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Part 5

EXPERIMENTAL MAGNESIUM ALLOYS

Part 5 Welding Tests on HK31A Sheet

Edited by

H. A. Johnson, 1st Lt., USAF

Materials Laboratory

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WRIGHT AIR DEVELOPMENT CENTER

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FOREWORD

This report was prepared by The Dow Chemical Company under USAF Contract No. AF(600)19147. The contract was initiated under Research and Development Order No. R615-15 BA, "New Experimental Alloys by the Powder Metallurgy Process", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt H. A. Johnson acting as project engineer.

ABSTRACT

The arc, gas and spot welding characteristics of HK31A sheet and plate were investigated. The alloy was very weldable by the arc and spot methods but difficulty was encountered in gas welding. Heavy plate, multiple pass arc welds were subject to oxide inclusions, the cause of which has not been definitely established. Weld strengths could be improved by aging heat treatments. The welds were subject to germination when solution heat treated at the recommended 1050°F temperature. The short time high temperature properties of the welds were not significantly different from the unwelded material. Spot welding techniques and properties appeared to be similar to those obtained on AZ31A sheet. Suggestions for continuing the evaluation of the welding characteristics of HK31A were included.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

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Part 5

WELDING TESTS ON HK31A SHEET

INTRODUCTION

The development of HK31A alloy for high temperature applications has necessitated the evaluation of the secondary properties of this alloy. This report covers the gas, arc and spot welding characteristics of HK31A sheet and plate.

SUMMARY OF RESULTS

1. Weldability.
   - A. Arc Welding.
     - (1) Circle weld tests. No cracking was obtained when HK31, HZ32, ZE42, ZE63 and EZ33 rods were used. Only crater cracks were obtained with AZ61, AZ92, ZE10, ZE62 and ZK20 rods.
     - (2) Fillet tack weld tests. No cracks were obtained with HK31, HZ32, ZE42 and ZE62 rods. AZ92A rod showed crater cracking.
     - (3) Butt weld tests. No cracking was obtained with HK31 rod on material from .051 to 1.1" in thickness.
   - B. Gas Welding.
     - (1) Tests were confined to butt welds in .051" sheet using the same rod compositions as with the arc circle tests. No cracking was obtained with any of the rods.
     - (2) Difficulty due to poor coalescence caused by improper fluxing action of the current Dow 450 flux led to suspension of further tests.
   - C. Spot Welding.
     - (1) Spot welding of .051" sheet on a Three-Phase Low

Frequency machine was easily accomplished. For schedules and results see Table VIII.

(2) Surface resistance values for cleaned sheet are given in Tables IX and X.

2. The room temperature properties of both arc and gas welds are given in Table III. Efficiencies of 76 to 80% were obtained on arc welds when sheet in the -H24 temper was used. Actual weld strengths were in the range of 31,500 to 33,500 psi with the bead intact, while slightly lower values were obtained with the bead ground flush.

3. Butt and fillet welds on 5/8" and 1.1" plate showed no cracking. Difficulty was experienced in obtaining sound welds due to oxide content of the plate metal and inadequate protection during welding; consequently no properties are included herein.

4. Welding Sheet and Cast Materials.

A. No cracking was obtained when cast HK31A was welded to HK31A sheet. Weld strength of 28,600 psi was obtained.

B. When cast AZ63A was welded to HK31A plate, cracking resulted with HK31A rod but not with AZ92A rod.

5. Welding HK31A sheet to other sheet alloys.

A. Satisfactory welds were made to ZE10 sheet with HK31A rod.

B. When welding to AZ31A sheet, cracking resulted with HK31A rod but not with AZ92A rod.

6. Corrosion of Welds.

The corrosion rates of welds with HK31A rod were less than 0.20 mcd and were about equal to those of the unwelded sheet.

7. Effects of heat treatment on weld properties. Table V.

A. Properties of sheet material in the -H24, -O, -T4 and

-T6 temper before and after welding are listed in group I.

B. Results of post weld aging treatments on welds made on sheet in the -T4 and -T6 condition prior to welding are given in group II. Aging 16 hours at 400F increased only the strengths of the welds made on the sheet in the -T4 condition.

C. Post weld solution treatments (-T4) at 1050F and 1000F (1 hour) resulted in germinated welds. No germination was obtained after 1/2 hour at 1000F or 2 hours at 950F. Each of the -T4 treatments from 1050 to 950F, when followed by aging (16 hours at 400F), resulted in an appreciable increase in weld strengths, as shown in group III.

D. Post weld aging treatments at various temperatures showed optimum properties were obtained at 500F and 600F for time periods up to 4 hours and at 400F for 16 hours.

8. Properties of welds at elevated temperatures.

A. In Table VI, the data showed slightly better strengths were obtained on welds with post weld -T6 treatment and on welds of -T6 sheet. The weld strengths, however, were not significantly different from the unwelded sheet.

B. In Table VII, the welds joining HK31A sheet to HM31A extrusion resulted in strengths equal to that obtained when HK31A was welded to itself.

CONCLUSIONS

1. HK31A alloy was not crack-sensitive and therefore was considered to be an extremely good weldable alloy. It could be readily arc and spot welded in sheet form. Some difficulty in obtaining sound arc welds in heavy plate was experienced and therefore additional work is needed.

2. Gas welding using the current commercial fluxes was not satisfactory because of poor fluxing action.

3. Spot welding could be performed on the equipment currently in use on magnesium. Settings and properties closely approached those for AZ31A sheet.

4. Cleaning for spot welding either by mechanical or chemical means was satisfactory. Chemical cleaning in 20% CrO_3+0.05% H_2SO_4 solution gave low surface resistance and long life.

5. HK31 sheet welded satisfactorily to HK31A cast material but when welded to AZ63A, some cracking was experienced with HK31A rod. Cracking was eliminated with AZ92A rod.

6. Welding to other sheet alloys appeared possible but care would be required when welding to AZ31A. Additional tests are needed for more definite conclusions.

7. Welding had no significant effect on corrosion rates.

8. Post weld solution heat treatments at temperatures below 1050F were necessary to avoid germination of welds.

9. Post weld aging could be used to increase the strengths of welds made on sheet either in the -H24 or in the -T4 condition prior to welding. Effects on sheet welds in the -T6 condition were not clear and need further investigation.

10. The short-time high temperature strengths were not significantly affected by welding.

RECOMMENDATIONS

1. When welding HK31A to itself, use HK31A rod. For maximum weld strengths, post weld aging for 6 hours at 400F is recommended. Current post weld -T6 treatments are not recommended because of germination in the weld metal.

2. For a more complete evaluation of the welding characteristics, further investigations of the following problems are necessary:

(1) Determination of heavy plate weld properties and methods of obtaining sound welds.

(2) Procedures for welding HK31A to other wrought and cast alloys.

(3) Determination of fatigue properties of welds.

(4) Investigation of suitable post weld solution heat treating conditions.

(5) Determination of spot welding characteristics and properties. The effects of pressure, current and post weld treatments need further investigation.

EXPERIMENTAL WORK DONE

Material.

Sheet material in thicknesses of .051" and .064" in the -H24 temper and plate in thicknesses of 5/8" and 1.1" in the as-rolled condition were available for the welding tests. The -H24 temper was changed to the -O or soft annealed condition by heating one hour at 725F. Since this alloy was heat treatable, the conditions for converting it to the-T6 temper were to heat 1/2 hour at 1050F and age for 16 hours at 400F.

Procedure.

1. Arc Welding.

The welding was performed on an A.C. high frequency stabilized machine, using a tungsten electrode and an inert shroud of helium for the thin sheet and a 50/50 mixture of helium and argon for the plate welds. The edges or areas to be welded were cleaned with a rotary wire brush. Welding current values were obtained with a current transformer and an A.C. ammeter.

All sheet welds were made without a back-up plate. The heavy plate welds were beveled to a 45 degree included angle and spaced 1/8" apart, although square butt edges with same spacing were also tried on the 5/8" plate.

For evaluation of weldability or weld cracking tendency, the "circle weld" and the "fillet tack weld" test pieces were used, as illustrated in Figure 1. These tests were performed on .064" sheet for comparison with other data. The circle test consisted of depositing a bead in a 2 1/2" diameter circle in the middle of an 8-inch square as shown. The cracking tendency was expressed as the percent of weld cracked by dividing the total length of the cracks by twice the circumference of the 2 1/2" circle, times 100. The tack welds were evaluated by indicating the number of cracks and their location.

