10 July 1944 NRL Report No. M-2325

Navy Department

Partial Report on

Weldability Tests of High Tensile Steel (BuShips Welding Tests No. 324 and No. 325)

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages:	Text	6	Tables	10	Plates	26

Authorization: BuShips ltrs 1-31-44 and 2-22-44 QP/W&C-(4)-(4)(692-334) and BuShips Project Order No. BP2R

Tests & Report by: G. G. Luther, Associate Metallurgist
F. S. McKenna, Lt. (jg) USNR
F. H. Laxar, Contract Employee
J. H. Goodyear, Contract Employee
K. E. Fritz, Contract Employee

Supervised by: Clarence E. Jackson, Senior Metallurgist
Head of Welding Section

Reviewed by: F. M. Walters, Jr., Superintendent,
Division of Physical Metallurgy

Approved by: A. H. Van Keuren, Rear Admiral, USN,
Director

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ABSTRACT

A comparison is made of the relative weldability of nine manganese-titanium steels, a manganese-vanadium steel and a mild steel. The direct ductility tests, the nick-bend and T-bend, classify these steels in approximately the same order of weldability. The indirect tests show a greater variation. The low weldability rating obtained for manganese-vanadium steel cannot be taken as indicative of the performance of this type of steel. The effect of titanium on the weldability of a steel cannot be determined from these tests.

AUTHORIZATION

1. This problem was authorized by Bureau of Ships letters dated 31 January 1944 and 22 February 1944, QP/W&C-(4)-(4)(692-334) and Bureau of Ships Project Order BP2R (BuShips Welding Test Nos. 324 and 325).

STATEMENT OF PROBLEM

2. Results of weldability and other tests on four commercial high tensile steels were reported in NRL Report No. M-2237 of 19 February 1944. The recognized difficulty encountered in welding high tensile steels has indicated the advisability of further study of the relative weldability of available commercial high tensile steels. A study of the weldability of ten commercial Navy high tensile steels and one mild steel is presented in this report. A suggestion for eliminating the under bead cracking in these and several other steels by varying the composition of the weld metal was reported in NRL Report M-2277 of 15 April 1944.

NARRATIVE OF ORIGINAL WORK AT THE NAVAL RESEARCH LABORATORY

3. This report includes all test results which have been obtained for the steels in this study. No brief is held regarding the exact relationship to weldability of some of the tests. For example, it is realized that the method of locating the Charpy impact specimens is not orthodox; however, these values were obtained in connection with another study and are included herewith for information only. This report also presents further information such as a dilatometric study and observations regarding the cleanliness and structure of the steels. End quench hardenability and continuous cool U-bend specimens are also included although these must be considered as indirect methods of measurement of weldability. These tests have been critically discussed in NRL Report No. M-2149 of August 1943.

MATERIALS

4. The chemical composition and source of supply of the plates (40.8 pound, 1" gage) studied in this investigation are given in Table I. A sample of mild steel was used for comparison with the high tensile steels. Six of the plates were of the manganese-titanium treated type with less than 0.01 per cent titanium, three plates were of the titanium bearing type with over 0.02 per cent titanium and one plate was of the manganese-vanadium type. It would be highly desirable if additional commercial manganese-vanadium heats were available for further study of this type of Navy high tensile steel. These undoubtably will be investigated as soon as the new production under the present issue of specification 48S5 is available.

PREPARATION OF SPECIMENS

5. The major direction of rolling of each steel was determined and samples for chemical analysis were taken. Sections were obtained by means of flame cutting and hack sawing for the following test specimens:

A. 0.505" diameter tensile (longitudinal and transverse)
B. Double-width Charpy V-notched impact (longitudinal and transverse)(Plate 1).
C. Inclusion and structure (Plates 2 to 12)
D. Dilatometric study.
E. End-quench hardenability (Plate 13)
F. Nick-bend plate and bead weld (longitudinal and transverse) (Plate 14).
G. T-bend (Plate 15).
H. Maximum bead weld hardness (Vickers and Knoop)
I. Grain size (heat affected zone)
J. Continuous cool U-bend (Plate 16).

TEST METHODS AND RESULTS

(a) Properties of Steels

6. The chemical compositions of the steels used in this investigation are shown in Table I. The carbon and manganese contents cover a comparatively narrow range; the carbon contents in the high tensile steels vary from 0.15 to 0.18 per cent, and manganese from 1.09 to 1.34 per cent. The tensile properties as determined by tests on 0.505 inch diameter test pieces (transverse and longitudinal) appear in Table II. The hardness of the plate material in these steels ranges from 138 to 154 Brinell (Table II).

7. Results of impact tests made at 70°F on transverse and longitudinal double-width Charpy V-notched impact specimens taken through the thickness of the plates (Plate 1) appear in Table III.

8. Unetched specimens of each steel were examined microscopically at a magnification of 100 diameters, and a count was made of the total number of inclusions (Table IV). The pieces were hardened by quenching from the austenitic state to aid in the retention of inclusions during polishing. A complete description of the method used is contained in NRL Report No. M-2159. Photomicrographs at 75 diameters of typical cross-sections of the steels are shown in Plates 2 to 12.

9. Transformation temperatures with slow heating (33°F/min.) and with two rates of cooling (80°F and 200°F/min.) were obtained dilatometrically for the steels in these tests (Table V).

10. Standard end-quench hardenability test specimens (Plate 13) were machined from $1\frac{1}{2}$" diameter bars forged from the original plate. The forgings were double-normalized from 1675°F before machining into test specimens. The end quench hardenability bars were quenched in a standard jig after heating at 2100°F for 75 minutes in a controlled atmosphere furnace. Two parallel flat surfaces were ground along the length of the bar to a depth of 0.10 inch. Rockwell "C" hardness surveys were made along the flats with the location of the impressions determined by a calibrated carriage.

11. The grain size of the bars was determined by electrolytically polishing the specimens, etching with nital-picral reagent and photographing two suitable microstructures at a magnification of 150 diameters. An actual grain count was made on an area of 5000 sq.mm. on the photograph.

12. The hardness value for 50 per cent martensite was determined for each steel, and the distance corresponding to this hardness was obtained from the end-quench hardenability curves (Plates 17 to 19). This distance was converted to "ideal diameter" (Table VI) using curves presented by Grossmann and reproduced in NRL Report M-2149.

(b) Weldability Tests of Steels

13. Transverse and longitudinal nick-bend specimens (Plate 14) were welded under NRL standard conditions (175 amperes, 26 volts, reversed polarity, 6 in./min.) using a 3/16 inch AWS E6010 electrode. These were tested at room temperature two and five days after welding. Unwelded transverse and longitudinal plate specimens were also tested. The results of these tests appear in Table VII. A full description of the nick-bend test is contained in a letter report to BuShips, Subject: Nick-Bend Test for Weldability (Tentative) dated 12 July 1944.

14. T-bend specimens were prepared (Plate 15) from all of the steels for which sufficient material was available. The plates were positioned so that all welding was done in a horizontal plane. The fillets were welded manually using 3/16" AWS E6010 electrodes, reversed polarity, 175 amperes and 26 to 28 volts. Twelve inches of electrode were deposited per four inch linear length of fillet and a forty-five second interval was maintained between the finish of one and the start of the next electrode. The plates were allowed to cool to room temperature before the second fillet was welded. Standard specimens were machined from these weldments and tested at room temperature, one, three and fourteen days after welding (Table VIII).

15. Sections about 3/8 inch wide were saw cut from the nick-bend weldments for bead weld fusion zone grain size and hardness studies. The sections were mounted, metallographically prepared, and lightly etched with nital-picral reagent. A survey of the

grain size at the fusion zone was made by photographing the structure at 150 diameters and actually counting the enlarged grains at three locations to a depth of 0.02 inch below the fusion line. Photomicrographs at 150 diameters of the heat affected zones are shown in Plates 20 to 25.

16. Vickers (10 kg. load) and Knoop (500 gm. load) hardness surveys were made of the heat affected zones under the bead welds. The maximum hardness values using both methods are reported in Table IX.

17. Standard U-bend specimens (Plate 16) were prepared from each steel. The specimens were heated to 2100°F in a controlled atmosphere furnace and continuously cooled at different rates in the furnace, air, oil and water. The specimens were notched after heat treatment and bent to failure in a guided bend testing jig with the notched side in tension. The angle of bend at maximum load and the average Vickers (10 kg. load) hardness were obtained for each specimen. From the resulting relation of ductility and hardness, the ductility corresponding to the actual maximum under- bead hardness of each steel was estimated. These results appear in Table X.

18. The results of the under bead cracking tests on these steels for welds prepared with Class I, Grade 1 electrodes (AWS E6010) and low alloy high tensile electrodes have been reported in NRL Report No. M-2277. It was shown in this report that the cracking tendency observed in the heat affected zone of high tensile steels using mild steel Grade 1 electrodes could be reduced by the use of high tensile electrodes.

<u>DISCUSSION OF RESULTS</u>

(a) Properties of Steels

19. In order to compare the performance of the steels in the various tests, profile curves of performance vs. steel numbers were plotted (Plate 26). In these curves good weldability as evaluated by each test is indicated by a high point. The scales were adjusted so as to indicate approximately equivalent sensitivity for all tests. The steels are arranged in order of decreasing weldability as indicated by an average of all results of the nick-bend bead weld tests.

20. Five of the nine manganese-titanium steels (#391, 392, 394, 395 and 396) meet the requirements of Navy Specification 48S5 regarding yield and tensile strengths; the remaining four steels (#314, 333, 334 and 393) have low yield strengths. The sample of manganese-vanadium steel has satisfactory yield strength and its tensile strength of 82,000 psi is the highest of the steels in this group. The yield and tensile strengths of the sample of mild steel are considerably lower than those of the high tensile steels as would be expected. The tensile

and plate hardness profile curves are of the same general shape, but have only a general correlation with the nick-bend or T-bend weldability tests.

21. The Charpy impact results indicate that the impact behavior of the steels is in general related to their nick-bend and T-bend performance.

22. The number of inclusions seems to have little relation to the other properties of the steel.

23. The results of the dilatometric studies showed only slight differences in the transformation temperatures for these steels. Data for faster cooling rates than could be obtained with the present equipment are needed in order to predict the behavior of these steels at cooling rates obtained in the welding process.

24. The end-quench hardenability results for this group of steels as indicated by the ideal critical diameter show only slight differences except for Mn-V steel #367 which has the highest hardenability of the steels in this group. The profile plot of ideal diameter shows only a general similarity to those of the nick-bend and T-bend tests.

(b) Weldability Tests of Steels

25. The results of the nick-bend test indicate that there is a considerable variation in the effect of welding on the ductility of the steels in this series. An examination of the data shows that the sample of mild steel suffers the least reduction in ductility when subjected to the standard welding technique. The sample of manganese-vanadium steel in this series has low ductility both in the plate and as welded. Other samples of manganese-vanadium are needed before concluding that this type of steel has low weld ductility. From the present data no statement can be made regarding the effect of titanium on weldability as one of the best steels contained less than 0.01 per cent titanium and the most unsatisfactory sample contained 0.025 titanium; at the same time the steels with 0.030 and 0.035 per cent titanium were average steels in this group.

26. For most of the steels studied the relative weldability as indicated by the T-bend test is in good agreement with that shown by the nick-bend test.

27. The maximum hardness in the heat affected zone as measured by the Knoop method bears little relationship to nick-bend performance; the Vickers maximum hardness values were only slightly better.

28. No general correlation can be made between the grain size in the heat affected zone and other properties.

29. The results of the continuous cool U-bend test are difficult to interpret due to the fact that it is impossible with ordinary cooling facilities to obtain a range of hardnesses in uniform steps. The maximum hardness encountered in the heat affected zone usually falls between the hardness ranges obtained for the furnace and air cooled and the oil and water quenched specimens. Until a method of cooling is available which will give a hardness close to that encountered in the heat affected zone, little reliance can be placed upon the results of this test.

CONCLUSIONS

30. From a study of the limited number of commercial steels available for these tests, the following conclusions are suggested:

1. The results of the direct ductility tests such as the nick-bend and T-bend tests on these steels show similar ratings for weldability.

2. The results of the indirect tests show a greater scatter, although the sample of mild steel is classified by all applicable tests as the most weldable in this group.

3. The low rating for the sample of manganese-vanadium steel in these tests cannot be taken as indicative of other samples of manganese-vanadium.

4. No statement can be made based upon the present data regarding the effect of titanium on weldability as the performance of these steels was not related to titanium content. It is hoped that the experimental manganese-vanadium and manganese-titanium steels being tested at this Laboratory will give useful information for a further analysis of the effects of vanadium and titanium in high tensile steels.

