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DETECTION OF CRACKS ADJACENT TO SPOTWELDS BY RADIOGRAPHY IN THIN STAINLESS STEEL SHEET

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GENERAL DYNAMICS/CONVAIR

MRG-289

29 January 1962

SUBJECT: Detection of Cracks Adjacent to Spotwelds by Radiography in Thin Stainless Steel Sheet

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ABSTRACT: Radiographs were made of two multispot circumferential joint specimens that had been cyclically loaded until cracks formed, ranging in depth from 2 to 100% of the sheet thickness. In a radiograph made using an x-ray tube with a standard glass window, cracks could be detected that were greater in depth than 23% of the sheet thickness (.013"). Using an x-ray tube with a beryllium window, cracks could be detected that were greater in depth than 15% of the sheet thickness (.010"). For thin sheet stainless steel it was recommended that a beryllium windowed x-ray tube be used because the radiographs could be read with greater facility and cracks of shorter depth could be detected.

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MRG-289

29 January 1962

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FROM: Materials Research Group, Dept. 592-1

SUBJECT: Detection of Cracks Adjacent to Spotwelds by Radiography in Thin Stainless Steel Sheet

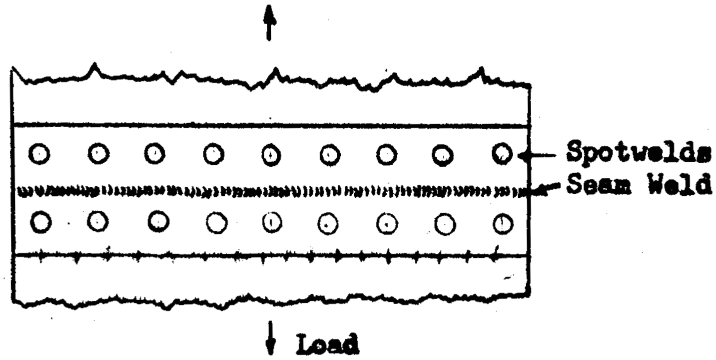
INTRODUCTION & PURPOSE:

During fabrication and subsequent testing of missile tanks made from thin stainless steel sheet cracks sometimes develop, particularly around the spotwelds in the weld joints. It is the purpose of this investigation to evaluate the ability of radiographic inspection to detect these cracks.

PROCEDURE AND RESULTS:

Material and Specimen Description

The two specimens used for radiographic evaluation were standard resistance spot and seamwelded joints that had been cyclically loaded at -423°F until cracks of various depths developed around the spotwelds. Details of the material and stress history are given below:



	Specimen #1	Specimen #2
Material	Type 301 ½H (MIL-S-5059)	Type 301 XH (0-71004)
Thickness	.010	.013
Heat No.	E87124	57104
Coil No.	——	453
Fatigue Stress, KSI	0-110	0-140
No. of Cycles	210	40
Test Temperature, °F	-423	-423

Dye Penetrant and Visual Examination

The spotwelds of both specimens were examined visually, at magnifications from 3X to 30 X, and by dye penetrant inspection. Dye penetrant revealed two cracks that came through to the surface in Specimen 1 and one through crack in Specimen 2. By visual examiation alone it was difficult to distinguish between an actual crack and the severe plastic deformation adjacent to a spotweld produced by the loads applied to the specimen.

Radiographic Examination

Both specimens were radiographed at Astronautics using production x-ray equipment. An x-ray tube with a beryllium window was used to radiograph Specimen 1 while a more commonly used tube with a glass window was used to radiograph Specimen 2. Beryllium, element number 4 in the periodic table, allows more radiation to pass through than the other heavier window materials, it also traps undesirable secondary electrons emitted from the target. Radiographs varying in density from 0.9 - 2.3 were made using the Be window, a density of 2.0 appeared to be the best. All radiographs were read by one experienced radiographer, those made with the Be window were sharper and easier to read. Cracks in the radiographs of these specimens appeared as black lines or areas curving around the perimeter of the spotweld nugget on the side away from the seamweld, see Figure 1. The radiographs indicated the presence of eight cracks in Specimen 1 (301 ½H) and eleven cracks in Specimen 2. These results, identifying each spotweld with its radiographic indication, are tabulated in Tables II and III respectively.

