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Second Partial Report

of

Research of the Weldability of Iron Alloys.

NAVAL RESEARCH LABORATORY
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ABSTRACT

Results are reported for hardness surveys on sections from single bead welds carried out on a large number of differing compositions of steel. A rational basis for evaluating the quench sensitivity (hardenability) of various grades of steel is indicated in the results obtained.

It is found that conditions existing in the high-temperature zone adjacent to a single bead fusion weld can be approximately duplicated by a special method of heating and quenching small specimens of the base metal. The maximum size of sample that can be used for reproducing the high temperature zone by the special heat treating methods is shown to be large enough to constitute a test bar for impact and cold bend tests.

AUTHORIZATION

1. This investigation was authorized by the following reference:

Reference (a). Eng.let.JJ46-1/L5(4-2-Ds) of 4 April 1935.

2. A first partial report (NRL Report M-1258) has previously (1 April 1936) been submitted in which the problem has been stated in detail and progress of the work discussed.

STATEMENT OF PROBLEM

3. The problem concerns an investigation of the physical and mechanical properties of the transition or heat-disturbed zone of parent metal next to the weld bead. The weldability of the parent metal is defined for the problem as the quench sensitivity (hardenability) and grain growth susceptibility as they affect the mechanical properties.

KNOWN FACTS BEARING ON THE PROBLEM

4. From the research reported in NRL Report M-1258, it was indicated that heat treatment at 1400°C. of samples of parent metal to reproduce maximum transition zone grain size would require special methods of conducting heat to the sample and samples of small mass.

5. The report indicated that a higher rate of heating of the samples to 1400°C. would probably result from a more rapid conduction of heat and would be obtained by heating the samples in a small drilled hole in a block of steel maintained at 1400°C. Another factor which was in doubt was the maximum cross section for a definite mass which could be heated uniformly through the section to 1400°C. for a time interval of sufficiently short duration to prevent excessive grain growth beyond that for the largest grain in the transition zone. The ultimate aim was to choose such a cross section that the mass would constitute a large enough sample to test for impact and cold bend and at the same time would duplicate the material of the transition zone.

METHODS AND MATERIALS

6. The series of steels for which approximate analyses were given in Report M-1258 have been analyzed at the laboratory and are given below. The analyses given below indicate that the series are not ideal in that the various chemical contents are not entirely constant while one of the elements is varied. The micro-structures of the materials in the as received condition are included below. For item 29 the coarse grain structure at the outer edges of the plate and the finer grain at the center are shown. For items 33 and 34 a magnification of 250X was required. Item 37 appears to be a duplicate of item 35 and will be re-identified as an additional bar of this item. It will be noted that items 4, 35, and 36 have not yet been included in welding tests due to material not having been received in time.

* Indicates analysis is approximate
and has not been completed.

CHEMICAL ANALYSES

Item	C	Mn	Si	Ni	Cu	Mo	V	Cr	Grade of Steel	As Received Condition
1	.17	.41	.17						(Plain carbon --	Hot rolled.
2	.25	.43	.20						(Killed heat.	
4	.44	.65	.24						(	
5	.21	.38	.003						(Plain carbon --	Hot rolled.
6	.27	.47	.0002-.002						(Rimmed heat.	
9	.24	.48	.23						(Manganese	Hot rolled.
10	.27	.74	.21						(Series.	
11	.29	1.06	.25							
13	.26	.46	.005						(Silicon	Hot rolled.
14	.28	.54	.058						(Series.	
15	.25	.43	.20							
17	.22	.52	.20			.19			(Molybdenum	Hot rolled.
18	.22	.47	.18			.50			(Series.	
19	.20	.50	.17			.79				
20	.24	.46	.0001						(Boiler	Hot rolled.
21	.25	.43	.19						(steels.	
22	.18	1.40	.21				.12		V Steel.	Hot rolled.
23	.15	.44	.20		.75	.17			Cu Mo Steel.	Hot rolled.
24	.28	.56	.27	3.57					Nickel Steel.	Hot rolled.
27	.06	.35	.002	1.95	.94				(Yoloy Steels.	Hot rolled.
28	.21	.70	.27	1.97	1.08				(	
29	.028	.19		2.08					Nickel iron.	Hot rolled.

CHEMICAL ANALYSES (cont'd)

Item	C	Mn	Si	Ni	Cu	Mo	V	Cr	Grade of Steel	As Received Condition
30	.09	.72	.047	.96	1.34	.11			(RDS Steel.	Normalized.
31	.24	.74	.012	.76	1.48	.16			(	
32	.12	.75	.48					.34	Cromansil	Hot rolled.
33	.11		.19			.51		5.85	(Low Cr-Mo	Annealed.
34	.065		.22	.55 Cb		.51		5.66	(Steels	
35	.27	.69	.20	2.31					Nickel Steel.	Hot rolled.
36	.27	.69	.21	2.5*					1-7/8" Nickel Steel.	Hot rolled.
37	.28	.68	.20	2.5*					Nickel Steel.	Hot rolled.

7. A 100 pound lot of Airco #78 heavy coated 3/16" welding rod was purchased for conducting welding tests on the steels shown above.

8. The Vickers-type hardness testing machine for making hardness surveys of the transition zone has been received at the Laboratory and all hardness tests reported in this and subsequent reports will be given in terms of the hardness obtained with the new machine.

9. The semi-automatic welding machine described in report M-1258 was employed for performing the single bead welds reported here.

WELDING TESTS

10. The items of steel given above were cut to form plates approximately 6" x 3" x 1/2" thick and were welded at a speed of 6 inches a minute using 180-190 amperes at 25-27 volts. A half inch section was cut from each plate transverse to the bead at a distance of 1/2" beyond the middle of the plate toward the crater where the weld was completed. The plates were clamped to the table on one side of the weld only, in order to prevent restraint during the heat cycle of the welding operation.

11. The 1/2" sections taken from each plate were prepared as for micro-examination by polishing, then etching with a 1% or 5% Nital solution as required. The hardness survey was then made by indentation with a 10 kilogram load at a distance of .05" below the top of the plate and at intervals of .02" in the transition zone. Outside of the transition zone indents were made at intervals of .05". The first indent in the transition zone was made immediately adjacent to the weld bead and could be exactly placed by preparing the machine beforehand. The choice of the conditions for the progressive survey of hardness across the weld transition zone was made after a series of tests had been made with 5 and 10 Kg loads at intervals of .01" and .005" apart in the transition zone and at intervals of .01" to .05" down from the face of the welded plate. It was found that consistent results could be obtained when the indents were made with the 10 Kg load spaced at intervals of .02" in the transition zone and .04" to .05" down from the face of the welded plate. In fact, for steels of considerable hardenability the indents could have been easily read if spaced at .01" intervals in the transition zone. In all of the tests, both diameters of the indents were read and averaged.