TABLE I CHEMICAL COMPOSITION

Steel	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	V	Ti
314	0.18	1.10	0.16	0.018	0.020	0.03	0.11	0.02	0.23	0.003	<0.01
333	0.18	1.09	0.16	0.017	0.022	0.04	0.12	0.025	0.22	0.00	0.004
334	0.17	1.10	0.17	0.018	0.024	0.04	0.12	0.018	0.22	0.00	0.005
367	0.16	1.12	0.26	0.019	0.027	0.05	0.08	0.02	0.19	0.09	
391	0.16	1.26	0.24	0.020	0.020	0.04	0.06	0.038	0.15	<0.01	<0.01
392	0.14	1.10	0.25	0.025	0.019	0.08	0.26	0.025	0.20	<0.01	<0.01
393	0.16	1.25	0.21	0.015	0.024	0.12	0.13	0.10	0.13	0.002	0.005
394	0.16	1.31	0.23	0.030	0.025	0.20	0.03	0.005	0.04		0.025
395	0.14	1.27	0.23	0.031	0.025	0.20	0.03	0.005	0.03		0.035
396	0.17	1.34	0.23	0.018	0.025	0.19	0.10	0.005	0.01		0.030
420	0.23	0.50	0.003	0.010	0.053	0.05	0.10	0.02	0.15		

Steel No.	Source
314	Washington Navy Yard (stock)
333	Washington Navy Yard (stock)
334	Washington Navy Yard (stock)
367	Washington Navy Yard (stock)
391	Portsmouth Navy Yard (excess stock)
392	Portsmouth Navy Yard (excess stock)
393	Bethlehem Ht. 67D689
394	Carnegie-Illinois (Homestead) Ht #46632
395	Carnegie-Illinois (Homestead) Ht #34571
396	Carnegie-Illinois (Homestead) Ht #41530
420	Naval Research Laboratory (stock)

TABLE II MECHANICAL PROPERTIES

Steel No.		Yield Strength psi	Tensile Strength psi	Elongation in 2 inch Per Cent	Reduction of Area Per Cent	Brinell Hardness	Vickers (10 kg) Hardness
314	T	40,000	71,000	32.5	61.8	140	145
		40,750	71,000	33.0	63.2		
	L	40,500	71,000	35.0	64.2		
		40,750	71,000	35.0	65.3		
333	T	40,000	70,250	32.5	59.5	140	140
		40,600	71,350	35.0	60.9		
	L	39,000	69,500	35.0	68.2		
		39,000	69,500	35.5	61.6		
334	T	44,400	72,300	34.0	59.9	143	148
		42,500	71,500	35.0	62.2		
	L	40,000	71,250	38.9	69.6		
		40,600	71,100	36.0	64.0		
367	T	57,000	82,000	30.0	60.2	153	178
		57,000	82,300	30.0	59.7		
	L	58,000	82,250	31.0	66.0		
		56,950	82,000	29.0	65.0		
391	T	46,000	74,250	32.5	64.5	138	160
		45,000	74,250	34.0	56.6		
	L	45,000	73,500	35.5	71.6		
		43,500	73,000	37.0	71.5		
392	T	45,500	73,750	35.0	61.4	142	158
		44,400	73,600	33.0	64.6		
	L	44,750	73,875	33.0	72.3		
		44,500	74,000	35.5	68.2		
393	T	40,000	70,500	31.0	50.0	143	151
		39,750	70,750	31.0	52.0		
	L	40,250	70,750	37.5	68.6		
		40,000	70,500	37.0	71.5		
394	T	54,625	77,750	32.5	59.8	146	170
		55,375	78,250	32.0	58.9		
	L	50,600	77,500	33.0	66.3		
		53,000	78,750	33.0	64.3		
395	T	53,500	77,750	32.0	64.3	146	166
		52,750	79,250	32.0	65.3		
	L	52,500	77,250	32.5	69.3		
		52,750	77,250	32.0	66.2		
396	T	54,625	79,500	29.0	47.5	154	167
		55,375	79,500	26.0	51.5		
	L	50,600	79,250	33.0	68.2		
		53,000	79,000	32.5	68.5		
420	L	33,000	66,000	39.0	56.2	127	139
		32,500	65,500	36.0	58.3		

TABLE III DOUBLE-WIDTH CHARPY V-NOTCHED IMPACT DATA

Steel No.		Impact Resistance ft. lb.	Average Impact Resistance ft.lb.
314	T	57	52
	T	48	
333	L	65	73
	L	82	
	T	58	61
	T	64	
334	L	79	82
	L	86	
	T	35	38
	T	41	
367	L	46	48
	L	51	
	T	34	36
	T	38	
391	L	109	100
	L	94	
	T	81	74
	T	68	
392	L	163	146
	L	130	
	T	80	77
	T	75	
393	L	69	69
	L	69	
	T	45	45
	T	45	
394	L	43	51
	L	60	
	T	43	41
	T	39	
395	L	28	34
	L	40	
	T	39	36
	T	33	
396	L	68	70
	L	73	
	T	30	32
	T	34	

Temperature of tests 70°F

* L-Longitudinal. T-Transverse

TABLE IV INCLUSION COUNT

Steel No.	Total Inclusions per.sq.in.
314	43,200
333	29,100
334	22,700
367	32,600
391	10,500
392	24,700
393	26,300
394	31,100
395	23,900
396	40,700
420	28,200

TABLE V TRANSFORMATION TEMPERATURE RESULTS

Steel No.	[1] Furnace Heat Ac_1	Ac_3	[2] Slow Cool Ar_1	Ar_3	[3] Furnace Drop Ar_1	Ar_3
	°F	°F	°F	°F	°F	°F
314	1328	1546	1116	1349	1033	1308
333	1349	1546	1116	1349	1074	1328
334	1349	1591	1137	1393	1094	1349
367	1349	1569	1137	1414	1116	1371
391	1328	1569	1116	1371	1074	1349
392	1328	1546	1116	1371	1074	1349
393	1328	1546	1116	1371	1053	1328
394	1349	1546	1137	1349	1053	1308
395	1328	1546	1116	1349	1094	1308
396	1349	1546	1137	1371	1094	1349
420	1328	1546	1200	1414	1159	1371

1. Heating Rate Between 1100°F and 1800°F - 33°F/min.
2. Slow Cooling Rate Between 1700°F and 800°F - 80°F/min.
3. Fast Cooling Rate Between 1700°F and 800°F - 200°F/min.

TABLE VI END QUENCH HARDENABILITY RESULTS

Steel No.	Hardness at 50 Per Cent Martensite	Jominy Distance Inches	D_i	Grain Size	D_i (Corrected to Grain Size 2.0)
	R_c		Inches		Inches
314	31.2	.200	1.68	3.1	1.82
333	31.2	.210	1.74	3.7	1.93
334	30.6	.215	1.77	3.8	2.04
367	30.2	.375	2.46	3.4	2.75
391	30.2	.150	1.42	3.9	1.63
392	29.3	.205	1.70	3.4	1.90
393	30.2	.225	1.80	2.6	1.90
394	30.2	.195	1.65	3.9	1.91
395	29.3	.200	1.68	3.5	1.88
396	30.6	.220	1.77	3.5	1.99
420	33.2	.148	1.45	3.3	1.60

TABLE VII NICK BEND TEST RESULTS

Steel No.		Plate			Weld: Two Days			Weld: Five Days		
		Angle at Maximum Load		Maximum Load*	Angle at Maximum Load		Maximum Load*	Angle at Maximum Load		Maximum Load*
		degrees		pounds	degrees		pounds	degrees		pounds
314	L	74	78	14,350	$25\frac{1}{2}$	26	13,250	29	30	13,700
	T	60	66	14,650	33	$25\frac{1}{2}$	13,875	--	--	------
333	L	70	74	15,325	18	20	13,070	50	47	15,750
	T	65	61	15,050	38	36	14,100	31	40	14,600
334	L	73	70	15,300	$24\frac{1}{2}$	$27\frac{1}{2}$	14,450	41	39	16,100
	T	41	47	15,475	16	$14\frac{1}{2}$	12,400	31	31	14,500
367	L	45	49	17,400	17	20	14,950	35	33	17,850
	T	55	42	17,950	18	15	15,225	32	30	17,650
391	L	77	70	15,400	28	31	13,875	43	44	15,550
	T	71	67	15,650	37	49	16,450	45	36	15,675
392	L	71	69	16,650	47	37	16,250	47	49	16,650
	T	49	61	16,850	26	28	14,000	41	44	16,500
393	L				19	19	12,300	42	42	15,800
	T	65	52	15,400	13	13	11,050	36	35	15,150
394	L	65	67	21,200	19	15	16,800	28	31	19,750
	T	44	41	20,800	13	11	15,800	9	26	19,100
395	L	67	67	16,300	28	--	14,950	47	--	16,750
	T	65	60	16,375	22	24	14,400	38	46	17,050
396	L	68	54	17,050	29	30	16,650	54	50	17,650
	T	35	33	15,600	11	11	12,350	33	39	16,550
420	L	71	74	13,550	48	51	13,300	54	54	14,000

* Average of two specimens

L - Longitudinal
T - Transverse

TABLE VIII T-EEND TEST RESULTS

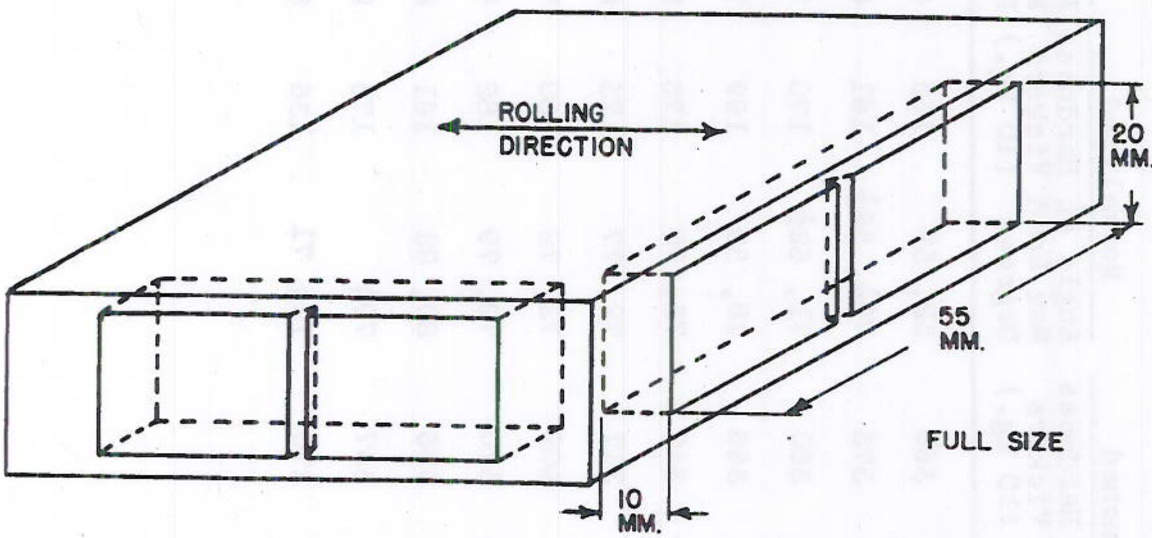
Steel No.	One Day			Three Days			Fourteen Days		
	Angle at Max. Load Degrees	Maximum Load Pounds	Type of Failure	Angle at Max. Load Degrees	Maximum Load Pounds	Type of Failure	Angle at Max. Load Degrees	Maximum Load Pounds	Type of Failure
314	57	15,850	2	58	16,000	2	67	15,600	2
	54	15,500	2	55	15,600	2	71	15,600	1
333	59	16,400	1	79	16,800	1	66	16,600	1
	59	17,250	1	65	17,100	1	55	16,400	1
334	54	16,700		69	17,300	2	73	17,200	1
	67	16,350	2	69	16,800	2	64	16,700	3
367	50	19,150	3	58	20,000	3	53	20,400	3
	61	20,750	3	57	20,150	3	49	18,600	3
391	64	17,350	2	65	17,400		67	17,000	0
	65	17,350	2	62	17,000	1	66	17,400	3
392	76	17,200	2	71	17,700	3	67	17,600	1
	81	17,800	2	Fillet on	upright	failed	68	17,500	1
393	67	17,000	2	60	16,600	2	60	16,600	3
	58	16,400	2	68	16,500	3	62	17,000	2
394	43	21,250	3	51	22,250	3	53	21,850	3
	37	20,750	3	45	21,750	3	47	21,500	3
395	62	17,500	3	65	17,500	3	62	17,500	3
	59	17,500	3	64	17,250	3	63	17,500	3
396	56	18,100	2	60	18,000	2	66	17,950	3
	50	17,700	2	59	18,000	2	52	17,250	2

TABLE IX MAXIMUM HARDNESS DATA

Steel No.	Max. Hard. Under Bead Weld-Knoop (500 gm)	Max. Hard. Under Bead Weld-Vickers (10 kg)	Hardness at .206 in. on Jominy Bar Vickers (10kg)	Max. Quench Hard. Vickers converted from Rockwell C	Per Cent Maximum Quench Hardness of Bead Welds	Fusion Line Grain Size		
						Left	Center	Right
314	358	279	315	495	56	2.6	3.7	2.2
333	334	283	308	495	57	2.6	3.5	2.3
334	358	299	306	485	62	2.9	4.1	3.2
367	316	287	394	470	61	2.6	3.4	3.4
391	338	294	279	470	63	2.9	4.1	1.9
392	300	292	288	445	66	3.2	2.2	2.2
393	348	314	328	470	67	2.6	3.5	2.2
394	316	322	314	470	69	4.3	4.4	3.6
395	316	268	295	445	60	2.9	4.3	2.7
396	316	284	327	485	59	2.8	3.8	3.7
420	225	207	258	553	37	3.3	6.7	2.9

