

DEVELOPMENT OF
NAVAPLSCIENLAB MECHANICAL PEENING PROCEDURE
FOR
IMPROVEMENT OF FATIGUE PROPERTIES OF HY-80 WELDS

Lab. Project 9300-1, Progress Report No. 1

(SR 007-01-01) Task 0856

15 April 1964


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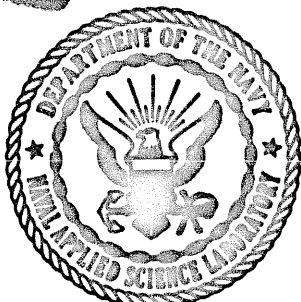
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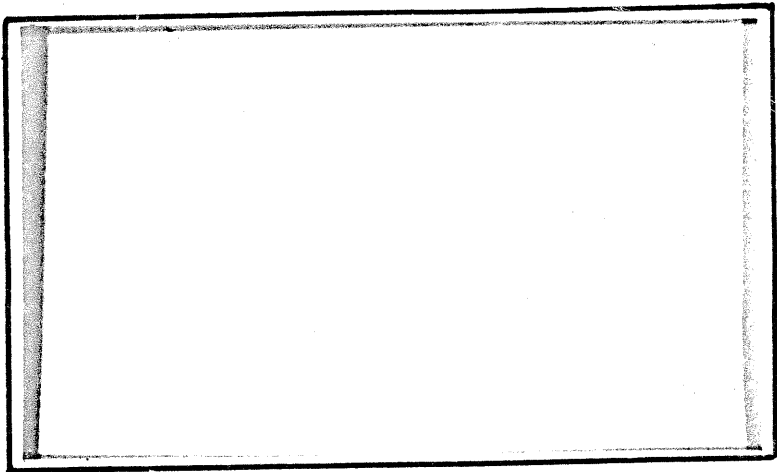
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TECHNICAL MEMORANDUM

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SUMMARY

The Naval Applied Science Laboratory mechanical peening procedure for improving the fatigue life of welds is described herein. Results of tests on HY-80 fillet welds at stress levels in the 60,000 to 180,000 psi range (0 to tension) have indicated that the fatigue lives of these weldments approximate those of prime base plate. The process is inexpensive and readily applicable to existing and new construction with currently available equipment and skills. Potential significant improvement of properties of welded structures, in addition to fatigue, might also be realized.

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ADMINISTRATIVE INFORMATION

- Ref: (a) Grinding and Shot Peening of HY-80 Welds - Effects Relative to Fatigue - I. L. Stern, BUSHIPS Conference Report of 12 Jan 1960
(b) NAVAPLSCIENLAB ltr 9310:PA:mg, Lab. Project 6160-2 of 16 Sep 1963
(c) BUSHIPS ltr R007-01-01 Ser 634B-634 of 22 Aug 1963
(d) NAVSHIPYDNYK MATLAB Project 6160-2 Progress Report 2 of 17 Jul 1961

1. This investigation was authorized by BUSHIPS letter R007-01-01 Ser 634B-634 of 22 August 1963 (SR 007-01-01, Task 0856).

ACKNOWLEDGMENTS

2. The work reported herein was under the overall direction of I. L. Stern, Head of the High Strength Steel Program. Preparation of weldments was supervised by L. Ginsburg. Consultation on fatigue aspects and tooling for mechanical peening was provided by H. V. Cordiano, Head, Mechanics Branch. The Bureau of Ships Program Manager is G. Sorkin (Code 341A) and BUSHIPS Project Engineer is T. Dawson (Code 634B).

BACKGROUND

3. In connection with the High Strength Steel Fabrication Program, the Naval Applied Science Laboratory has been conducting studies of the fatigue properties of HY-80 welds, and methods for their improvement. References (a) and (b) indicated the degree of improvement derived from grinding, shot peening and a combination of grinding and shot peening for stress levels up to 60,000 psi. While some improvement was noted, grinding, as well as shot peening, was expensive and not conveniently applicable.