WELD QUENCH TESTS

12. A large block of steel was obtained by cutting a section from an 8" shaft and was provided with a 3/8" drilled hole in which the samples were placed for heating to 1400°C. Another 3/8" hole provided a means of determining the block temperature with a Pt-PtRh thermocouple. Another thermocouple was placed in the graphite-resistance furnace itself in order to observe the temperature gradient on heating up and to determine when equilibrium conditions had been established between the furnace and the block.

13. For the quench tests only two steels, items #1 and #2, were used. This was in order to determine standard conditions for mass and thickness of the samples, and time at temperature to duplicate maximum grain size next to the weld bead and maximum hardness. For this purpose rods of these two items were prepared in sizes of 1/2" and 1/4" round. The rods were then cut into a series of samples 1/2", 3/4" and 3" long for each of the two different diameters and for each of the items. Each sample was provided with a drilled and tapped hole less than 1/8" deep into which was threaded a 1/8" steel rod thus providing a means for introducing the samples into, and removing them from the furnace. The time for which the samples remained in the furnace at 1400°C varied from 15 seconds to 1-1/2 minutes for the 1/2" and 3/4" long samples and for the 3" long samples from 45 seconds to 2 minutes.

14. The effect of preheating the samples to 600°C on the rate of heating at 1400°C was also determined for a few of the samples. For this test a furnace, just in front of the furnace at 1400°C, was maintained at 600°C where the samples were heated to preheating temperature and quickly transferred to the furnace at 1400°C.

DATA OBTAINED

15. Table 1 gives the summary of results obtained in the hardness survey of the weld sections cut from the 6" x 3" plates. The results are also shown in Plates 6 and 7 where the reproducibility of welding conditions is indicated in curves for items 10 and 23 which were welded in duplicate. The maximum hardness is indicated in each curve by the vertical line and the parent metal hardness by the horizontal line (numerical values given above and below the horizontal line in each curve).

16. Grain size data have been obtained for welds of items 1 and 2 (shown in table 2) for the largest grains observed for one cross section of the weld immediately adjacent to the weld bead. The method of obtaining this data consisted of tracing the largest grains at 100 X magnification on transparent paper and measuring the area of each grain with a planimeter. Grain size determinations are in progress for the other welds and will be reported when available.

17. Grain size of some of the weld quench samples has been determined and is reported in Table No. 2, together with the hardness of the samples. For the quenched samples of item #1 it was difficult, and in many cases impossible, to determine grain boundaries. Therefore, only those samples of item #1 are reported in Table 2 which could be given with reasonable assurance of accuracy. The microstructure of item 2 shows a considerable contrast between the sorbite grains and ferrite envelopes, thereby giving greater assurance of an accurate grain count.

18. It should be noted that in Table 2 under item #2, samples #222, 226 and 243 held at temperature for 45 sec., 30 sec., and 30 sec., respectively showed considerable grain size gradient from center to outside of the cross section. It was furthermore noted that these samples when

removed from the furnace were slightly below the color of the furnace, thus indicating that they had not quite reached 1400°C. The smaller grain size of the micrographs also indicates this conclusion.

19. All grain size counts reported are the averages of a number of counts taken on different fields of the samples. The grain size was not uniformly the same in any of the samples but a nearer approach to uniformity was noted for the samples preheated to 600°C and the 1/4" round, 3" long samples held for 1-1/2 minutes at 1400°C.

CONCLUSIONS AND RECOMMENDATIONS

(a) Facts Established

20. Grain Size Data - The grain size of the largest grains next to the bead of a single bead weld of items #1 and #2 has been determined and found to have considerable variation. The results for items #1 and #2 welds show practically identical grain size when expressed in terms of maximum grain and average grain size (in Table 2) although there is not an exact identity in the range of grains.

21. Since the grain sizes of welds of items #1 and #2 are practically the same we should expect the quenched samples of items #1 and #2 to show identical grain size for the same heat treatment. A comparison of data for the quenched samples given in Table #2 indicates that there is a fairly close correspondence but with a tendency of item #1 toward a slightly larger grain size. This latter observation may, however, have been due to the less definite grain boundaries of item #1 than existed for item #2.

22. From Table 2 it is also shown that for item #2 quenched from 1400°C samples #223, 227, 244 and 251 reach an average grain size which is between the maximum for the weld and the average. However, the maximum grain size in these samples is greater than for the weld as can be seen from the micrographs.

23. A rough approximation of the heating rate of the weld quench samples heated to 1400°C was obtained by sighting into the hole of the steel block on removing the samples from the furnace and noting the difference in the color of the sample and the block. Table 3 is a result of these approximate observations which indicate the effect of mass on the heating rate. Equal masses appear to heat to temperature in equal time. However, an indication of the difference the larger cross section (1/2" compared with 1/4" diameter) has on the grain size for the same mass is given in a comparison of Plate 4, samples 2-8 (1/2" rd x 3/4" long, mass = .15 cu.in.) and Plate 5, sample 2-51, the center of the larger cross section is shown here to have been at temperature for such a short time that as rapid grain growth was not possible as for the 1/4" section. In addition, as already mentioned, the grain size varies considerably from center to outside in the 1/2" section and is fairly uniform for the 1/4" section.

24. Weld Hardness Survey - It has been established by means of progressive hardness surveys of the weld sections that the quench sensitivity

of a number of different steels may be reliably determined by subjecting them to reproducible welding conditions and progressively exploring the cross section with a hardness testing machine such as was used for tests reported here and plotted in curves of Plates 6 and 7. The curves may be regarded as indicating the effect that an increase in cross section would have across a welded joint since the curves indicate increasing hardness and therefore increasing tensile strength. It must, however, be noted that the weld bead itself has not been surveyed for hardness and may for certain grades be above or below the maximum for the transition zone, although for actual welds the rod would be chosen to give slightly higher properties than for the parent metal. Attention is directed to the shape of the curves with the suggestion that it may be important not only to note the maximum hardness but also to consider whether the hardness rises gradually from the parent metal (fillet type-gradient) as for the curves in general, whether it sinks first then rises gradually (round notch-gradient) as for the curves for items 30, 31 (normalized) and item 24 or whether we have a sharp rise (sharp notch-gradient) as for items 33 and 34.

25. The hardness of the 1/4" round weld quench samples, cooled in air, is shown to nearly approach the maximum hardness in the transition zone. A moderately faster air cooling by means of a fan or air blast will probably duplicate the zone hardness although with the thinner samples (.197") which will be used for future tests (see paragraph 26 below), it may not be necessary to go to higher velocity air cooling.