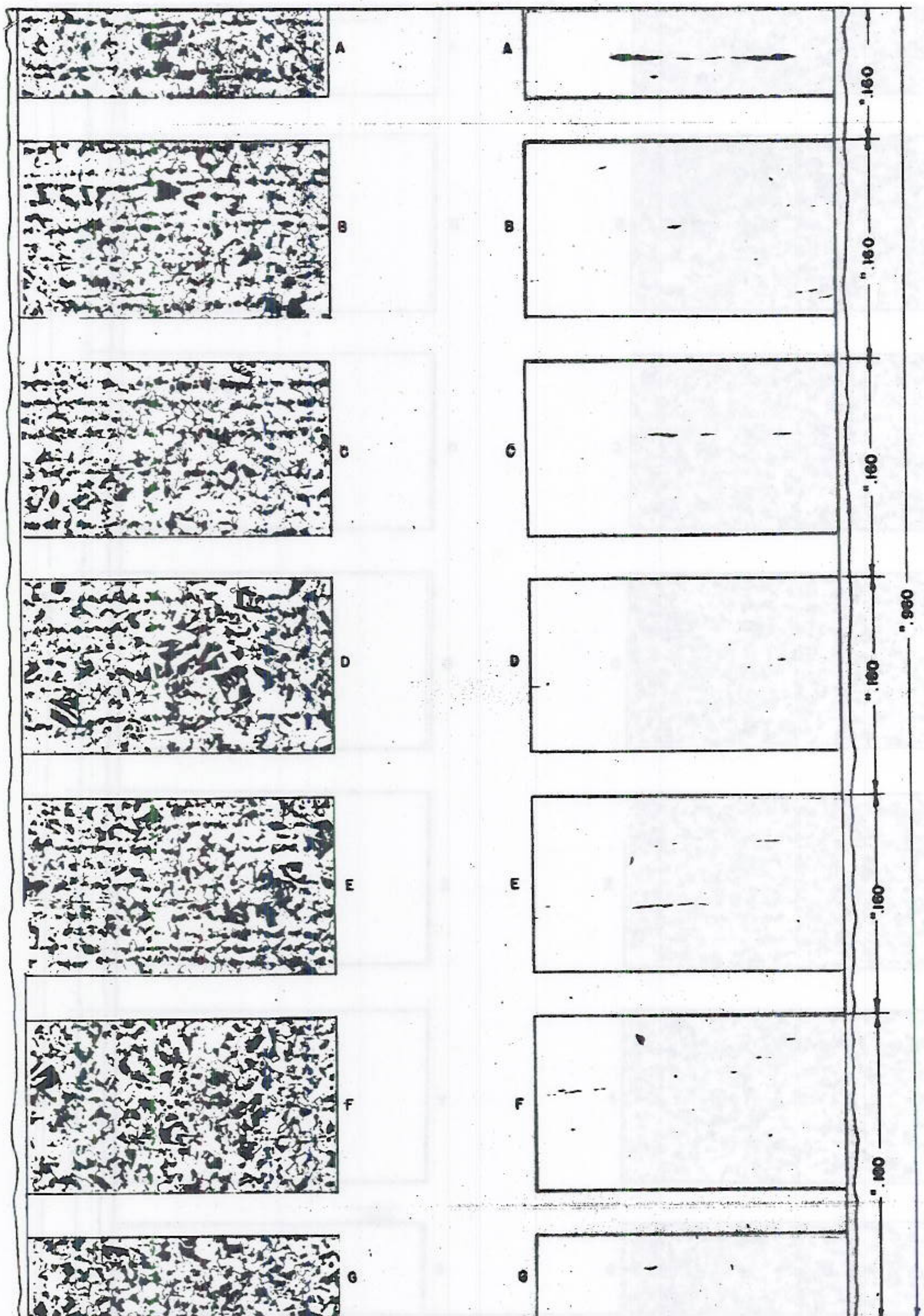
TABLE X CONTINUOUS COOL U-BEND DATA

Steel No.	Water Quenched		Oil Quenched		Normalized		Annealed		Estimated Angle at Max. Load for Bead Weld Max. Hard. Deg.
	Angle at Max. Load Degrees	Hardness Vickers (10 kg.)	Angle at Max. Load Degrees	Hardness Vickers (10 kg.)	Angle at Max. Load Degrees	Hardness Vickers (10 kg.)	Angle at Max. Load Degrees	Hardness Vickers (10 kg.)	
314	13, 15	429	7½, 10	366	52, 59	165	69, 74	136	30
333	16½, 16½	413	10½, 9½	373	70½, 58½	161	86, 87	138	34
334	15, 16½	421	10½, 8½	380	71, 62½	170	75, 85	120	34
367	13, 17	413	8, 12	366	48, 59	199	74, 95	146	34
391	17½, 17½	401	17½, 17½	342	72, 70	173	80½, 82	143	39
392	15, 15½	394	18	317	72, 77	173	87½	140	33
393	19½, 17	429	12, 12½	409	72, 72	180	78, 77½	142	37
394	16, 15	413	16½, 16½	370	72, 79	182	87, 85	146	38
395	10, 11	383	19½, 23	336	80, 82	161	86½, 87	131	43
396	17½. 16½	397	17	357	79½	173	88½	138	44
420	12, 9	333	12, 11	270	72½, 71	136	88, 85½	114	50



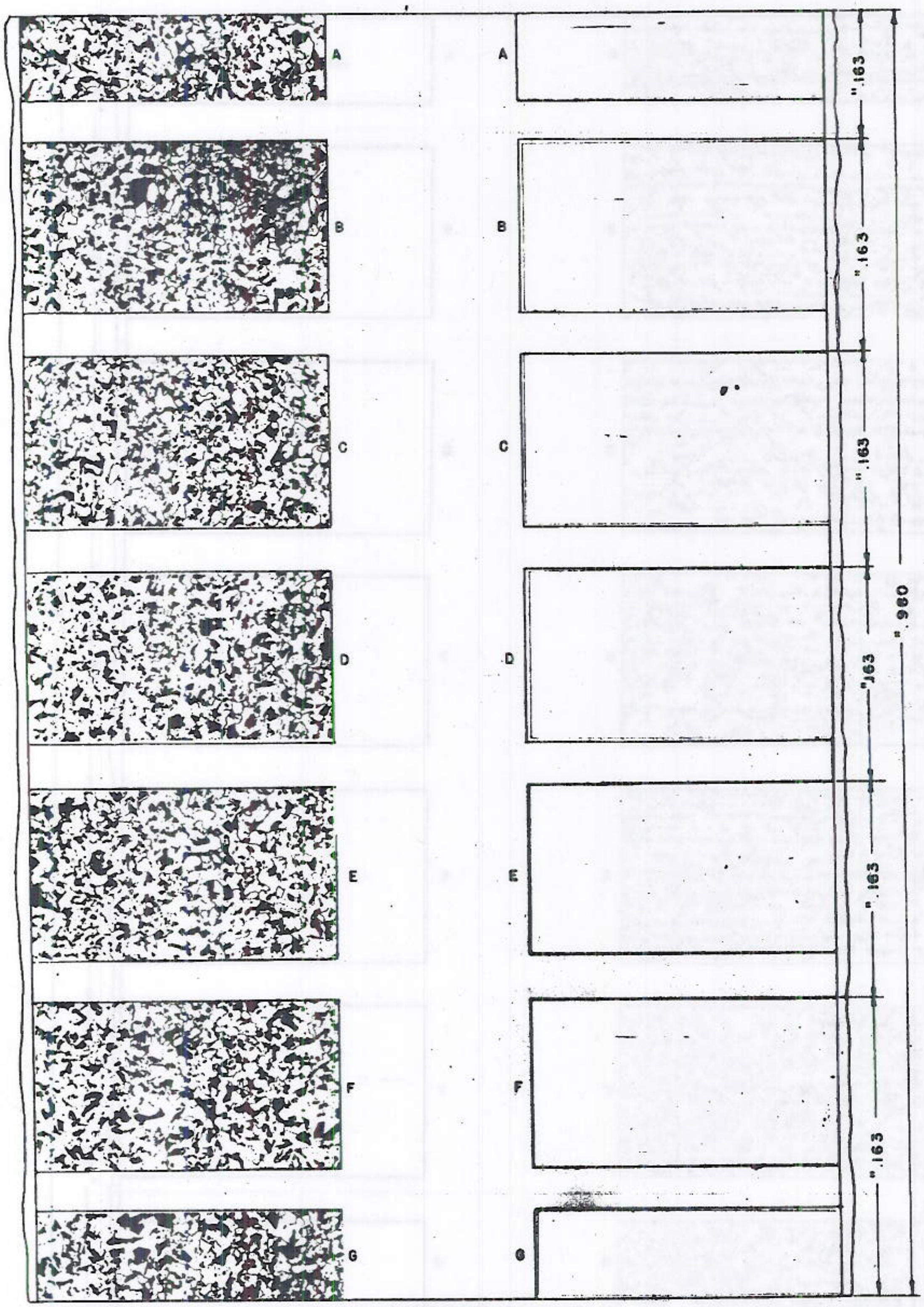
DOUBLE-WIDTH CHARPY IMPACT SPECIMENS

LONGITUDINAL AND TRANSVERSE; STANDARD 2 MM. DEPTH, 0.01" RADIUS V-NOTCH.



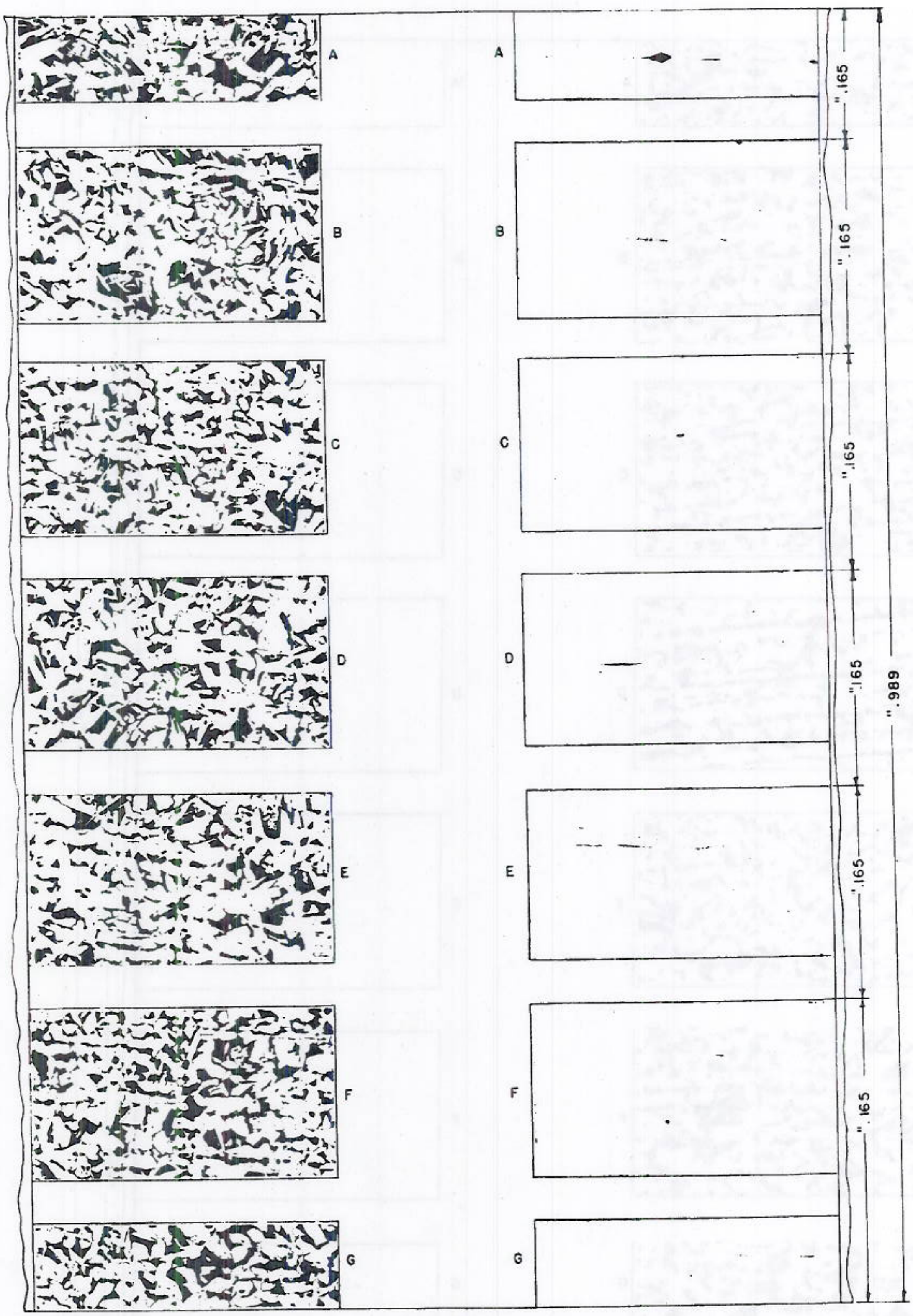
STEEL 314
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X