2. Gas Welding.

A neutral oxy-acetylene flame and Dow No. 450 Flux were used. The sheet edges were cleaned with a rotary wire brush and the welding rod with steel wool prior to application of the flux in the form of a water paste.

3. Spot Welding.

Tests were limited to the .051" thickness sheet in the -H24 temper. The material was cleaned with a rotary wire brush prior to welding. Preliminary tests to obtain the range of settings from dud to expulsion for a given electrode force were carried out on 1" X 4" strips. Then the range of settings was explored with weld panels consisting of two pieces, 4"X7", with an overlap of 1 inch and a spot spacing of 1 inch. This resulted in a panel with 7 spots. The first five spots were used for shear strength tests and the last two for sectioning and metallographic examination. The welded panels were radiographed before removal of spots.

Spot welding tests were conducted at the National Electric Welding Machines Co. on their No. X4622 Special Aluminum Spot Welder. This machine was a low frequency converter type, rated at 150 KVA - 3 Phase - 60 cycles. The electrodes were Mallory Elkalloy A, 1 1/2" in diameter, with 3" radius dome tips.

Preliminary tests on pre-weld cleaning by chemical and mechanical methods were carried out by surface resistance measurements. Tests were made on 1" X 4" strips under a 1000-lb. force using a Biddle Microhmmeter for resistance measurement.

RESULTS

1. Arc welding tests on thin sheet.

The circle weld test results on .064" HK31A sheet in the -H24 and -O tempers are listed in Table I. No evidence of cracking was found when HK31, ZE10, ZE42, ZE63 and EZ33 rods were used. Some cracking was obtained when M, AZ61A, AZ92A, ZE10 and ZE62 were used but the cracking appeared to be associated with points of starting and stopping. The cracks were at the bottom of the sheet transversely across the bead and propogated slightly along the junction of the weld. The cracking obtained was caused by hot short condition of the deposited rather than of the base metal. The temper condition of the sheet had no effect on weldability.

The results of fillet tack weld tests with HK31, ZE42, ZE62, HZ32 and C rods appear in Table II. Cracking was evident only with C rod but this could be considered to be extremely mild. The crater cracking could be eliminated by proper technique and therefore was not considered serious.

2. Gas Welding.

The same welding rods used in the circle tests in Table I were also used in gas welds. The gas welding tests were limited to butt weld joints in .051" sheet for determination of weld strengths. Considerable difficulty was experienced because of poor coalescence and poor control of drop down. Deposition of the commercial welding rods M, J1 and C, was readily accomplished but the drop down with J1 and C was excessive and could not be controlled because of high fluidities and their relatively low freezing points. The ZE series of rods as well as HK31 and HZ32 rods were extremely difficult to use. The weld puddle was coated with a thin film so that the end of the rod had to be pushed in to break the film before fusion with the puddle could occur. While welds were made with all the rods, the difficulties encountered would exclude welding from any production consideration. In view of the difficulties, no further gas welding tests were carried out, but the welds made were nevertheless tested for strengths. A modification of flux composition to make welding easier appeared to be indicated. No indication of weld cracking was evident in any of the gas welds.

3. Properties of Arc and Gas Welds in Thin Sheet.

The room temperature tension test results on sheet arc and gas welds made with the various alloy rods are summarized in Table III. The values represent the average of three to four bars for each condition. The individual test bar values were included only in the file copy. The original sheet strength in the -H24 temper was 41,400 psi. After welding, the strengths of arc welds with the bead left on varied from 31,500 to 33,500 psi for all rods except M, which showed a tensile strength of 29,400. The weld efficiencies therefore were 76 to 80.5% and 71% for M rod welds. The elongation dropped from 4.3 to about 1%. With the bead ground off, the weld strengths decreased and the elongation increased. The extremely low values of 21,100 and 25,500 psi for J1 and C rod appeared to be due to precipitation effects as a result of incompatibility of Al and Zr in magnesium. Most of the fractures were through the weld metal.

The gas welds with the bead on resulted in slightly lower weld strengths than the arc welds. The values varied from 27,000 to 32,600 psi for the different rods. The efficiencies were 65 to 78.5%. However, the elongations were up to 3%. The welds with the beads ground off had strengths of 26,700 to 28,700 psi. Welds with rods HK31, HZ32, ZE42 and ZE63 showed inclusions in the fractures, and, consequently, their strengths were omitted from the table.

4. Plate Welding Tests.

A series of butt and continuous fillet welds were made on 5/8" HK31A-F plate as shown in Figure 2. The welds were sectioned transversely at 1-inch intervals and examined for cracks and penetration. The fillet welds, made in a single pass, were sound and showed no evidence of cracking. However, the butt welds showed a slight evidence of black oxide inclusions, believed to have been caused by insufficient protection from oxidation during welding. No evidence of weld cracking was observed. It was originally intended to obtain properties of the welds but the results of tests showed that the original plate contained cold cracks caused by improper rolling procedure. Consequently, the test values were discarded.

A little of 1.1" HK31A-F plate was also available for welding tests. The joints attempted are also shown in Figure 2. However, difficulty was experienced in obtaining sound welds. Numerous streaks and stringers of oxide particles were visible in the welds. The oxide content appeared to increase with each bead. Therefore, strength data were not obtained. However, no cracking in the welds was detected. Cross sections of butt welds this and other plate thicknesses is shown in Figure 3.

5. Welding Cast to Wrought Material.

A 3/8" X 3" X 8" cast HK31A-F panel was butt welded to the same size HK31A rolled panel. The edges were beveled to a 45 degree included angle and the panels welded in three passes at 240 amps. each. The weld was sound and free of cracks. In the tension test, the fracture occurred in the cast panel side of the test bar, with a value of 28,600 psi tensile strength, 16,400 psi yield strength and 8% elongation in a 2" gage length.

Circle weld cracking tests using a 2 1/2" diameter weld circle with the cast material at the center of an 8-inch square sheet, are shown in Figure 4. In the upper test piece, the sheet was .209" thick. Two test pieces were made without any evidence of cracking. No cracking was observed in the lower test piece, which consisted of a .051" sheet and the same casting.

Two butt welds of 3/8" X 3" X 8" AZ63A-F panel to 5/16" HK31A rolled plate were made. The edges of each were beveled to 22 1/2 degree angles. Four passes at 160 amps each were required for each weld. The first weld was made with HK31A rod. The result was a cracked piece in the heat affected zone on the AZ63A side of the weld. The second weld was made with AZ92A rod and was free of cracks.

6. Welding HK31A Sheet to Other Sheet Alloys.

Butt welds of .064 HK31 to .064 ZE10 sheet with HK31A rod were satisfactory. However, no strength data were obtained. When attempts were made to weld HK31A to AZ31A sheet with HK31A rod, the welds cracked the full length at the junction in the AZ31A side. When AZ92A rod was substituted for HK31A, the cracking was eliminated.

7. Corrosion of Welds.

The corrosion tests were carried out on .064" HK31A -H24 sheet and butt welds made with AZ92A, HK31A and HZ32A rods. The weld bead was ground to within 1/32" of the sheet and the specimens were then pickled in acetic acid and sodium nitrate to remove .001" per surface. The corrosion tests were made in the usual 14 day-alternate immersion in 3% NaCl solution. The results are listed in Table IV. The corrosion rates for welds with HK31 and HZ32 rods were the same as for the unwelded sheet.

The welds made with AZ92A rod showed somewhat higher rates. The corrosion was more pronounced in the deposited AZ92A weld metal. However, the increase should not be considered unusual and would not be noticeable under the ordinary service conditions.

8. Effects of Heat Treatments on Properties of Welds.

The results of the various heat treatments of the original sheet and the welds are listed in Table V under four separate groups. The first group contains the properties of the sheet material in the four tempers -H24, -O, -T4 and -T6 before and after welding. The results showed that efficiencies of about 70% were obtained on -H24 and -T6 tempers with a reduction in elongation from 11.5 and 15.3% down to 1.5 and 2.5%. In the second group, the results of post weld heat treatments on welds made on sheet in the -T4 and -T6 condition showed that the standard -T5 treatment increased the strengths of the -T4 sheet welds to values in the range obtained on -H24 sheet welds, but had no significant effect on the welds in -T6 sheet. The third group of data showed that post weld -T6 treatments involving solution treatments down to 950F gave as good strengths as the recommended 1050F temperature. The lower temperatures were examined because of the known tendency of the welds to germinate at the high solution treating temperature. The results indicated that germination was eliminated at 950F for 2 hours, and at 1000F for 1/2 hour. Finally, in the fourth group, the results indicated that aging of welds up to 4 hours at 500 and 600F to obtain increased strengths could be used in place of the 16 hour treatment at 400F. However, this appeared to be at the expense of ductility and considerably more data should be gathered before a definite recommendation is made.