Metallographic Examination

All spotwelds were identified, see Figure 1, sectioned through the center parallel to the direction of load and prepared metallographically for examination. All specimens were examined in both the as-polished and etched condition. Etching was found to darken the cracks but did not extend their depth appreciably. Crack depth and nugget dimension measurements were made in the etched condition. All cracks initiated in the heat-affected-zone adjacent to the nugget and propagated from the faying surface to the outer surface. Crack depths, measured with a micrometer eyepiece, and calculated percent penetrations for Specimen 1 are given in Table I; percent penetrations for each crack in Specimen 2 are tabulated in Table III. Typical examples of these cracks were photographed at 100X and 500X and are shown in Figures 2 through 13. Of the sixteen spotwelds in Specimen 1 (301 ½H), 3 showed no evidence of cracks, 11 were partially cracked and 2 were through cracks. In the spotwelds of Specimen 2 (301 XH), 8 showed no evidence of cracks, 7 were partially cracked and one was a through crack.

It was noted that most of the cracks were confined to spotwelds on one side of the seamweld. To determine if this may have been caused by a difference in nugget diameter or penetration, all welds were carefully measured. There was no appreciable difference. The nugget diameters were on the low side of MPS 43.01B requirements but met all the penetration requirements. The actual values for Specimen 1 are given in Table I.

DISCUSSION

The cracks indicated by radiography are compared with actual cracks, revealed by sectioning and microscopic examination, in Tables II and III for Specimens 1 and 2 respectively. The radiograph of Specimen 1, made using a beryllium window, detected all cracks greater in depth than 15% of the sheet thickness. There were no false indications. The indications in the radiograph of Specimen 2 (Table III), made using the standard glass window, were not as straight forward. Two cracks with depths of 23% of the sheet thickness were not detected, while one crack only 5% of sheet thickness in depth was detected. In addition there were 5 false indications. No explanation can be given at this time for these false indications.

CONCLUSIONS & RECOMMENDATIONS:

On the basis of the data obtained from the evaluation of two spotwelded circumferential joints in type 301 stainless steel, it is concluded cracks can be detected by radiography in thin (.010"- .013") stainless steel sheet that are greater in depth than:

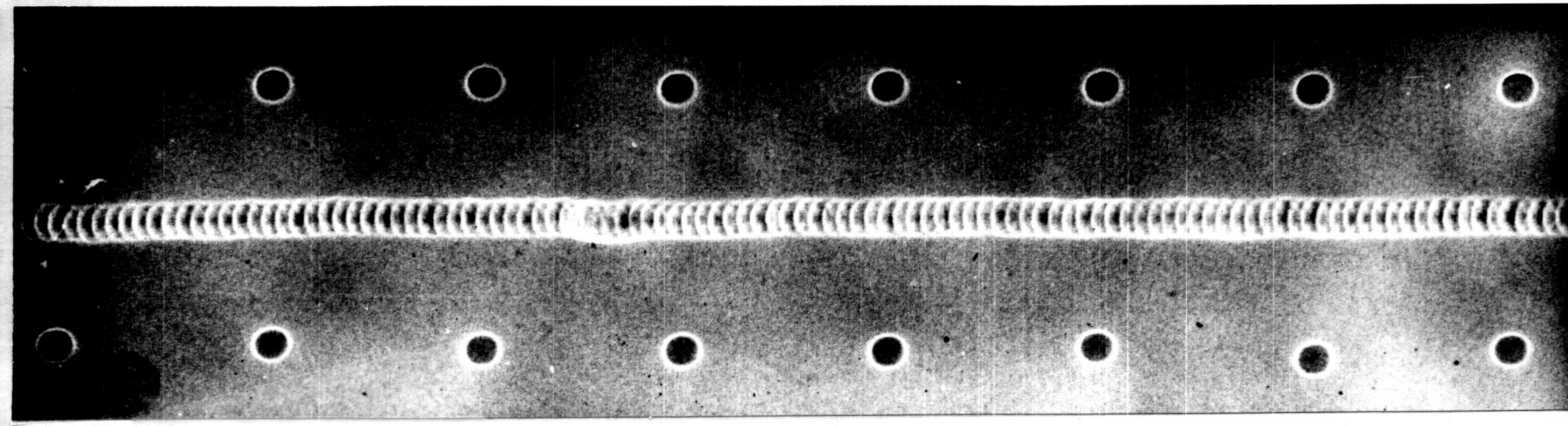
(1) 15% of the sheet thickness, using a x-ray tube with a Be window

(2) 23% of the sheet thickness, using a x-ray tube with a glass window

For thin sheet stainless steel it is recommended that radiographs be made using a x-ray tube with a beryllium window because they can be read with greater facility and cracks of shorter depth can be detected.