4. In accordance with reference (c), the Laboratory extended its studies of methods for improvement of fatigue from the 60,000 psi to 120,000 psi (equivalent elastic stress) range and included mechanical peening as an additional process for consideration. With respect to the latter, the Bureau in reference (c) suggested a mechanical peening method. NAVAPLSCIENLAB modification of the suggested method led to the development of the mechanical peening procedure recommended herein.

OBJECTIVE

5. The objective of the facet described herein was to develop a mechanical peening method for the improvement of the fatigue properties of HY-80 fillet welds, which would be economical and readily applicable under shipyard conditions.

EXPLORATORY STUDIES

6. Exploratory studies with various methods of mechanical peening of HY-80 fillet welds indicated the following:

a. Wide thin chisels with edges similar to that shown in reference (c) ($1/4$ " radius, $7/8$ " wide, $3/16$ " thick) caused excessive cutting and gouging of metal and incomplete coverage.

b. Wide, thin chisels similar to the above with increased edge thickness (to $9/32$ ") reduced the chipping tendency. These chisels appeared promising, but they could not always accommodate surface and corner irregularities in contour. As a result, coverage was not complete. Increase of edge thickness or radius to achieve better coverage interfered with access to the root corner, which is the most critical area.

c. Spherically pointed chisels (approximately $1/4$ " radius) were the easiest for operation and contouring and produced the most deformation. However, the resulting surfaces were dimpled.

d. Various other modifications to chisels similar to those described above did not achieve any significant improvement.

e. A No. 2 pneumatic chipping hammer yielded optimum results. A lighter type gun could not provide sufficient force to move the required amount of metal. In view of the excellent results obtained with the No. 2, Type 2 hammer, a heavier tool was considered undesirable because its excessive weight would interfere with accessibility and increase operator fatigue.

NAVAPLSCIENLAB MECHANICAL PEENING PROCEDURE

7. In view of the results obtained in the exploratory studies, a two step procedure was adopted which used a spherical nose chisel for deformation and contouring, and a blunted chisel for dressing. The procedure is fully described in Figures 1 and 2. The peening produced is shown in Figures 3 and 4. All peening operations were performed at room temperature.

8. The basis for selection of the procedure, which is illustrated in Figures 1 through 5, was achievement of the following:

a. Minimum cost - Approximately \$0.20 per foot with negligible equipment cost.

b. Contour - Smooth generous radius ($7/32$ " + $1/32$ "). (See Figure 5)

- c. Surface finish - smooth, uniform in appearance. (See Figure 4)
- d. Metal movement - appreciable and uniform, includes movement of weld-HAZ, base metal junction. (See Figure 5)
- e. Minimum metal flaking.
- f. Coverage - complete, into fillet corners and extending well beyond critical HAZ and stress concentration areas. (See Figures 4 and 5)
- g. Minimum operator effort and skill required.
- h. Reproducible. (See Figure 5)
- i. Equipment - simple, only conventional shipyard caulking guns and chisels required.

SPECIMEN PREPARATION PROCEDURE

9. A total of 16 tee fillet welded specimens similar to those of Figure 7 were prepared for testing in the NAVAPLSCIENLAB plate type fatigue machine. Details of specimen layout and preparation are shown in Figures 6 and 7. All welding was conducted in accordance with NAVSHIPS 250-637-3 and with joint design and procedure previously described in reference (d). Eight specimens were tested in the as-welded condition, and the other eight specimens mechanically peened in accordance with the procedure of Figure 1. The specific peening conditions used for each specimen are shown in Table 1.

FATIGUE TESTING PROCEDURE

10. The 16 specimens (8 as-welded, 8 mechanically peened) were subjected to cyclical loading, varying from zero to a maximum, with the fillets in tension, at the rate of 12 cycles per minute, in the Plate Fatigue Machines described in detail in reference (d). The plate specimens were tested to ultimate failure, which was considered to have occurred when the deflection under the maximum load increased 100 per cent over the deflection at the start of the fatigue run.

