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WATERTOWN ARSENAL

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MEMORANDUM REPORT

NO. WAL 642/146

BY

William L. Warner
Sr. Welding Engineer

DATE 25 May 1948

WATERTOWN ARSENAL
WATERTOWN, MASS.

WELDING

Hard-Surfacing by Metal-Arc Welding

Memorandum Report WAL 642/146

O.O. Project TB4-40F

WATERTOWN ARSENAL LABORATORY

Authorized by: ORDTB-Materials 25 May 1948

O.O. Project Number: TB4-40F

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Priority: 3B

Title of O.O. Project: Hard-Surfacing by Welding

WAL Project No: 13.1-T

TITLE

HARD-SURFACING BY METAL-ARC WELDING

Preliminary Study of
Commercially Available Electrodes for Hard-Surfacing

OBJECT

1. To obtain comparative data on several commercial brands of hard-surfacing welding electrodes, available in the Welding Laboratory, and the weld metal deposits obtainable, with reference to the following factors:-

a. Smoothness and ease of operation of electrode.
b. Surface smoothness and soundness of deposit.
c. Deposit hardness level.
d. Susceptibility to check cracking or separation from the base metal.
e. Chemical composition of deposit.
f. Abrasion resistance of deposit.
   (1) Dry abrasion
   (2) Wet abrasion
   (3) Various contact pressures
   (4) Various lengths of stroke
   (5) Various rates of stroke
   (6) Various lengths of testing time
g. Corrosion resistance of deposit.
h. Metallographic structure of deposit.
i. Susceptibility of deposit to hardening by cold working (peening) and the effect of such hardening on abrasion resistance.

2. If possible, to develop a practicable test for determining comparative abrasion resistance of hard-surfacing weld deposits. With such a test it is hoped to be able to classify commercial brands of electrodes, and perhaps welding rods, for qualification and acceptance under Specification 57-203-5.

SUMMARY

1. In the work covered by this report some nineteen (19) commercial brands of hard-surfacing electrodes were tested of which twelve (12) brands gave weld metal deposits suitably free from porosity and cracks to permit of abrasion and corrosion testing. The data obtained pertain primarily to objectives 1a, b, c, d, e, f(2), f(6), g, and h.

2. Welding data are given in Table I, compositions of weld metals in Table II and abrasion test data in Tables III and IV. Electrodes B and D show highest abrasion resistance and Electrode C the lowest. See Tables V and Va. All three electrodes are brands presently approved under Specification 57-203-5.

3. Corrosion test data are given in Table VI. These data indicate that those weld metals which gave highest abrasion resistance exhibit lowest corrosion resistance.

4. The results of metallographic examination of nine (9) of the twelve (12) weld metals abrasion tested are shown by Figures 9 to 17 inclusive.

CONCLUSIONS

1. The data included in this report are regarded as indicating trends since the program of testing originally planned was not completed.

2. The abrasion test data indicate that two of the electrodes, approved under Specification 57-203-5, deposit weld metal having the highest resistance to abrasion of any of the twelve (12) metals tested, whereas the weld metal from a third approved electrode brand exhibits the lowest resistance to abrasion. Thus the combination of soundness and hardness level of weld metal does not appear to be an adequate criterion of abrasion resistance.

3. Those weld metals which gave good abrasion resistance appear to have the lowest resistance to corrosion.

4. There does not appear to be a typical metallographic structure of weld metal, indicative of good abrasion resistance, which can be used as a criterion for approval testing.

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INTRODUCTION

U. S. Army Specification 57-203-5 (7 October 1944) covers two classes of welding electrodes for hard-surfacing as follows:-

> Class A - Hard-Facing, Ferrous Alloy (See Par. E-4)
> Class B - Hard-Facing, Ferrous Alloy, partially austenitic (See Par. E-5)

> Paragraph E-4. "Class A electrodes are intended for depositing surfacesresistant to abrasion where subsequent machining is not required. These electrodes are used with direct current only."

> Paragraph E-5. "Class B electrodes are intended for use in hard-facing where cold working under load will harden the surface, thus increasing the wearing qualities. They are used with direct current only."

The Detail Requirements prescribed for these two classes of welding electrodes are as follows:-

Hardness (Par. E-2b). "The hardness of weld metal deposited by Class A electrodes shall be not less than 475 Brinell with the steel ball, 3000 Kg. load (Rockwell C-49). The hardness of weld metal deposited by Class B electrodes shall be not more than 286 Brinell with the steel ball, 3000 Kg. load (Rockwell C-30). When peened, as prescribed by paragraph F-5c, the weld metal of Class B electrodes shall exhibit a minimum hardness of 488 Brinell with the steel ball, 3000 Kg. load (Rockwell C-50)."

Smoothness & Soundness (Par. E-2c). "Electrodes shall be capable of producing on low carbon steel plate, Class A, U. S. Army Specification 57-114-1, by a commercially practicable procedure, a weld deposit, free of cracks and injurious porosity, which will not require the grinding off of more than 1/16 inch in depth of the deposited metal at any point to obtain a continuously plate surface for the hardness test."

The methods of testing the hard-facing deposits, for qualification by laboratory test, are prescribed as follows:-

Hardness & Soundness (Par. F-3d). "The hardness and soundness of deposit of the electrodes shall be determined by making a single-layer deposit of at least 2 square inches in area on low carbon steel plate not less than 1/2-inch thick. The surface of this deposit shall be ground off sufficiently to make at least nine Rockwell "C" hardness determinations, not less than 1/4 inch apart, and a visual and magnetic examination for cracks and porosity in the deposited metal."

Peening (Par. F-5c). "The peening test for weld metal deposited by Class B electrodes shall be performed with an air hammer under the following conditions:

1. Maximum air pressure, 90 pounds.
2. Air hammer to be equipped with piston of not over 1 1/8-inch diameter and having a maximum length of stroke of 2 inches.
3. Peening tool with spherical face of not less than 2-inch radius.
4. Peening to be performed in a continuous operation on the ground surface of the deposit such that an area of 2 square inches is adequately covered in not less than 20 seconds nor more than 30 seconds of elapsed time. Following this operation the peened surface may be reground for hardness testing but in no case more than a 1/32-inch depth of metal shall be removed for this purpose."

Radiography (Par. F-5d). "Radiographic examination may be made of any test deposits laid down with the electrodes to determine compliance with paragraph E-2c."

The inadequacy of these requirements for properly classifying hard-facing materials is recognized but they represent the best compromise which could be reached based upon the data available when the specification was prepared. However, because of the realization that hardness and soundness of deposit do not necessarily indicate the ability of a metal to resist abrasion it was desired to investigate a number of commercial brands of hard-facing welding electrodes which were available in the Welding Laboratory. It was thought that some method of abrasive testing these metals might be found which would give a more practicable and reliable basis for appraisal than the determination of soundness and hardness of metal deposit as prescribed by Specification 57-203-5.

It was originally planned to obtain data also on the response of certain of these metals to peening after deposition but this phase of the program was not started because of termination of the work on this project due to personnel reduction on 1 July 1947. This report, therefore, covers the deposition and abrasion and corrosion testing of the deposits from some nineteen (19) brands of electrodes, as listed in

Table I, completed prior to 1 July 1947. Electrodes B, C and D had previously received approval under Specification 57-203-5 by Laboratory Qualification Test as prescribed above for Class A Electrodes.

TEST PROCEDURE

The first operation in testing the electrodes consisted in depositing a pad of weld metal (two layers in all cases, except two) with each of the electrodes to be tested, using the welding conditions indicated by Table I. Each pad was approximately 2 1/2 inches wide by 6 inches long deposited on a piece of 1/2-inch thick plain low carbon steel plate about 3 inches wide by 9 inches long. The pads were deposited on the plate in the flat position.

After welding was completed each pad was carefully examined for porosity, cracks and any evidence of separation of the weld metal from the base metal. If any of these defects were found the pad involved was eliminated from further testing. As shown by Table I twelve (12) of the pads were judged satisfactory for abrasive testing and each of these was then machined and ground to the approximate dimensions shown by Figure 1. From each of these samples two test specimens of the size and shape shown by Figure 2 were prepared for abrasive test.

a. Abrasive Test

The test conditions chosen for abrasion testing were quite arbitrary. The size and type of abrasive block selected is shown by Figure 2. It was decided to run the test with the abrasive surface flat and the test apparatus was operated so as to move the abrasive block back and forth with the test specimen held stationary and in contact with the abrasive surface by a compression spring. The abrasive block shown by Figure 2 was clamped flat upon the bed of a sliding carriage such that the movement of the block during the test was longitudinal as indicated by Figure 2. The test specimen was held face down on the flat surface of the abrasive block by a calibrated compression spring assembled in a yoke which spanned the sliding carriage and was bolted to the base of the machine.

A preliminary tryout of this setup was made with a dry abrasive block but after a very short run of a few minutes duration it was found that the abrasive block glazed over and lost its abrasive character. This necessitated a tryout of either one of the two suggested modifications of test method -

(1) immersion of the abrasive block in some sort of a solvent which would float off the particles

of abrasion and thus prevent the abrasive surface from glazing over, or

(2) tilt the whole mechanism through 90° in order to put the abrasive surface in a vertical position so that the particles of abrasion would drop away without imbedding in the abrasive surface.

Since the second method would involve considerable redesign of the apparatus as well as machine-work and delay in running the tests it was decided to try the solvent idea. The sliding carriage was fitted with sides of sufficient size to hold a depth of liquid adequate to just cover the abrasive surface and several trial runs were made using Salvasol #5 as the solvent. These runs definitely indicated the feasibility of operation over considerable periods of time without glazing of the abrasive surface and consequently the data on abrasion included in this report were obtained by tests run with the abrasive block completely immersed in Salvasol #5. No tests were made with the abrasive surface vertical and without a solvent.

b. Hardness

Both the Rockwell and the Vickers methods were used. The Vickers (with 10 Kg. load) surveys were made with impressions taken 0.02" apart in the approximate locations shown by Figure 3. Rockwell "C" readings were taken on the top surface of the abrasion specimens (Figure 2) in the end zones which are not affected by the abrasion test.

c. Chemistry

Since the metals included in this investigation were too hard for machining, it was necessary to obtain samples for chemical analysis by a somewhat unorthodox method. A specimen similar to that shown by Figure 4 was used and the low carbon steel base metal was completely removed by machining and grinding so that only the hard-facing metal remained. This hard-facing metal plate was broken up with a hammer and reduced to a coarse powder in a mortar and pestle. This coarse powder was then dissolved by acid to form a solution for analysis.

d. Corrosion

The corrosion test specimens of the hard-facing deposits are as shown by Figure 5. In preparing these specimens care was exercised to remove all of the low carbon base metal from the back of the hard-facing metal deposit.

For the corrosion tests a 10% sodium chloride solution was used at a room temperature and the specimens were suspended in this solution using special Nichrome V wire holders coated with stopoff Unichrome 323.

The specimens were thoroughly cleaned, before immersion in the salt solution, by degreasing with trichlorethylene, then anodic cleaning in an alkaline cleaner, rinsing in hot water and drying with compressed air. Each specimen was then carefully weighed and immersed in the salt solution.

During the test compressed air was used to provide aeration and agitation of the salt solution. The compressed air was available only during the day shift (8:00 AM - 4:30 PM).

At the end of each run the samples were removed from the salt solution, rinsed in warm water, scrubbed with soap and toothbrush, again rinsed in warm water, given a 5-volt cathodic treatment in 10% ammonium citrate at 120°F. for one minute, rinsed in hot water (about 120°F.), and dried with compressed air. Specimens were then carefully weighed and the weight lost determined.

e. Metallography

After the Vickers hardness surveys had been made as indicated in Figure 3 the specimen surfaces were repolished for microexamination. Etching was done with Vilella's Reagent. Photomicrographs were taken at 250 diameters at the following approximate locations:

A & E - Center of 2nd layer of hard-facing metal
B & F - Junction of 2nd & 1st layers
C & G - Center of 1st layer
D & H - Junction of 1st layer and base metal

Photomicrographs at 1000 diameters were also taken at the first three locations cited above. (See Figures 9 to 17).

TEST DATA & DISCUSSION

a. Abrasive Test

The results of abrasive testing these hard-facing metals by the procedure described are given by Tables III and IV. It will be noted that the duration of test was 6 hours for the data of Table III whereas for the data of Table IV the duration was 3 hours. Different specimens from the same sample (Figure 1) were used for each of the two tests but otherwise the testing conditions were the same for both specimens.

While these data are regarded as inadequate to establish an abrasion testing criterion for qualification tests of commercial brands of electrodes it is of interest to note that Electrodes B, C and D are approved under Specification 57-203-5 in accordance with the test requirements as given in the Introduction to this report.

It is apparent from the data of these two series of abrasion tests that the weight lost and amount of abrasive wear may be proportional to the length of time under abrasion, at least in the case of Specimens #2, 4 and 13. With the other metals tested the weight lost and amount of abrasive wear are considerably greater in proportion in that the results of the 6-hour test are from 3 to 10 times the results from the 3-hour test. These ratios are indicated by Table V.

These data indicate quite clearly that acceptance of hard-facing metals on the basis of hardness values does not necessarily insure satisfactory abrasion resisting properties. Considerable further testing of these materials under a variety of loads and abrasive conditions would be necessary to establish satisfactory criteria for qualification testing of abrasion resistance under Specification 57-203-5.

b. Hardness & Soundness

The results of the Vickers hardness surveys are shown by Table VI. The Rockwell "C" values obtained on the abrasion test specimens are given in Tables III and IV. It may be noted that nearly all of the metals tested in the abrasion test show Rockwell hardness values above the C-49 minimum presently specified for qualification under 57-203-5. From the standpoint of soundness all but two of the metals tested in abrasion, as listed in Table IV, were free from check cracks (Table I). The surface appearance of the weld deposits from which these nine samples were taken is shown by Figures 6, 7 & 8. These data indicate that hardness level is not a satisfactory criterion for determining abrasion resistance.

c. Chemistry

The results of chemical analyses of these weld metals are given by Table II. It may be noted that two of the three approved brands of weld metal (#2 & #4) contain nearly 5% tungsten each whereas the third (#3) contains none of this metal. Two others (#5 & #12) each contain about 1% tungsten and the rest of the metals do not. In all cases chromium appears to be a base element of composition together with high carbon.