26. A review of Table 3 together with Table 2 and micrographs of the weld quench samples leads to the conclusion that the half size Charpy impact specimen is as close as possible to an ideal sample for reproducing transition zone metal. The dimensions for the sample 10 mm (.394") x 5 mm (.197") x 50.8 mm (2.00") show a thinner cross section than for the 1/4" round samples reported here and we should therefore expect to obtain a higher hardness for the same quench and greater uniformity of microstructure across the section. Table 3 indicates the mass of the half size Charpy to be practically the same as the 1/4" rd x 3" long samples and should require the same time to heat to 1400°C. The half size Izod shown in Table 3, while of higher mass than the half size Charpy, will nevertheless be investigated as to ability to reproduce transition zone metal.

27. A review of Table 3 together with micrographs of the 1/2" round and 1/4" round weld quench samples indicates that standard size 10 mm square Charpy and Izod samples cannot be used for reproducing the high temperature portion of the transition zone because of the longer time required to heat the larger mass to 1400°C and the non-uniformity of grain size and other properties in the larger cross section.

28. The data for the samples preheated to 600°C before heat treating at 1400°C represent an anomalous condition which will not be commented on at the present time. The average grain size is shown to be smaller than identical samples without preheat. These results will be rechecked in the next run of weld quench samples but the important conclusion is that it is possible to reproduce high-temperature transition zone metal without preheating the sample.

29. A survey of the results of the progressive hardness tests on the single bead welds provide considerable information as indicated in the curves and charts. The maximum hardness produced in the transition zone as a function of carbon or alloy content is of most interest but the effect is masked to some extent by the lack of a series of steels with exactly the same content of carbon or alloy while the other elements are varied. The effect of carbon, however, is unmistakable in increasing the hardness as shown by comparison of items 1 and 2, 5 and 6, 27 and 28, 30 and 31 shown in curve 8, Plate 9, where little difference in the pairs exists except for the carbon.

30. Grain size data for all of the items welded has not yet been completed nor have the impact tests been made to determine the mechanical properties of the overheated metal. It is therefore impossible at this stage to correlate quench sensitivity with toughness or weldability. Preliminary to assembly of the complete data the chart of Plate 10 grades the steels as to percentage increase in hardness compared with absolute increase and original hardness. A better basis for comparison than original hardness would probably be the yield and tensile strengths and their ratio but the problem already involves so much detail as to preclude the determination of these values for the materials.

SUMMARY AND DISCUSSION

31. Weld quench tests indicate an ideal mass and cross section for the 5 mm x 10 mm half size Charpy impact specimen. Samples of practically the same mass and thicker section heated for 1-1/2 minutes at 1400°C reach an average grain size which is within the limits of the largest and the average for the large grains next to a single bead weld of the same parent metal. Samples of this size may be used for determining the impact value of the overheated metal and it may also be possible to make tests for cold-bend ductility on the same size sample.

32. Progressive hardness surveys across the single bead weld section indicate a method of rating the quench sensitivity of a series of steels. In the absence of maximum grain-size data for all the weld transition zones and the lack of impact and cold bend test results it is considered to be unreliable to use quench sensitivity alone as a criterion of weldability. A consideration and discussion of the effect of carbon and alloy on weldability is therefore to be held in abeyance pending the assembly of the complete data.

33. Curve 5 of Plate 8 gives the maximum hardness found in the transition zone in decreasing order for the items welded. The single cross-hatched portion indicates the absolute increase in hardness while the double cross-hatched section indicates the parent metal hardness. This is shown again in curve 6 where the items are arranged in order of decreasing parent metal hardness and the maximum hardness is shown to be scattered throughout the range. Curve 7 arranges the actual increase in hardness in decreasing order for the items investigated. Curve 8 is arranged in the order of increasing carbon and alloy contents and gives a comparison of the maximum hardness obtained for the items. Below the zero line of curve 8 the absolute increase in hardness is given in order that the relationship between this value and maximum hardness may be compared. The curves of Plate 10 are of

most practical value if we consider the curve C for parent metal hardness to indicate the relationship that we can expect to exist for the tensile strengths of the original plate material. There is a fairly close correspondence between ultimate strength and hardness which justifies this comparison. On the basis of this correspondence some conclusions can be made to summarize the results.

(a) Item 30 appears to have a desirably high tensile strength for the normalized plate while the hardness increase is among the lowest for the series.

(b) Item 27 is next in line in possessing the two desirable properties of low quench sensitivity and high parent metal strength.

(c) Both 30 and 27 have low carbon contents and depend on the alloy content for strengthening the ferrite rather than the precipitation of iron carbide, as is the case for the plain carbon steels. Carbon is therefore indicated as a potent hardener of the transition zone and must be kept low in order to decrease the quench sensitivity in welding.

(d) The effect of manganese in increasing the hardness is shown in curve 8 of Plate 9 and in Plate 10 for items 9, 10, 11 and also for item 22.

(e) Silicon in the range of 0 - .20% appears to be ineffective with respect to hardening. Even when present to the extent of .48% as in item 32 a low hardenability is obtained.

(f) Molybdenum added to a plain, medium carbon steel increases the original tensile strength when present to the extent of .50% and .80% but transition zone hardenability does not increase consistently with increasing Mo. This can be seen in curves of Plate 10 and curve 8 of Plate 9 for items 17, 18 and 19 where item 18 with higher Mo than item 17 appears to have a lower hardenability. On the other hand items 23 and 30 with lower Mo contents than item 17 appear to have lower hardenability although in the case of items 23 and 30 strict comparisons cannot be made due to the other alloy contents and the low carbon contents.

(g) Nickel alone is not responsible for hardening of the transition zone as shown by item 29 with low carbon of 0.03%. The high hardenability of item 24 should be regarded as due to the high carbon-nickel combination. Another example of the ineffectiveness of nickel alone in promoting hardenability is cited for item 27 in which the Ni is practically the same as for item 29 and shows practically equal hardenability.

(h) Considering the steels of high hardenability as a group of items 33, 24, 34, 28, 31, we note that these grades are not usually considered weldable unless the work is preheated and receives stress relief or annealing treatment after welding. We would therefore not encounter in practice the high maxima for the transition zone as indicated for the single bead welds. Such a hardness survey as here reported would, however, classify those steels for which special welding methods would be required.

(i) The increase in hardenability with carbon content of the plain carbon steels has been carried only up to .25 - .27% carbon due to the higher carbon compositions not being available at the time of the welding tests. The item 4 steel of approximately .45% carbon now available will be run through the welding tests and results reported and plain carbon steel with carbon of around .35% will soon be received in response to a requisition for the material.