Spot Weld Numbers

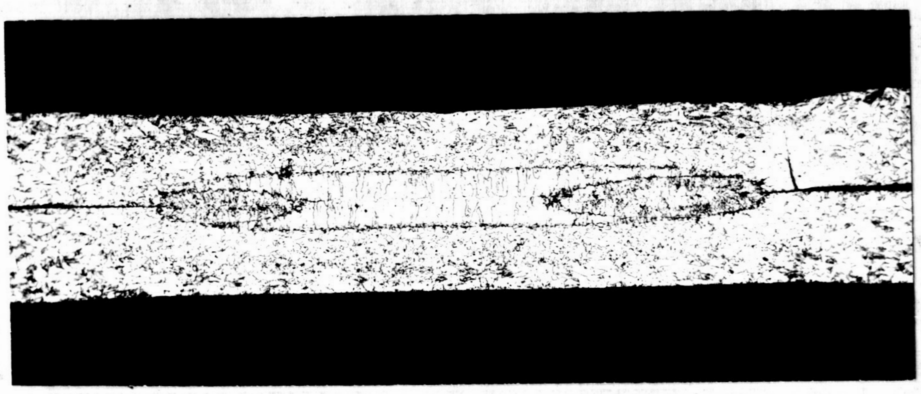
8 7 6 5 4 3 2 1



Spot Weld Numbers

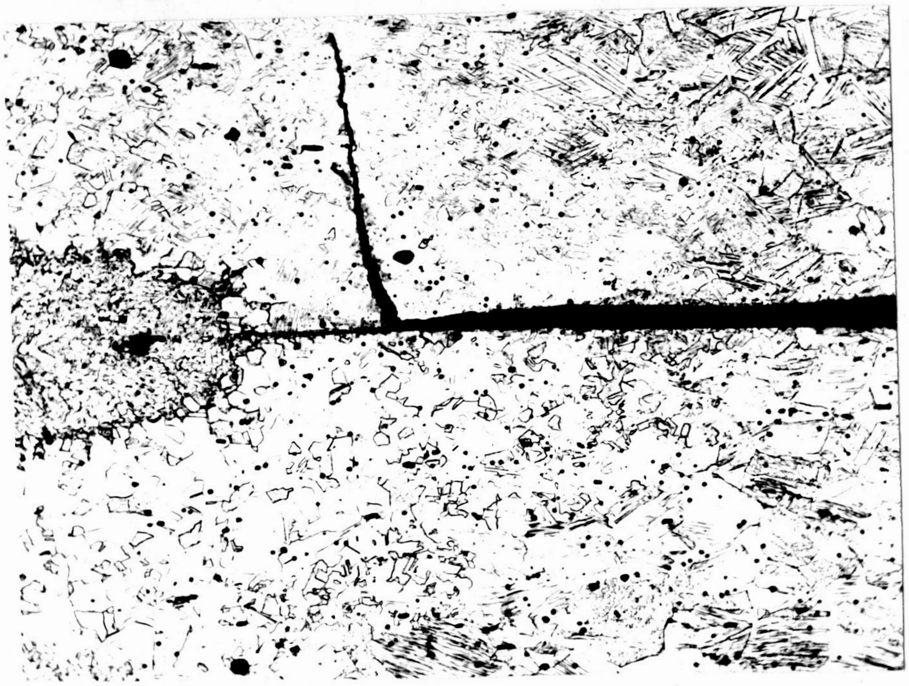
16 15 14 13 12 11 10 9

FIGURE 1 - Enlargement (approx. 2.4X) of the radiograph of the weld joint configuration of the fatigue specimen fabricated from 301 half hard, Ht. No. E87124. This print was made so that it appears as if the actual radiograph is being observed (black is black and white is white). The cracks can be seen as black crescent shaped areas on the upper periphery of the spotweld nuggets, top row. (Nos. 1, 2, 3, etc.)