It is interesting to note that Specimen #13 which shows an abrasion resistance nearly equal to #2 and #4 does not contain tungsten but does have the highest carbon content (0.84%) of any of the metals tested. These data suggest that the chemistry of weld metal is not a satisfactory criterion for determining abrasion resistance.

d. Corrosion

The results of the corrosion tests as shown by Table VII, while generally inconclusive, do show that Specimen #8 is most resistant to corrosion by the salt solution used for this test. The other metals appear to be affected to about the same extent as plain low carbon steel.

It is interesting to note that, although Specimen #3 has slightly more chromium than Specimen #6, its corrosion resistance is noticeably less. It is possible that this result is due to the higher manganese content of Specimen #3 over Specimen #6 (see Table II). This observation is further strengthened by the fact that Specimens #2 and #4 show the greatest weight lost in corrosion (at 154 hours) but have the largest manganese content (3%-4%) with a low chromium content (3%-4%), and both exhibit the best abrasion resistance. This suggests that what is good for abrasion is not good for corrosion or visa versa.

e. Metallography

The results of microexamination are shown by Figures 9 to 17 inclusive. In each of these Figures the approximate locations of the photomicrographs in the weld metal deposit are shown on the macrograph. All of these metals appear to be dendritic and on the higher magnification (1000 diam.) a number of them show acicular structure characteristic of martensite at the 50 Rockwell "C" hardness level.

Specimens #2 and #4, which show best abrasion resistance under the conditions of testing used, do not show like structures although both are of similar composition except for carbon (Figures10E & 12E). The poorest metal in resistance to abrasion, Specimen #3, is a manganese-chromium steel of hardness level about the same as Specimens #2 and #4 but its structure appears to be more like that of white cast iron.

Specimen #4, which gave best abrasion resistance of all the metals tested, exhibits a rather fine-grained homogeneous structure with no grain boundary segregation (Figure 12E). Whether such a structure of hard metal is generally indicative of good abrasion resistance irrespective of composition at a 50 Rockwell "C" hardness level is not known.

TABLE I

Welding Data
Hard Facing Deposits

Sample No.	Electrode	Amperes	Volts	Weld Beads	Elec. Res. Covering	X-Ray Data	Remarks
1	A - 5/32"	100	22	3/4" Weave	O.K. 90V.	Scattered porosity No cracks	O.K. for Abrasive Test
2	B - 5/32"	100	22	1/4" String	O.K. 90V.	Scattered porosity No Cracks	O.K. for Abrasive Test
3	C - 5/32"	125	24	7/16" Wea.	O.K. 90V.	Scattered porosity No Cracks	O.K. for Abrasive Test
4	D - 5/32"	120	24	3/8" Wea.	O.K. 90V.	Scattered porosity Few small cracks	O.K. for Abrasive Test
5	E - 5/32"	125	21	5/16" Str.	O.K. 90V.	No porosity or cracks	O.K. for Abrasive Test
6*	F 3/16"	165	22	13/16" Wea.	Under 30V.	Coarse porosity Many cracks	N.G. for Abrasive Test
[illegible]	G - 5/32"	155	20	1/2" Wea.	Very low	Coarse porosity Many cracks	N.G. for Abrasive Test
8	H - 5/32"	130	20	5/16" Str.	O.K. 90V.	Scattered porosity No cracks	O.K. for Abrasive Test
9	I - 5/32"	140	24	5/8" Wea.	Below 60V.	Scattered porosity One small crack	O.K. for Abrasive Test
10	J - 3/16"	160	24	1/2" Wea.	Under 30V.	Coarse porosity Badly cracked	N.G. for Abrasive Test

* One layer only. Others two layers.

General Note: Direct current, reverse polarity (electrode positive)
Base metal plain low carbon steel plate 1/2" thick
No Preheat. Interpass temperature 300° F. maximum.

TABLE I

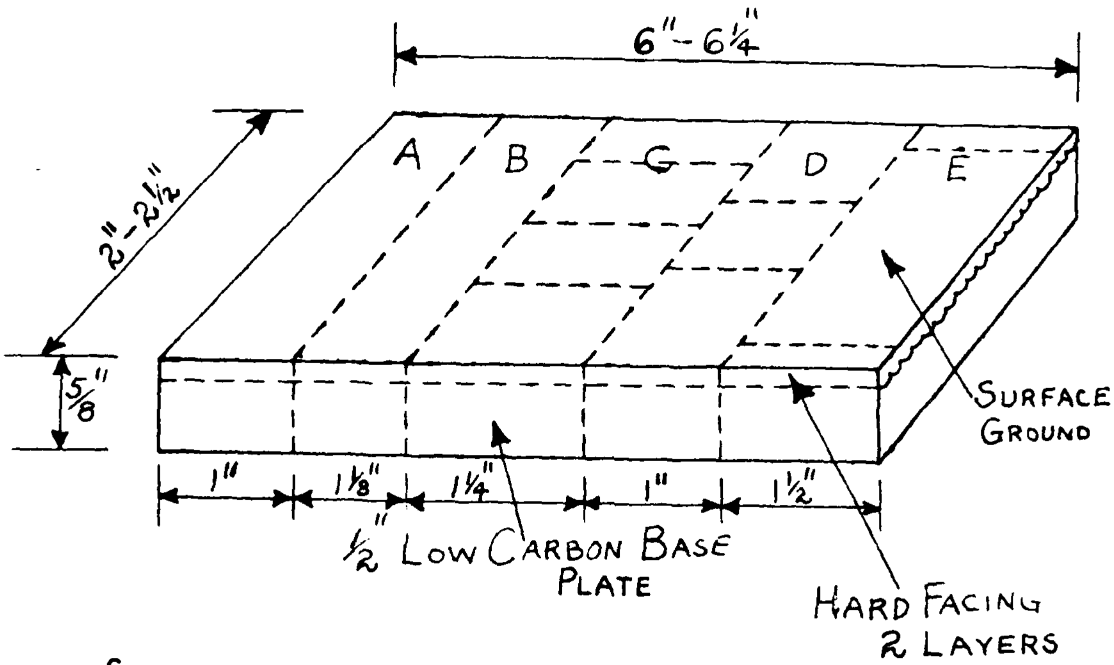
TABLE I - Continued

Sample No.	Electrode	Amperes	Volts	Weld Beads	Elec. Res. Covering	X-Ray Data	Remarks
11*	K - 1/4"	185	24	13/16 Wea.	Too low	Badly cracked	N.G. for Abrasive Test
12	L - 3/16"	180	20	------	O.K. 90V.	Scattered porosity No cracks	O.K. for Abrasive Test
13	M - 5/32"	125	22	3/8" Wea.	------	Scattered porosity No cracks	O.K. for Abrasive Test
14	N - 5/32"	160	21	5/8" Wea.	Too low	Badly cracked	N.G. for Abrasive Test
15	O - 5/32"	165	20	5/8" Wea.	Too low	Badly cracked	N.G. for Abrasive Test
16	P - 5/32"	160	22	5/8" Wea.	Too low	Badly cracked	N.G. for Abrasive Test
17	Q - 5/32"	148	19	5/8" Wea.	Below 40V.	One crack	O.K. for Abrasive Test
18	R - 5/32"	148	19	5/8" Wea.	O.K. 90V.	No cracks	O.K. for Abrasive Test
19	S - 5/32"	148	19	5/8" Wea.	Below 30V.	No cracks	O.K. for Abrasive Test

* One layer only. Others two layers.

General Note: Direct current, reverse polarity (electrode positive)
Base metal plain low carbon steel plate 1/2" thick
No preheat. Interpass temperature 300° F. maximum.

TABLE I - Continued



Section

A – Hold for Check & Special Tests

B – Spectrograph & Chemical Analysis (Figure 4)

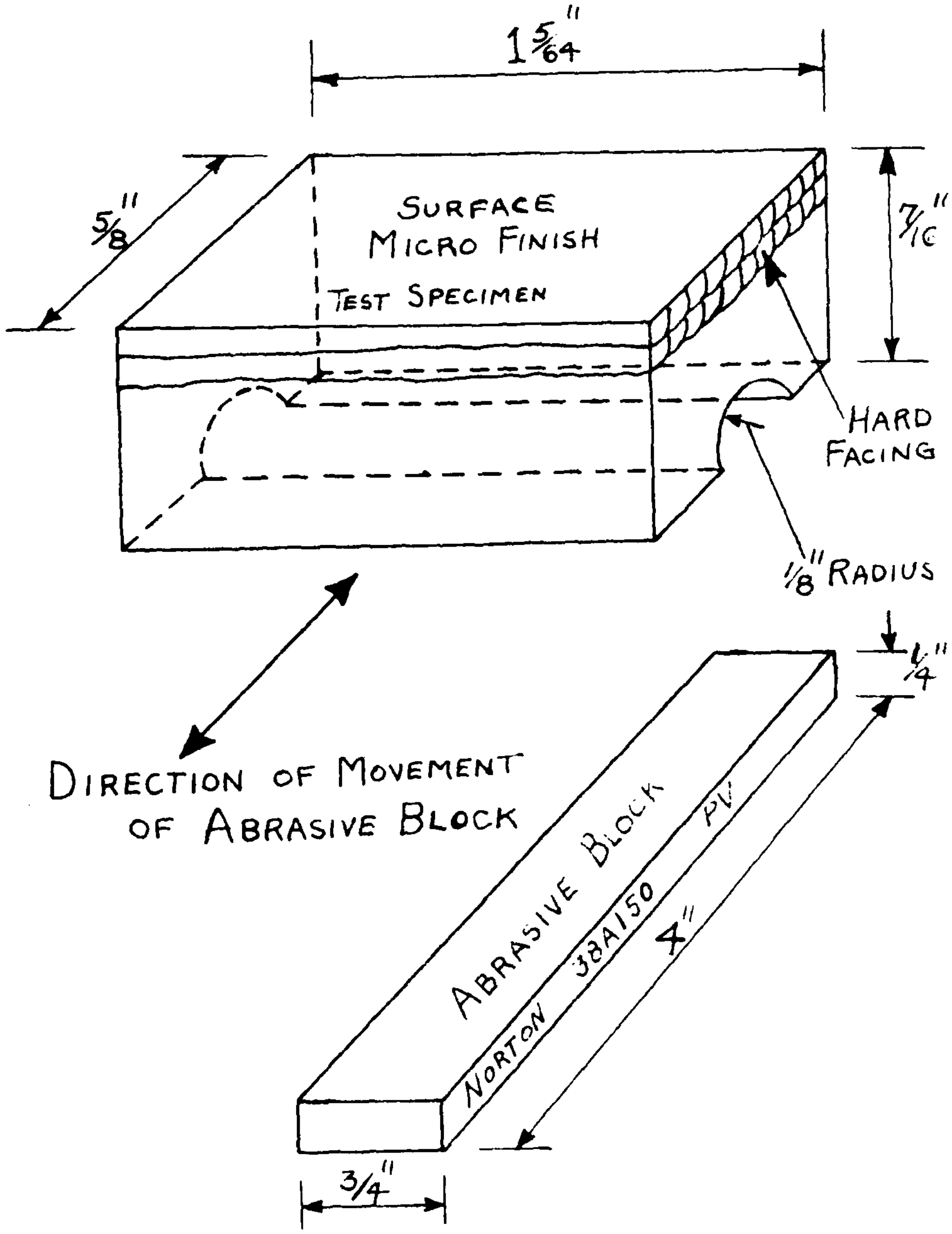
C – Abrasion Test (Figure 2)
2 Specimens

D – Micro & Vickers Hardness Test (Figure 3)

E – Corrosion Test (Figure 5)