9. Elevated Temperature Properties of Welds.

The short time high temperature tensile test results of welds in .064" sheet with the bead left intact or given in Table VI. The best strengths were obtained on welds with the post weld -T6 treatment and on the welds in which the original metal was in the -T6 condition. However, as has been indicated previously, post weld -T6 treatments resulted in germination of the weld metal and could not be recommended for practical uses. Comparison with previous data on sheet material showed that the weld properties at elevated temperatures were not significantly different from the sheet values. Tests on welds with the bead ground flush indicated lower properties at elevated temperatures might result but this needs rechecking before definite conclusions are drawn.

The properties of welds joining HK31A sheet to HM31A extrusions with HK31A rod are listed in Table VII. The results showed that the properties were equivalent to those obtained on HK31A when welded to itself. This was readily explained by the observation of tension test fractures. At elevated temperatures, the failures occurred in HK31A side of the welds, whereas at room temperature the failure was in the HM31A side. No difficulty was experienced in welding the two alloys together.

10. Spot Welding.

The machine settings and results of welding .051" sheet are given in Table VIII. The results showed that the critical welding force at which weld cracking and shrinkage were eliminated was between 1500 and 2000 lbs. The shear strength and spot diameter values are the average of five specimens. The plot of the weld strengths against the diameters of the welds resulted in a straight line relationship as shown in Figure 5. The plotted values included both sound and defective welds in order to cover the range sufficiently. The use of welds with internal defects was permissible since it was a generally accepted fact that they had no effect on static shear strength. At the bottom of Table VIII are a few values for AZ31A-0 spot welds for comparison. The results indicated that spot strengths and machine settings were comparable for the two alloys.

The surface resistance results after the various cleaning treatments are given in Table IX. The material was satisfactorily cleaned by mechanical means. It also cleaned to very low surface resistances by the Dow spot weld cleaning solution of 20% CrO_3 + .05% H_2SO_4. A minimum time of 2 minutes resulted in resistances below 10 microhms. This was considerably better than normally obtained on AZ31A sheet. The chemically cleaned sheet appeared to have good life as shown by the data in Table X. Even after standing for 142 hours, the surface resistance was less than 15 microhms.

11. Metallography.

The microstructure of sheet welds made with the different composition rods are shown in Figures 6-11. Extremely fine grained weld metal was obtained with all the rod alloys. The M1A resulted in columnar grains at the junction, Figure 10 and finer, equiaxed grains inside the weld. The aluminum containing rods showed black precipitate and the normal colorless Mg-Al compound, as shown in Figure 9. The zinc containing rods gave a cored structure at the junction, as in Figure 11 with HZ32A rod. The extent of germination in the weld metal after various -T4 treatments is illustrated in Figures 12 and 14. The effect of germination was not readily apparent on mechanical properties. Germination was not visible in samples heat treated 1/2 hour at 1000F, Figure 13 or 2 hours at 950F, Figure 15. The effect of solution treatment (-T4) on one set of samples is shown in Figures 16 and 17. The grains were a mixture of fine and coarse with pronounced stringers of compound. Whether this was typical or not due to the high temperatures used could not be definitely stated. However, there has been no evidence of unusual grain coarsening in the heat-affected zone. The appearance of typical spot welds in .051" HK31A sheet made at 2000 and 2500 lbs electrode force are shown in Figures 18-20.

DISCUSSION

The outstanding feature of HK31A alloy has been its good weldability or freedom from cracking. It could be welded with almost any rod composition both by the arc and by the gas method. However, the latter method, while it allowed welding of small experimental samples would not be practical because of the difficulty experienced in depositing the weld metal. The flux did not appear to have the cleaning action on HK31A that it possessed on the standard commercial alloys. Indications were that flux composition would have to be modified to make the process useful commercially.

This investigation was somewhat handicapped because sheet and plate material were not available in sufficient quantity and in time to allow adequate completion of the program before expiration of the contract. As a consequence, many problems remained to be worked on. The chief problem appeared to be unsoundness in multiple pass heavy plate welds. This was partly due to the rapid oxidation, a characteristic of this alloy, and partly from oxide inclusions present in the original rolled metal. It appeared that insufficient protection was afforded by the shielding gases but additional work would be necessary to determine if the sound welds could be obtained. Another problem of equal importance was the development of techniques and procedures for welding HK31A material to other commercial wrought and cast alloys. Preliminary results had indicated that in welding AZ31A sheet and AZ63A casting to HK31A, an AZ92A welding rod was necessary to eliminate cracking. Other problems that need some investigation are the fatigue characteristics, post weld heat treatments and spot welding. Indications were that spot welding could be readily accomplished but actual data on properties and effects of spot welding variables were needed as a guide to the fabricators.

TABLE I. RESULTS OF CIRCLE WELD TESTS ON HK31A SHEET IN THE -H24 AND -O TEMPERS WITH VARIOUS RODS. HELIUM SHIELD, 50 AMPERES A.C.

Panel No.	Rod Alloy	Total Cracks Length, Inches	% Weld Cracked	No. Crater Cracks
		Alloy 75211-H24 Temper		
1111-3	3/32" M	.66	4.2	0
1111-4	1/8" J	.44	2.8	1
1111-5	1/16" ZE10	0	0	Several
1111-6	3/32" ZK20	.11	0.7	Several
1111-7	1/8" ZE63	0	0	0
1111-8	1/8" EZ33	0	0	0
1111-9	1/8" C	.44	2.8	0
1111-10	1/8" C	.44	2.8	1
1111-11	1/8" C	.66	4.2	2
1111-12	1/8" HK31	0	0	0
1111-13	1/8" HK31	0	0	0
1111-14	1/8" HK31	0	0	0
1111-15	1/8" HZ32	0	0	0
1111-16	1/8" HZ32	0	0	0
1111-17	1/8" HZ32	0	0	0
1111-18	1/8" ZE42	0	0	0
1111-19	1/8" ZE42	0	0	1
1111-20	1/8" ZE42	0	0	2
1111-21	1/8" ZE62	.22	1.4	2
1111-22	1/8" ZE62	0	0	1
1111-23	1/8" ZE62	.22	1.4	1
		Alloy 75211-O Temper		
1112-1	1/8" HK31	0	0	
1112-2	1/8" HK31	0	0	

TABLE II. RESULTS OF FILLET TACK-WELD TESTS ON .064" HK31A-H24 SHEET. (72 AMPS. A.C., HELIUM SHIELD.)

Sample No.	Rod		No. Cracks			Remarks
	Size	Alloy	Top	Bottom	Log	
75211-1	1/8"	HK31	0	0	0	
-2	1/8"	HK31	0	0	0	
1112-9	1/8"	C	0	0	0	3 Crater cracks in beads.
-10	1/8"	C	0	0	0	3 Crater cracks in beads.
-11	1/8"	ZE42	0	0	0	
-12	1/8"	ZE42	0	0	0	
-13	1/8"	HZ82	0	0	0	
-14	1/8"	HZ82	0	0	0	
-15	1/8"	ZE62	0	0	0	
-16	1/8"	ZE62	0	0	0	

TABLE III. ROOM TEMPERATURE TENSION TEST RESULTS ON ARC AND GAS WELDS IN .051" HK31A-H24 SHEET. (VALUES ARE THE AVERAGE OF 3 TO 4 BARS.)