TABLE 1

SUMMARY OF HARDNESS TESTS ON WELDS

Welding Conditions

Airco #78, 3/16" heavy coated rod, 180-190 amperes, 25-27 volts, Speed of 6"/minute.

Hardness Testing Conditions

Vickers type hardness testing machine, 10 Kilogram load. Indents .05" from top of plate (welded face) .02" apart in transition zone and .05" apart outside.

Item	Transition Zone Max.	Transition Zone Min.	Parent Metal	Hardness Increase HV10 units	Hardness Increase Percent
1	193	151	135	58	42
2	221	166	148	73	49
5	203	151	143	60	42
6	243	166	150	93	62
9	224	160	143	81	57
10	287	187	172	115	67
11	312	197	181	131	72
13	230	164	150	80	53
14	237	185	157	80	51
15	227	160	151	76	50
17	230	179	153	77	50
18	254	197	177	77	44
19	287	230	186	101	54
20	218	160	143	75	53
21	243	160	148	95	64
22	312	218	197	115	58
23	237	179	160	77	48
24	503	230	212	291	137
27	195	168	155	40	26
28	405	215	206	199	97
29	170	142	126	44	35
30	254	195	200	54	27
31	397	212	218	179	82
32	221	168	152	69	45
33	437	160	152	285	188
34	383	218	171	212	124

TABLE 2

GRAIN SIZE DETERMINATIONS

Welded Samples

Item 1

Area (in square inches at 100 X) of 12 large grains found in item 1 weld cross section: 1.07, .89, .73, .68, .66, .58, .55, .55, .52, .50, .48, .42, Av. = .63

Maximum grain size = .93 grains/sq.in at 100 X.

Average grain size = 1.56 grains/sq.in. at 100 X.

Item 2

Area (in square inches at 100 X) of 13 large grains found in item 2 weld cross section: 1.07, .89, .88, .82, .74, .67, .65, .64, .63, .58, .57, .43, .37, Av. = .68

Maximum grain size = .93 grain/sq.in. at 100 X.

Average grain size = 1.47 grains/sq.in. at 100 X.

Quenched Samples

Sample No.	Size	Time at Temperature (1400°C)	Grain Size (grains/in² at 100X)	Hardness HV10	Micrograph
Item 1					
123	1/4" rd x 3/4"	1 min.	.96	174	Plate 3
127	1/4" rd x 1/2"	45 sec.	1.0	177	Plate 3
144	1/4" rd x 1/2"	(600°C preheat) 45 sec.	1.22	179	Plate 3
151	1/4" rd x 3"	1-1/2 min.	.96	167	Plate 5
Item 2					
222	1/4" rd x 3/4"	45 sec.	1.68	181	None
223	1/4" rd x 3/4"	1 min.	1.12	195	Plate 4
226	1/4" rd x 1/2"	30 sec.	2.21	183	Plate 4
227	1/4" rd x 1/2"	45 sec.	1.02	195	Plate 4
243	1/4" rd x 1/2"	(600°C preheat) 30 sec.	2.48	179	Plate 4
244	1/4" rd x 1/2"	(600°C preheat) 45 sec.	1.14	193	Plate 4
251	1/4" rd x 3"	1-1/2 min.	1.01	195	Plate 5

TABLE 3

APPROXIMATE HEATING RATE OF WELD QUENCH SPECIMENS

Sample Size	Volume (cu.inches)	Approximate Time to reach 1400°C
1/2" rd x 3/4"	.15	1-1/2 minutes
1/2" rd x 1/2"	.098	1-1/4 minutes
1/4" rd x 3/4"	.037	1 minute
1/4" rd x 1/2"	.025	3/4 minute
1/4" rd x 3"	.15	1-1/2 minutes
10 mm x 5 mm x 50.8 mm Charpy	.16	1-1/2 min.or less (Estd
10 mm x 5 mm x 74 mm Izod(single)	.23	1-1/2 min.+ (Estd).
Standard Charpy 10 x 10 mm.	.31	1-1/2 min.+ (Estd).
Standard Izod (single) 10 x 10 mm.	.46	1-1/2 min.+ (Estd).

INDEX OF PHOTOMICROGRAPHS

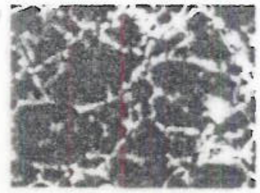
All micrographs were originally at a magnification of 100 X, except where otherwise stated (reduction of approximately 7/9 made in reproduction).

Plate	Sample	History
3	1-22	Item 1, 1/4" rd 3/4" long, 3/4 min. at 1400°C.
3	1-23	Item 1, 1/4" rd 3/4" long, 1 min. at 1400°C.
3	1-26	Item 1, 1/4" rd 1/2" long, 1/2 min. at 1400°C.
3	1-27	Item 1, 1/4" rd 1/2" long, 3/4 min. at 1400°C.
3	1-43	Item 1, 1/4" rd 1/2" long, 1/2 min. at 1400°C.
3	1-44	Item 1, 1/4" rd 1/2" long, 3/4 min. at 1400°C.
4	2-7	Item 2, 1/2" rd 1/2" long, 3/4 min. at 1400°C.
4	2-8	Item 2, 1/2" rd 1/2" long, 1 min. at 1400°C.
4	2-23	Item 2, 1/4" rd 3/4" long, 1 min. at 1400°C.
4	2-26	Item 2, 1/4" rd 1/2" long, 1/2 min. at 1400°C.
4	2-27	Item 2, 1/4" rd 1/2" long, 3/4 min. at 1400°C.
4	2-43	Item 2, 1/4" rd 1/2" long, 1/2 min. at 1400°C.
4	2-44	Item 2, 1/4" rd 1/2" long, 3/4 min. at 1400°C.
5	$1-W_3$	Item 1, large grains adjacent to weld bead.
5	1-51	Item 1, 1/4" rd 3" long, 1-1/2 min. at 1400°C.
5	$2-W_3$	Item 2, large grains adjacent to weld bead.
5	2-51	Item 2, 1/4" rd 3" long, 1-1/2 min. at 1400°C.