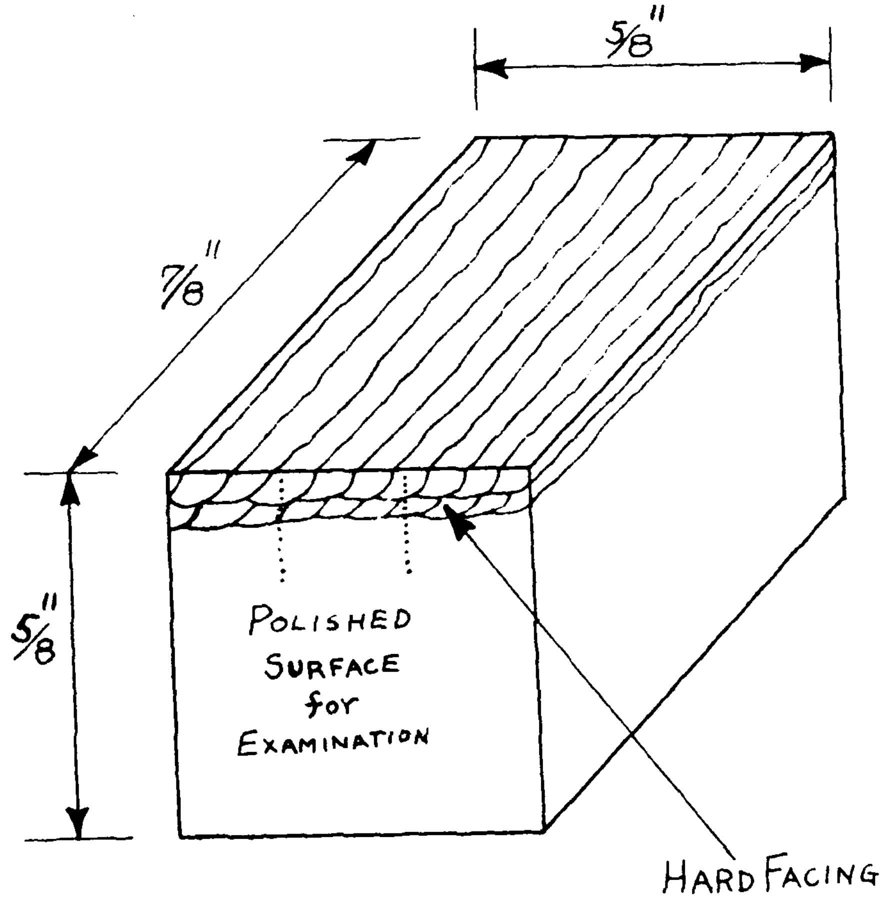
Hard Facing Deposit Layout

Figure 1



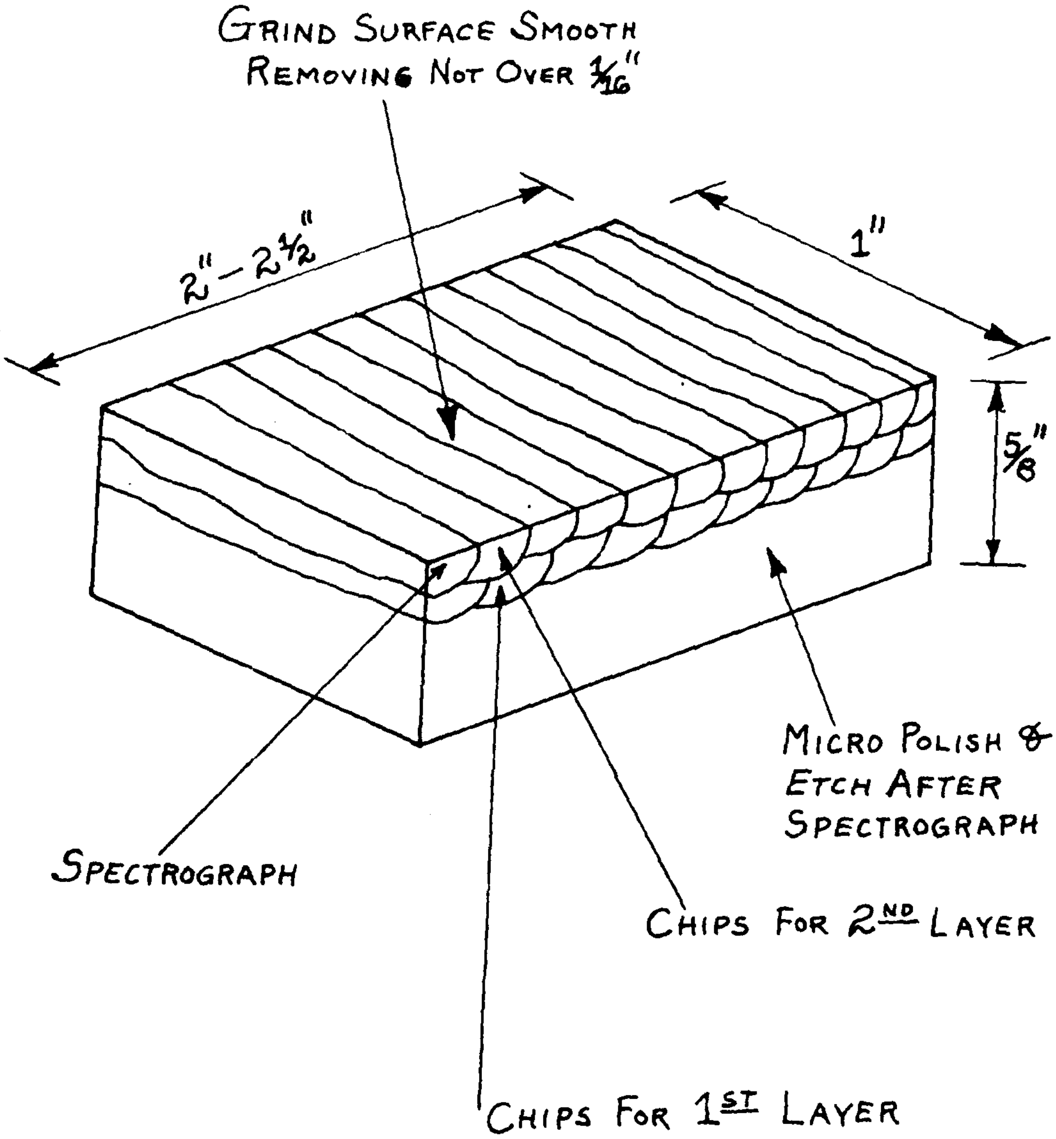
Test Specimen & Abrasive Block

Figure 2



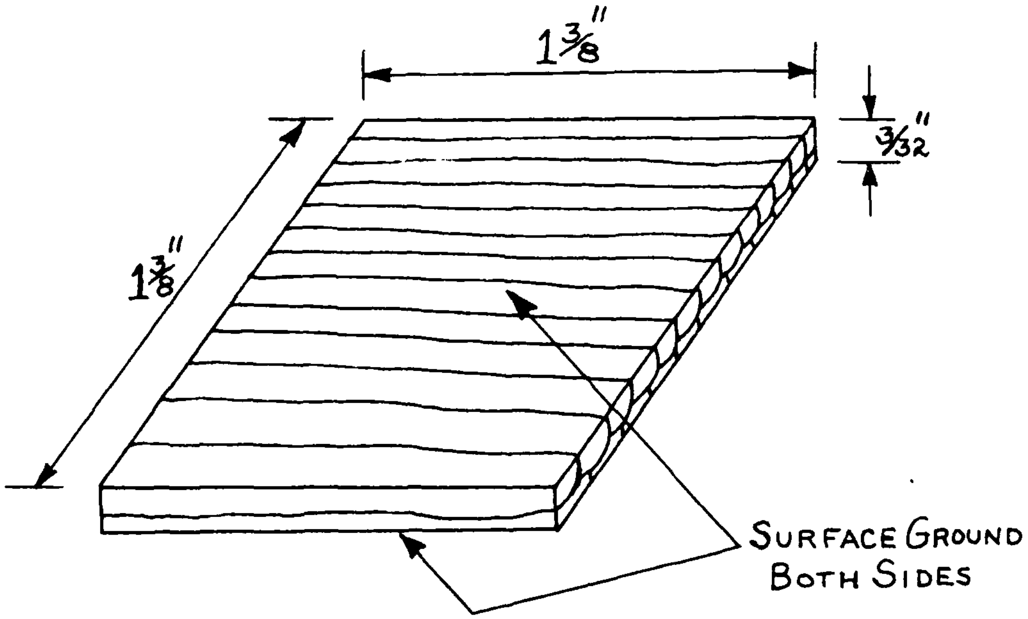
SPECIMEN
for
HARDNESS & MICRO

FIGURE 3



SPECIMEN
for
SPECTROGRAPH & CHEMICAL ANALYSIS

FIGURE 4



CORROSION SPECIMEN
OF
HARD FACING METAL

FIGURE 5

TABLE II

Chemical Composition of Weld Metals (%)

Sample	C	Mn	Si	S	P	Ni	Cr	Mo	V	Cu	W	Electrode
1	0.56	0.19	0.39	0.028	0.024	0.13	3.19	1.99	0.06	0.13	—	A
2	0.66	3.99	0.44	0.015	0.010	0.07	3.85	0.14	0.14	0.03	4.67	B
3	0.395	1.28	0.86	0.018	0.009	0.09	11.21	0.04	0.115	0.16	—	C
4	0.43	3.40	0.40	0.013	0.023	0.09	3.25	0.07	0.06	0.03	4.97	D
5	0.36	0.72	0.47	0.014	0.006	0.07	2.76	6.89	0.66	0.01	0.90	E
8	0.45	0.85	0.82	0.013	0.008	0.08	10.26	0.04	0.12	0.03	—	H
9	0.75	0.93	0.47	0.012	0.023	0.07	8.69	0.41	0.08	0.06	—	I
12	0.335	0.33	0.28	0.015	0.008	0.04	2.64	5.88	0.66	0.01	1.06	L
13	0.845	0.74	0.53	0.012	0.021	0.06	7.46	0.39	0.08	0.08	—	M
17	0.57	0.98	0.71	0.015	0.025	0.18	5.27	0.47	0.12	0.08	—	Q
18	0.505	4.34	0.83	0.010	0.027	7.33	16.17	0.68	0.19	0.10	—	R
19	0.705	4.34	0.79	0.012	0.033	8.64	16.83	0.03	0.20	0.08	—	S

TABLE II

TABLE III

Abrasion Test Data (6-hour run)

Specimen	Electrode	Weight-grams Before	After	Lost	Thickness-in. Before	After	Wear	Rockwell "C"
1	A	33.4445	33.1160	0.3285	0.4375	0.4323	0.0052	54 - 56
2	B	33.4947	33.3845	0.1102	0.4366	0.4353	0.0013	49 - 51
3	C	33.4045	32.7480	0.6565	0.4439	0.4330	0.0109	52 - 54
4	D	33.9095	33.8300	0.0795	0.4363	0.4356	0.0007	50 - 57
5	E	34.3045	34.0040	0.3005	0.4429	0.4382	0.0047	52 - 56
8	H	33.4125	32.8020	0.6105	0.4396	0.4296	0.0100	53 - 54
9	I	33.2780	32.9710	0.3070	0.4387	0.4336	0.0051	48 - 52
12	L	34.0135	33.5640	0.4495	0.4432	0.4361	0.0071	51 - 57
13	M	33.4540	33.2545	0.1995	0.4389	0.4360	0.0029	42 - 55
17	Q	34.7460	34.2760	0.4700	0.4427	0.4345	0.0082	54 - 61
18	R	34.4405	32.9585	1.4820	0.4428	0.4179	0.0249	19 - 21
19	S	32.4263	31.5546	0.8717	0.4143	0.3997	0.0146	24 - 26

Test Conditions: Load on specimen 50 lb.
Unit pressure on abrasion surface 107 lb.sq.in.
Length of stroke 1"
Rate of stroke 60/min. (See Figure 2)
Time of run 6 hours.
Abrasive block immersed in Salvasol #5

TABLE III

TABLE IV

Abrasion Test Data (3-hour run)

Specimen	Electrode	Weight-grams Before	Weight-grams After	Weight-grams Lost	Thickness-in. Before	Thickness-in. After	Thickness-in. Wear	Rockwell "C"
2	B	34.4145	34.3642	0.0503	0.4338	0.4329	0.0009	47 - 51
3	C	32.3560	32.2324	0.1236	0.4260	0.4240	0.0020	52 - 55
4	D	34.4920	34.4505	0.0415	0.4377	0.4370	0.0007	49 - 54
5	E	34.5260	34.4985	0.0275	0.4382	0.4378	0.0004	51 - 56
8	H	33.8255	33.7260	0.0995	0.4380	0.4360	0.0020	54 - 57
9	I	33.9175	33.8435	0.0740	0.4387	0.4376	0.0011	45 - 51
12	L	32.7440	32.6020	0.1420	0.4125	0.4105	0.0020	51 - 59
13	M	33.8160	33.6825	0.1335	0.4385	0.4360	0.0025	47 - 57

Test Conditions: Load on specimen 50 lb.
Unit pressure on abrasion surface 107 lb/sq.in.
Length of stroke 1"
Rate of stroke 60/min.
Time of run 3 hours. (See Figure 2)
Abrasive block immersed in Salvasol #5

TABLE V

Weight Lost & Abrasive Wear vs. Time of Test*

Sample No.	Weight Lost - Grams 3-Hour Test	6-Hour Test	Ratio*	Abrasive Wear - Inches 3-Hour Test	6-Hour Test	Ratio*
2	.0503	.1102	2.20	.0009	.0013	1.45
3	.1236	.6565	5.30	.0020	.0109	5.45
4	.0415	.0795	1.93	.0007	.0007	1.00
5	.0275	.3005	10.90	.0004	.0047	11.75
8	.0995	.6105	6.15	.0020	.0100	5.00
9	.0740	.3070	4.16	.0011	.0051	4.65
12	.1420	.4495	3.16	.0020	.0071	3.55
13	.1335	.1995	1.48	.0025	.0029	1.16

*Using the value for the 3-Hour Test as unity

TABLE Va

Comparison of Metals on the Basis of Weight Lost & Abrasive Wear

Sample No.	Weight Lost 3 Hours	6 Hours	Abrasive Wear 3 Hours	6 Hours
2	1.83	1.39	2.25	1.86
3	4.50	8.30	5.00	15.60
4	1.51	1.00	1.75	1.00
5	1.00	3.82	1.00	6.71
8	3.61	7.70	5.00	14.30
9	2.69	3.86	2.75	7.30
12	5.17	5.65	5.00	10.10
13	4.85	2.51	6.25	4.15

TABLES V & Va

TABLE VI

Vickers Hardness Range (10 Kg. Load)

Specimen	Maximum	Average	Minimum
1	657	602	548
2	585	505	394
3	649	572	514
4	665	595	525
5	613	551	425
8	620	566	525
9	642	524	417
12	627	524	401
13	620	529	478

TABLE VII

Weight Lost in 10% Sodium Chloride Solution (Mg/Dm2)
at Room Temperature

Specimen	Hours in Solution 21	44	66	75	88	110	124	132	147	154	Remarks
Low C. Steel	46.5	96.5	134		184	223		283		368	Control Spec.
18/8	2.1	2.1		3.5			1.8		3.9		Control Spec.
1	53.6	123	184		224	272		347		408	
2	59.0	123	171		216	258		357		417	
3	41.1	96.5	150		190	230		282		328	
4	53.6	125	167		221	264		351		412	
5	53.6	119	152		188	229		301		346	
8	35.7	85.8	121		150	180		201		213	
9	41.2	95.2		167			281		322		
12	59.7	114	169		240	280		350		407	
13	55.7	121	164		205	246		306		367	