Rod Alloy	Arc Welds T.S. 1000 psi	Arc Welds % Elong. 2 in.	Gas Welds T.S. 1000 psi	Gas Welds % Elong. 2 in.
		Weld Bead On.		
M1	29.4	1.2	27.6	2.3
AZ61	31.9	1.0	26.4	1.5
AZ92	31.7	1.0	30.2	2.1
HK31	32.6	1.0	29.4	2.1
HZ32	32.6	1.0	27.7	1.6
ZE42	32.6	1.0	29.1	1.5
ZE62	32.1	1.0	28.4	2.0
ZE63	33.5	1.0	31.0	2.6
EZ33	33.5	1.0	32.6	2.1
ZK20	31.6	1.0	28.4	1.6
ZE10	31.9	1.0	29.3	2.3
		Weld Bead Ground Off.		
M	27.1	2.6	20.6	2.1
AZ61	21.1	1.8	27.0	3.0
AZ92	25.5	2.3	26.8	3.0
HK31	29.1	3.0	19.4	1.8
HZ32	21.8	2.5	22.2	2.1
ZE42	28.0	2.3	21.1	1.5
ZE62	30.9	2.5	27.2	3.1
ZE63	24.5	1.3	18.4	1.2
EZ33	31.6	2.3	27.6	2.5
ZK20	31.2	3.0	28.7	3.5
ZE10	29.3	2.5	24.4	2.5
		Original Sheet		
	41.4	4.3		

TABLE IV. RESULTS OF CORROSION TESTS ON .064 HK31A-H24 SHEET ARC WELDS. (14 DAYS ALTERNATE IMMERSION IN 3%NaCl.)

Welding Rod	Corrosion Rate MCD		
	1	2	Avg.
Sheet	20	16	18
AZ92A	25	22	24
HK31	13	17	15
HZ32	17	18	18
ZE62	19	18	19

MCD - Milligrams per square centimeter per day.

TABLE V. EFFECTS OF VARIOUS HEAT TREATMENTS ON PROPERTIES OF HK31A SHEET WELDS.

Original Condition of Sheet	Post Weld Treatment	Sheet Properties 1000psi T.S.	Y.S.	% E 2in.	Weld Properties 1000 psi T.S.	Y.S.	% E 2in.
	GROUP I						
-H24	None	41.4	34.9	11.5	30.3	24.4	1.5
-O (1Hr-725F)	"	35.1	27.0	21.5	27.6		3.1
-T4 (1/2Hr-1050F)	"	29.3	16.6	20.3	26.6		6.6
-T6 (1/2Hr-1050F+ 16Hr-400F)	"	38.4	21.0	15.3	28.3		2.5
	GROUP II Post weld treatments on -T4 and -T6 Sheet Welds.						
-T4	-T5 (16Hrs-400F)				31.3		3.3
-T4	1Hr-725F				25.7		5.0
-T4	1Hr-625F				28.3		3.0
-T6	-T5 (16Hrs-400F)				28.9		2.1
-T6	1Hr - 625F				24.6		1.3
-T6	1Hr - 725F				24.9		4.0
	GROUP III Post weld -T4 and -T6 Treatments.						
-H24	-T4				27.1		8.8
-H24	-T6				32.9		4.6
-H24	1/2Hr-1000F				27.2		11.3
-H24	1/2Hr-1000F+T5				33.3		4.5
-H24	1Hr-1000F				27.8		12.5
-H24	1Hr-1000F+T5				35.3		6.1
-H24	2Hr-950F				26.3		6.8
-H24	2Hr-950F+T5				33.2		5.5
	GROUP IV Post weld -T5 Treatments						
-H24	1Hr-725F				28.7		2.8
-H24	1Hr-625F				32.6		1.0
-H24	2Hr-600F				31.7		1.0
-H24	4Hr-600F				32.4		1.0
	GROUP V						
-H24	8Hrs-600F				30.8		1.0
-H24	16Hrs-600F				29.0		1.0
-H24	2Hrs-500F				32.6		1.0
-H24	4Hrs-500F				35.3		1.0
-H24	8Hrs-500F				31.5		1.0
-H24	16Hrs-500F				31.5		1.0

TABLE VI. SHORT TIME HIGH TEMPERATURE TENSILE TEST RESULTS ON WELDS IN .064 HK31A SHEET.

Sheet Temper Before Welding	Post Weld Treatment	Testing Temp. F	Tensile Properties ⊕ 1000 psi T.S.	Y.S.	% E 2in.
-H24	As Welded	70	30.3	24.4	1.5
-H24	As Welded	400	22.9	17.1	2.8
-H24	As Welded	500	21.3	17.1	11.0
-H24	As Welded	600	14.3	8.2	55.5
-H24	-T6	70	32.9	----	4.6
-H24	-T6	400	22.9	14.8	12.3
-H24	-T6	600	17.5	12.3	17.5
-T6	As Welded	70	27.4	----	2.3
-T6	As Welded	400	21.3	14.3	7.5
-T6	As Welded	600	19.1	12.2	14.3
-O	As Welded	70	27.6	----	3.1
-O	As Welded	400	17.2	14.2	29.0
-O	As Welded	600	11.2	8.2	46.8
-H24	As Welded-B.G.+	400	19.1	13.8	6.0
-H24	"	500	19.4	14.9	5.8
-H24	"	600	12.9	6.7	31.8

+ B.G. - Bead ground flush.

⊕ Average of 2 test bars.

TABLE VII. SHORT TIME ELEVATED TEMPERATURE TEST RESULTS ON HK31A TO HM31A WELDS.

Alloy Tempers Before Welding		Post Weld Treatment	Testing Temp. F	Tensile Properties ⊕			Location of Fracture
				1000 psi		% E	
HK31A	HM31A			T.S.	Y.S.	2in.	
-H24	-F	As Welded	70	29.2	23.7	1.6	HM31A
-H24	-F	As Welded	400	21.2	17.1	4.5	HK31A
-H24	-F	As Welded	600	14.4	9.6	10.0	HK31A
-H24	-F	-T5	70	31.2	23.2	1.8	HM31A
-H24	-F	-T5	400	23.2	19.7	15.0	HK31A
-H24	-F	-T5	600	14.9	9.4	30.8	HK31A
-H24	-T5	As Welded	70	27.4	23.9	1.0	HM31A
-H24	-T5	As Welded	400	21.3	16.6	5.5	HK31A
-H24	-T5	As Welded	700	14.5	9.9	46.5	HK31A

⊕ Average of 2 test bars.

TABLE VIII. SPOT WELD MACHINE SETTINGS AND RESULTS ON .051" HK31A-H24 SHEET. TESTS ON NATIONAL 150KVA 3 PHASE LOW FREQUENCY MACHINE.

Panel No.	Current Course	Current Fine	Electrode Force, Lbs	Heat Time Pulses	Shear* Strength, Lbs	Spot Diam. in.	Radiograph Results
129-1	3	8	1000	2	516	.21	Shrink -S Exp. All
-2	3	6	1000	3	731	.28	Shrink -E Exp. All
-3	3	6	1000	2	400	.18	Shrink -S Exp. 2-5
-4	3	4	1000	2	410	.19	Shrink -M
-5	3	2	1000	2	347	.17	Shrink -M
-6	2	8	1000	2	326	.15	Shrink -M
-7	2	4	1000	2	276	.15	Shrink-SL
-8	2	1	1000	2	189	.11	Shrink-SL
-10	4	4	1500	2	615	.25	Shrink -S Exp. 3+7
-11	4	2	1500	2	501	.21	Shrink -S Exp. 1
-12	3	10	1500	2	458	.20	Shrink -M
-13	3	8	1500	2	387	.18	Shrink -M
-14	3	4	1500	2	292	.15	Shrink-SL
-18	4	8	2000	2	647	.25	Shrink-SL4
-19	4	4	2000	2	570	.24	Shrink-SL 1,3,6,7
-20	3	10	2000	2	362	.17	Sound
-21	3	8	2000	2	325	.16	Sound
-22	2	2	2000	5	652	.26	Cracks 2,3,4,6
-26	6	2	2500	2	721	.28	Cracks Exp.1,3,5
-27	5	10	2500	2	710	.29	Sound Exc.5
-28	5	5	2500	2	653	.27	Sound
-29	4	10	2500	2	610	.24	Sound
-15	3	4	1500	2	267	.15	Cracks5,6,7
-16	3	10	1500	2	505	.21	Cracks 3,7
-17	4	4	1500	2	601	.24	Cracks,All Exc.1,3,5,6
-23	3	8	2000	2			No Spots
-24	4	4	2000	2	366	.17	Sound
-25	4	8	2000	2	529	.21	Sound