11. Two each of as-welded and mechanically peened specimens were run at nominal stress levels of 60,000 and 80,000 psi and "equivalent elastic stress" levels of 100,000 and 120,000 psi. The "equivalent elastic stress" levels were arrived at by adjusting the pressure for each plate to give a desired maximum unit strain at the critical section of 0.0033 and 0.0040, respectively, as measured with SR-4 strain gages. These strains correspond to "equivalent elastic stress" of 100,000 and 120,000 psi, based on the engineering stress-strain diagram. It should be noted here that because of the restraint due to the Poisson effect in

in a plate type specimen, the "equivalent elastic stress" is, according to plate theory, about 10 per cent higher than that calculated on the basis of the engineering stress-strain diagram from slender uniaxial specimens.

12. During the course of the test, a continuous chart record of cyclical deflection at the center of the plate was obtained for the entire test of each plate. In addition, maximum and minimum deflections measured with dial indicators were recorded at intervals of 500 or 1000 cycles. Observations were also made throughout the test to determine the number of loading cycles at which a crack started and progressed to various lengths along the toe of the weld. The cracks were detected by observing the flow of SAE-10 oil, applied in a light coating along the critical section, into and out of the crack as the plate flexed under load.

RESULTS

13. Fatigue data obtained on as-welded and mechanically peened specimens are summarized in Tables 2 and 3, respectively. The thickness indicated for each specimen represents an average of nine measurements taken along the critical section. In general, cracks were observed to start at one or more locations at the toe of the fillet weld. These cracks grew in length while others started at new locations. The various cracks joined each other to form larger cracks until finally a single continuous crack was formed along the weld. In the case of the mechanically peened welds, the cracks were more difficult to detect, probably because the metal at the surface was initially in compression. In addition, some of the early indications were not true cracks; but were localized interfaces between deformed metal and underlying base metal. These were not considered cracks unless they propagated along the weld to form true cracks. The first two digits of the specimen numbers designated in Tables 2 and 3, duplicate the first two numbers of the plates for which analyses and properties are shown in Table 4.

14. Fatigue lives, based on a 10 per cent increase in deflection over the initial deflection, are shown plotted on S-N coordinates, Figure 8, for both the as-welded and mechanically peened tee fillet welds. This 10 per cent criterion formed the basis for all previous curves submitted for plate type fatigue tests. The lines passing through the data have been fitted by eye. The S-N curve previously reported for base plate is also shown for comparison. It will be observed that although the "equivalent elastic stress" levels were the same for as-welded and mechanically peened plate specimens the resulting nominal stresses based on calculations were significantly higher for the mechanically peened specimens. Apparently the relief of residual stresses by mechanical peening permitted greater loads to be applied before significant plastic deformation took place. The lines drawn through the test data are widely separated at a stress of 60,000 psi and converge as they reach a nominal stress of 120,000 psi. At 60,000 psi the mechanically peened fillet welds show fatigue lives equal to those of the base plate and are about forty times greater than those of the as-welded tee fillets. Comparisons at other levels may be conveniently made from Figure 8.

15. Typical curves showing variation of deflection with number of cycles for the as-welded and the mechanically peened tee fillet welded plate specimens are shown on Figures 9 and 10, respectively

CONCLUSIONS

16. A new mechanical peening procedure has been developed which achieves an unprecedented increase in the fatigue life of HY-80 fillet welds. The procedure is rapid, inexpensive and readily applicable with current shipyard skills and equipment.

17. The beneficial effects obtained by applying the NAVAPLSCIENLAB mechanical peening process to HY-80 tee fillet weld assemblies may be summarized as follows:

Nominal Stress (0 to tension) psi	Increased Fatigue Life as Compared to "As-Welded" Condition (Approximately)	Comparative Life Reported Unwelded Base Plate (Reference (d))
60,000	40 times	Equivalent
80,000	10 times	Equivalent
100,000	3 times	Base plate data not available.
120,000	"As-welded" data not available.	Base plate data not available.

ADDITIONAL WORK REQUIRED

18. While the results obtained are very promising with regard to fatigue, the effects of mechanical peening have not been assessed in other respects. The following are some of the more important data which should be obtained:

- a. Extent of improvement obtained under fatigue loads other than 0 to tension, (such as 0 to compression and alternating tension and compression).
- b. Applicability to joints other than tee fillets (such as butt welds).
- c. Applicability to steels higher and lower in strength than HY-80 and structural materials other than steel (such as aluminum, titanium, etc.)

d. Corrosion fatigue properties.

e. Possible presence of surface embrittlement introduced by cold work, and its significance if present.