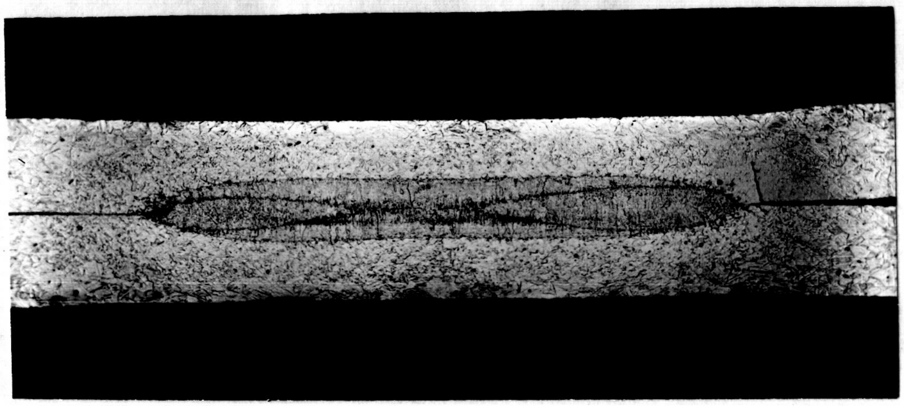
Magnification: 50x Etchant: Electrolytic oxalic acid

FIGURE 2 - Cross- sectional view thru the centerline of spot weld No. 2 (see Fig. 1). Note the secondary weld nugget which is the result of extended welding time when a pulsating current resistance spot weld machine is used. The fatigue load was applied to the top sheet and directed to the right. This crack was detected by radiography.



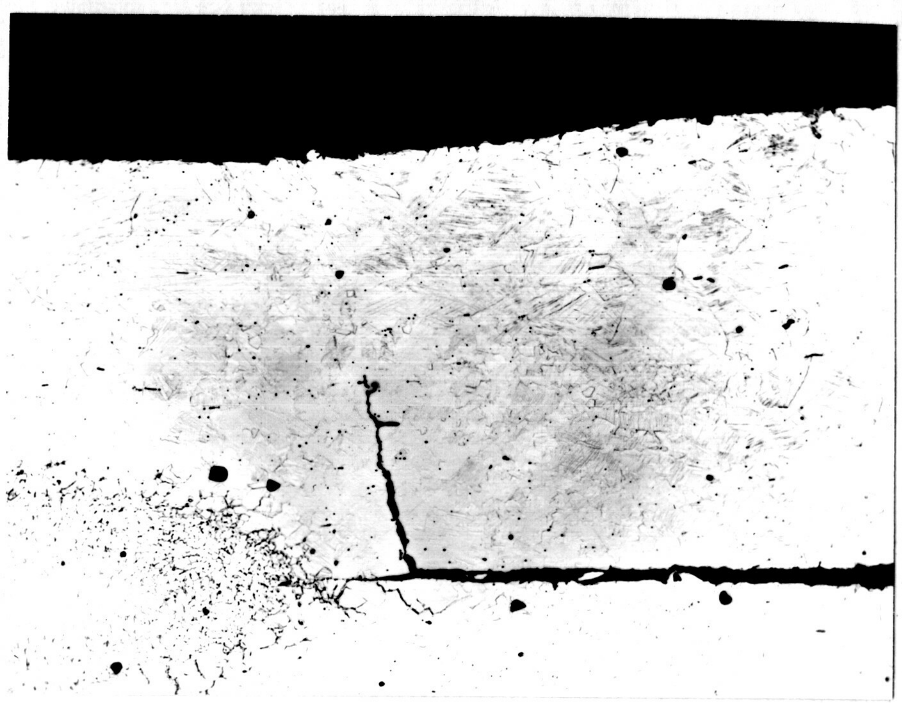
Magnification: 250x Etchant: Same as above

FIGURE 3 - Same spot weld as above except at a higher magnification to show the fatigue crack in greater detail. The crack length is 0.006" or 65% thru the sheet thickness.



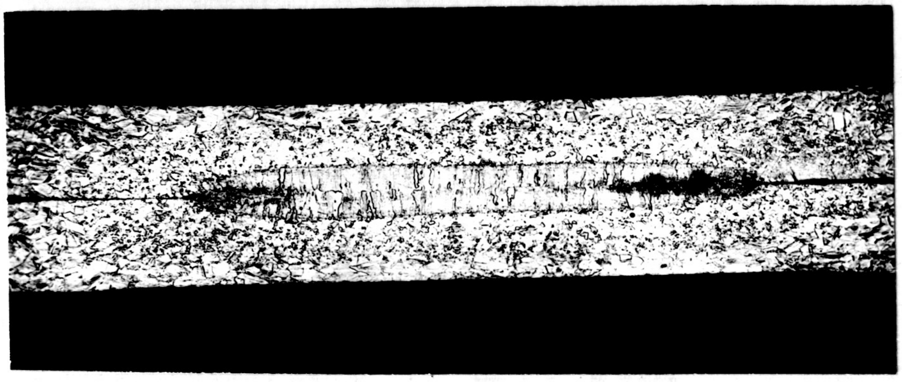
Magnification: 50x Etchant: Electrolytic oxalic acid

FIGURE 4 - Cross-sectional view thru the centerline of spot weld No. 4 (see Figure 1). The load was applied to the top sheet and directed to the right. Radiographic inspection detected a slight indication of a crack.