TABLE VII

ELECTRODE D　　ELECTRODE E　　ELECTRODE F

1 NOV 1946

FIGURE 7

WTN.121-682

ELECTRODE M

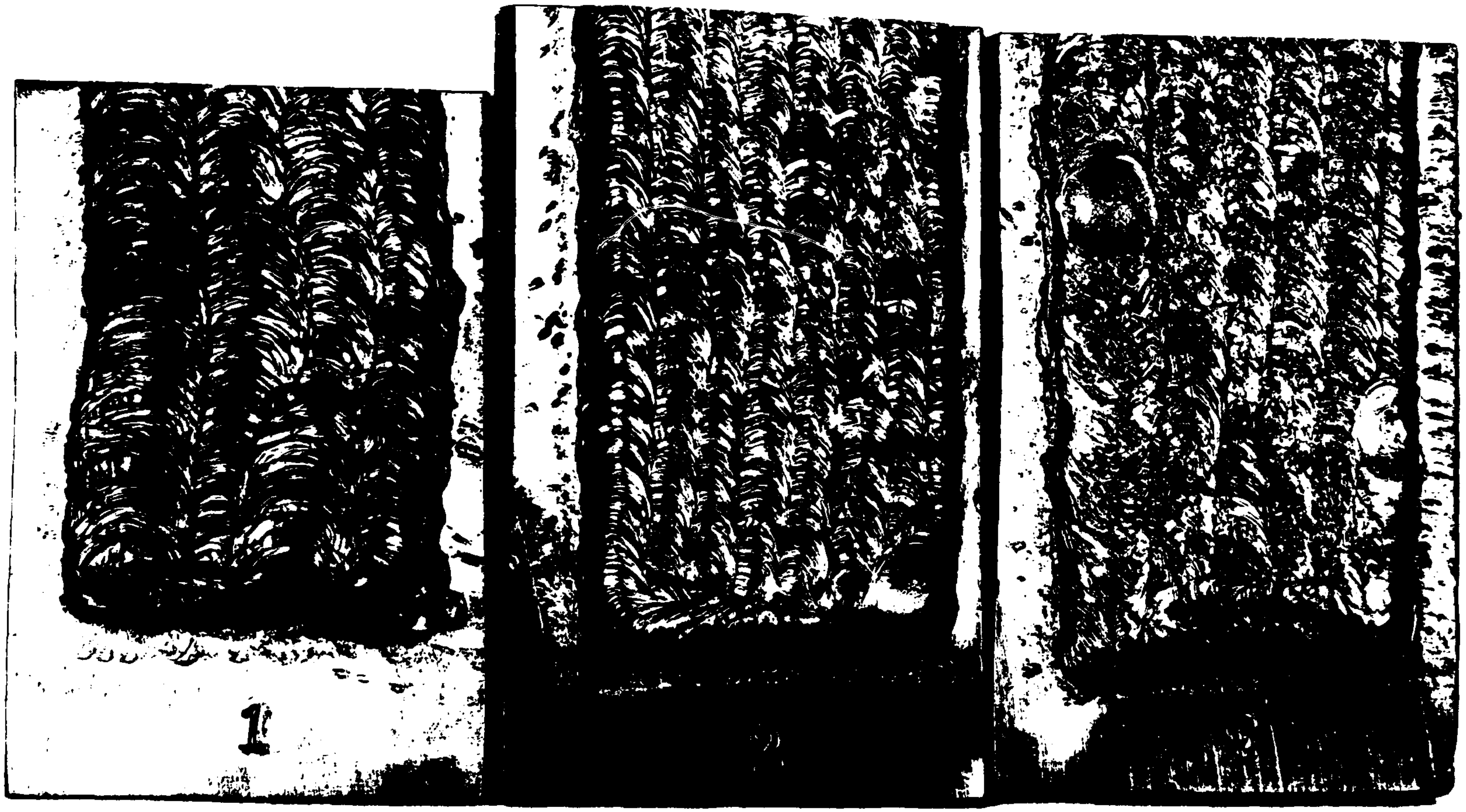
ELECTRODE H

ELECTRODE I

1 NOV 1946

FIGURE 8

WTN.121-683

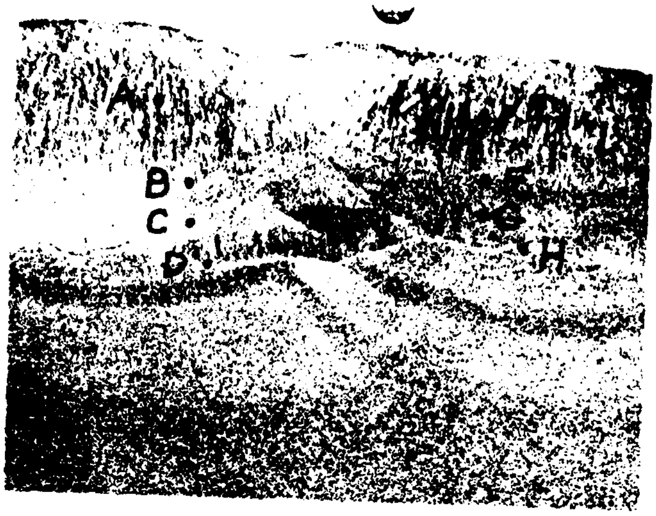


ELECTRODE A ELECTRODE B ELECTRODE C

1 NOV 1946

FIGURE 6

WTN.121-681

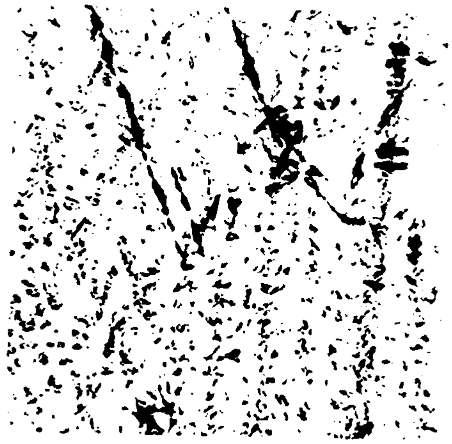


Weld Metal

Base Metal

SPECIMEN NO. 1 x3

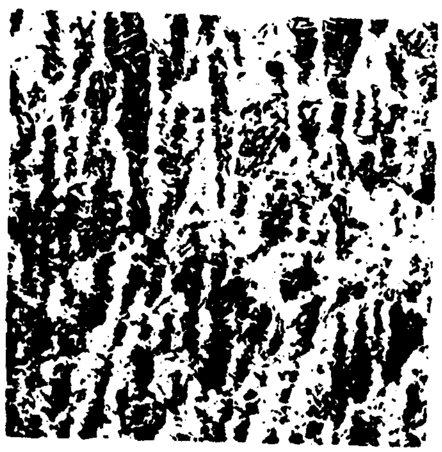
2ND Layer

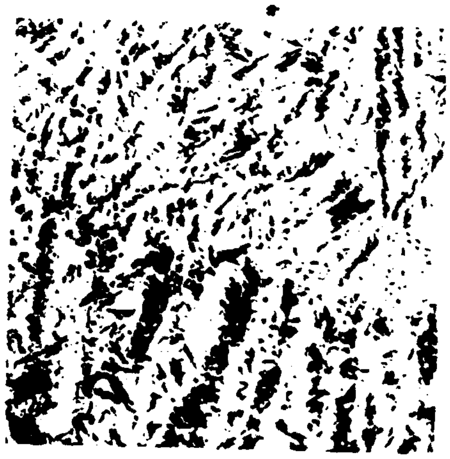


A X250 E

2ND Layer

1ST Layer

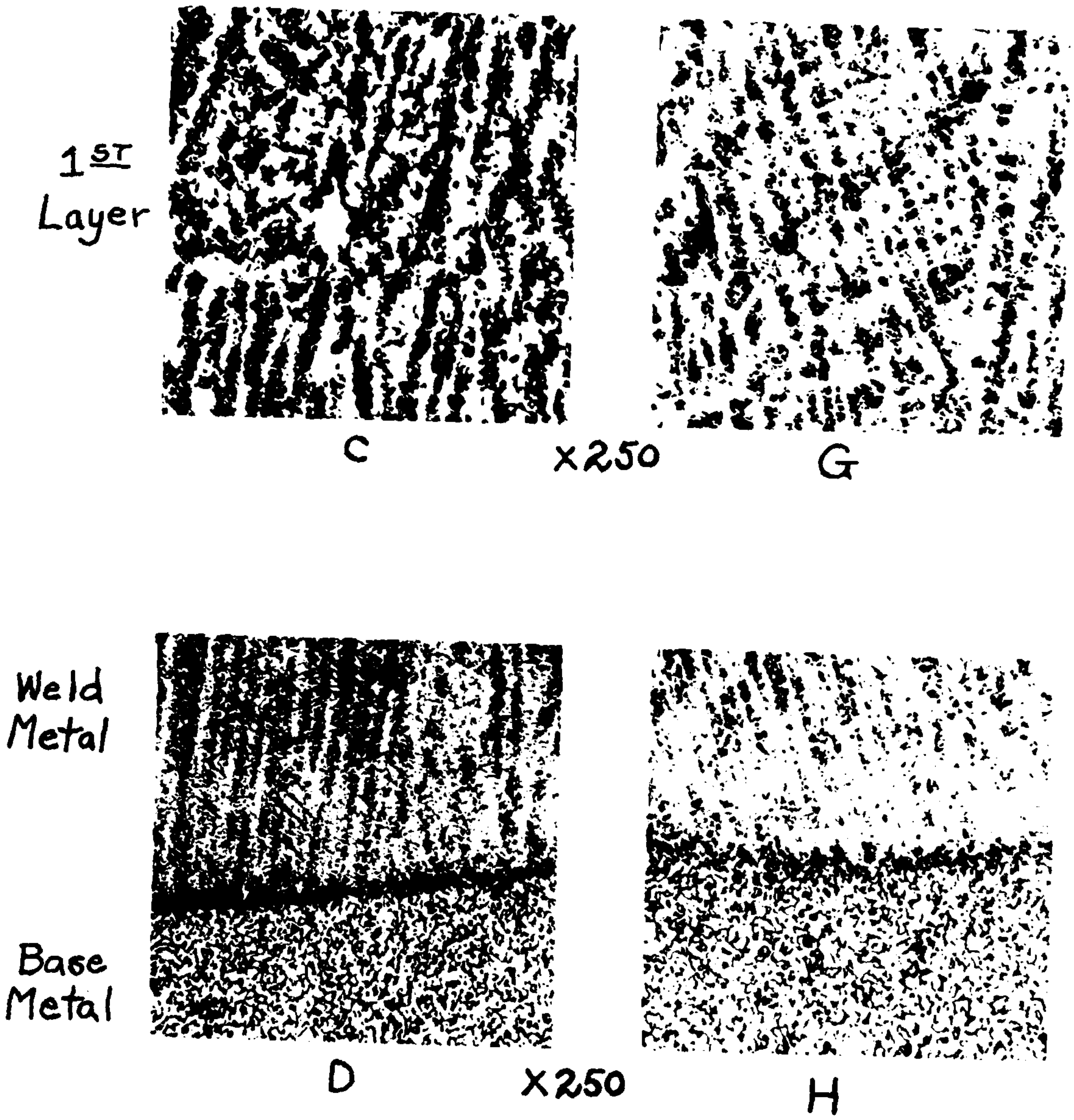




WTN.639-9281

B X250 F

1



HARD-FACING METAL, ELECTRODE A

WTN.639-9282

FIGURE NO. 9

2

E X1000

F X1000

WTN 63Q-0283

G X1000

1

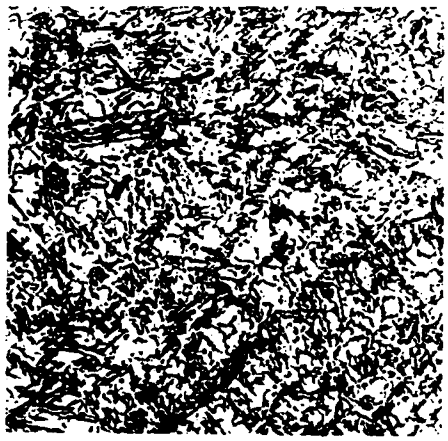
3

Weld Metal

Base Metal

SPECIMEN NO. 2 x3

2ND Layer



A X250 E

2ND Layer

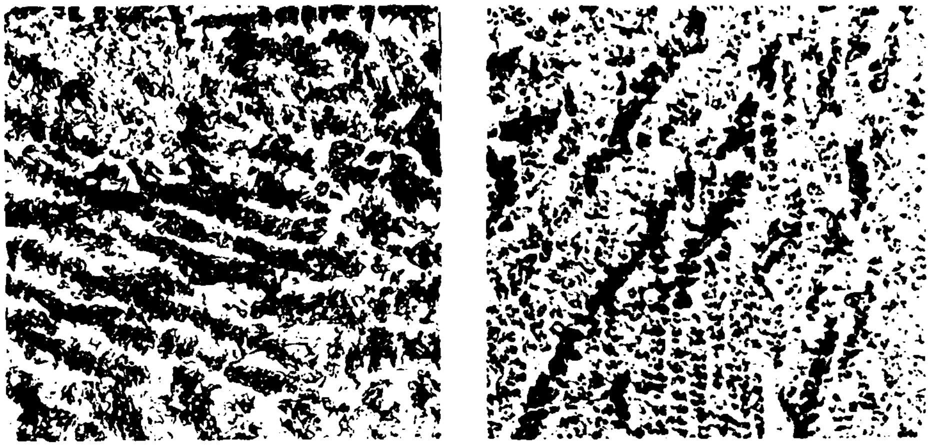
1ST Layer

WTN.639-9284

B X250 F

1

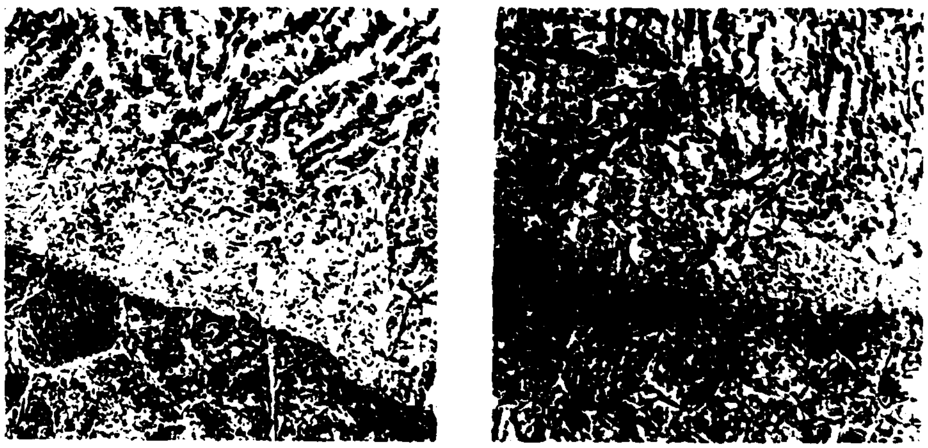
1st Layer



C x250 G

Weld Metal

Base Metal



D x250 H