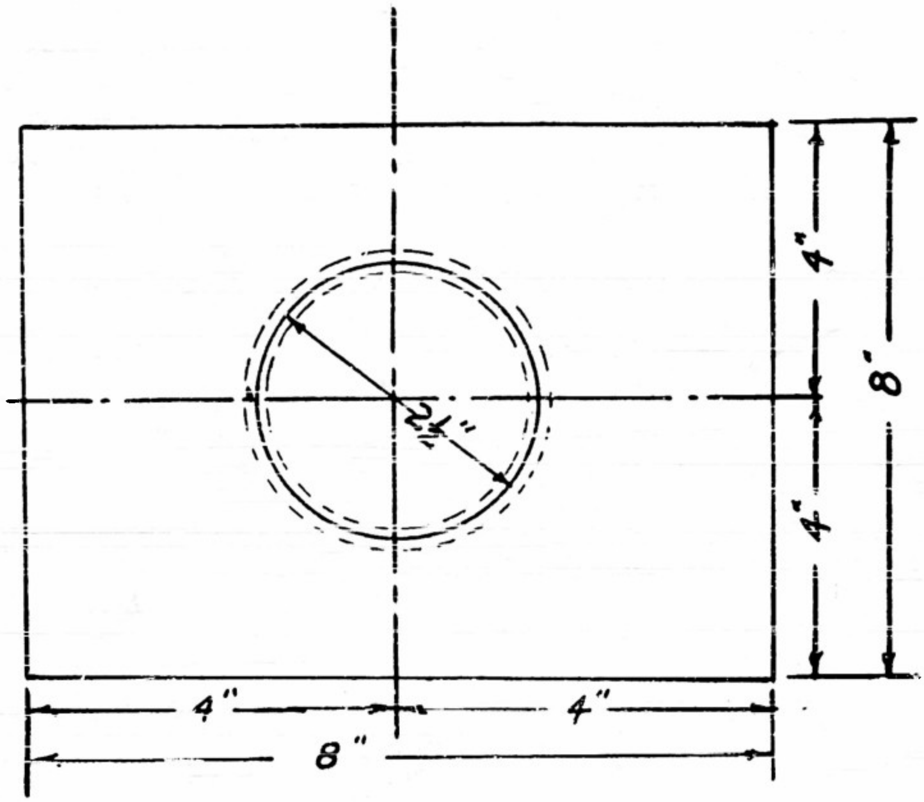
S-Severe E-Excessive M-Moderate SL-Slight Exp.-Expusion
Exc.-Except *= Average of 4 to 5 tests.

TABLE IX. SURFACE RESISTANCE OF HK31A-H24 SHEET AFTER CLEANING BY SEVERAL DIFFERENT METHODS.

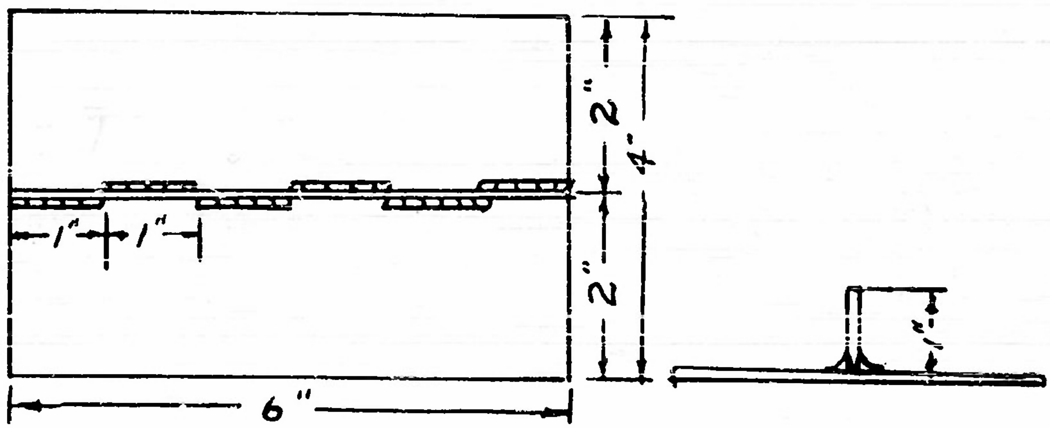
Cleaning Method	Resistance in microhms 1	2	3	4	5	Average
As received	500	1400	3400	1900	1900	1820
Rotary wire brushed	5	13	16	14	19	13
Abraded with #150 Aloxite Cloth	2	3	3	3	3	3
Abraded with #240 Aloxite Cloth	4	5	4	5	6	5
Dow Treatment #15	53	28	32	32	38	37
Dow Treatment #16	1100	690	2600	1700	1800	1580
$20CrO_3 + .05H_2SO_4$ -30Sec.	11	36	33	31	31	28
" " -1Min.	17	11	12	12	13	13
" " -2Min.	18	10	9	9	9	11
" " -4Min.	4	3	4	5	5	4
" " -6Min.	3	3	3	3	3	3
" " -8Min.	4	5	4	5	3	4
" " -10Min.	5	5	5	6	6	5
" " -15Min.	4	4	4	4	4	4

TABLE X. SURFACE RESISTANCE OF HK31A-H24 SHEET CLEANED IN $20\% CrO_3-0.05H_2SO_4$ (4 Min. Dip) AFTER EXPOSURE TO VARYING AND CONSTANT CONDITIONS.

Time After Treatment	Laboratory Atmosphere Microhms 1	2	3	4	5	Avg.	Constant Temp.+Humidity Microhms 1	2	3	4	5	Avg.
0	2	2	3	3	3	2.6						
1 Hr.	3	3.5	4	4	4	3.7	3	4	4	3.5	4	3.7
4 Hr.	3	4.5	5	5	5	4.5	3.5	4	4	4	3.5	3.8
8 Hr.	3	4	4.5	4	4.5	4	4	3.5	3.5	4	3	3.6
16 Hr.	5	6.5	5	4	4.5	5	3	3	3	3	3	3
24 Hr.	4.5	6	6	7.5	8	6.4	2.5	2	2	2.5	3	2.4
48 Hr.	9	12	12.5	17	20	14.1	3.5	3	3	3	3.5	3.2
72 Hr.	8	8	9	10	9	8.8	3	4	3	3.5	3.5	3.4
142 Hr.	13	11	11	13	12	12	4	4	4	4	4	4



CIRCLE WELD – .064" SHEET



FILLET TACK WELD – .064" SHEET

FIG. 1. WELDABILITY TEST PIECES

9-25-63 R.K.

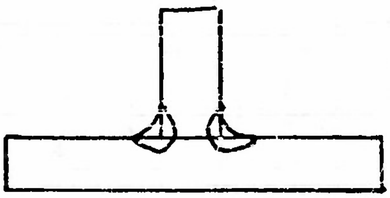
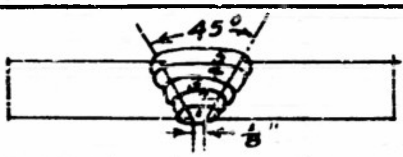
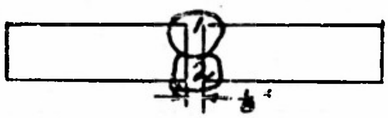
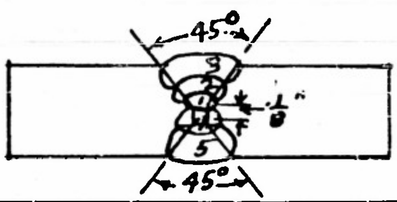
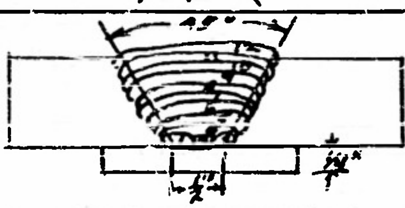
JOINT DESIGN	THICKNESS	CURRENT, AMPS.
	5/8	1. 360 2. 360
	5/8	1. 200 2. 240 3. 300 4. 300 5. 300 6. 500
	5/8	1 300 2 340 3 340 4 340 5 340
	5/8	1 500 2 560
	1.1	1 320 2 480 3 560 4 560 5 560
	1.1	1 320 2 320 3 320 4 400 5 400 6 400 7 400 8 400 9 400 10 400 11 400 12 400

FIG. 2. FILLET AND BUTT JOINTS IN HEAVY PLATE WELDING OF HK31A ALLOY.