PLATE 2



STEEL 333
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X

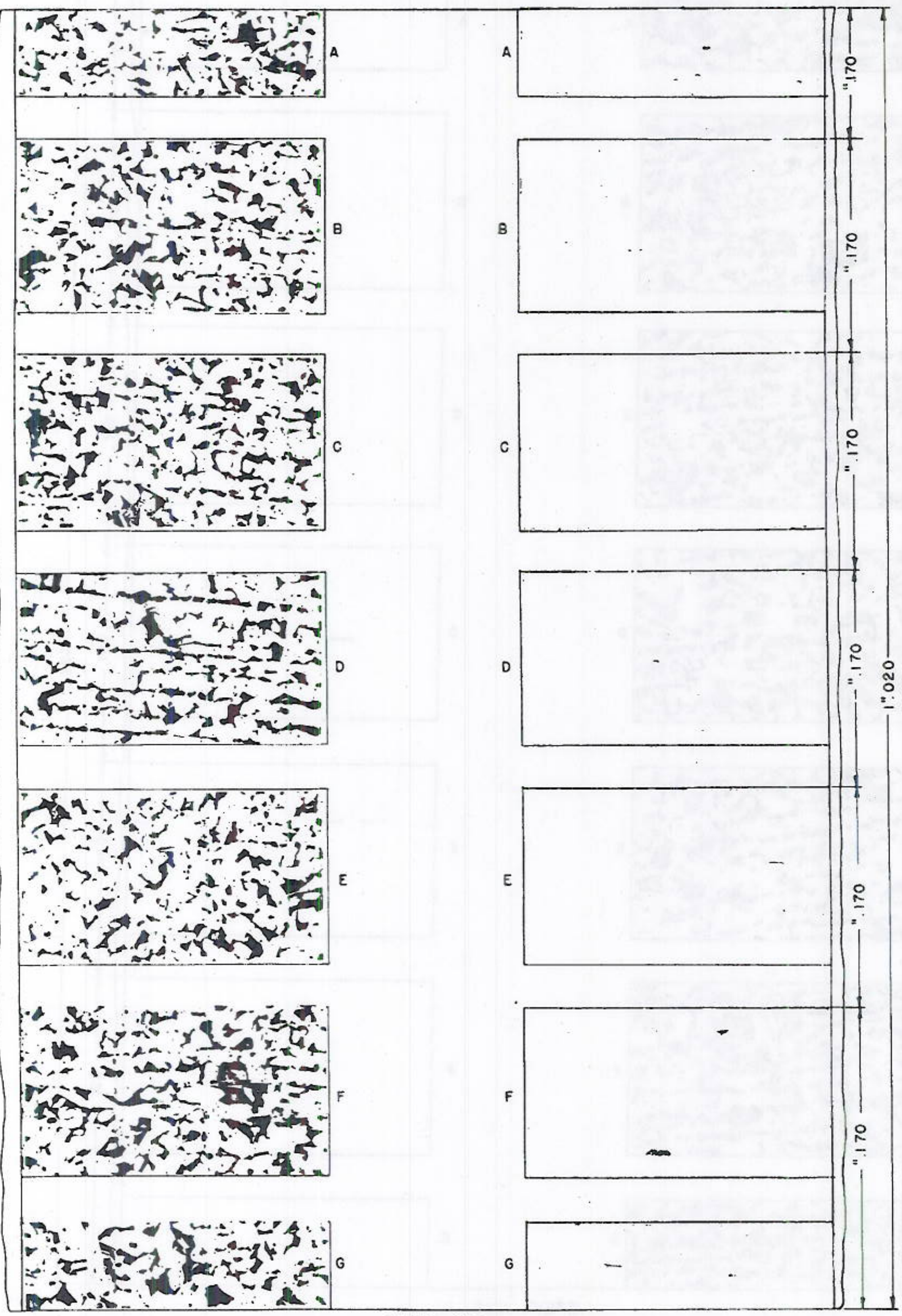
PLATE 3



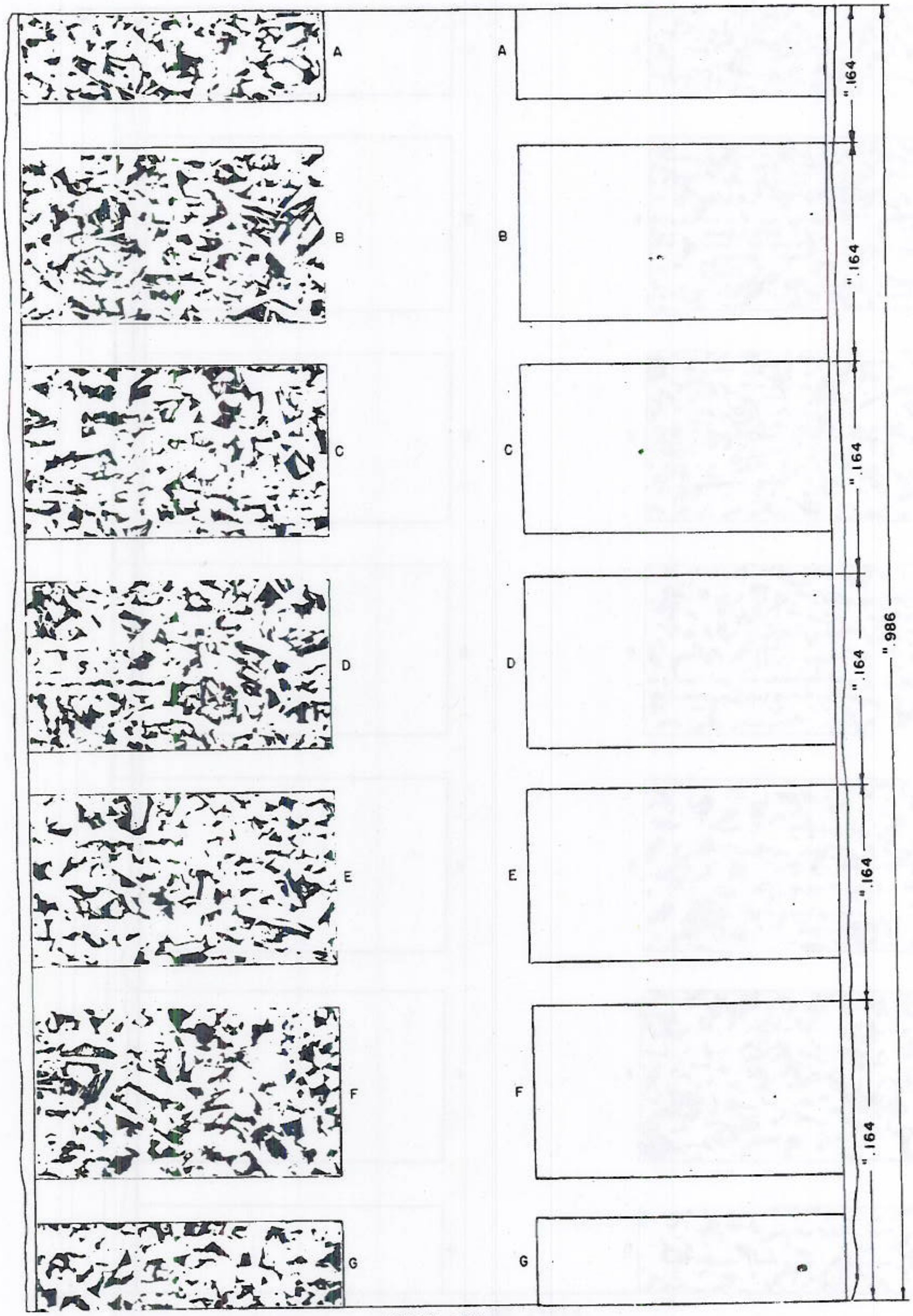
STEEL 334

STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X

PLATE 4

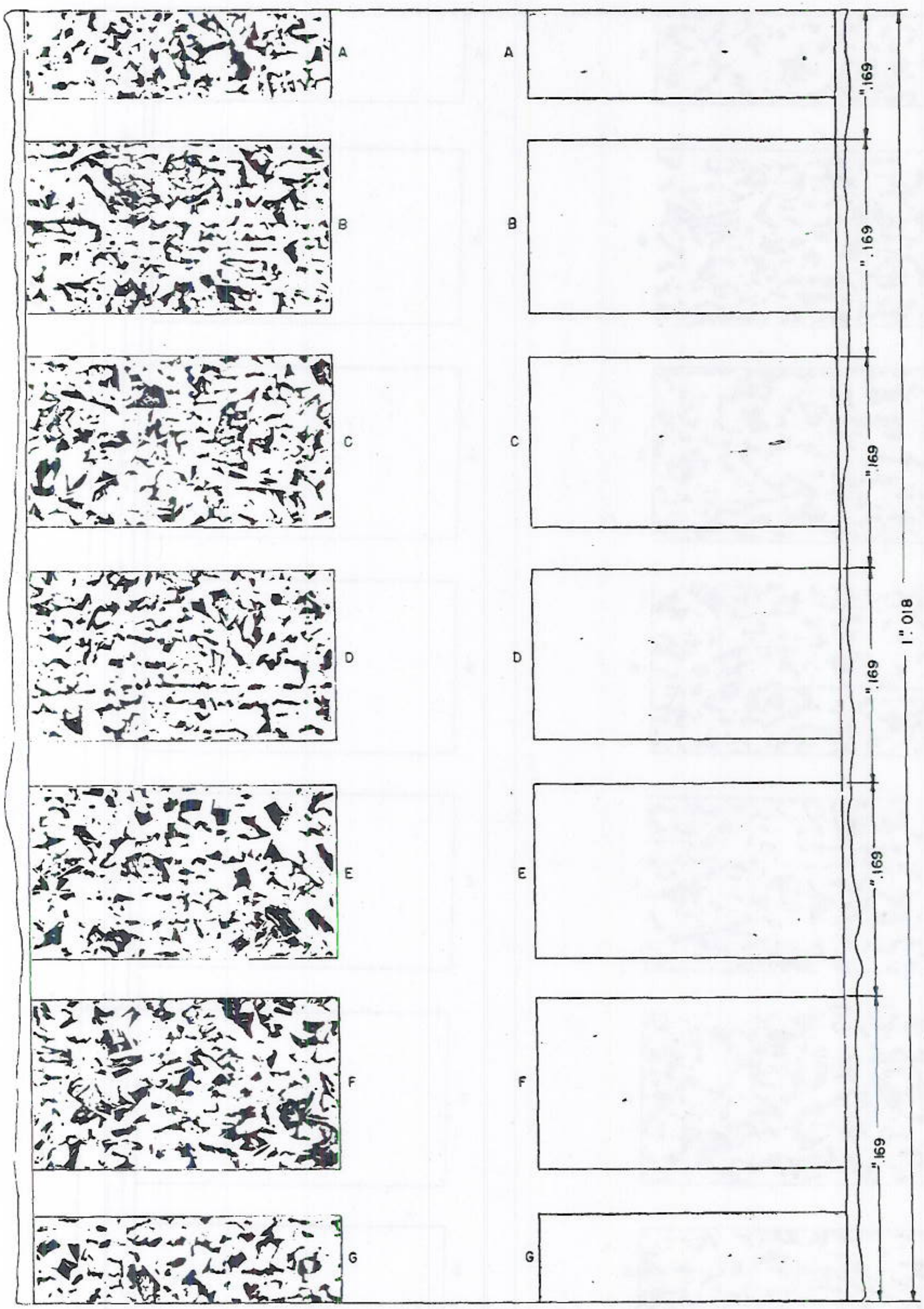


STEEL 367
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X



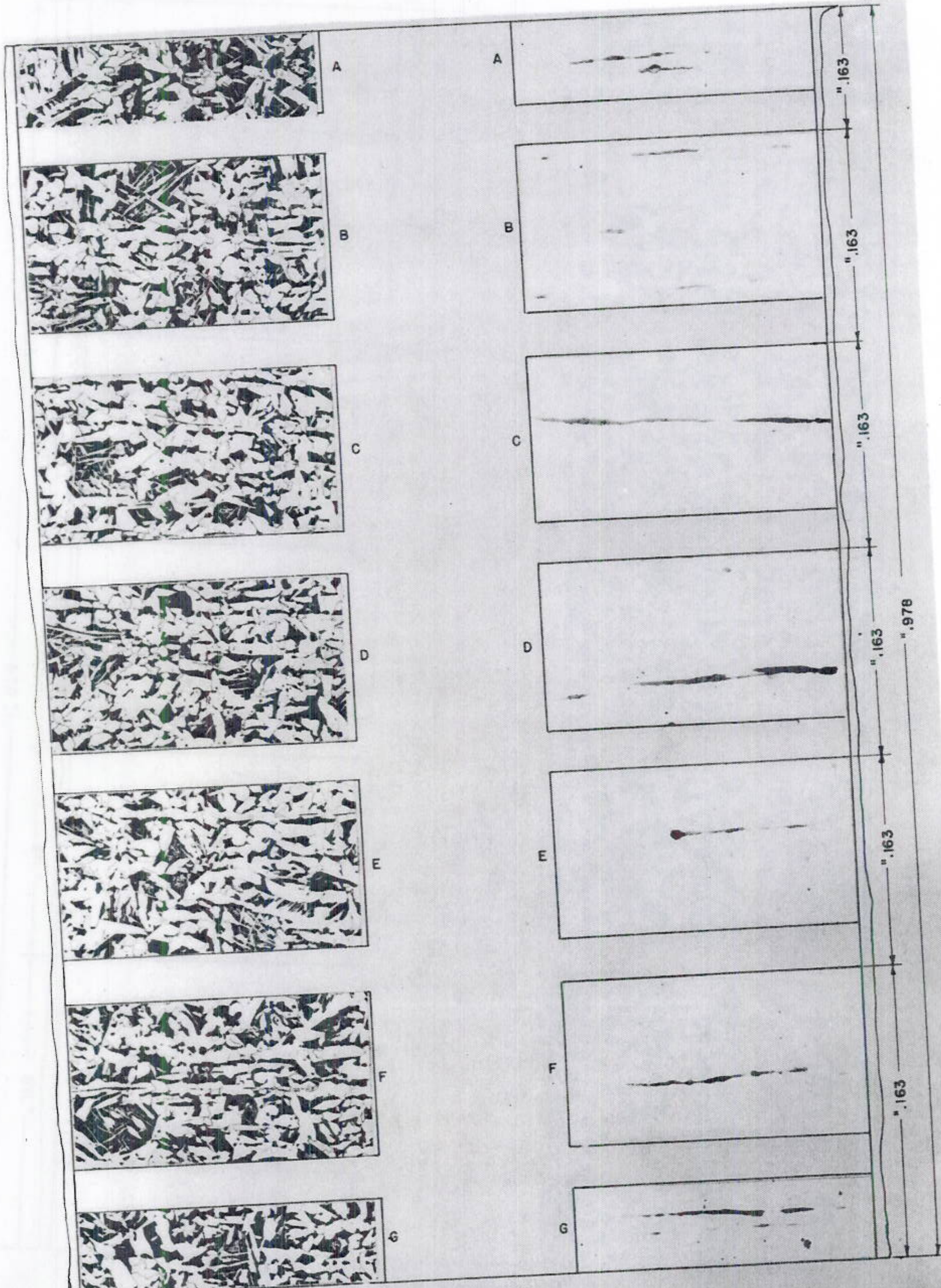
STEEL 391
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X