APPLICATIONS

19. The facility with which weld and adjacent contour can be changed and the apparent minimization or removal of residual tensile stresses at the toes of the welds suggests additional important applications for the subject process. Two of the most probable are as follows:

a. Attainment of increased static and dynamic (impact and explosion resistance) properties by minimization or residual tensile stress and reduction of areas of stress concentration (especially at weld toes) achieved by mechanical peening for optimum contour.

b. Reduction in extensive delayed post-weld cracking which is sometimes encountered in heavy ship weldments fabricated under conditions of high restraint.

20. Application of the subject procedure will minimize or eliminate the residual tensile stress at the toes of welds; these residual tensile stresses are believed to be the principal factor in the formation of this type of cracking.

RECOMMENDATIONS

21. It is recommended that the NAVAPLSCIENLAB mechanical peening procedure be further explored as a means of improvement of fatigue properties of weldments in existing and future ships and structures.

22. Application of the process to existing HY-80 welded ships and structures should be initiated in those areas which are prone to early fatigue failure.

23. It is also recommended that exploratory data relative to the facets outlined in paragraph 18 above be obtained prior to widespread application of the process to actual ship structures.

24. It is further recommended that the investigation of the subject process be extended to acquire data relative to its possible significant advantages noted in paragraph 19 above, in respect to improvement of static and dynamic properties and minimization of delayed cracking of weldments.

FUTURE WORK

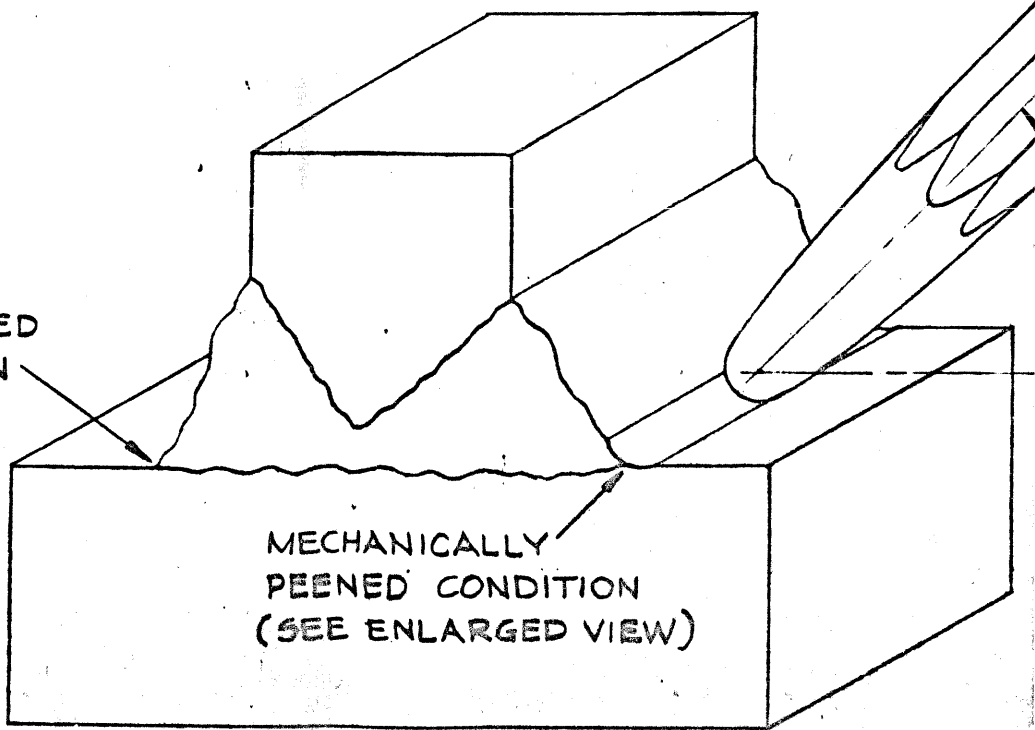
25. NAVAPLSCIENLAB representatives expect to visit BUSHIPS in the near future to discuss; (a) the potential applicability of the subject process and (b) the acquisition of the additional information discussed in paragraphs 18 and 19 above. It is understood that the Bureau desires early investigation of the fatigue lives of mechanically peened butt welds.