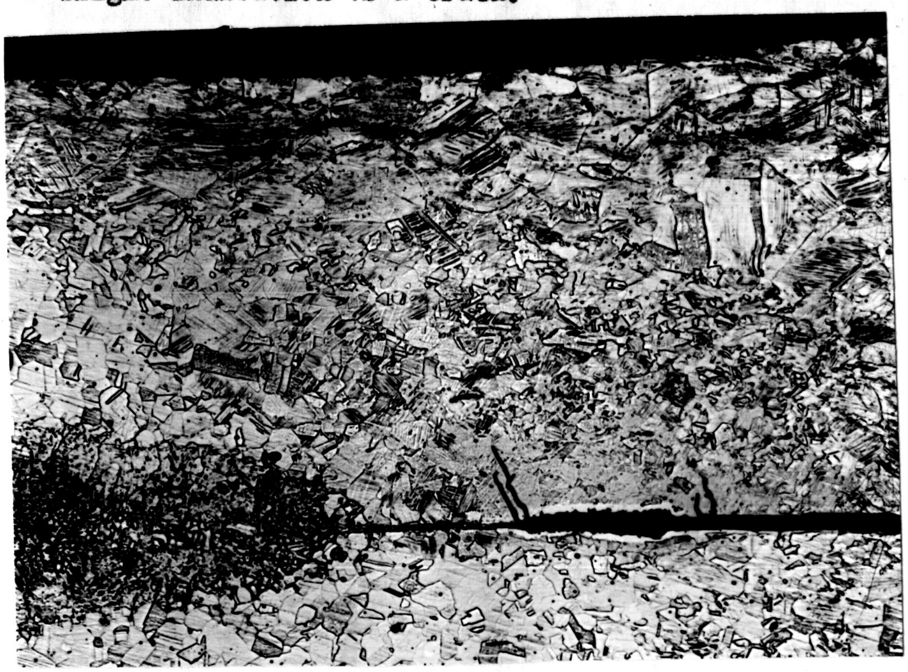
Magnification: 250x Etchant: Same as above

FIGURE 5 - Same spot weld as shown in Fig. 4 exeept at a higher magnification to show the fatigue crack in greater detail. The crack length is 0.004" or 46% of the sheet thickness.



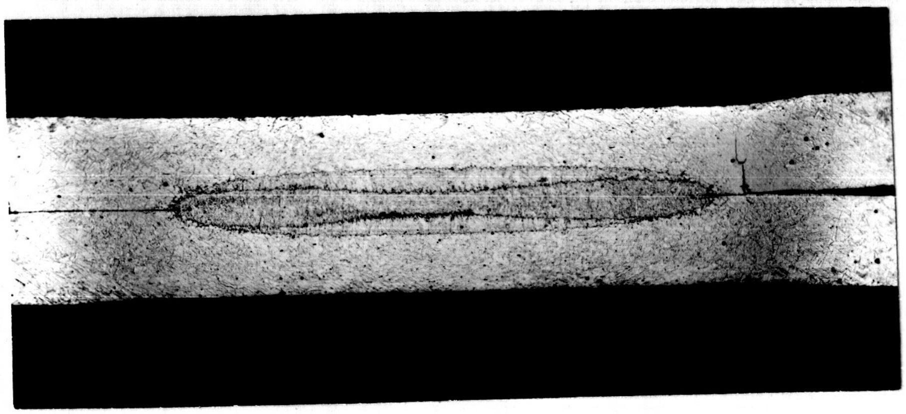
Magnification: 50x Etchant: Electrolytic oxalic acid

FIGURE 6 - Cross-sectional view thru the centerline of spot weld No. 5 (see Fig. 1). The load was applied to the top sheet and directed to the right. The four fine cracks are not readily visible in this photomicrograph (see Fig. 7). Radiographic inspection detected a slight indication of a crack.