PLATE 6



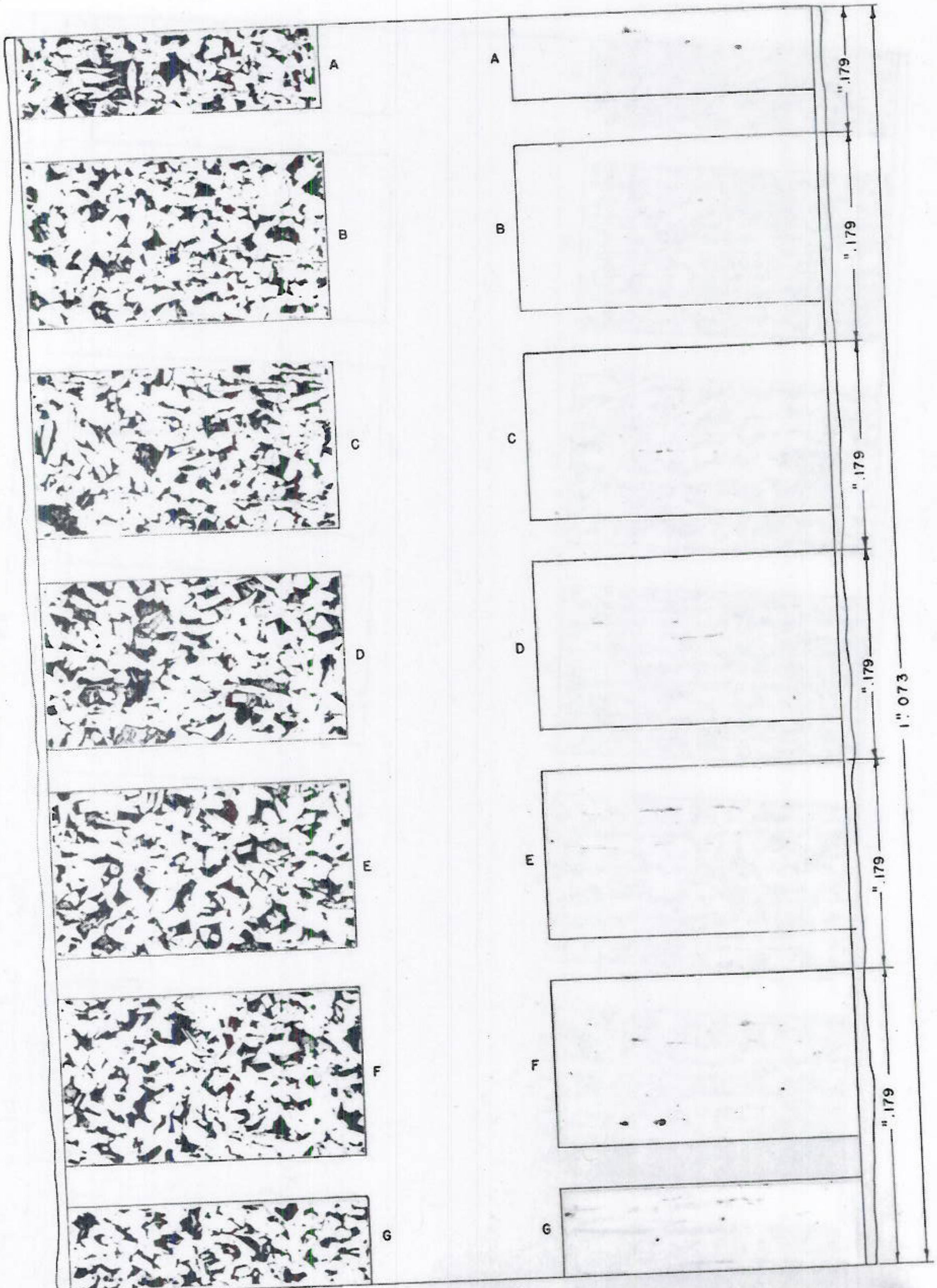
STEEL 392
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X

PLATE 7

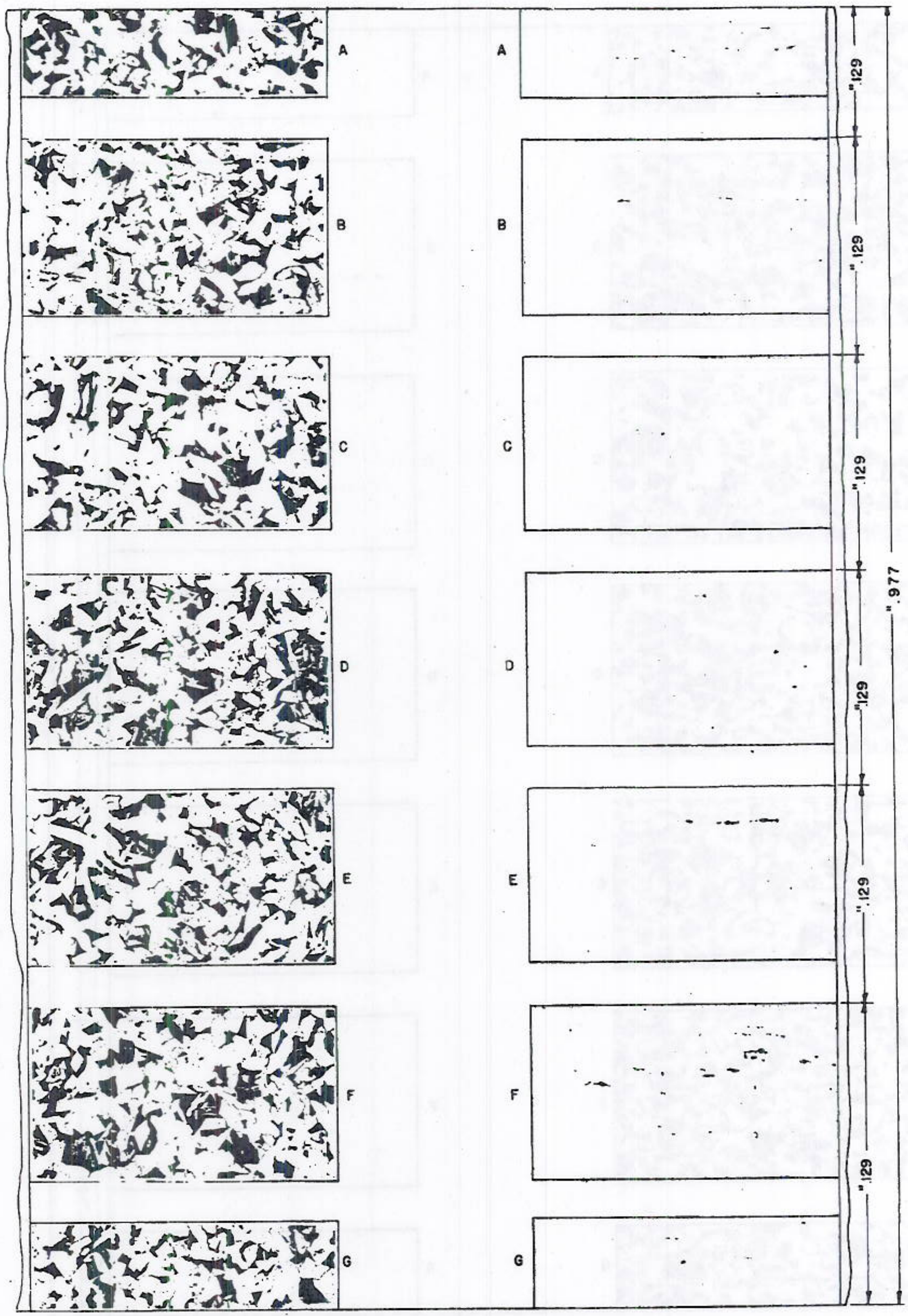


STEEL 393
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS

75 X

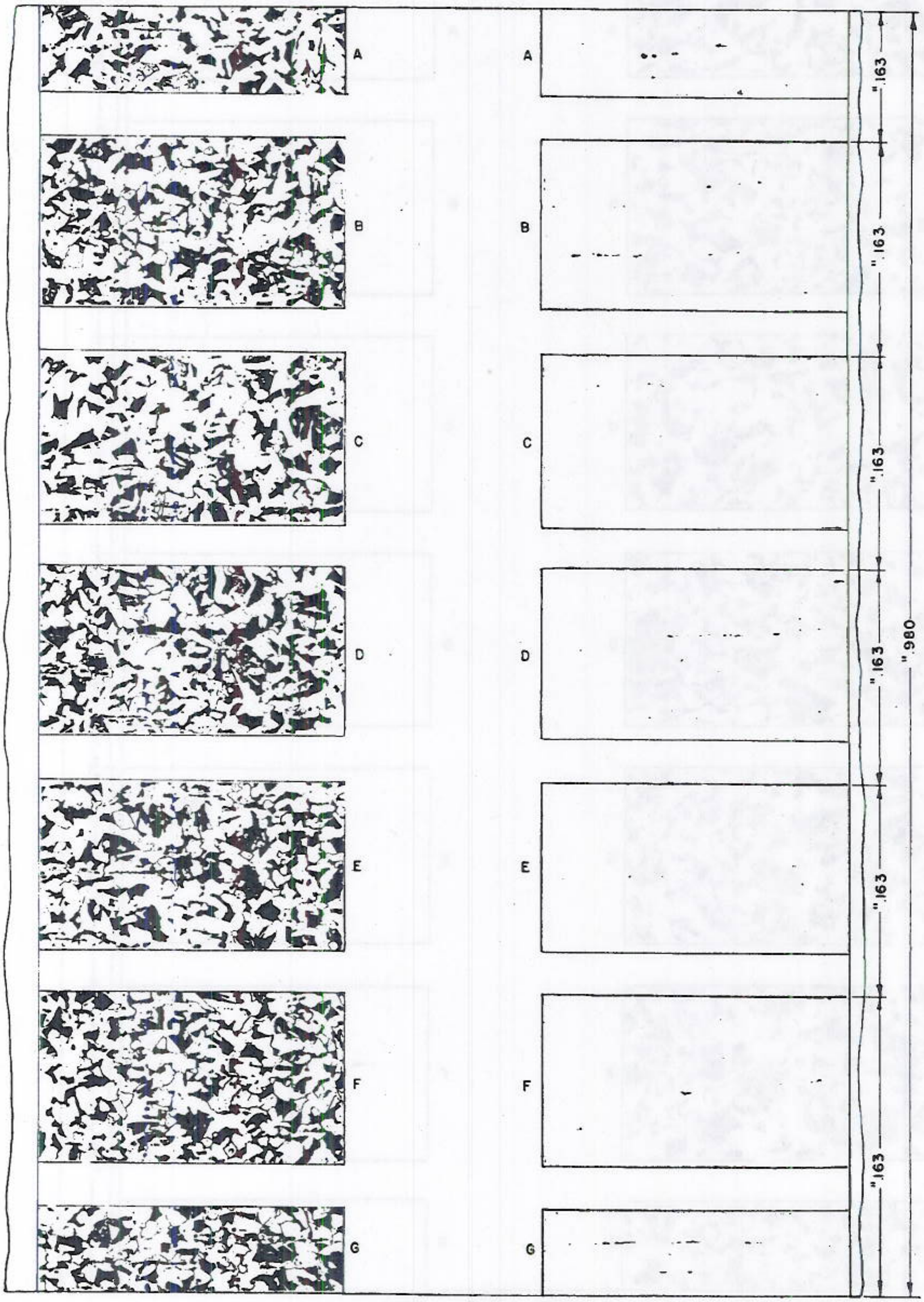


STEEL 394
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X



STEEL 395
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X

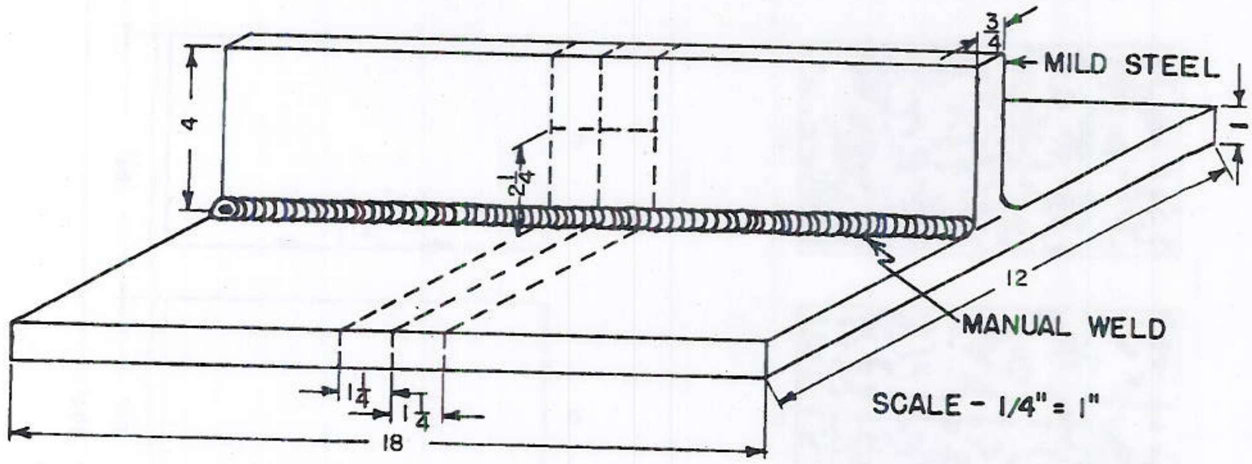
PLATE 10



STEEL 396
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75 X

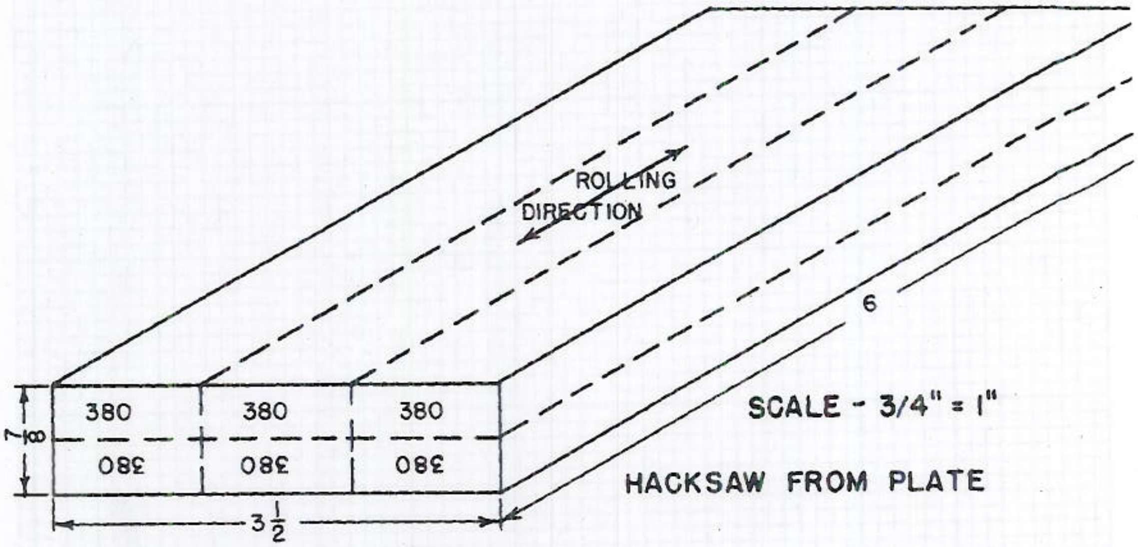
PLATE 11

STEEL 420
STRUCTURE AND INCLUSION STUDY
THROUGH THICKNESS
75X



WELDING TECHNIQUE - 175 AMPERES, 26 VOLTS, 4" INCREMENTS WITH 9-1/4" LENGTH OF 3/16" ELECTRODES.