26. A study of the metallurgical nature and properties of fillets peened by the subject process and characteristics of fatigue fractures in these fillets is being made and will be reported in approximately 3 months.

27. Studies relative to residual stresses in these weldments are underway under SF013-03-02, Task 2025.

28. Specimen preparation has been completed and fatigue tests are currently underway to determine the effects of grinding and shot peening HY-80 fillets, in fatigue life at stresses in the 60,000 psi to 120,000 psi equivalent elastic stress range. Associated residual stresses of these weldments are also being studied.

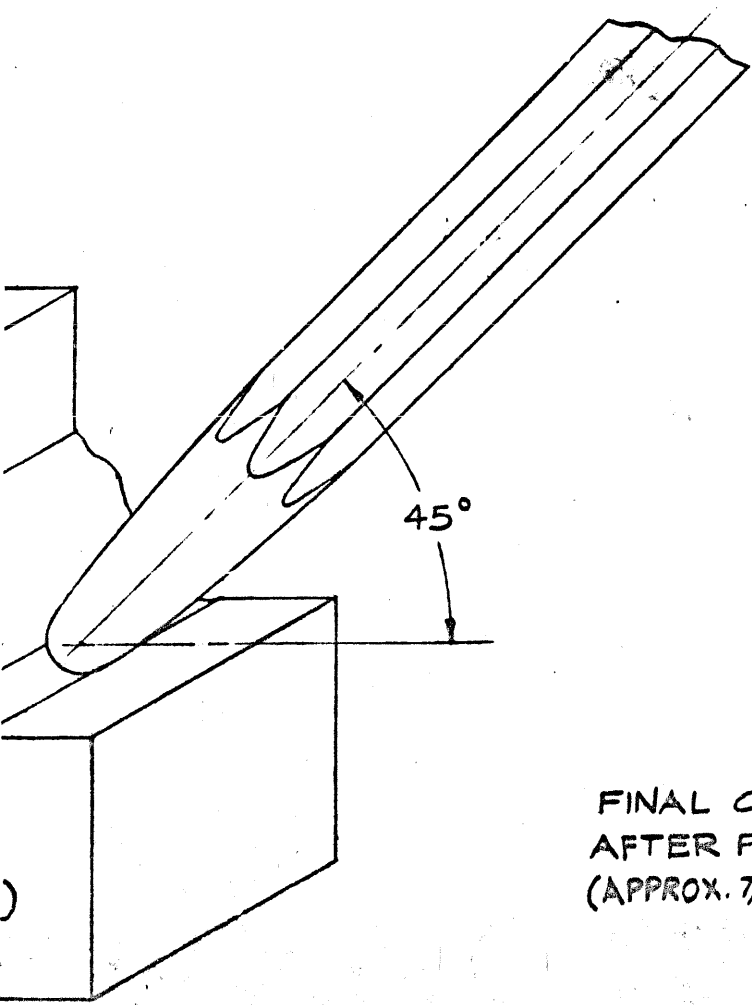
AS WELDED
CONDITION



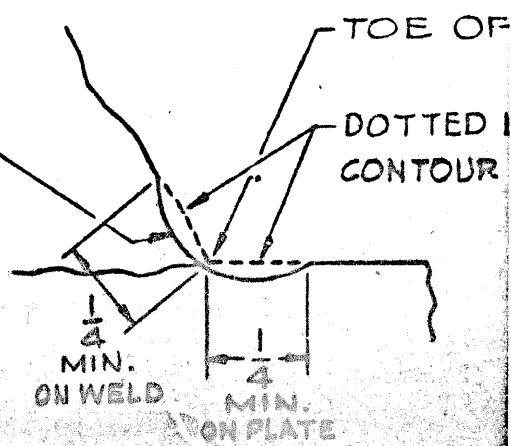
MECHANICALLY
PEENED CONDITION
(SEE ENLARGED VIEW)