ITEM 1

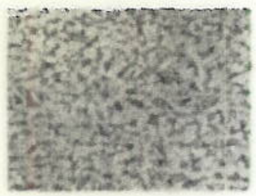
ITEM 2

ITEM 4



ITEM 5

ITEM 6



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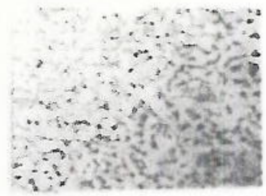
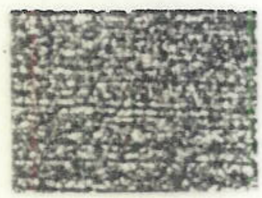


ITEM 10

ITEM 11



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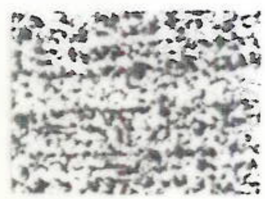
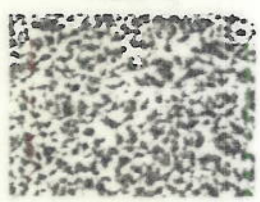


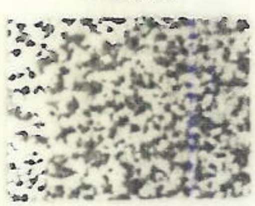
ITEM 14

ITEM 15



ITEM 17

ITEM 18



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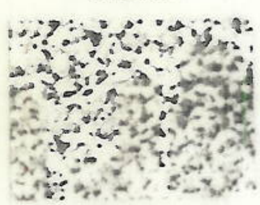
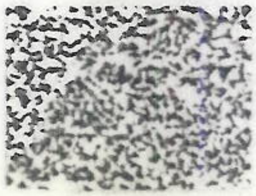


ITEM 20

PLATE I

ITEM 21



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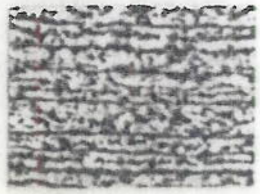

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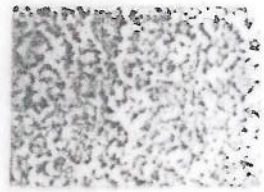
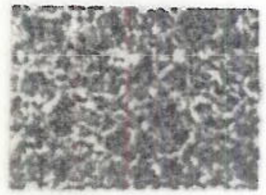


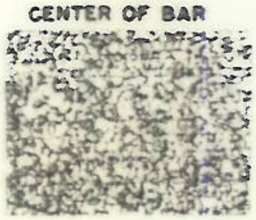
ITEM 24

ITEM 27

ITEM 28

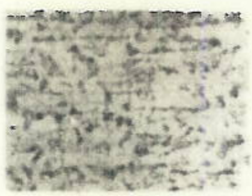


ITEM 29
CENTER OF BAR



ITEM 29
OUTER EDGE OF BAR

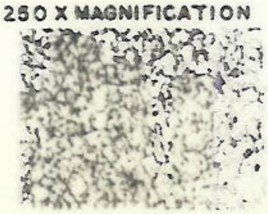
ITEM 30



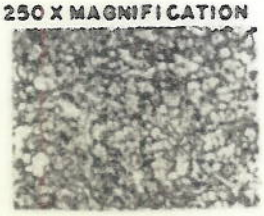
ITEM 31

ITEM 32

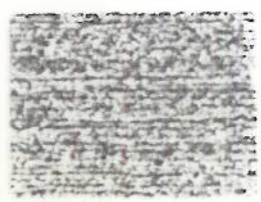
ITEM 33
250 X MAGNIFICATION



ITEM 34
250 X MAGNIFICATION



ITEM 35



ITEM 36

ITEM 37

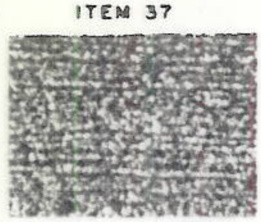
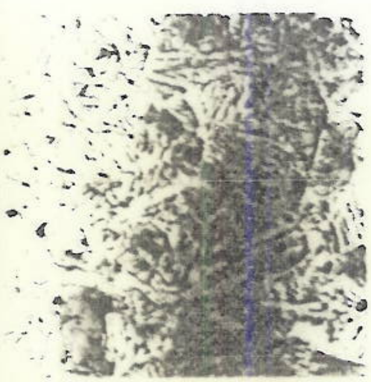


PLATE 2

1-22

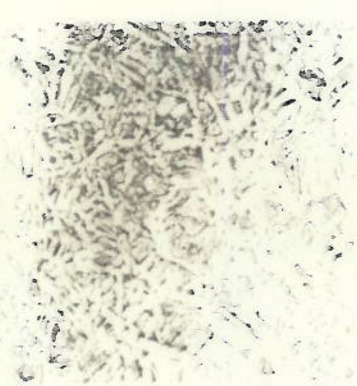


1-23

1-26

1-27

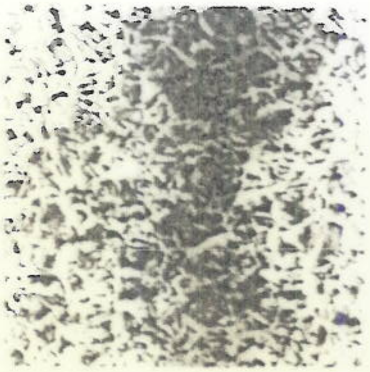
1-43



1-44

PLATE 3

2-7



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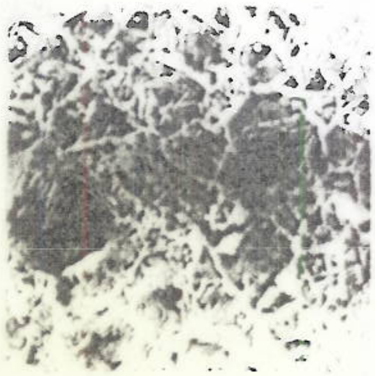

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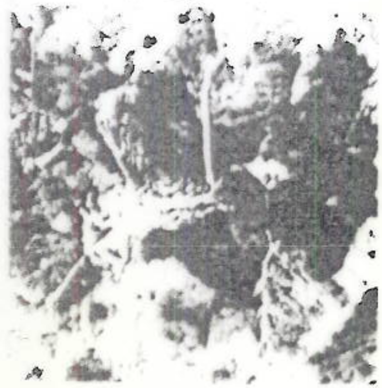

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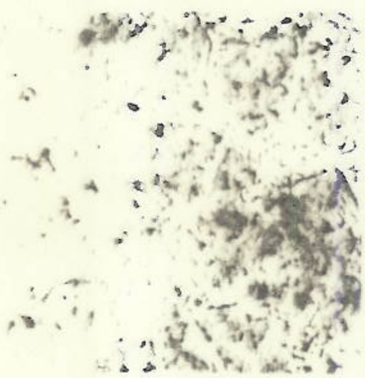