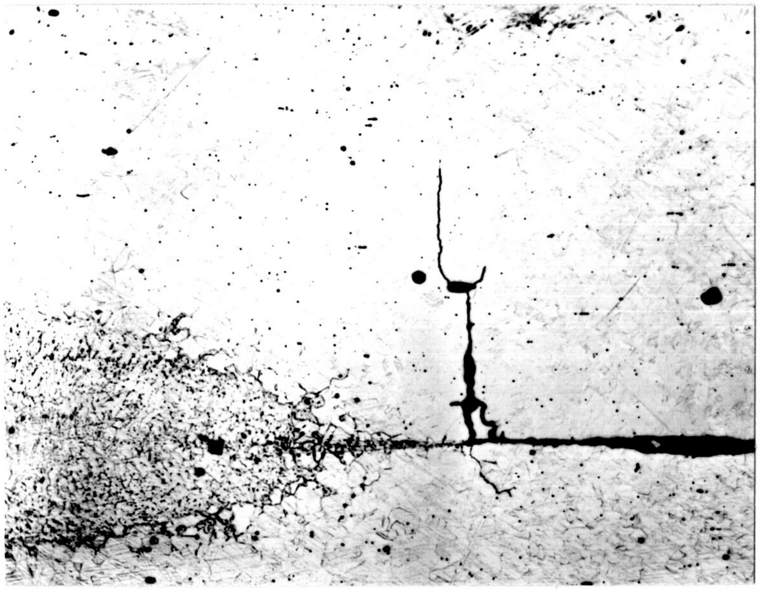
Magnification: 250x Etchant: Same as above

FIGURE 7 - Same spot weld as shown in Figure 6 except at a higher magnification so that the four fine cracks are made visible. The shortest crack is 0.0005" while the longest crack is 0.0015" (respectively 5% and 16% thru the sheet thickness.



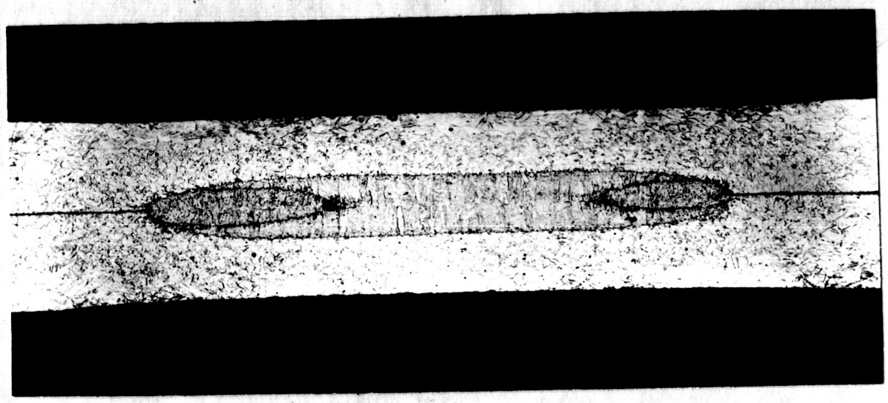
Magnification: 50x Etchant: Electrolytic oxalic acid

FIGURE 8 - Cross-sectional view thru the centerline of spot weld No. 6 (see Fig. 1). The load was applied to the top sheet and directed to the right. Radiographic inspection detected a crack.



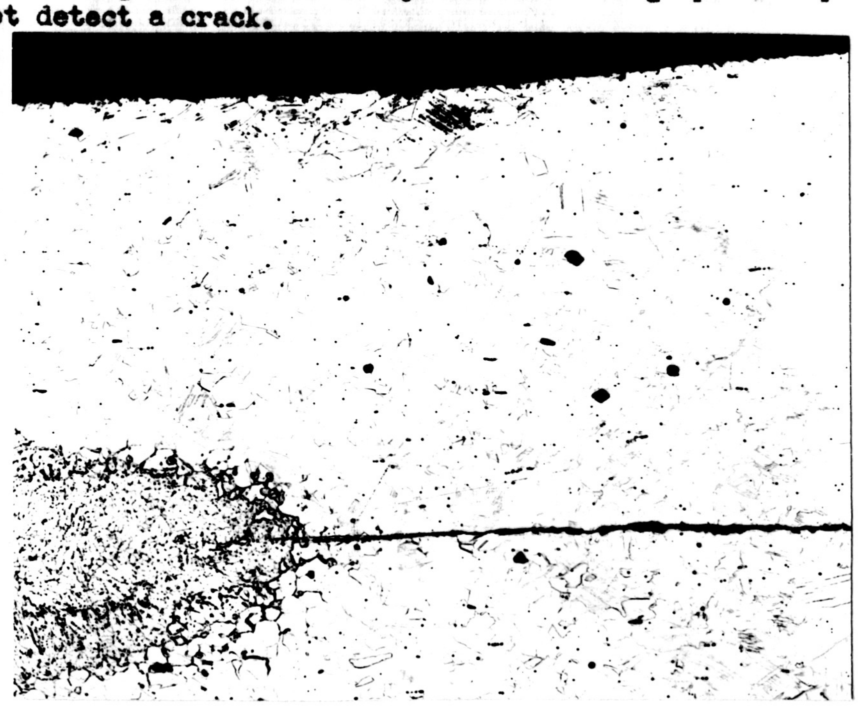
Magnification: 250x Etchant: Electrolytic oxalic acid