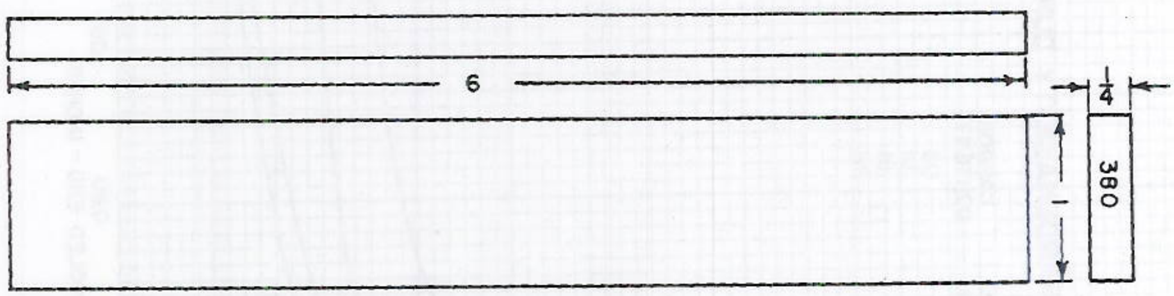
TEE - BEND TEST ASSEMBLY



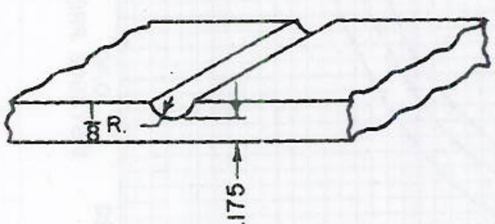
SCALE - 3/4" = 1"

HACKSAW FROM PLATE

SHAPE TO SIZE



FULL SIZE



HEAT TREAT BY COOLING FROM 2100°F.
GRIND NOTCH ON OUTSIDE SURFACE AND BEND USING 1" DIAMETER PLUNGER.
MEASURE ANGLE AT MAXIMUM LOAD.
MEASURE VICKERS HARDNESS OF EACH SPECIMEN.

CONTINUOUS COOL BARS SHOWING FINISHED DIMENSIONS AND LOCATION OF PIECES PRIOR TO MACHINING

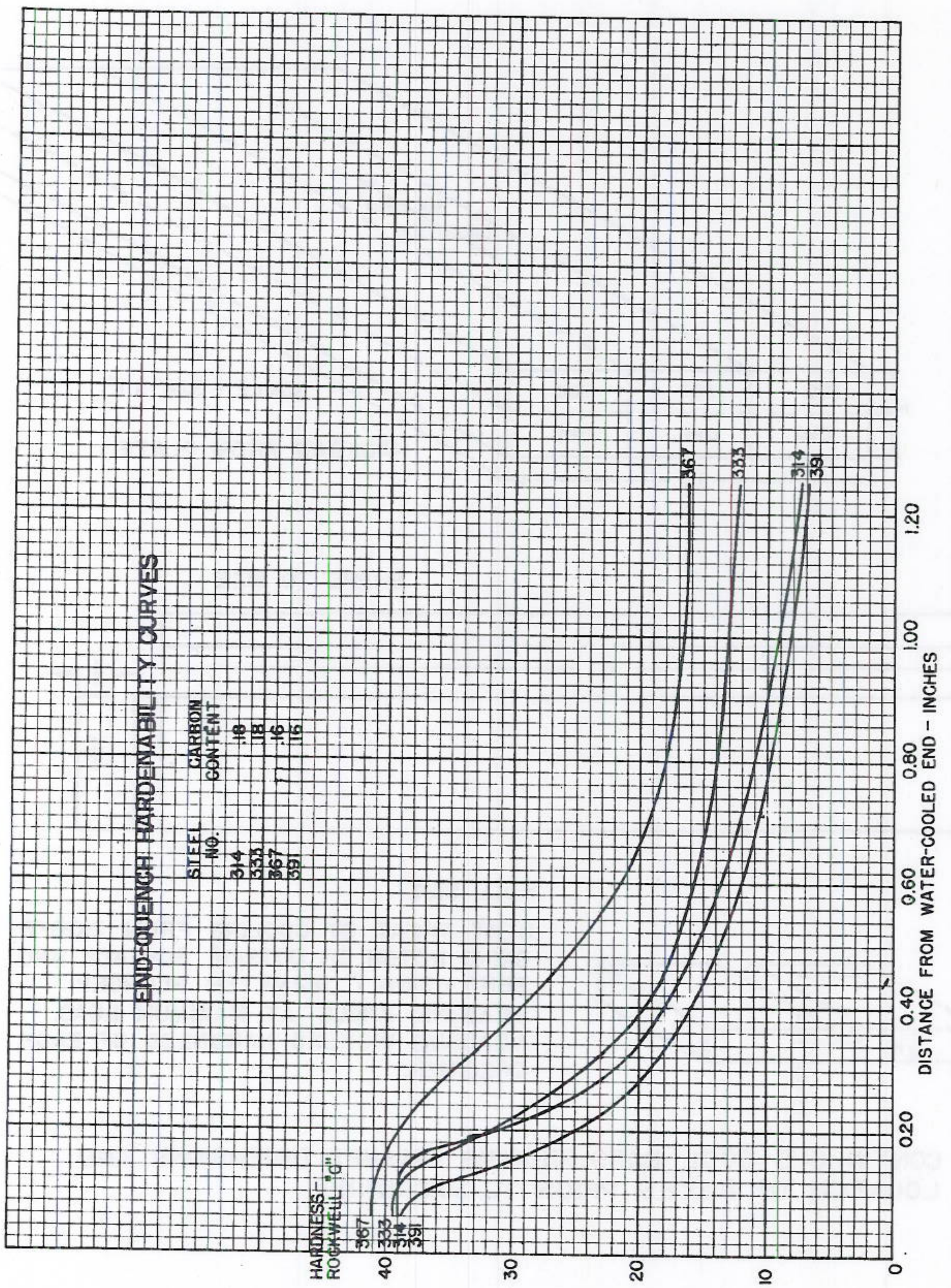

END-QUENCH HARDENABILITY CURVES
STEEL NO.
CARBON CONTENT
314 .18
333 .18
367 .16
391 .16
HARDNESS-ROCKWELL "C"
40
30
20
10
0
0.20
0.40
0.60
0.80
1.00
1.20
DISTANCE FROM WATER-COOLED END - INCHES
367
333
314
391

PLATE 17

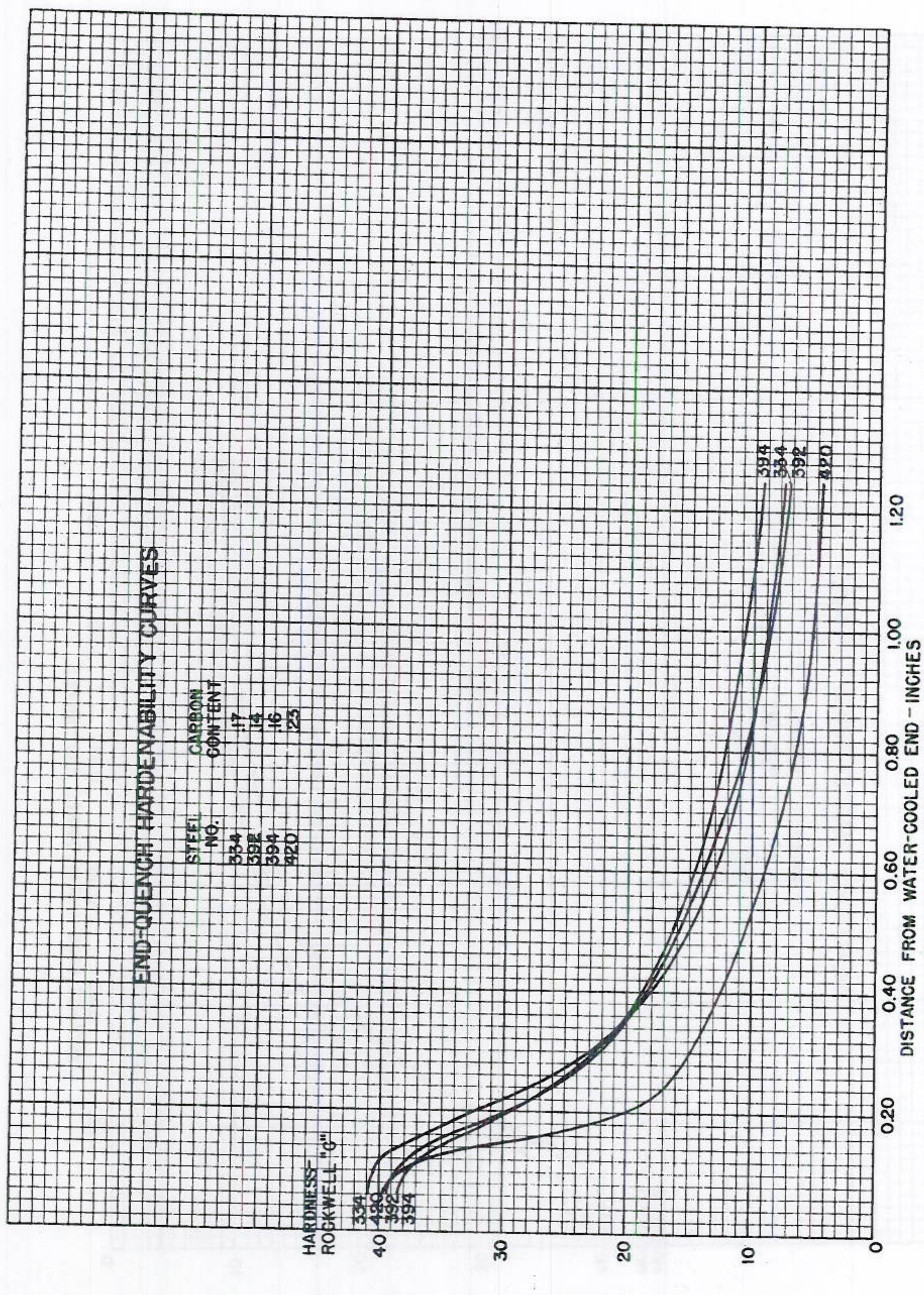

END-QUENCH HARDENABILITY CURVES
STEEL NO.
CARBON CONTENT
334 .17
392 .14
394 .16
420 .23
HARDNESS ROCKWELL "C"
40
30
20
10
0
0.20
0.40
0.60
0.80
1.00
1.20
DISTANCE FROM WATER-COOLED END - INCHES
334
420
392
394
394
334
392
420