HARD-FACING METAL, ELECTRODE B

WTN.639-9285

FIGURE NO. 10

2

E X1000

F X1000

WTN.639-9286

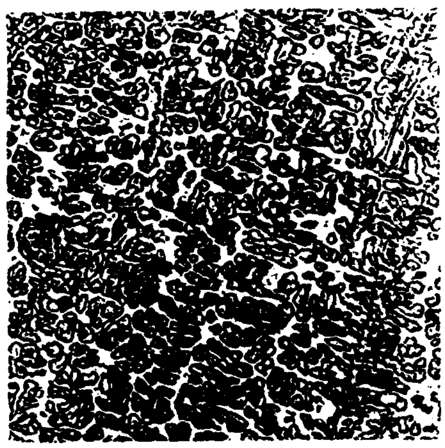
G X1000

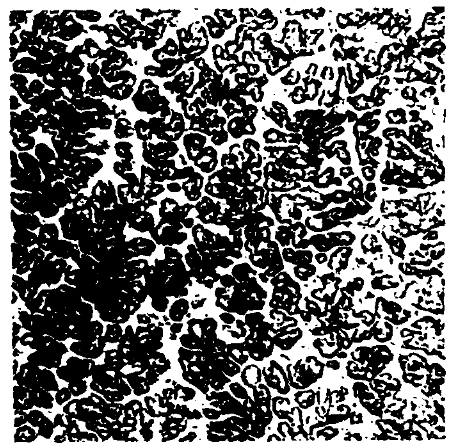
②

3

SPECIMEN NO. 3 x3

2ND Layer

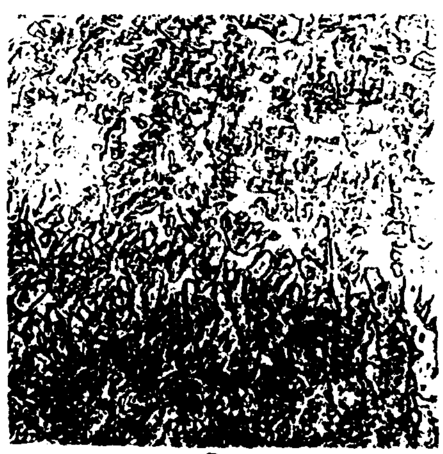




A X250 E

2ND Layer

1ST Layer



WTN.639-9287

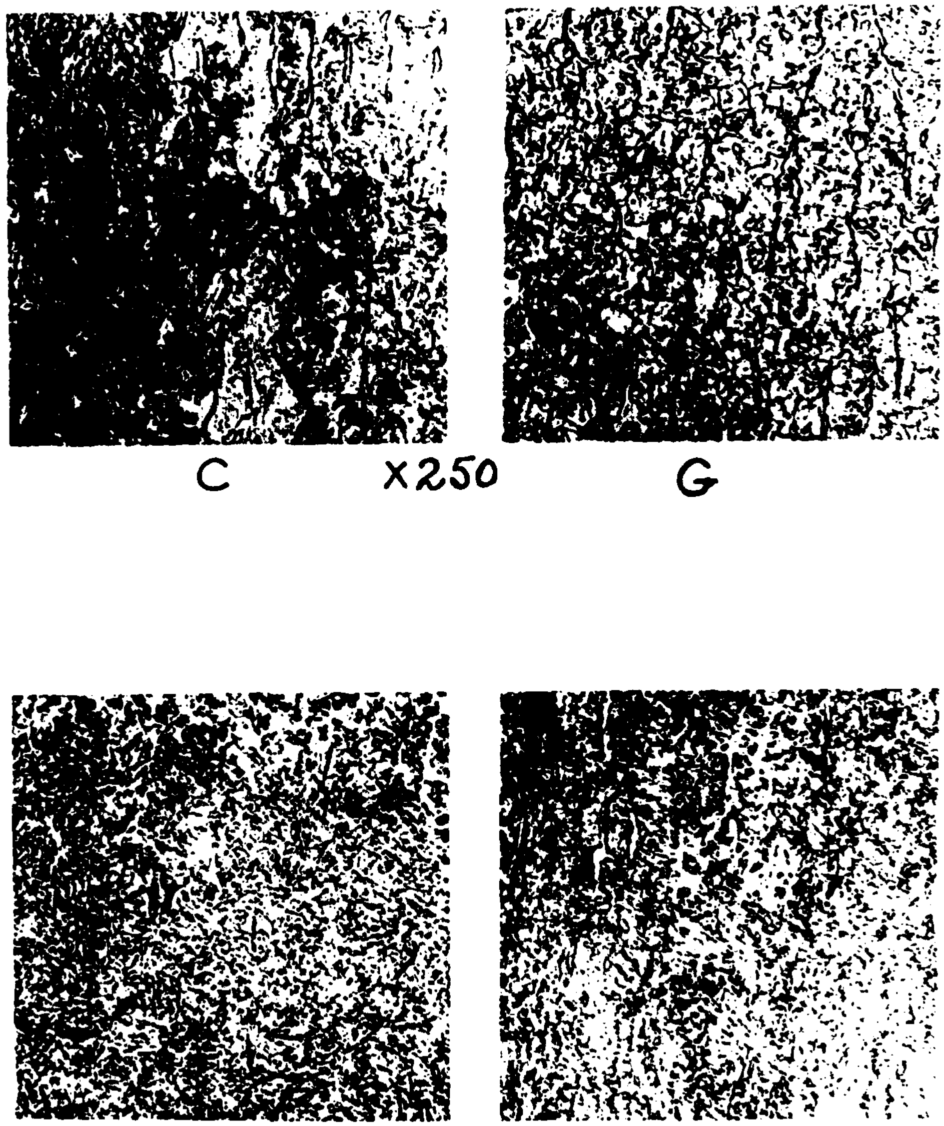
B X250 F

1

1st Layer

Weld Metal

Base Metal



C X250 G

D X250 H

HARD-FACING METAL, ELECTRODE C

WTN.639-9288

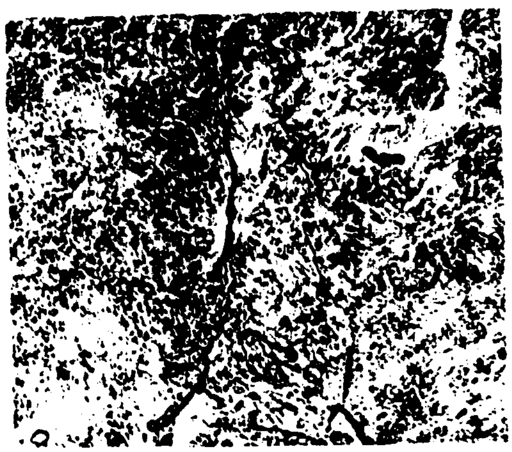
FIGURE NO. 11

2

E X1000

F X1000

WTN.639-9289

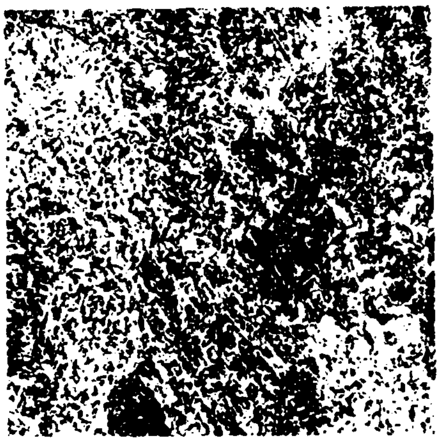


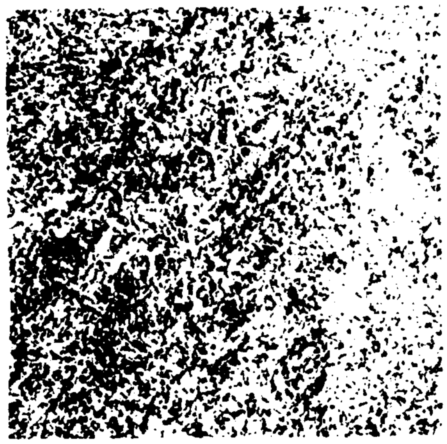
G X1000

3

SPECIMEN NO. 4 x3

2ND Layer

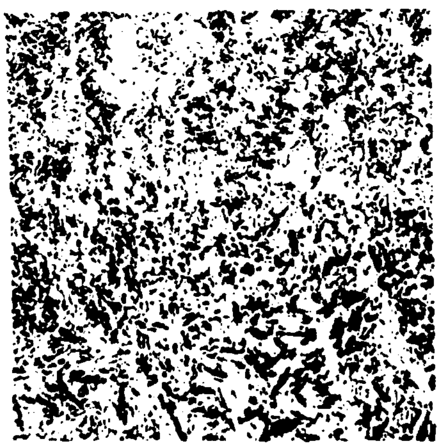


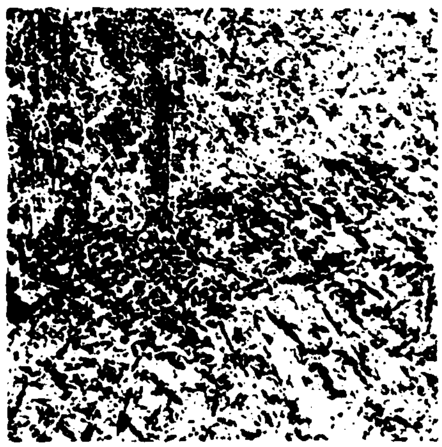


A x250 E

2ND Layer

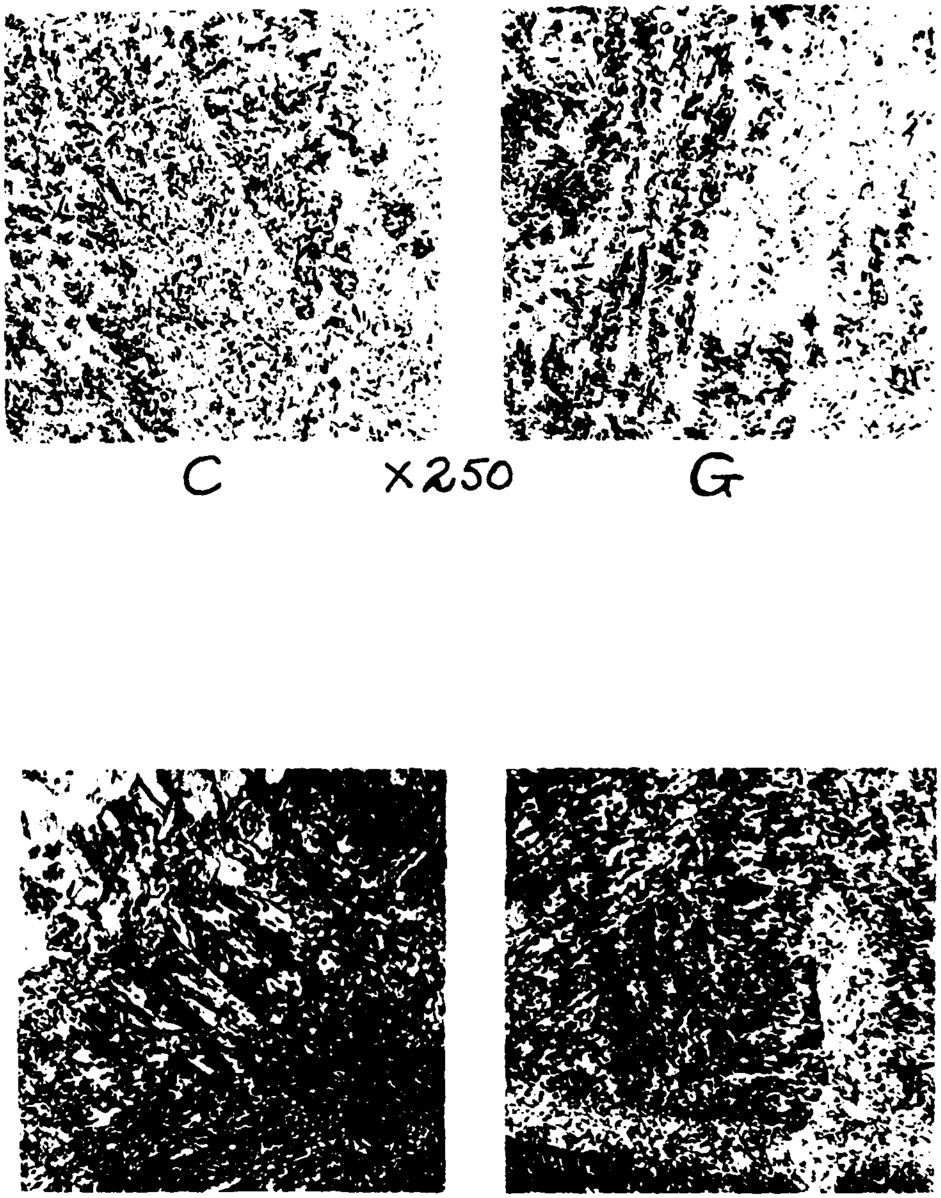
1ST Layer





WTN.639-9290

B x250 F



HARD-FACING METAL, ELECTRODE D

WTN.639-9291

FIGURE NO. 12

2

E ×1000

F ×1000

WTN.639-9292

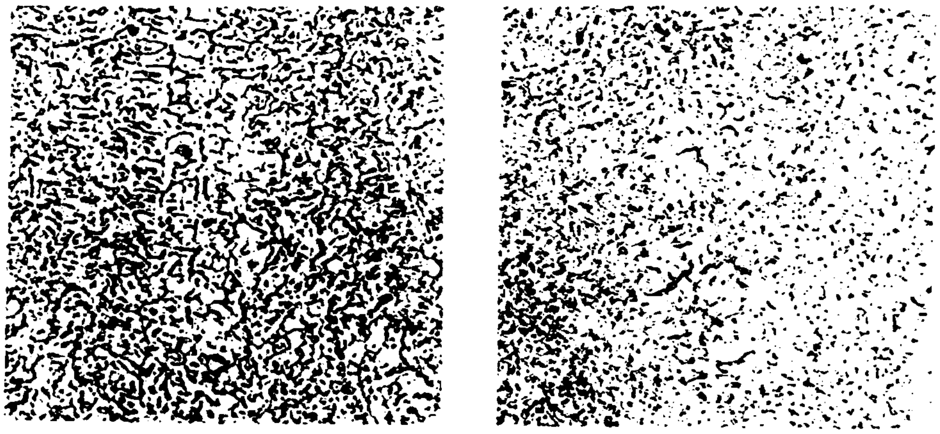
G ×1000