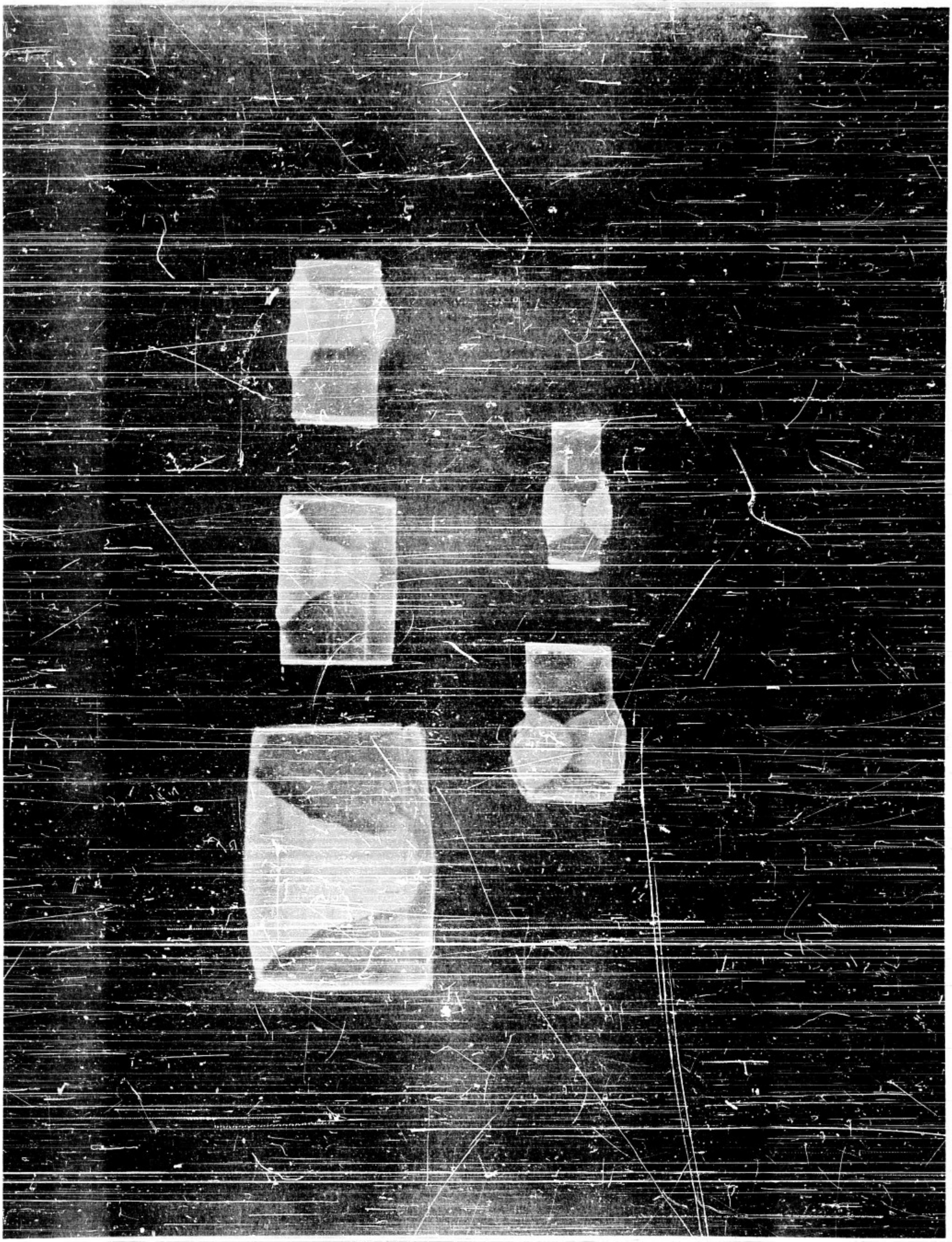


Figure 3. Appearance of Butt Weld Sections in HK31A Plate.

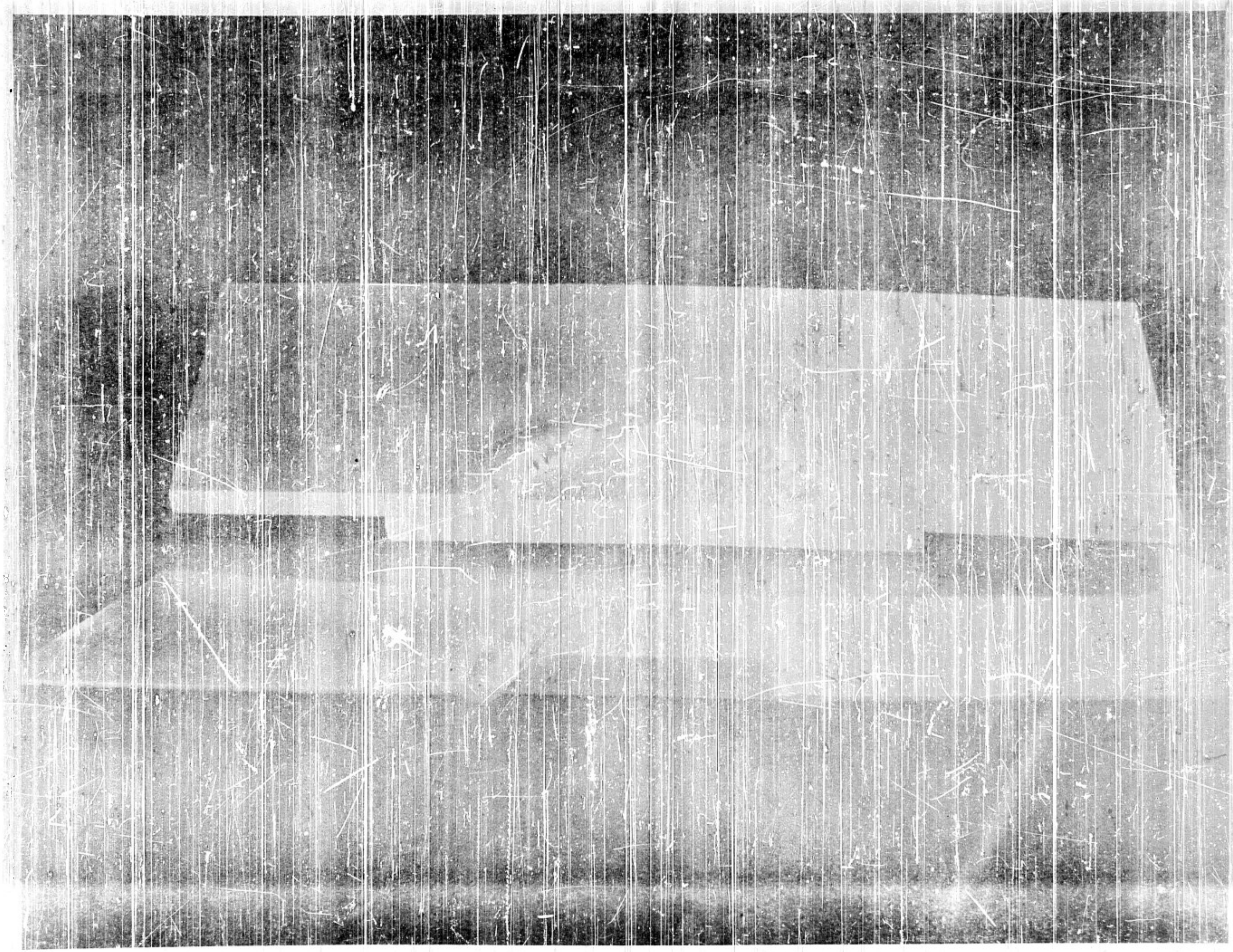


FIGURE 4. Circle Test Pieces of Cast Material Welded to Rolled Plate and Sheet.