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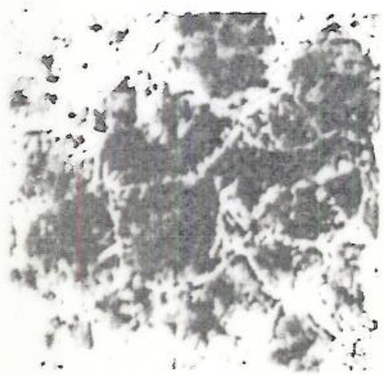
2-43



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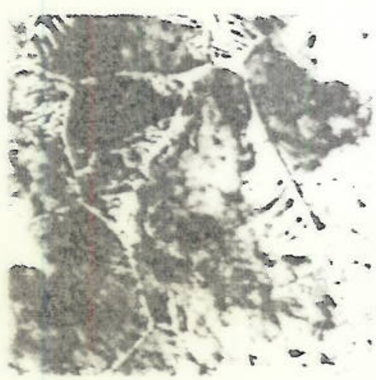
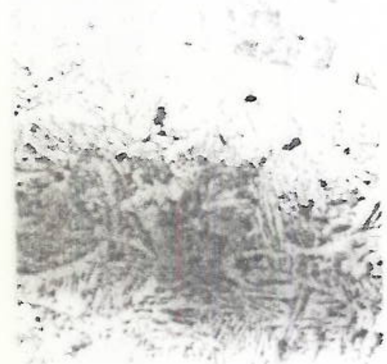


PLATE 4

1 W_3

1—51



2 W_3

2—51

PLATE 5

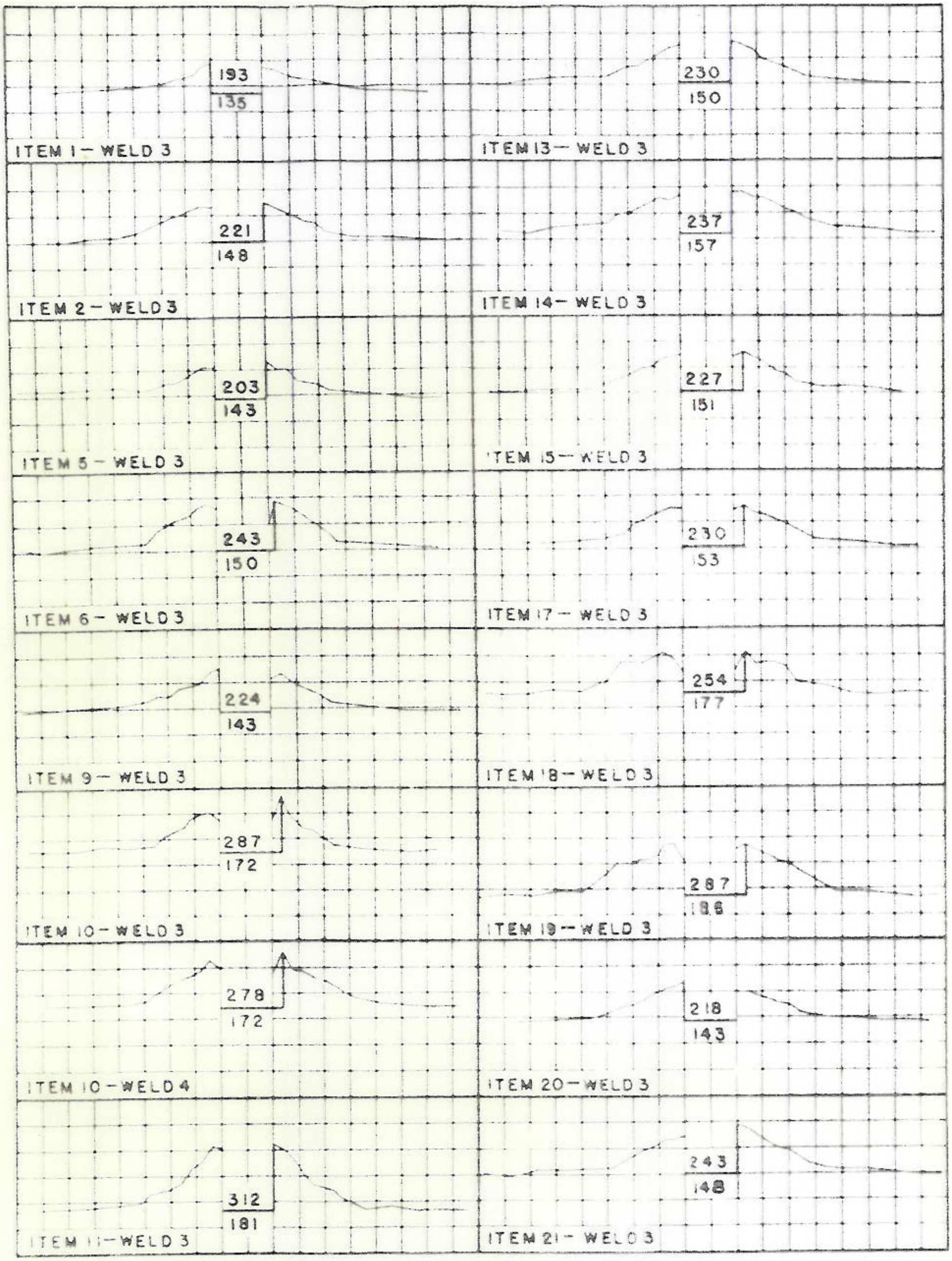

193
135
ITEM 1 — WELD 3
230
150
ITEM 13 — WELD 3
221
148
ITEM 2 — WELD 3
237
157
ITEM 14 — WELD 3
203
143
ITEM 5 — WELD 3
227
151
ITEM 15 — WELD 3
243
150
ITEM 6 — WELD 3
230
153
ITEM 17 — WELD 3
224
143
ITEM 9 — WELD 3
254
177
ITEM 18 — WELD 3
287
172
ITEM 10 — WELD 3
287
186
ITEM 19 — WELD 3
278
172
ITEM 10 — WELD 4
218
143
ITEM 20 — WELD 3
312
181
ITEM 11 — WELD 3
243
148
ITEM 21 — WELD 3