PLATE 18

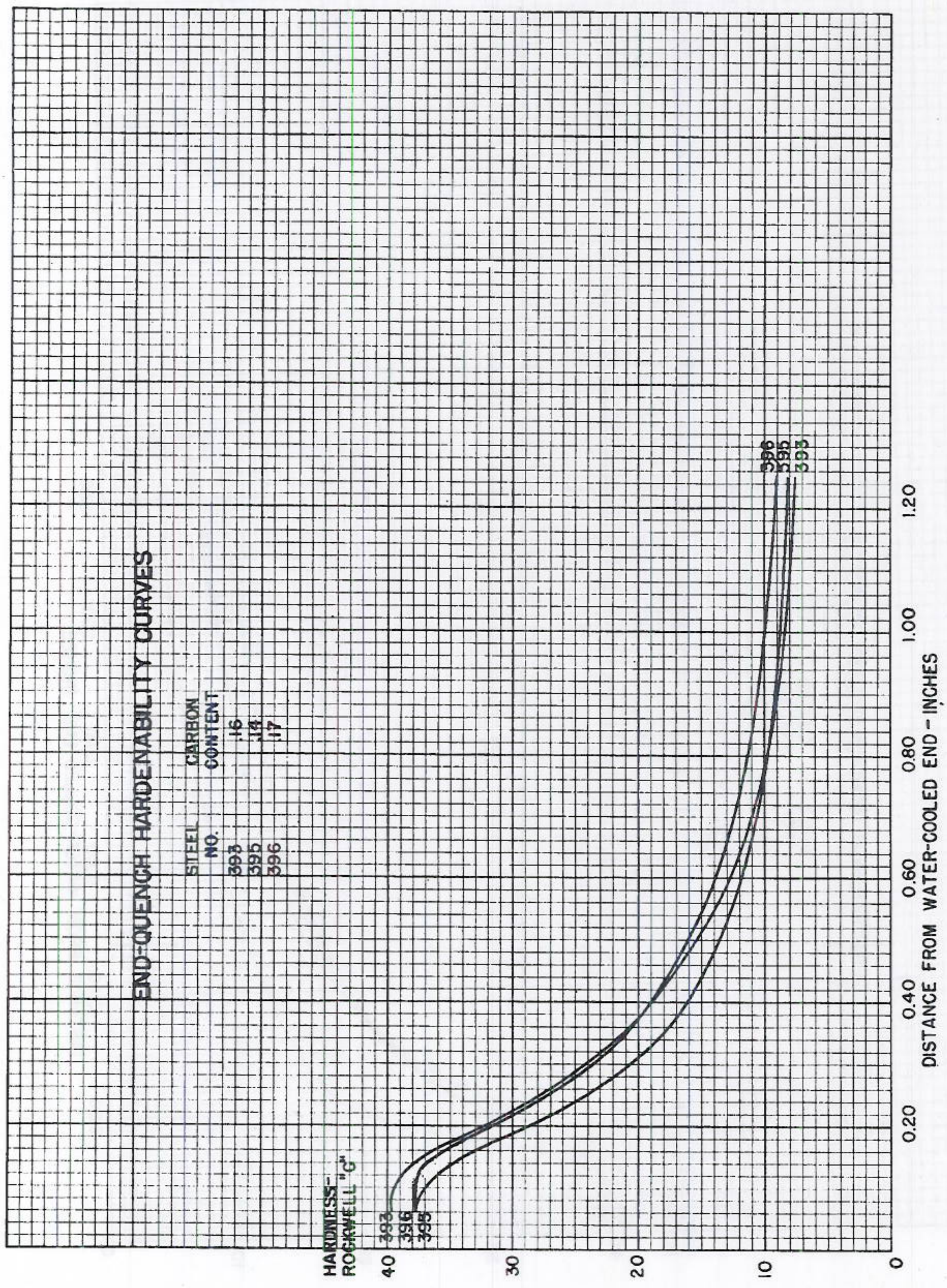
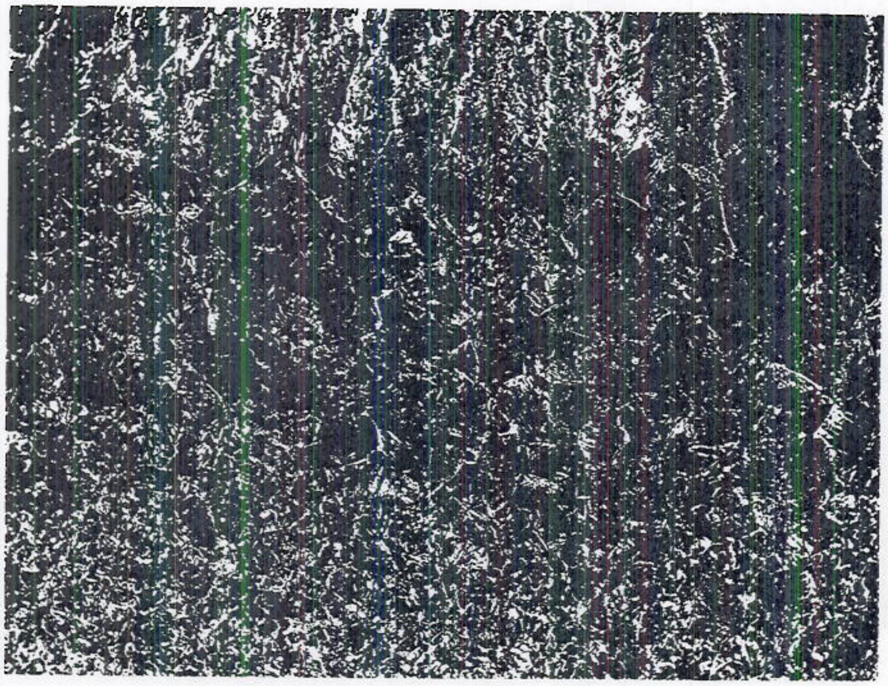

END-QUENCH HARDENABILITY CURVES
STEEL NO.
393
395
396
CARBON CONTENT
.16
.14
.17
HARDNESS-ROCKWELL "C"
40
30
20
10
0
0.20
0.40
0.60
0.80
1.00
1.20
DISTANCE FROM WATER-COOLED END - INCHES
393
396
395