4

3

SPECIMEN NO. 5 x3

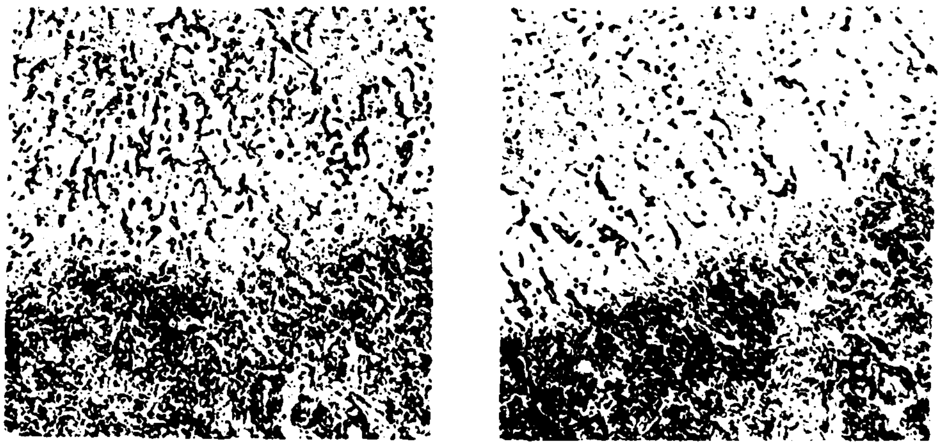
2ND Layer



A x250 E

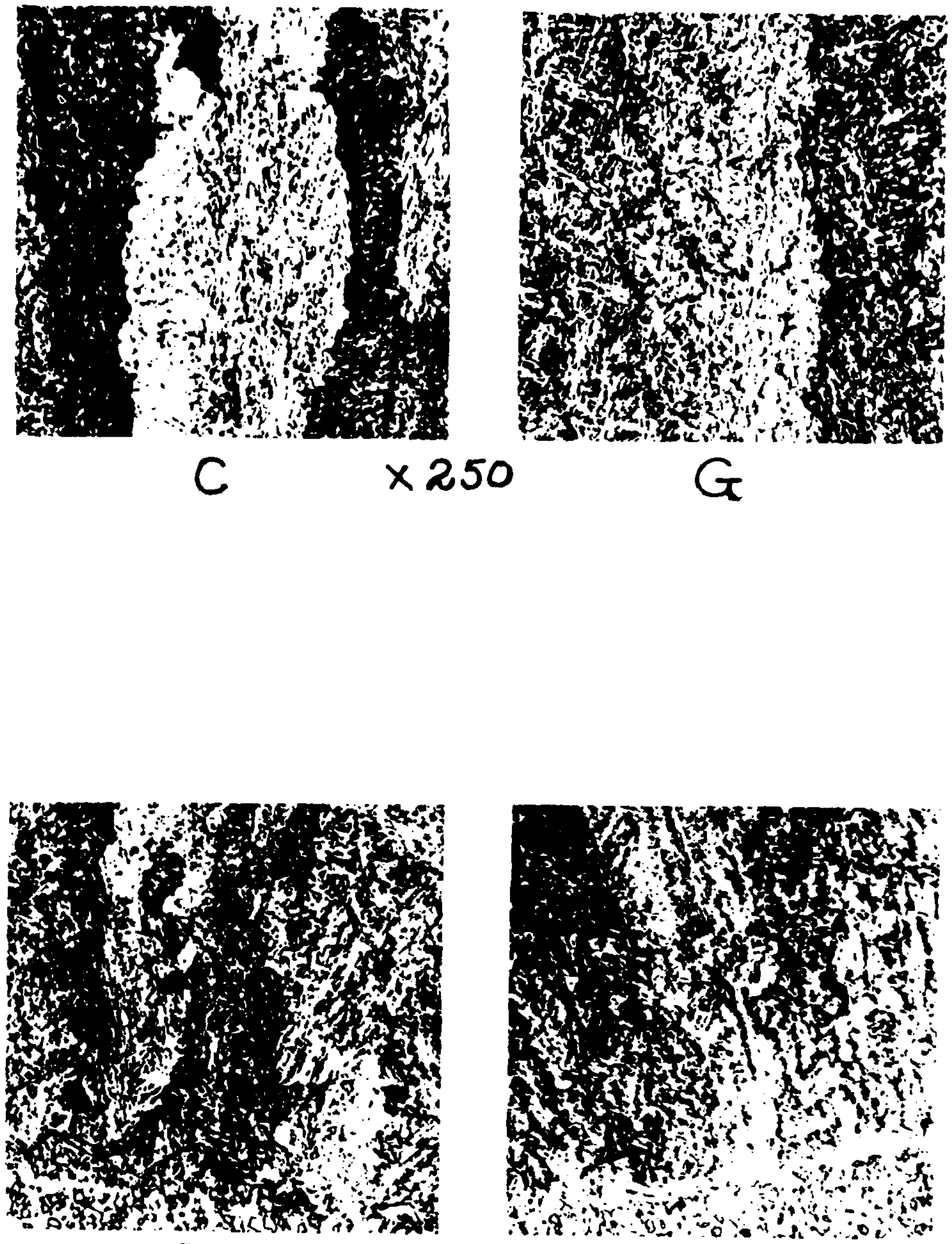
2ND Layer

1ST Layer



WTN.639-9293

B x250 F

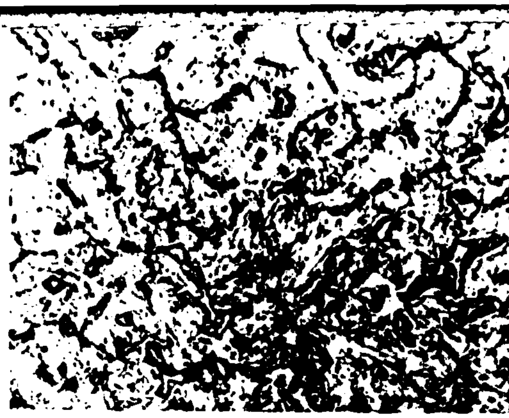


WTN.639-9294

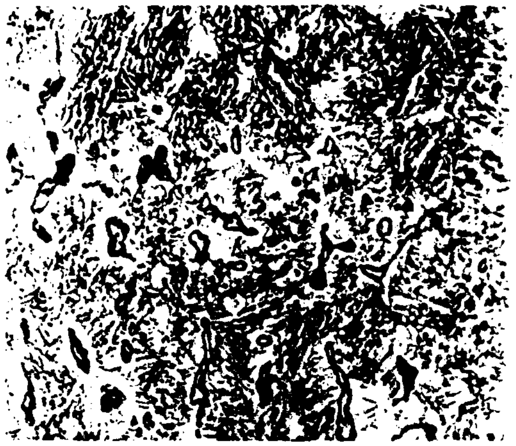
HARD-FACING METAL, ELECTRODE E

FIGURE NO. 13

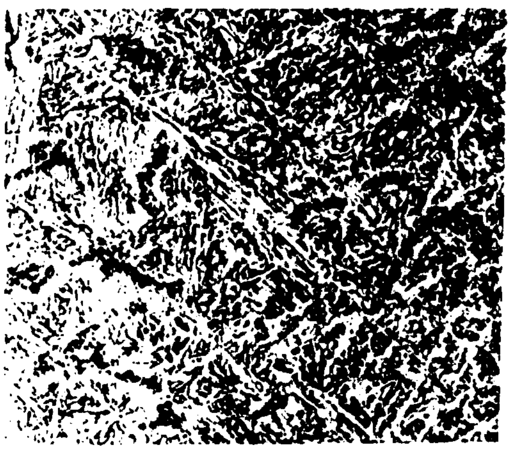
2



E X1000



F X1000

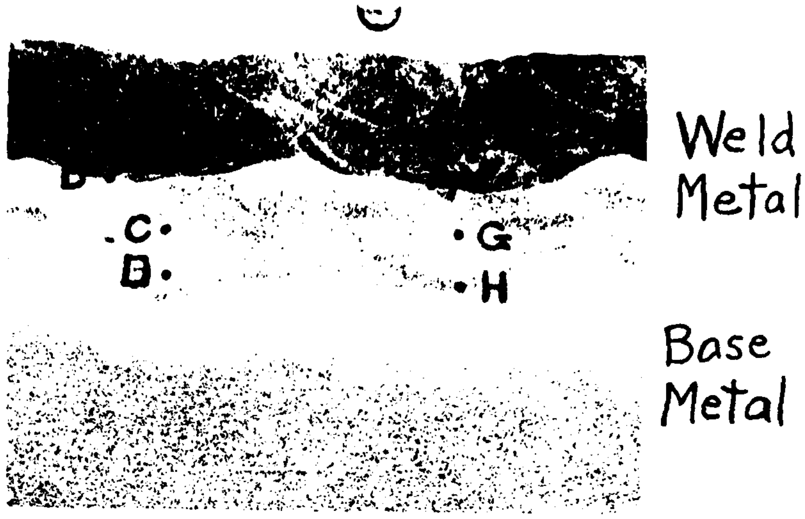


G X1000

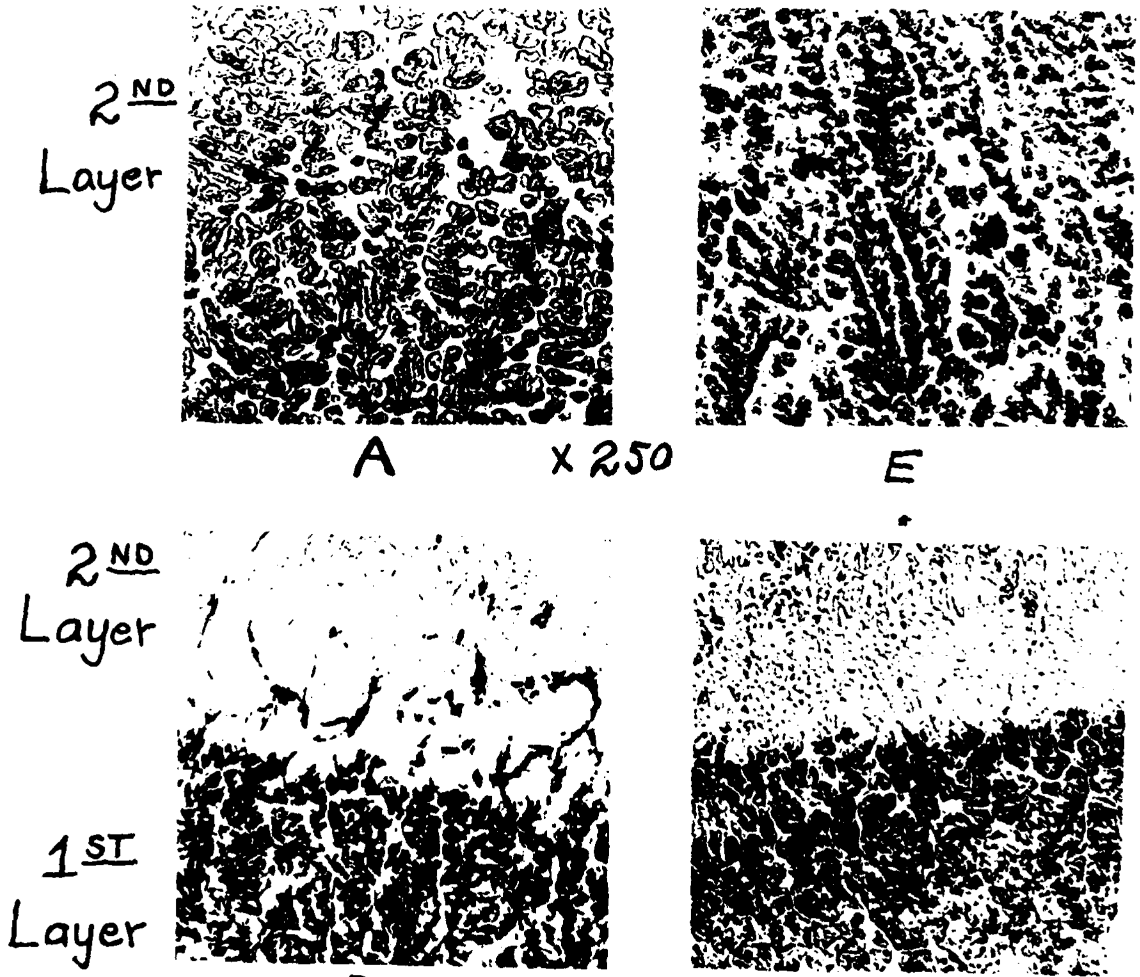
WTN.639-9295

⑤

3



SPECIMEN NO. 8 x3



A x250 E

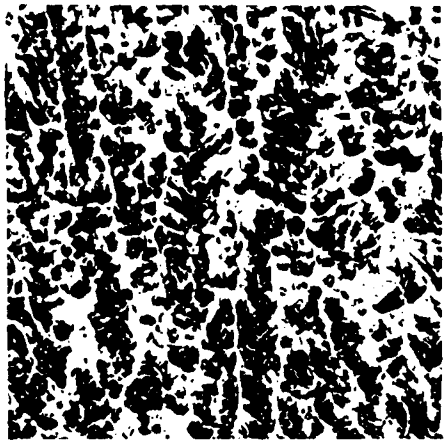
B x250 F

WTN.639-9296

Weld Metal

Base Metal

1ST Layer



C ×250 G

Weld Metal

D ×250 H

Base Metal

HARD-FACING METAL, ELECTRODE

WTN.639-9297

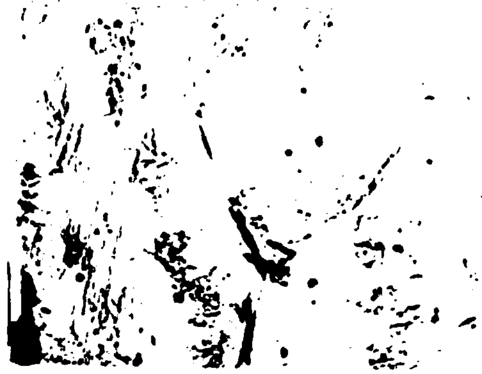
FIGURE NO. 14

2

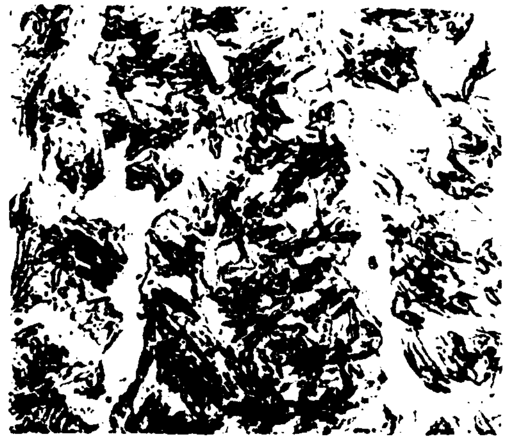
G

H

'RODE H



E ×1000

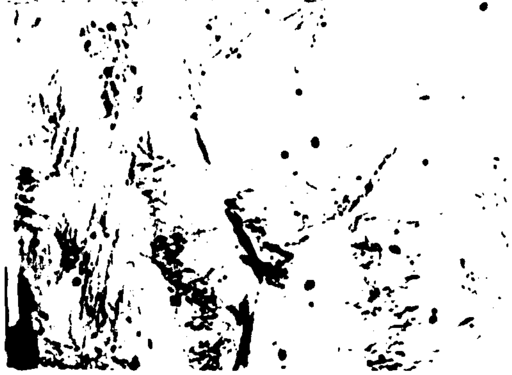


F ×1000

G ×1000

WTN.639-9298

3



E ×1000

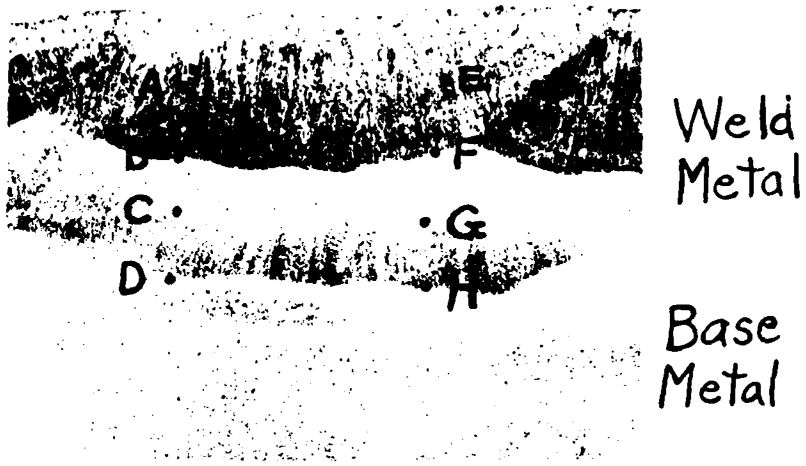
F ×1000

WTN.639-9298

G ×1000

(8)