FIGURE 9 - Same spot weld as shown in Fig. 8 except at a higher magnification. The crack length is 0.0056 or 61% of the sheet thickness. Note that as the crack propagated thru the load sheet, it branched into two parts at an inclusion. Note also that a fine crack is present in the unloaded sheet. This fine crack appears to be a continuation of the major crack in the loaded sheet.



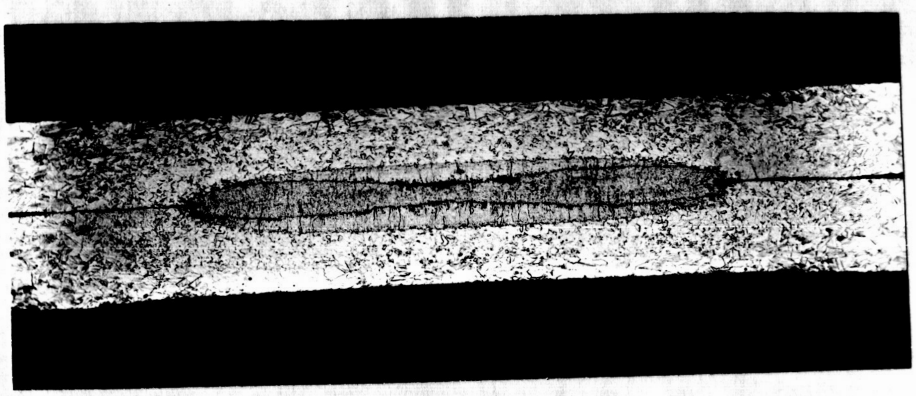
Magnification: 50x Etchant: Electrolytic oxalic acid

FIGURE 10: Cross-sectional view thru the centerline of spot weld No. 9 (see Fig. 1). The load was applied to the top sheet and directed to the right. No crack is present. Radiographic inspection did not detect a crack.



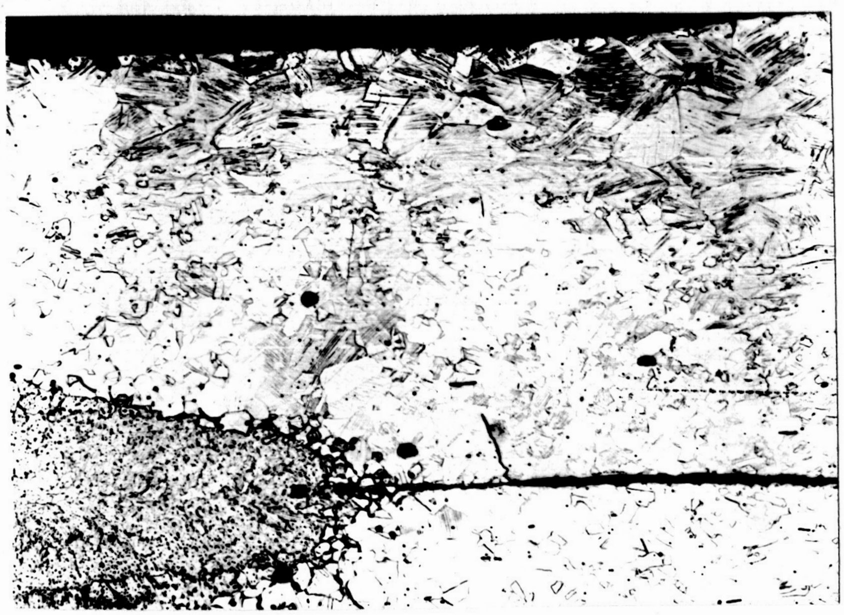
Magnification: 250x Etchant: Same as above

FIGURE: 11 - Same spot weld as show in Fig. 10 except the area where the fatigue cracks would occur is shown at a higher magnification. Load was applied to the top sheet and directed to the right.



Magnification: 50x Etchant: Electrolytic oxalic acid

FIGURE 12 - Cross-sectional view thru the centerline of spot weld No. 12 (see Fig. 1). The load was applied to the top sheet and directed to the right. Radiographic inspection did not detect a crack.