PLATE 19

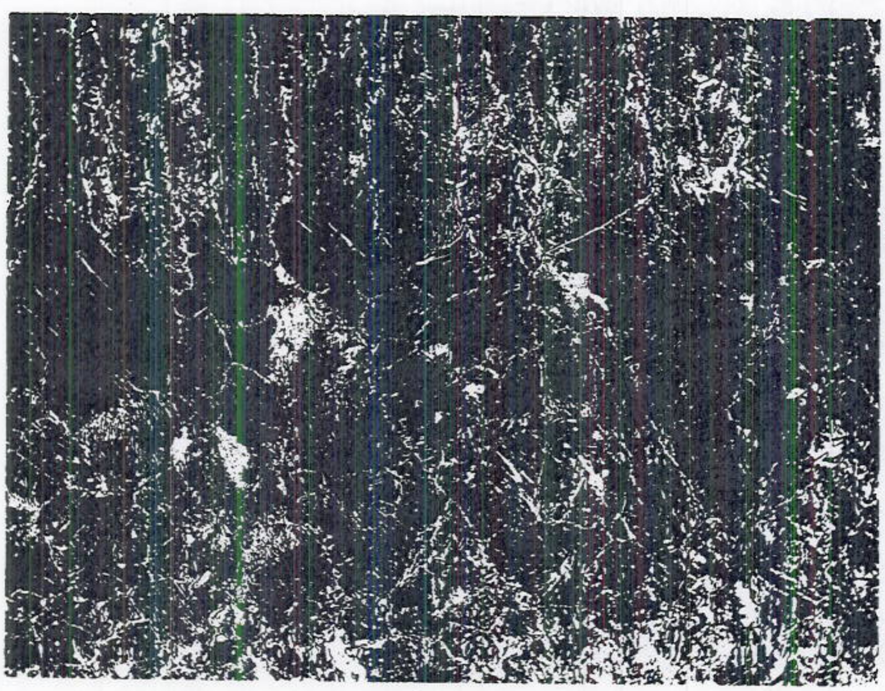
BEAD WELD MICROSTRUCTURES - 150X



WELD

HEAT-AFFECTED ZONE

STEEL 314

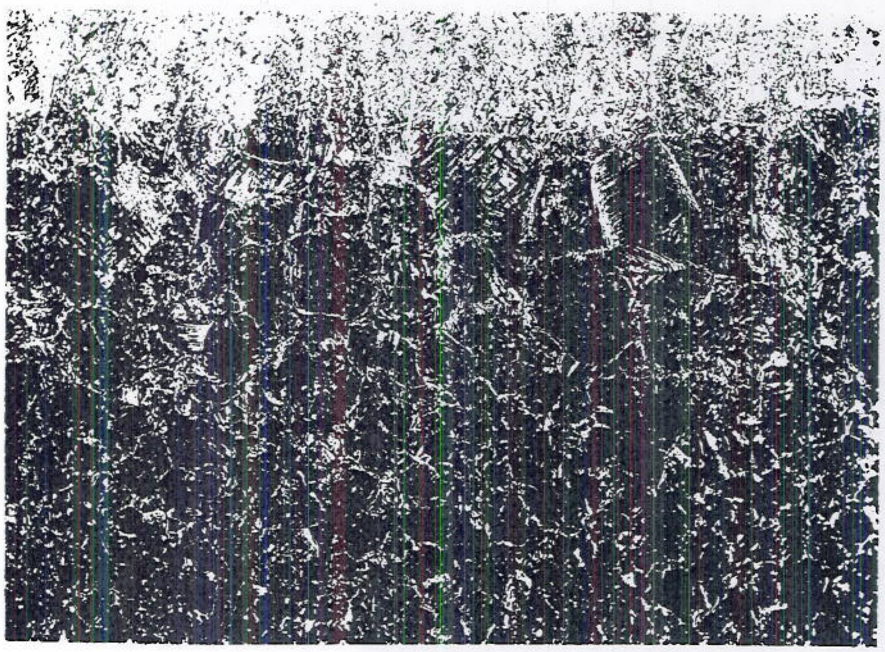


WELD

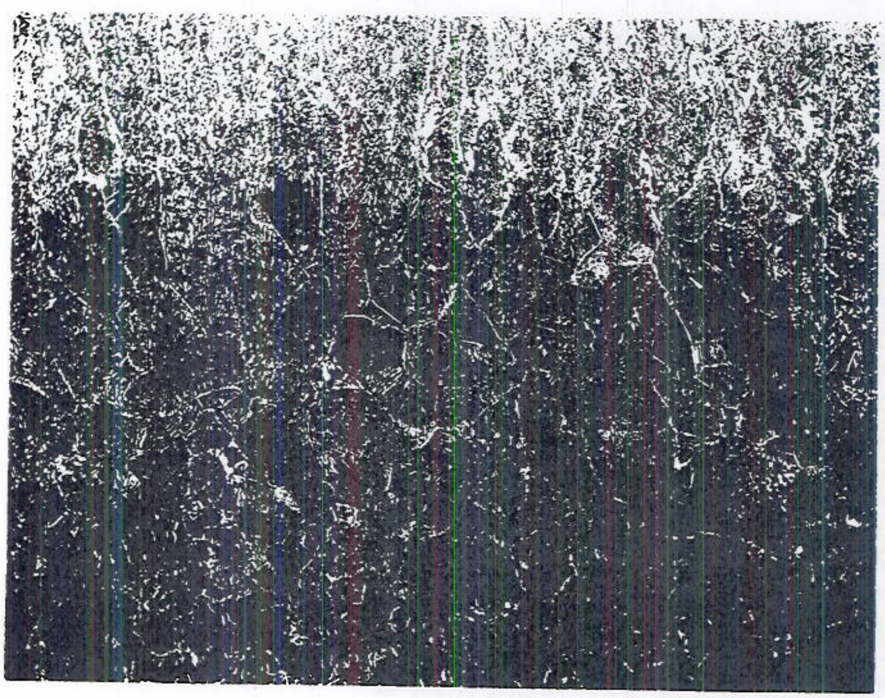
HEAT-AFFECTED ZONE

STEEL 333

BEAD WELD MICROSTRUCTURES - 150X

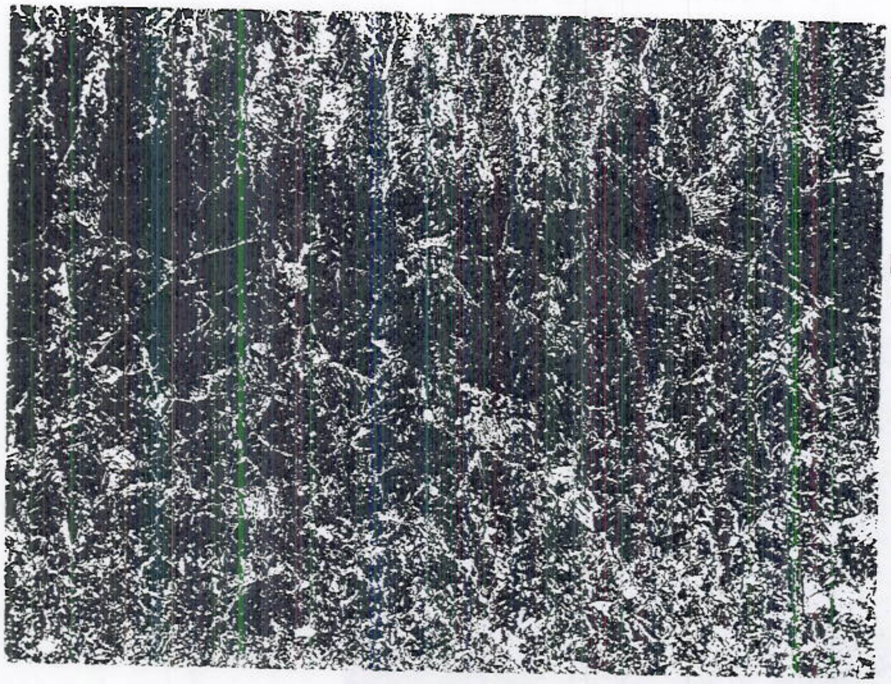


STEEL 334



STEEL 367

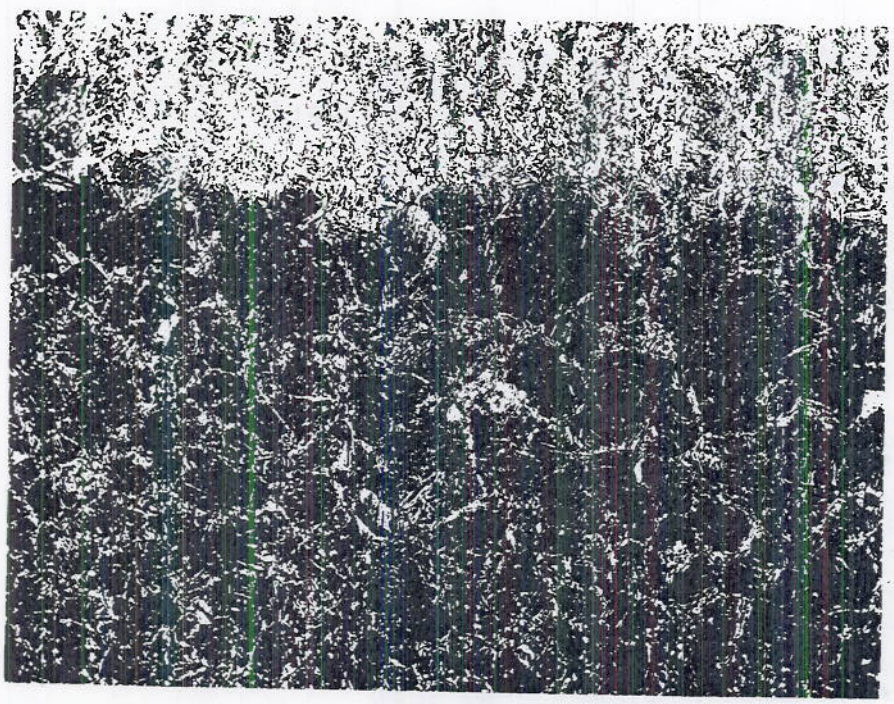
BEAD WELD MICROSTRUCTURES - 150X



WELD

HEAT-AFFECTED ZONE

STEEL 391

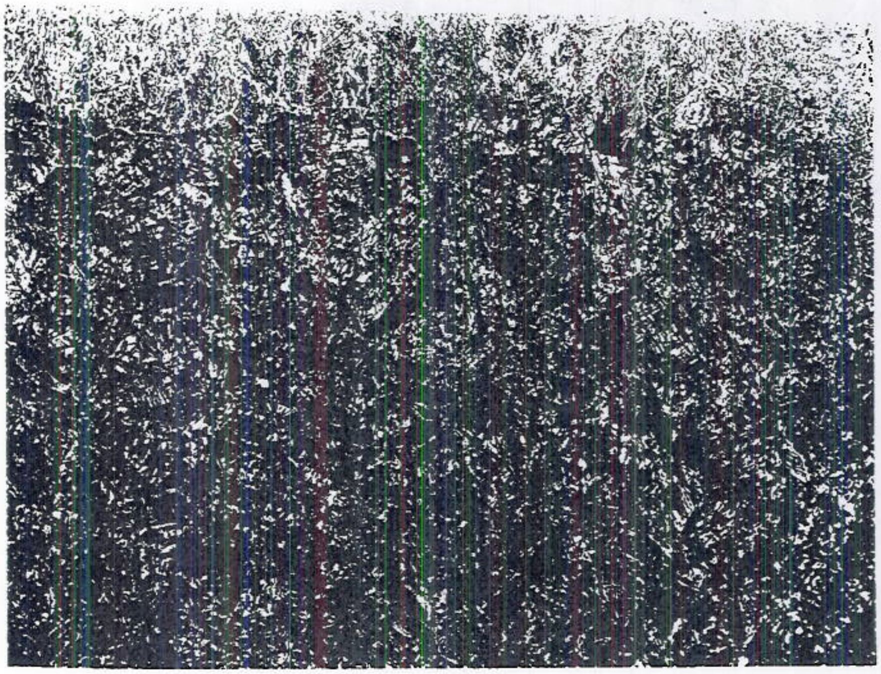


WELD

HEAT-AFFECTED ZONE

STEEL 392

BEAD WELD MICROSTRUCTURES-150X



WELD

HEAT-AFFECTED ZONE

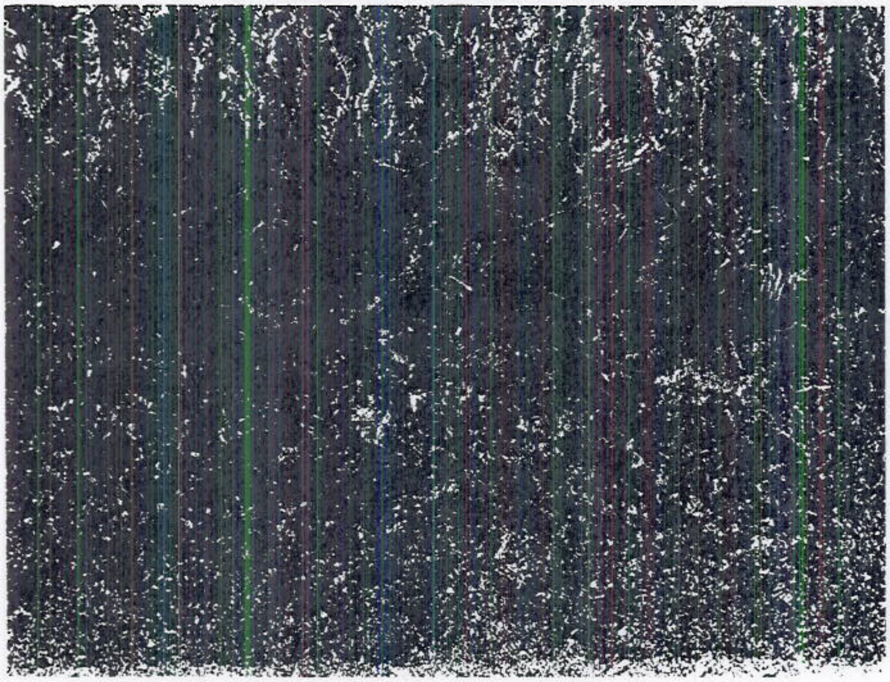
STEEL 393

WELD

HEAT-AFFECTED ZONE

STEEL 394

BEAD WELD MICROSTRUCTURES - 150X



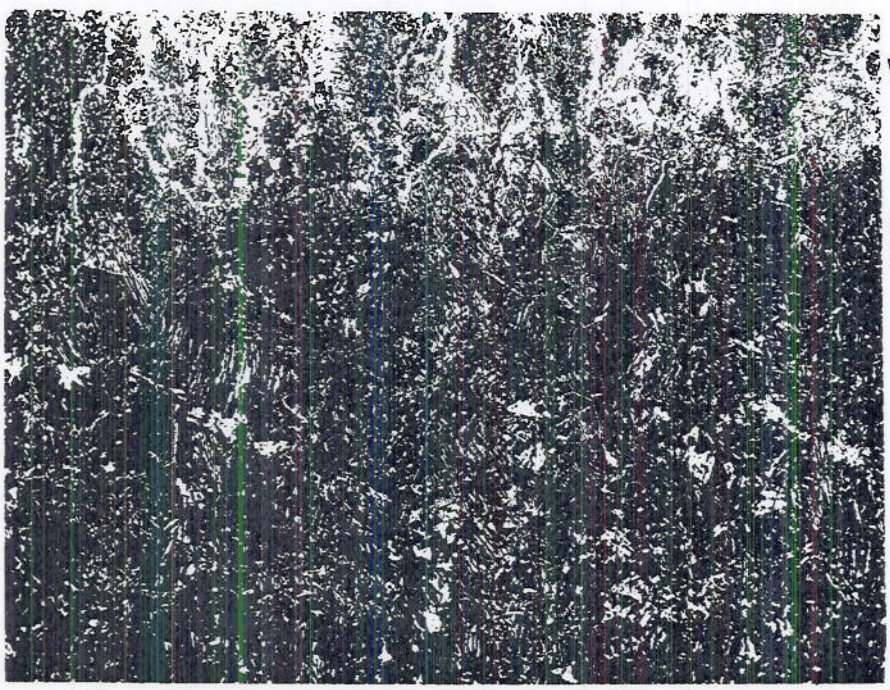
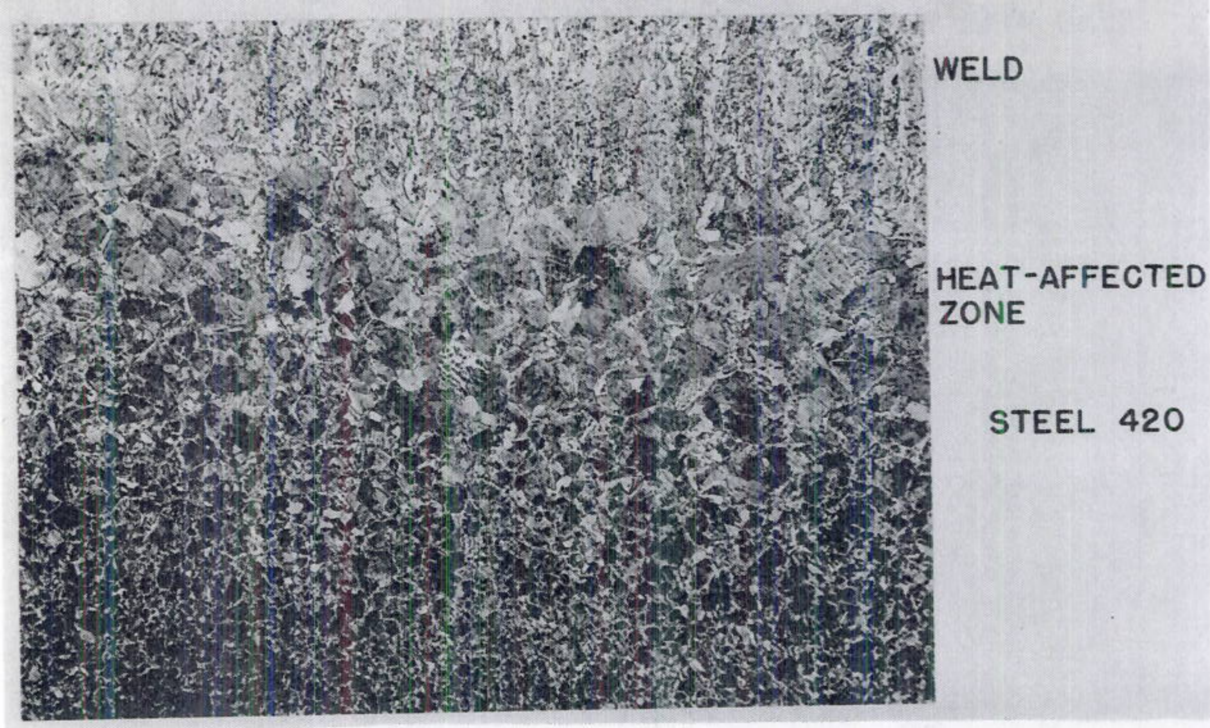
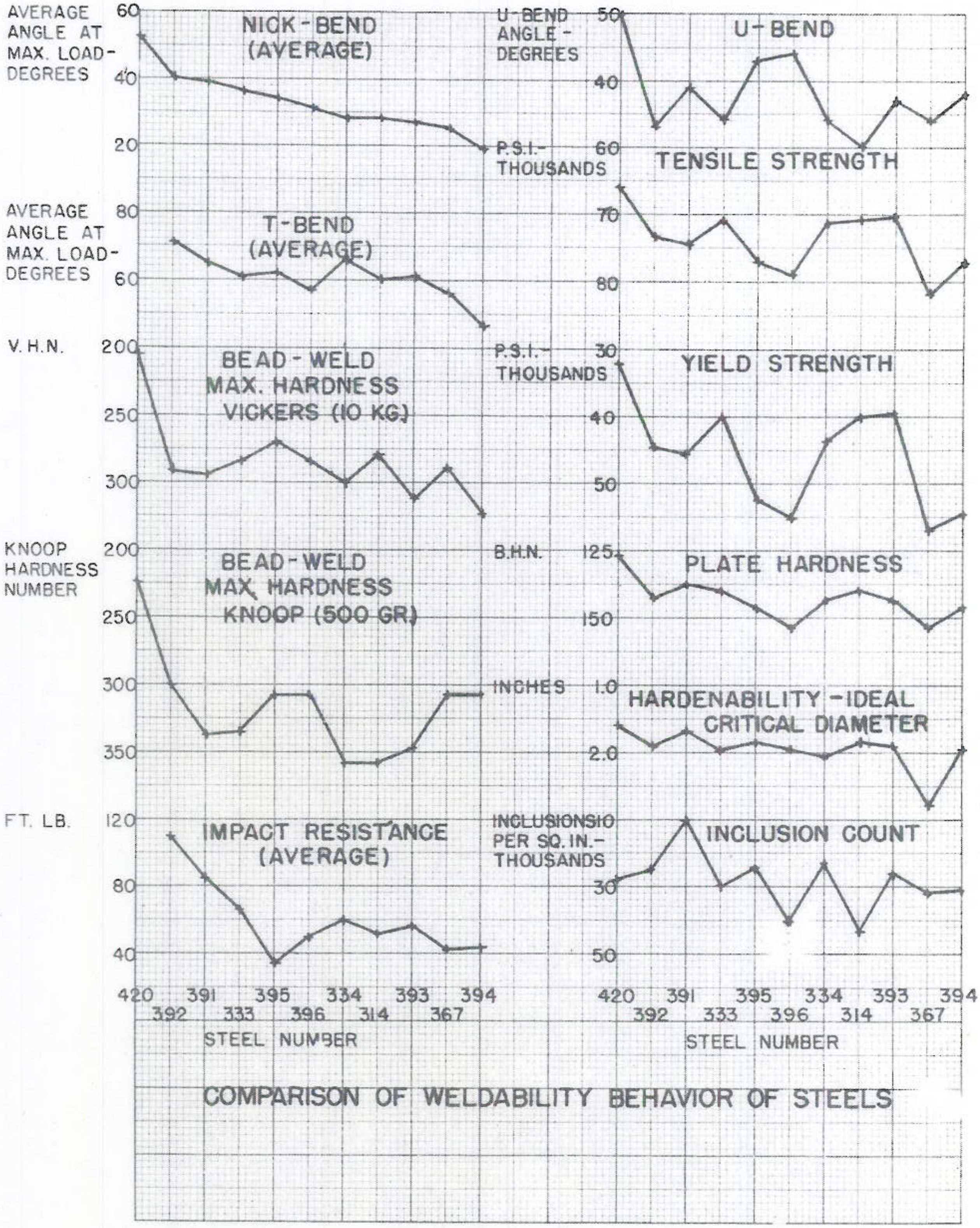


PLATE 24

BEAD WELD MICROSTRUCTURE - 150X





COMPARISON OF WELDABILITY BEHAVIOR OF STEELS

PLATE 20