4

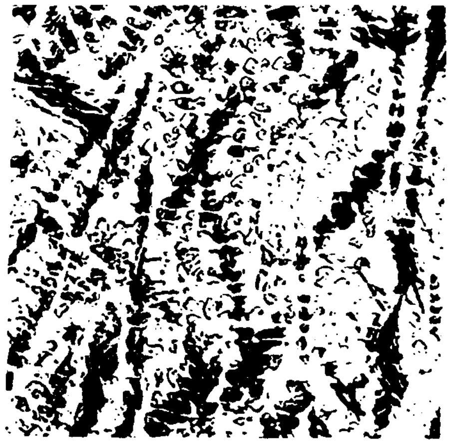


SPECIMEN NO. 9 x3

2ND Layer

A

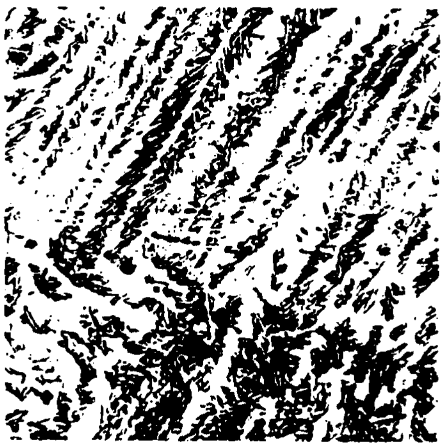
x250



E

2ND Layer

1ST Layer

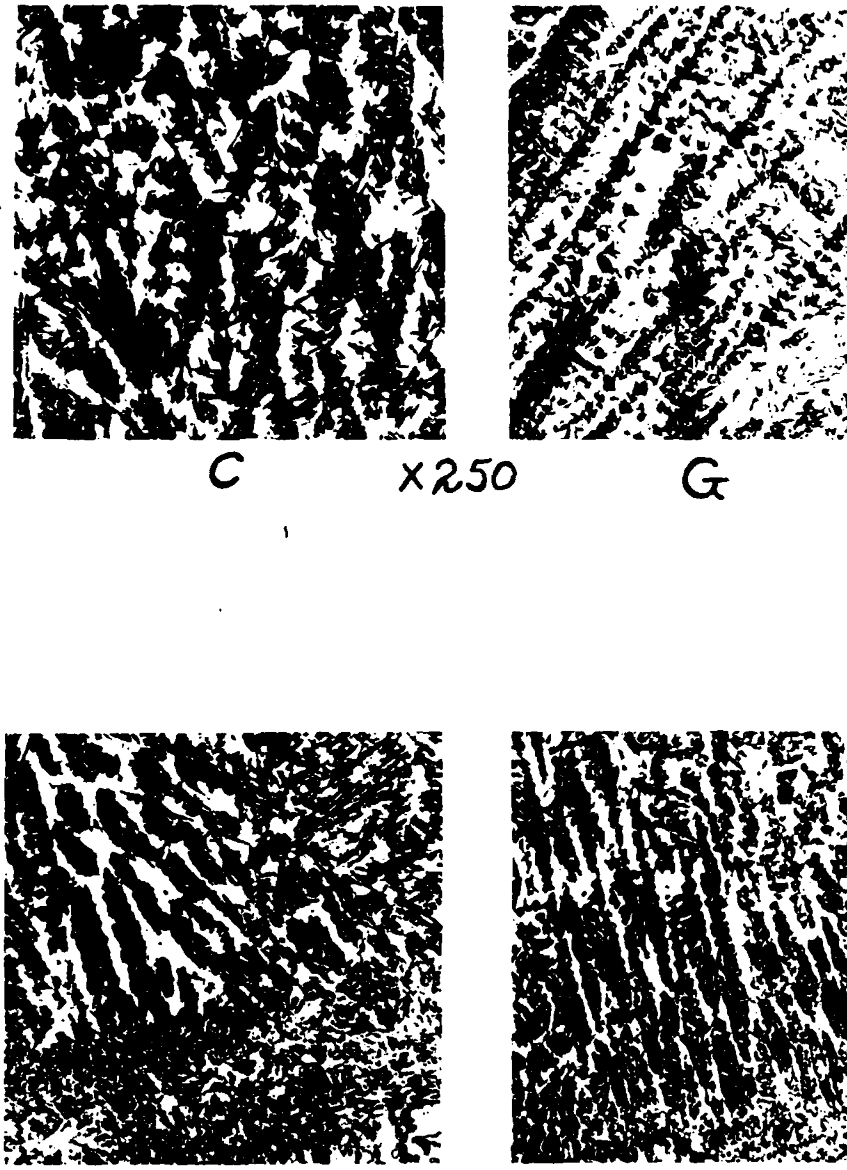


B

x250

F

WTN.539-0299



HARD-FACING METAL, ELECTRODE I

WTN.639-9300

FIGURE NO. 15

2

)DE I

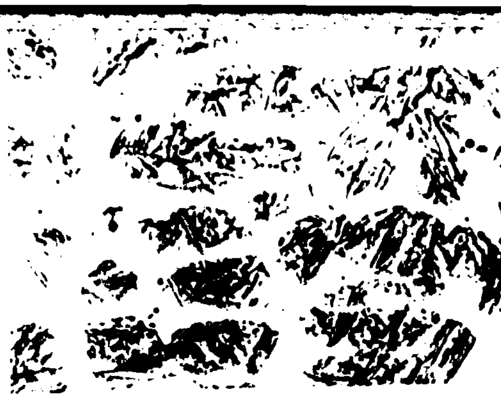
WTN.639-9301

E ×1000

F ×1000

G ×1000

3



E ×1000

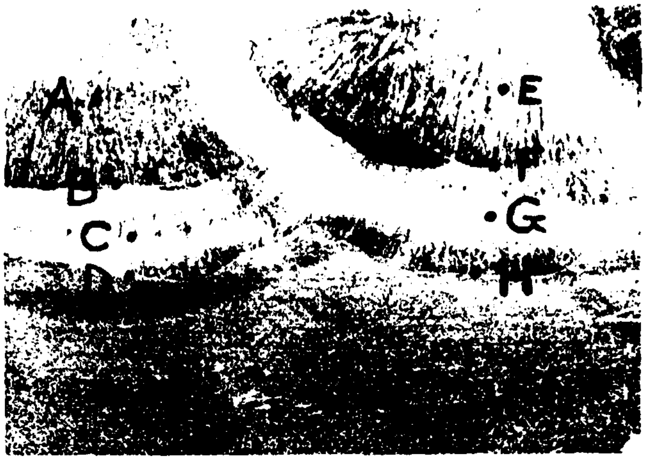
F ×1000

WTN.639-9301

G ×1000

⑨

4

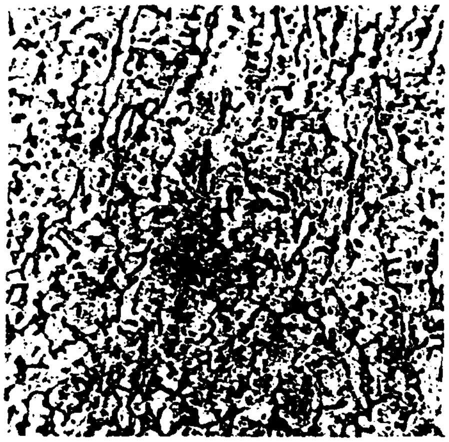


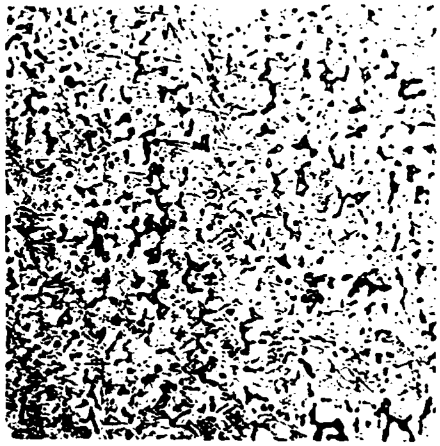
Weld Metal

Base Metal

SPECIMEN NO. 12 x3

2^ND^ Layer



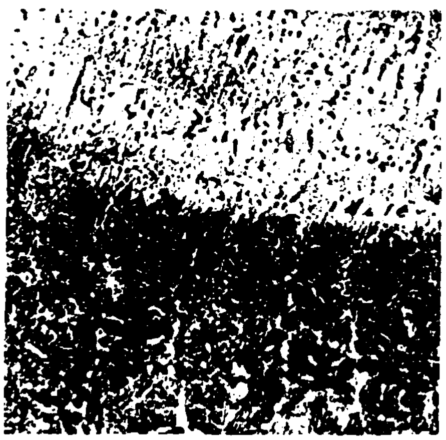


A x250 E

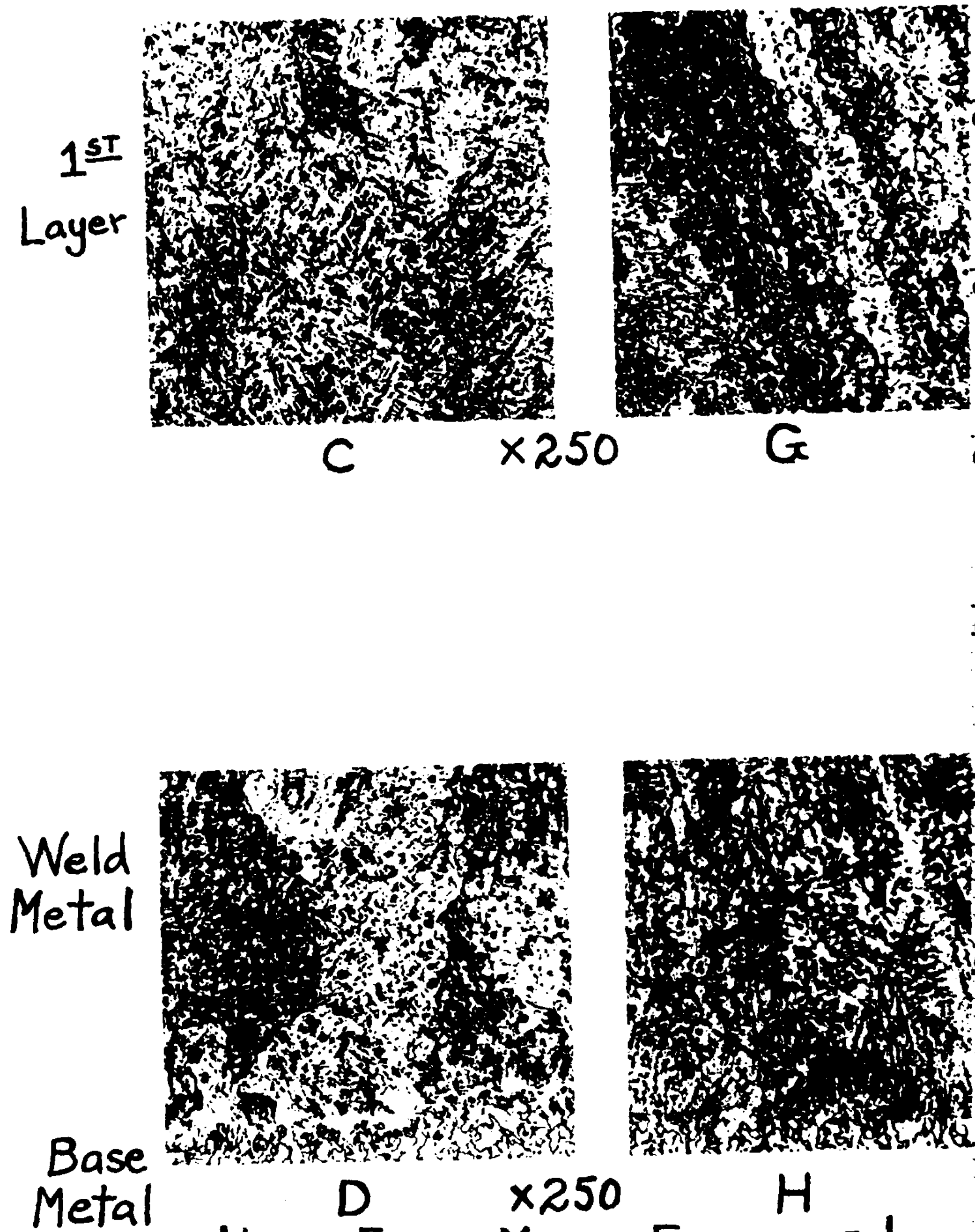
2^ND^ Layer

1^ST^ Layer

WTN.639-9302



B X250 F



WTN.639-9303

HARD-FACING METAL, ELECTRODE L

FIGURE NO. 16