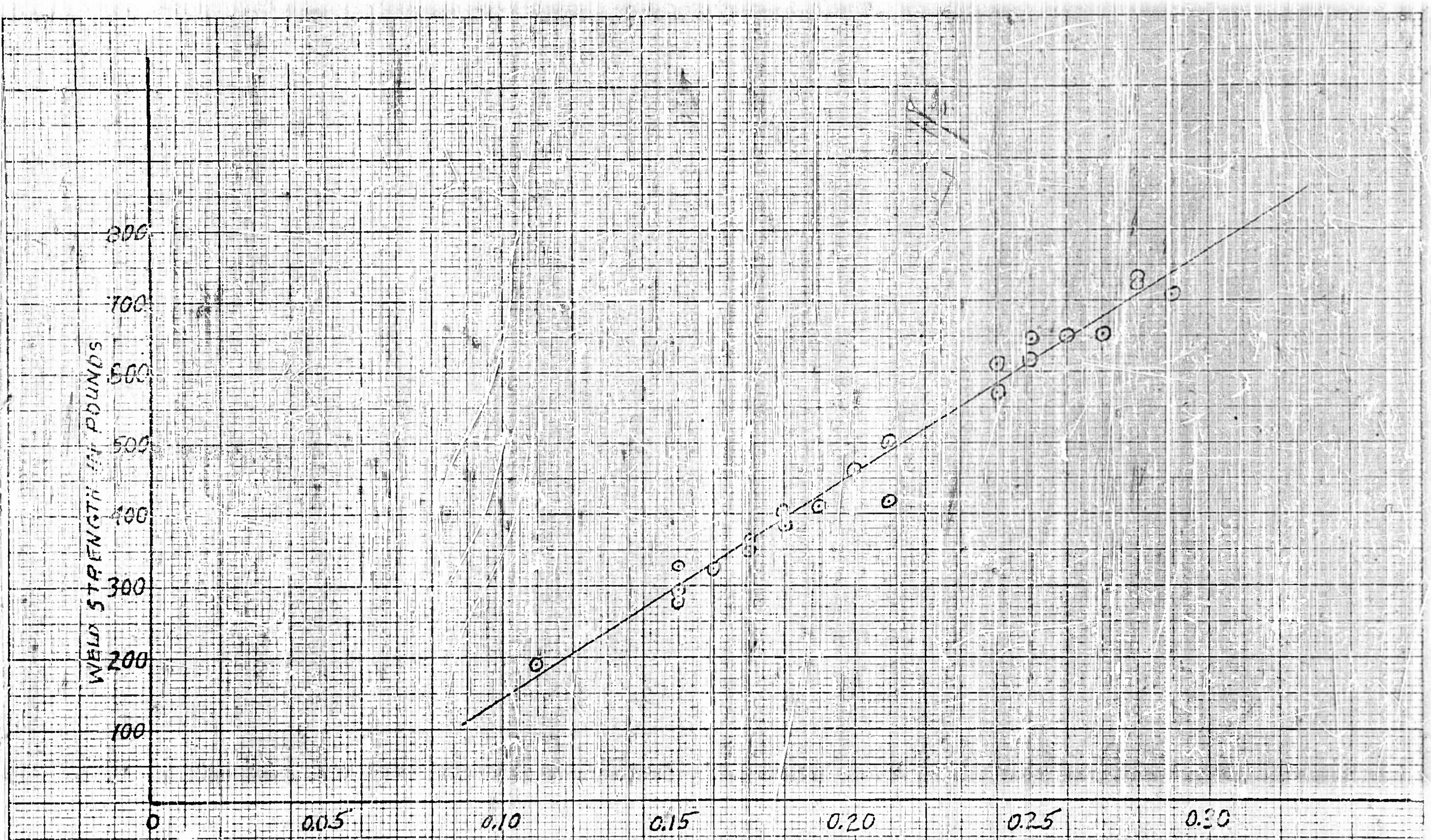
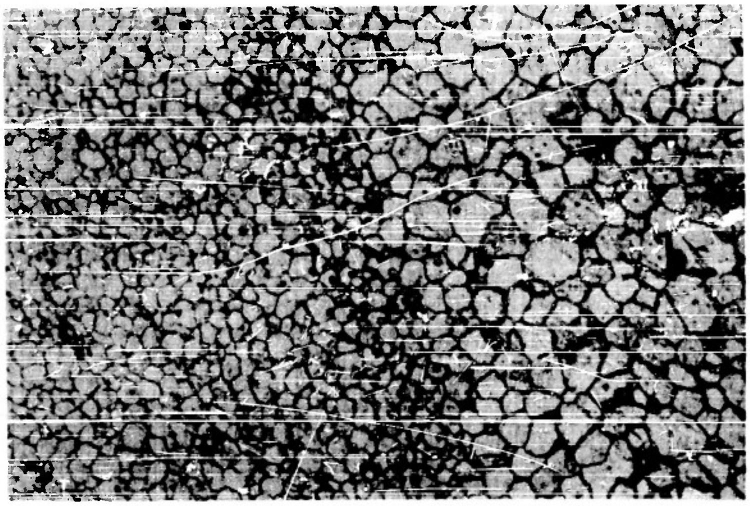


FIG. 5 RELATION OF SPOT STRENGTH TO SPOT DIAMETER IN .051" HK31A-H24 SHEET.
SINGLE FORCE 2 PULSE LOW FREQUENCY CURRENT WELDS. AVERAGE OF 4 TO 5 SPOTS.

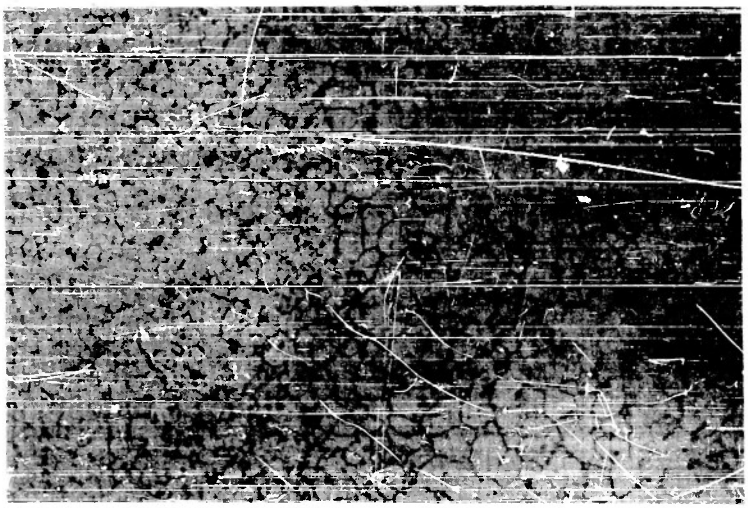
2-25-54 P.K.



Neg. 33837 200X
75147 Acet. Glycol

FIGURE 6

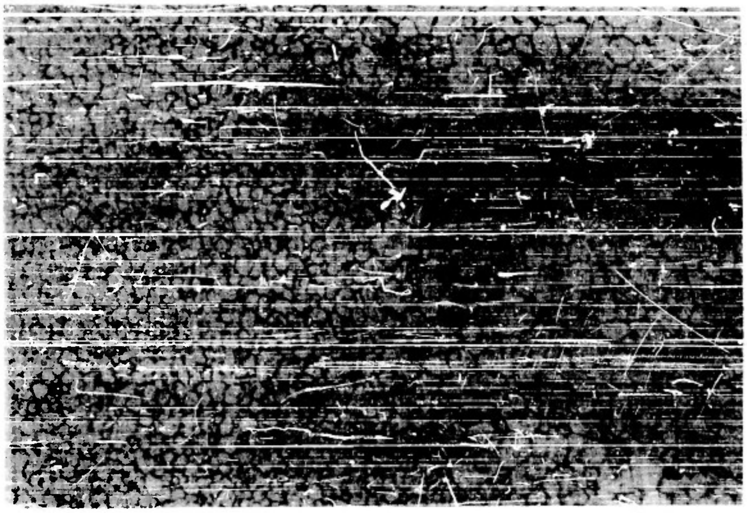
.051" HK31A-H24 Gas Welded With HK31A Rod. Weld finer grained than sheet.



Neg. 33838 200X
75147 Acet. Glycol

FIGURE 7

.051" HK31A-H24 Sheet Arc Welded With HK31A Rod. Weld at left.



Neg. 33841 200X
75211

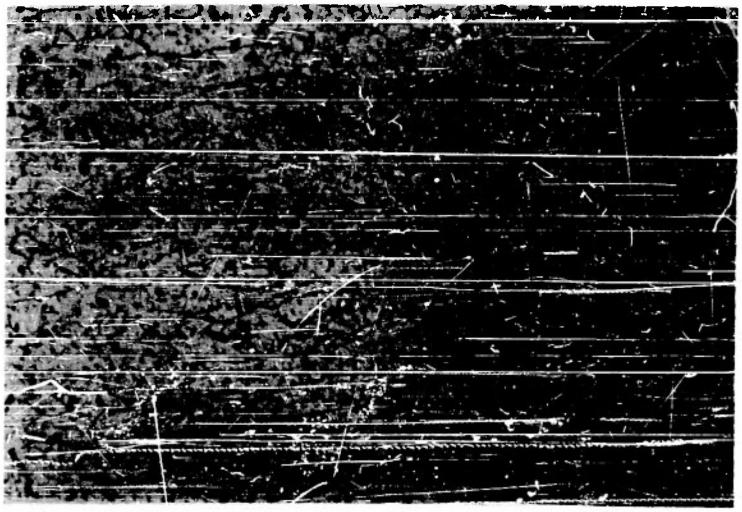
FIGURE 8

.064" HK31A-O Arc Welded with HK31A Rod. Weld fine grained at left.