Magnification: 250x Etchant: Same as above

FIGURE 13:- Same spot weld as shown in Fig. 12 except at a higher magnification so that the fatigue crack is made visible. The crack length is 0.0014" or 15% of the sheet thickness.

TABLE I Results of the Metallographic Examination of Spot Welds from the Fatigue Specimen Fabricated from 301 Half Hard, Mil-S-5059, Ht. No. E87124, Ga. 0.010"

Spot Weld No. (See Fig. 1)	Weld Nugget Dia., In.	Weld Penetration	Depth of Crack, Inches	%Penetration into Sheet
1	0.060	39	0.020 (1)	100
2	0.062	38	0.006	65
3	0.060	33	0.010 (1)	100
4	0.062	38	0.0041	46
5	0.059	33	0.0005 (2)	5
			0.0015 (2)	16
6	0.057	40	0.0056	61
7	0.062	39	0.005	60
8	0.058	36	0.004	41
9	0.062	33	No Crack	0
10	0.060	28	< 0.0001	Approx. 1.0
11	0.059	31	No Crack	0
12	0.056	32	0.0014	15
13	0.055	34	0.0014	15
14	0.062	38	0.0002 (2)	2
			0.0005 (2)	5
15	0.059	41	0.0002	2
16	0.060	39	No Crack	0
MPS 43.01 B requirements	0.060 - 0.080	20 - 90		

(1) Through crack
(2) Two cracks

TABLE II Results of Radiographic and Metallographic Examination of Spot Welds from the Fatigue Specimen Fabricated from 301 Half Hard, Mil-S-5059, Ht. No. E87124; Ga. 0.010"

Spot Weld No. (See Fig. 1)	Radiographic Examination[1]	Metallographic Examination
1	Crack present	Crack present - thru entire load sheet
2	Crack present	Crack present - thru 65% of load sheet
3	Crack present	Crack present - thru entire load sheet
4	Slight indication of a crack	Crack present - thru 46% of load sheet
5	Slight indication of a crack	Cracks present - longest crack 16%, shortest crack 5% all thru load sheet
6	Crack present	Crack present - thru 61% of load sheet
7	Crack present	Crack present - thru 60% of load sheet
8	Crack present	Crack present - thru 41% of load sheet
9	No Crack	No Crack
10	No Crack	Crack present - thru approx. 10% of load sheet
11	No Crack	No Crack
12	No Crack	Crack present - thru 15% of load sheet
13	No Crack	Crack present - thru 15% of load sheet
14	No Crack	Cracks present - longest crack 5%, shortest crack 2% all through load sheet
15	No Crack	Crack present - thru 2% thru load sheet
16	No Crack	No Crack

Total number of cracks found by radiography	8
Total number of cracks found by metallography	13
Total number of cracks as found by radiography, but not confirmed by metallography	0
Total number of cracks as found by metallography, but not detected by radiography	5[2]

1. Beryllium window attachment used for the radiographic inspection
2. Cracks depths ranged from 1 to 15% of load sheet thickness.

TABLE III Results of Radiographic and Metallographic Examination of Spot Welds in the Fatigue Specimen Fabricated from 301 extra hard, 0-71004, Ht. No. 57104, Cl. No. 453, Ga. 0.013"

Spot Weld No.	Radiographic Examination[1]	Metallographic Examination
1	Slight indication of a crack	No Crack
2	Crack present	Crack present - thru 50% of load strut
3	Crack present	Crack present - thru entire load sheet
4	Slight indication of a crack	No Crack
5	Slight indication of a crack	No Crack
6	No Crack	No Crack
7	No Crack	No Crack
8	Crack present	No Crack
9	Crack present	Crack present - thru approx. 90% of load sheet
10	Slight indication of a crack	No Crack
11	Slight indication of a crack	Crack present - thru 50% of load sheet
12	Crack present	Crack present - thru 75% of load sheet
13	No Crack	Crack present - thru 23% of load sheet
14	No Crack	Crack present - thru 23% of load sheet
15	No Crack	No Crack
16	Crack present	Crack present - thru approx. 5% of load sheet

Total number of cracks found by radiography	11
Total number of cracks found by metallography	8
Total number of cracks as found by radiography but not confirmed by metallography	5
Total number of cracks as found by metallography, but not detected by radiography	2[2]

1. Standard production radiographic equipment used for the inspection.
2. Crack lengths were both 23% of the load sheet thickness.