2

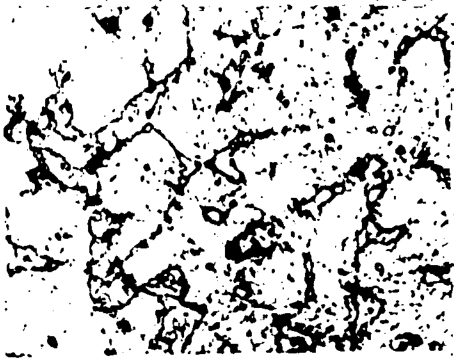
G

H

ELECTRODE L

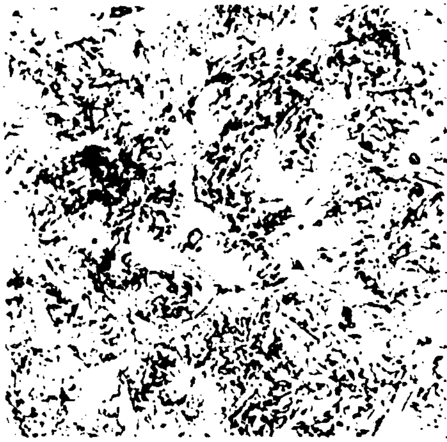
3

WTN.639-9304



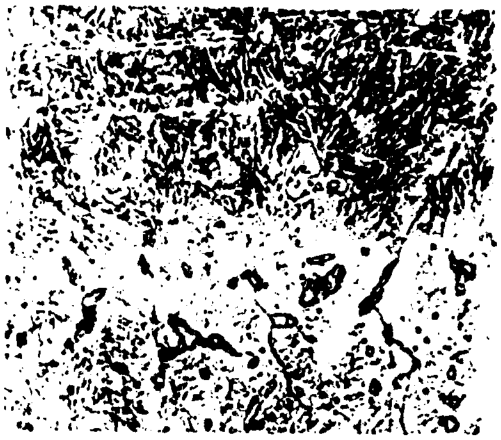
E x1000

F x1000



G x1000

E ×1000



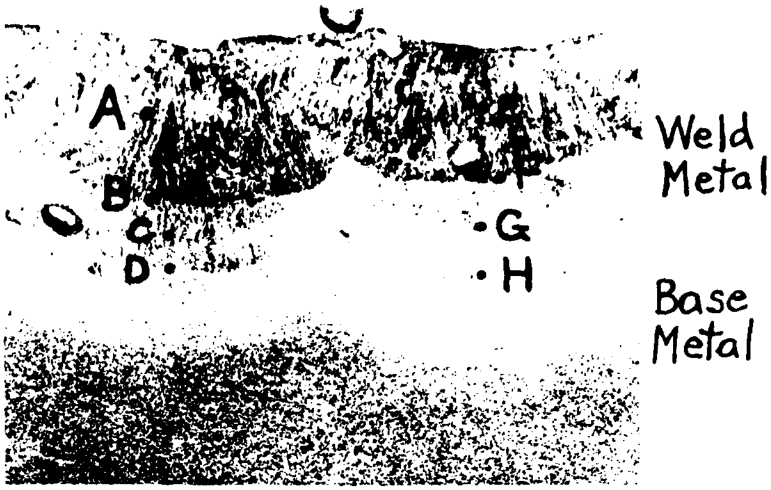
F ×1000

G ×1000

WTN.639-9304

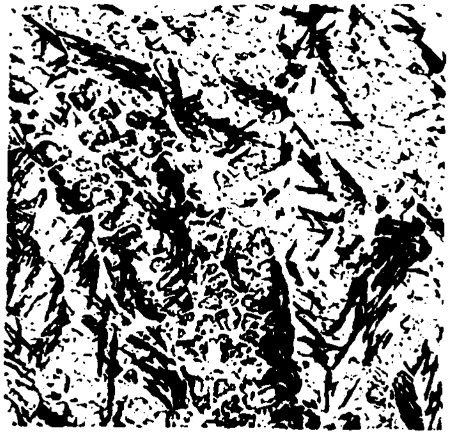
(12)

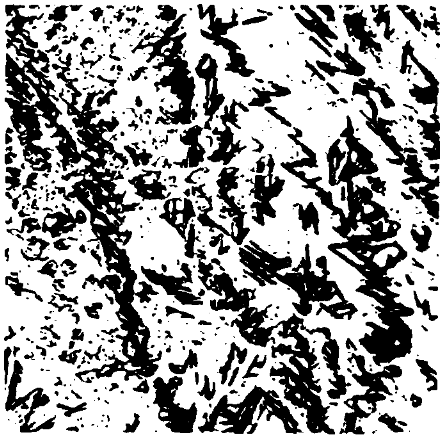
4



SPECIMEN NO. 13 x3

2ND Layer

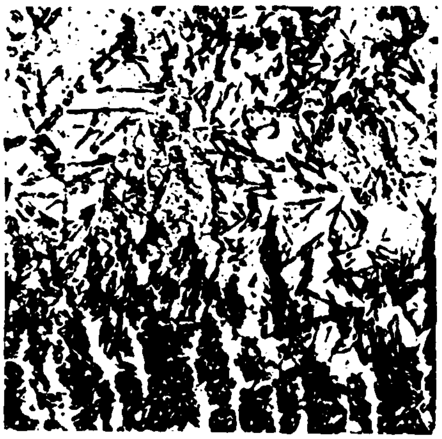


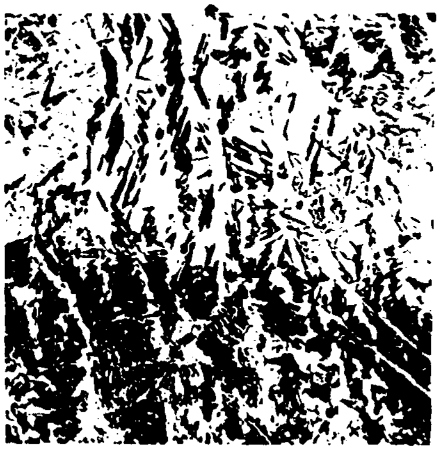


A x250 E

2ND Layer

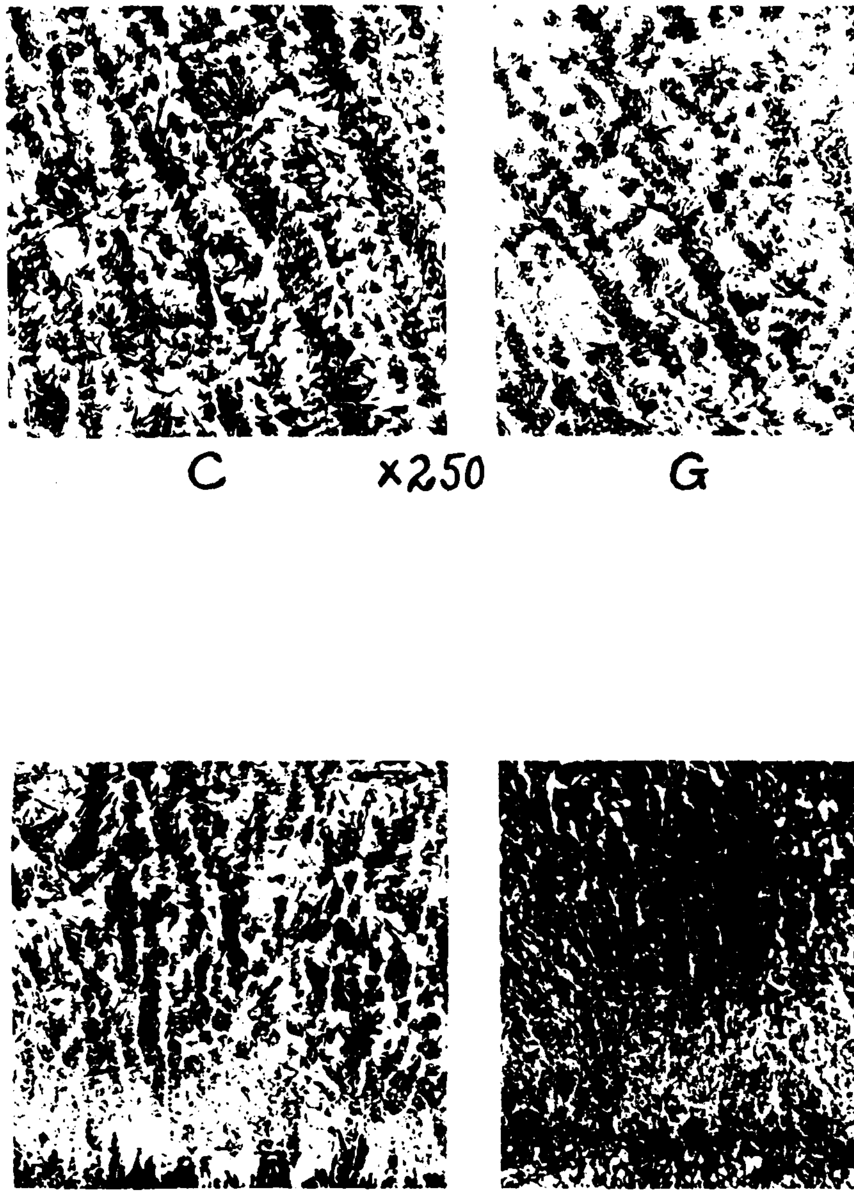
1ST Layer





WTN.639-9305

B x250 F



1ST Layer

C ×250 G

Weld Metal

Base Metal

D ×250 H

HARD-FACING METAL, ELECTRODE M

WTN.639-9306

FIGURE NO. 17

2

G

H

ECTRODE M

E ×1000

F ×1000

G ×1000

WTN.639-9307

3

E ×1000

F ×1000

WTN.639-9307

G ×1000

(13)

4