Neg. 33842 700X
75211-C Acet. Glycol

FIGURE 9

.064" HK31A-H24
Arc Welded with AZ92A rod. Weld at left.



Neg. 33843 200X
75211-M

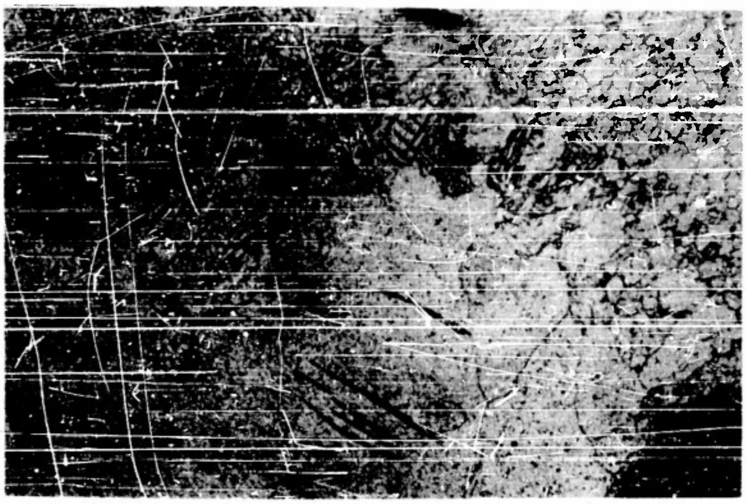
FIGURE 10

.064" HK31A-H24 Welded with M1A Rod. Weld at left. Note columnar grains at junction.

Neg. 33844 200X
75211

FIGURE 11

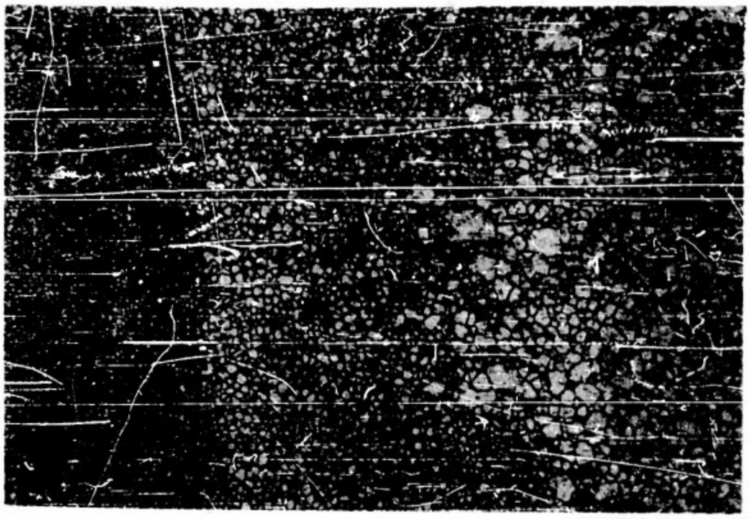
.064" HK31A-H24 Welded with HZ32A Rod. Note coring in heated zone and fine grained weld metal at left.



Neg. 33852 50X
75211-13-1 Acet. Glycol

FIGURE 12

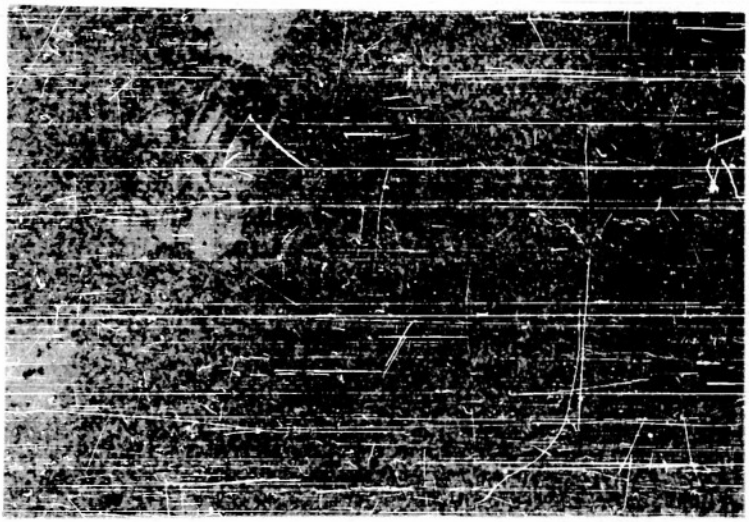
Germination in HK31A weld metal. Heat Treated - 1/2Hr. at 1050F.



Neg. 33853 50X
75211-13-3

FIGURE 13

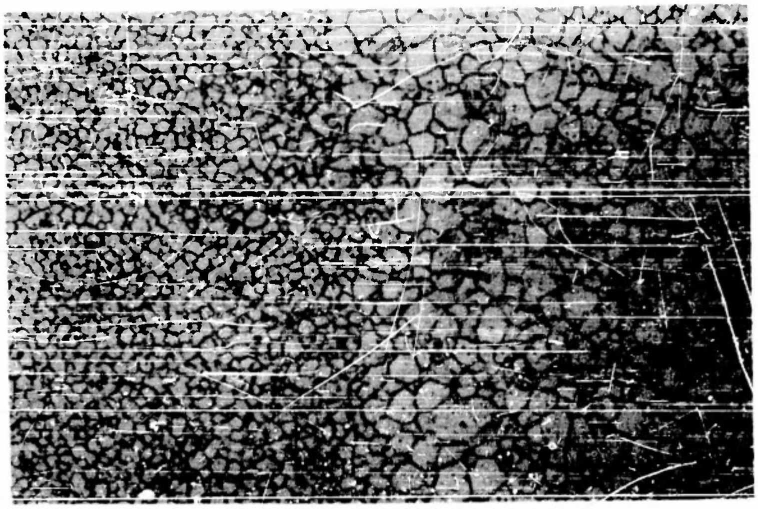
HK31A Weld Metal at the left. Heat treated 1/2 Hr. at 1000F. No germination.



Neg. 33854 50X
75211-13-6

FIGURE 14

Germination in HK31A weld metal after heat treatment at 1000F for 1 Hr.



Neg. 33855 200X
75211-13-7 Acet. Glycol

FIGURE 15

HK31A weld junction after heat treating 2 Hrs. at 950F. Weld is fine grained weld to the left.

Neg. 33856 200X
75211-H4

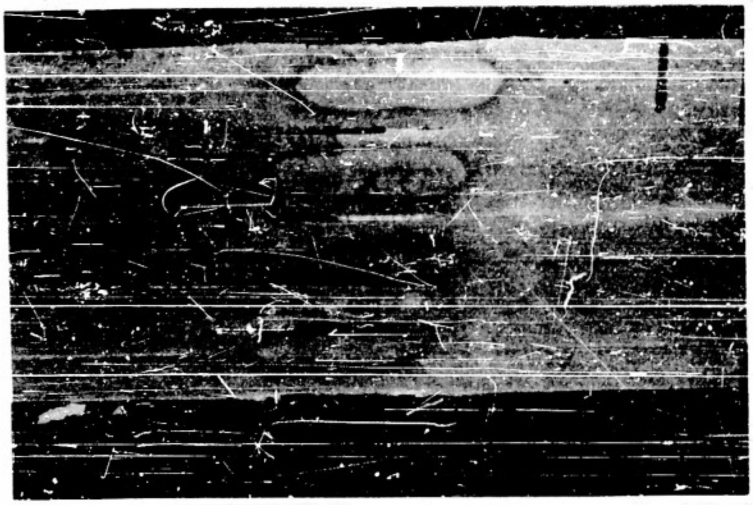
FIGURE 16

Weld junction, weld at left. Sheet in the -T4 temper (1/2 Hr. at 1050F) before welding. Post weld -T5 treatment.

Neg. 33857 200X
75211-H4

FIGURE 17

HK31A-T6 sheet structure. Note compound stringers and mixture of large and small grains.



Neg. 33775 4X
75147-19,-20

FIGURE 18

Spot welds in .051" HK31A-H24 made at 2000 lbs. electrode force.

Neg. 33776 4X
75147-28,-29

FIGURE 19

Spot welds in HK31A made at 2500 lbs. electrode force.

Neg. 33835 50X
75147-28-7

FIGURE 20

Spot weld in HK31A at higher magnification.