,700	14.5	55.8	29
	2	.022	0	183,700	148,100	14.0	53.4	19
	3	.033	0	182,700	141,200	14.0	54.0	19
	4	.045	0	181,100	135,600	14.5	53.2	19.5
8324	1	0.000	0.10	189,000	172,400	13.5	53.5	29.0
	2	.022	0.10	188,900	178,600	14.2	55.3	23.0
	3	.033	0.10	187,600	175,700	14.5	55.2	22.5
	4	.045	0.10	185,300	173,700	14.5	54.8	23.0
<u>MANGANESE-MOLYBDENUM STEELS</u>								
8325	1	0.000	0	174,000	158,300	14.5	57.0	22.0
	2	.022	0	177,000	160,800	14.0	53.1	21.0
	3	.033	0	175,200	160,000	14.0	54.4	21.0
	4	.045	0	176,200	161,100	14.5	53.0	22.5
8326	1	0.000	0.10	169,800	164,200	15.7	56.9	38.0
	2	.022	0.10	170,200	166,200		57.0	32.5
	3	.033	0.10	169,200	165,600	15.2	57.2	33.0
	4	.045	0.10	168,700	166,300	15.2	56.9	32.0

(1) See Table 13 for complete chemical analysis.

(2) These are added, not actual, amounts.

(3) 0.10 per cent Al added.

Cast Alloy Steels Treated with Calcium and SeleniumChemistry and Hardenability - Table 15.

According to Gagnebin (U.S. Patent No. 2,258,604) the deleterious effect of the film-type sulfide inclusions is practically eliminated by a treatment with calcium and selenium. These additions were tried by adding the calcium and selenium separately as calcium silicide and elemental selenium, and also by adding them in the form of a special mixture recommended by the patent.

Although there are some variations in hardenability in these steels, there does not appear to be any definite trend with respect to either the calcium plus selenium additions or the degree of deoxidation.

Mechanical Properties - Table 16.

The special treatment of these steels with calcium and selenium has contributed nothing to their ductility or impact values.

P. C. Rosenthal

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Approved:

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Supervising Metallurgist

CHL:kh:ic:RS
July 16, 1942

TABLE 15. CHEMISTRY AND HARDENABILITY DATA ON CAST NICKEL-CHROMIUM-MOLYBDENUM AND MANGANESE-MOLYBDENUM STEELS MADE WITH CALCIUM PLUS SELENIUM ADDITIONS

Heat No.	Chemistry ⁽¹⁾ , %											Jominy Hardenability		
	C	Mn	Si	S	Ni	Cr	Mo	Se ⁽²⁾	Ca ⁽²⁾	Al ⁽³⁾	End Hardness Rc	Number of 16th of an inch to obtain a drop of:	5 Rc	10 Rc
NICKEL-CHROMIUM-MOLYBDENUM STEELS:														
8229	.24	.83	.39	0.030	.40/.60	.40/.60	.30/.40	-	-	0	47.0	5.5	7.0	
8230	.23	.84	.50	0.030	.40/.60	.40/.60	.30/.40	-	-	0.10	45.5	8.0	10.5	
8231	.22	.84	.42	0.040	.40/.60	.40/.60	.30/.40	0.03	0.05	0	48.5	5.0	7.0	
8232	.24	.84	.51	0.031	.40/.60	.40/.60	.30/.40	0.03	0.05	0.10	46.5	6.0	8.0	
8233	.20	.69	.34	0.039	.40/.60	.40/.60	.30/.40	0.10	0.15	0	46.0	4.0	4.5	
8234	.23	.84	.39	0.027	.40/.60	.40/.60	.30/.40	0.10	0.15 ⁽⁴⁾	0.10	47.0	6.0	7.5	
8309	.22	.86	.40	-	.40/.60	.40/.60	.30/.40	0.03 ⁽⁴⁾	0.05 ⁽⁴⁾	0	46.0	5.0	6.5	
8310	.22	.80	.36	0.033	.40/.60	.40/.60	.30/.40	0.03 ⁽⁴⁾	0.05 ⁽⁴⁾	0.10	46.5	4.5	5.5	
8311	.21	.85	.35	0.036	.40/.60	.40/.60	.30/.40	0.10 ⁽⁴⁾	0.15 ⁽⁴⁾	0	(5)	(5)	(5)	
8312	.25	.87	.44	0.034	.40/.60	.40/.60	.30/.40	0.10 ⁽⁴⁾	0.15 ⁽⁴⁾	0.10	47.5	4.5	6.0	
MANGANESE-MOLYBDENUM STEELS:														
8315	.26	1.40	.44	0.041	-	-	.30/.40	-	-	0	50.5	7.0	8.5	
8316	.26	1.39	.43	0.032	-	-	.30/.40	-	-	0.10	50.0	5.0	6.0	
8313	.27	1.43	.39	0.038	-	-	.30/.40	0.03	0.05	0	50.0	5.5	7.0	
8314	.26	1.47	.47	0.033	-	-	.30/.40	0.03	0.05	0.10	51.5	5.0	7.0	
8317	.29	1.49	.37	0.034	-	-	.30/.40	0.10	0.15	0	51.5	5.5	8.0	
8318	.27	1.40	.37	0.031	-	-	.30/.40	0.10	0.15 ⁽⁴⁾	0.10	50.5	3.5	4.5	
8319	.27	1.48	.34	0.035	-	-	.30/.40	0.03 ⁽⁴⁾	0.05 ⁽⁴⁾	0	50.5	6.0	7.5	
8320	.29	1.48	.41	0.032	-	-	.30/.40	0.03 ⁽⁴⁾	0.05 ⁽⁴⁾	0.10	50.5	7.0	9.0	
8321	.27	1.48	.37	0.038	-	-	.30/.40	0.10 ⁽⁴⁾	0.15 ⁽⁴⁾	0	51.0	5.5	7.5	
8322	.29	1.53	.41	0.029	-	-	.30/.40	0.10 ⁽⁴⁾	0.15 ⁽⁴⁾	0.10	52.0	7.0	9.0	