PLATE 6

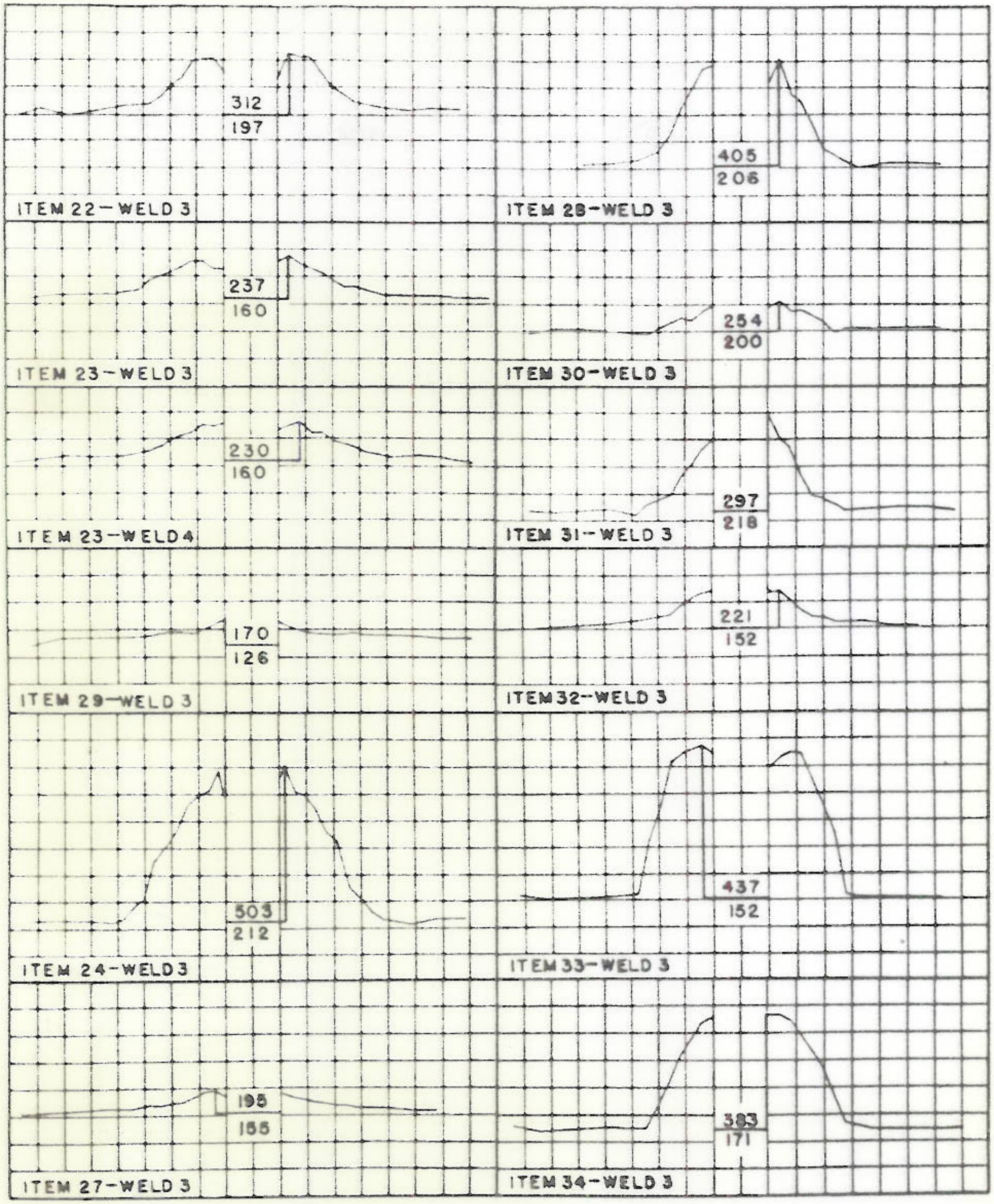
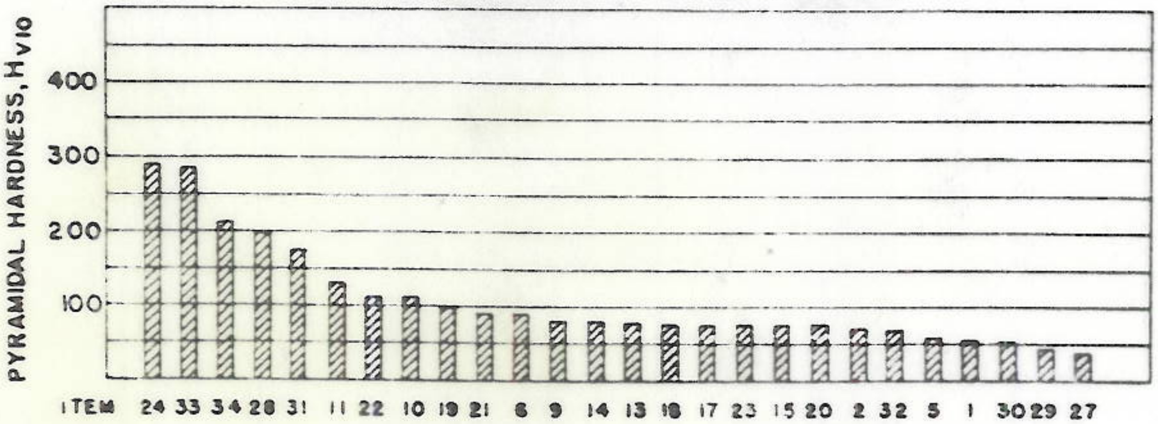

312
197
ITEM 22-WELD 3
405
206
ITEM 28-WELD 3
237
160
ITEM 23-WELD 3
254
200
ITEM 30-WELD 3
230
160
ITEM 23-WELD 4
297
218
ITEM 31-WELD 3
170
126
ITEM 29-WELD 3
221
152
ITEM 32-WELD 3
503
212
ITEM 24-WELD 3
437
152
ITEM 33-WELD 3
195
155
ITEM 27-WELD 3
383
171
ITEM 34-WELD 3

PLATE 7

CURVE 7:—HARDNESS DIFFERENTIAL BETWEEN PARENT METAL AND MAXIMUM HARDNESS FOR TRANSITION ZONE.



CURVE 8:—COMPARISON OF MAXIMUM HARDNESS AND HARDNESS DIFFERENTIAL FOR W_3 WELDS ON BASIS OF CARBON AND ALLOY CONTENTS.