(1) Phosphorus contents are less than 0.04 per cent.

(2) These are added amounts, not actual. Except when otherwise noted, calcium was added as calcium silicide and selenium as elemental selenium.

(3) These are added amounts. (4) Added as a compressed mixture containing 10% iron powder, 20% fluorspar, 11% selenium, 58% calcium silicide and 1% dextrine. (5) Casting too porous to use.

TABLE 16. MECHANICAL PROPERTIES OF CAST NICKEL-CHROMIUM-MOLYBDENUM
AND MANGANESE-MOLYBDENUM STEELS MADE WITH CALCIUM
PLUS SELENIUM ADDITIONS

Heat No.	Chemistry ⁽¹⁾ , %			Mechanical Properties*				Impact, Ft.-Lbs. Izod
	Se ⁽²⁾	Ca ⁽²⁾	Al ⁽³⁾	Ultimate	Yield	Ductility		
				Tensile Strength Lbs./Sq.In.	Strength Lbs./Sq.In.	% EL	R. of A.	
<u>NICKEL-CHROMIUM-MOLYBDENUM STEELS</u>								
8229	--	--	0	137,750	124,100	17.7	53.8	41.0
8230	--	--	0.10	133,600	123,100	16.0	43.5	35.0
8231	0.03	0.05	0	137,600	129,700	19.0	55.2	37.5
8232	0.03	0.05	0.10	133,300	125,400	13.0	30.8	24.0
8233	0.10	0.15	0	135,400	126,900	17.5 ⁽⁵⁾	50.4	31.0
8234	0.10	0.15	0.10	133,500	124,100	14.5	38.9	24.0
8309	0.03	0.05	0	138,300	128,000	18.0	44.7	40.0
8310	0.03	0.05	0.10	128,750	121,600	15.7	39.1	33.5
8311	0.10	0.15	0	(4) 117,500	(4) --	(4) --	(4) --	37.5
8312	0.10	0.15	0.10	136,900	129,300	15.7	40.1	31.0
<u>MANGANESE-MOLYBDENUM STEELS</u>								
8315	--	--	0	140,250	126,250	17.5	41.6	37.0
8316	--	--	0.10	129,200	121,700	14.7	30.1	31.5
8313	0.03	0.05	0	138,500	128,300	9.5	17.7	35.5
8314	0.03	0.05	0.10	134,000	125,500	14.7	34.4	22.0
8317	0.10	0.15	0	139,900	127,900	17.7	42.0	29.5
8318	0.10	0.15	0.10	132,200	122,600	14.5	29.3	21.5
8319	0.03	0.05	0	(5) 142,250	(5) 130,000 ⁽⁵⁾	18.5	(5) 49.3	36.0
8320	0.03	0.05	0.10	132,000	126,000	16.2	36.0	28.5
8321	0.10	0.15	0	133,100	120,300	18.7	49.4	39.5
8322	0.10	0.15	0.10	134,800	125,100	16.0	37.3	30.0

(1) See Table 15 for complete analysis

(2) (3) These are added amounts

* All results are an average of two tests

(4) Blowholes in bar

(5) One specimen only

-- 1 OF 1
-- 1 - AD NUMBER: A953286
-- 5 - CORPORATE AUTHOR: BATTELLE MEMORIAL INST COLUMBUS OHIO COLUMBUS
-- LABS
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-- 9 - DESCRIPTIVE NOTE: QUARTERLY REPT. NO. 2,
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