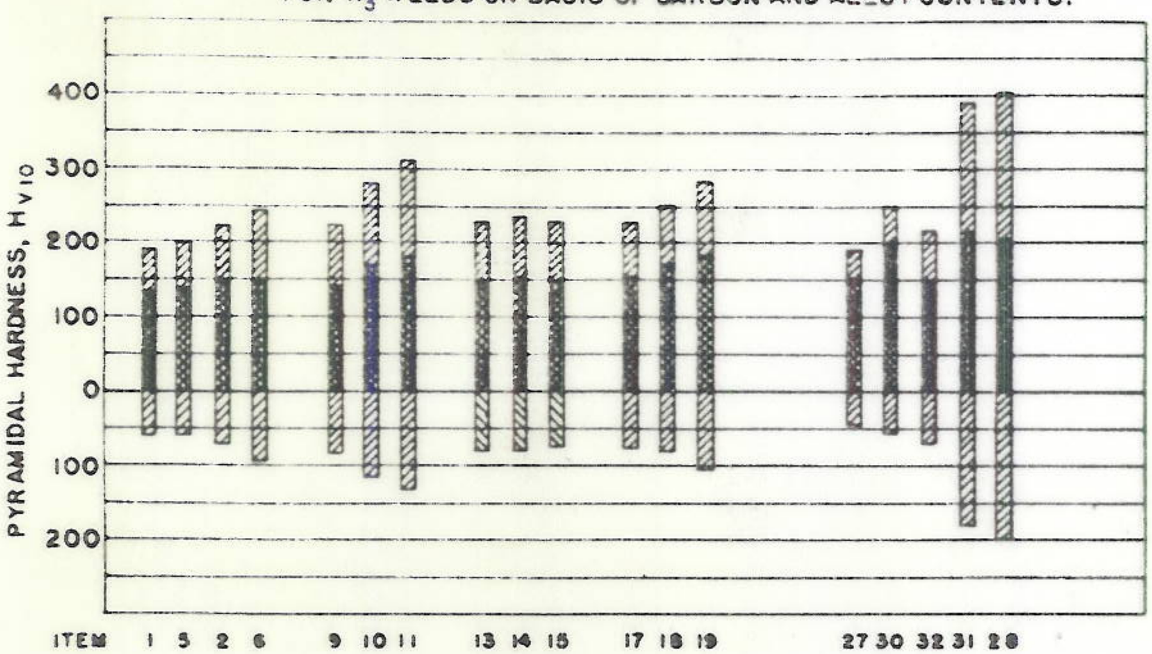
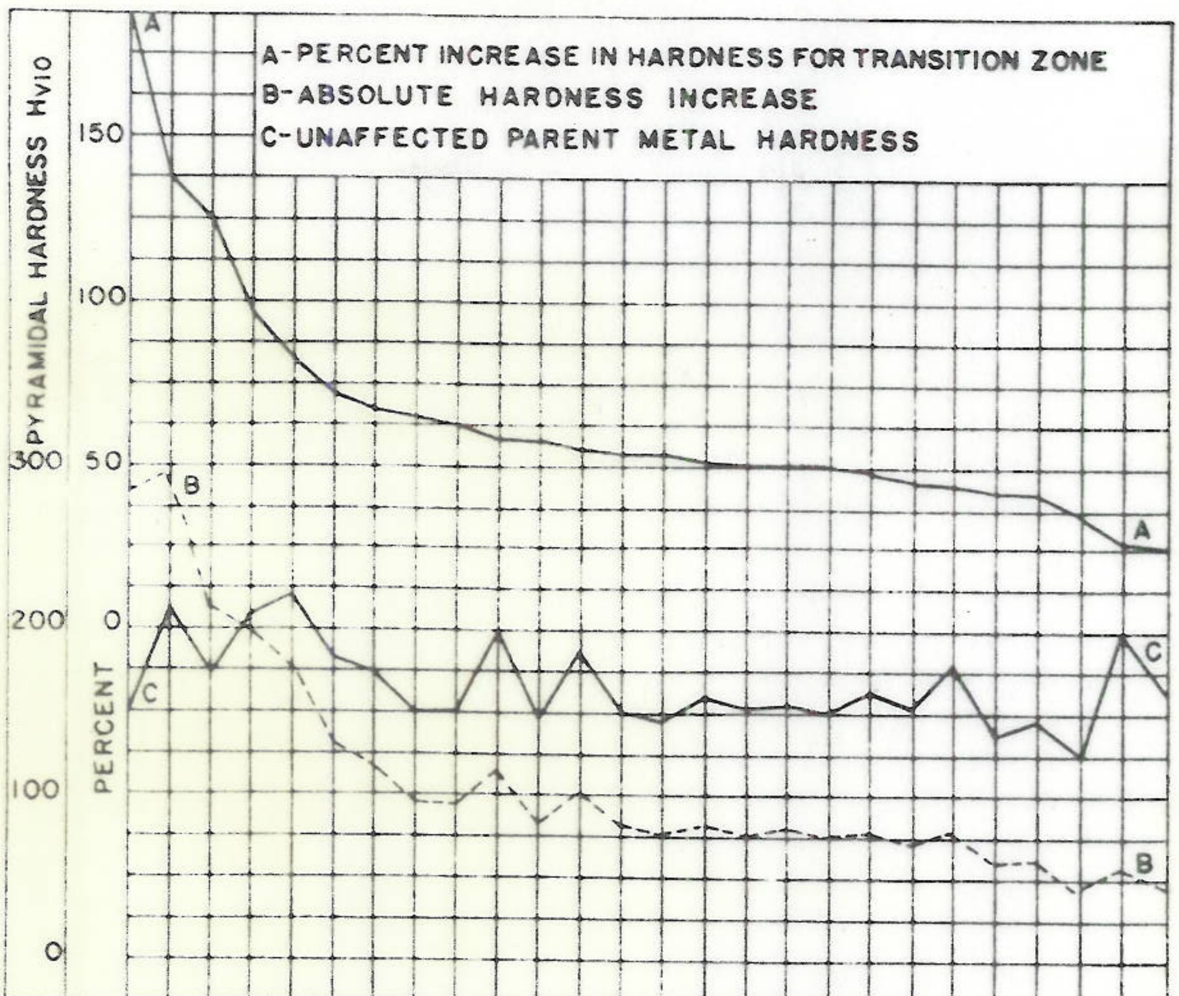


PLATE 9



ITEM	33	24	34	28	31	11	10	21	6	22	9	19	13	20	14	15	17	2	23	32	18	1	5	29	30	27
C	.11	.28	.065	.21	.24	.29	.27	.25	.27	.18	.24	.20	.26	.24	.28	.25	.22	.25	.15	.12	.22	.17	.21	.028	.09	.06
Mn	—	.56	—	.70	74	1.06	.74	.43	.47	1.40	.48	.50	.46	.46	.54	.43	.52	.43	.44	.75	.47	.41	.38	.19	72	.35
Si	.19	.27	.22	.27	.012	.25	.21	.19	.0062 .002	.21	.23	.17	.005	.0001	.058	.20	.20	.20	.20	.48	.18	.17	.003	—	.047	.002
Ni				1.97	.76																			2.08	.96	1.95
Cu				1.08	1.48														.75						1.34	.94
Mo	.51		.51		.16							.79					.19		.17		.50				.11	
V										.12																
Cr	5.85		5.66																	.34						
Cb			.55																							
P					—																				—	

NOTE: DASH — ABOVE INDICATES PRESENCE OF ELEMENT BUT NO ANALYSIS.

PLATE 10