TEE WELDMENT

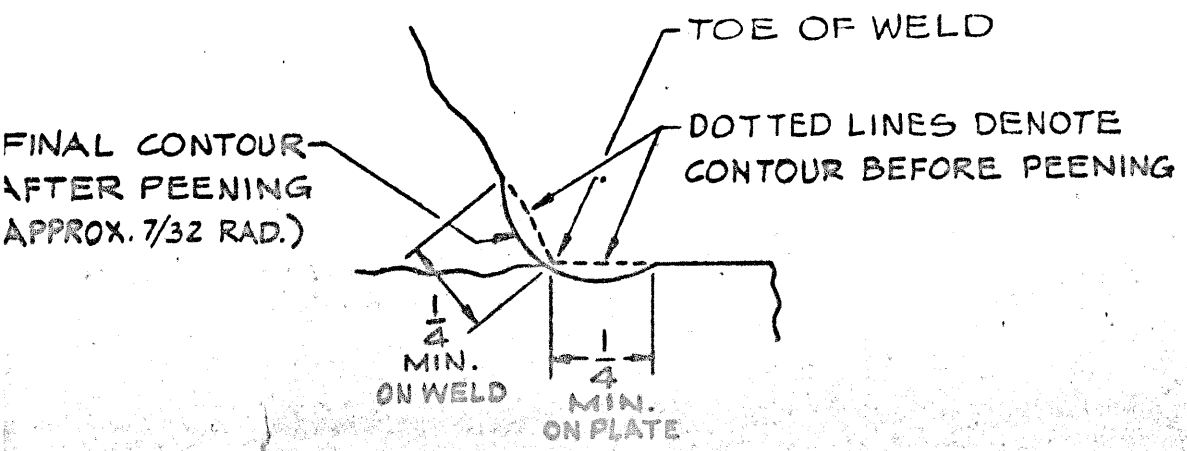
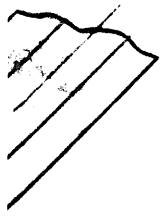




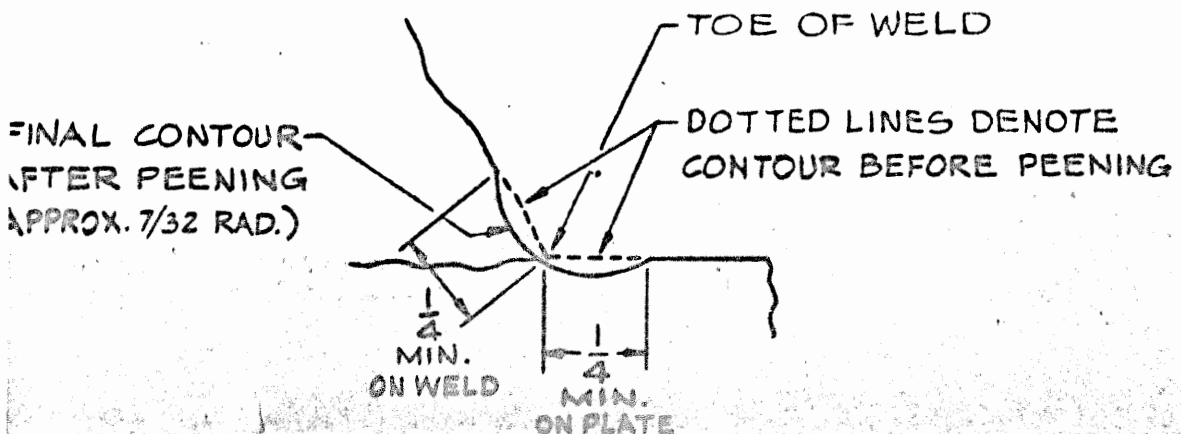
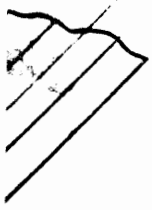
FINAL CONTOUR
AFTER PEENING
(APPROX. 7/32 RAD.)



ENLARGED VIEW
OF TEE WELDMENT TOE



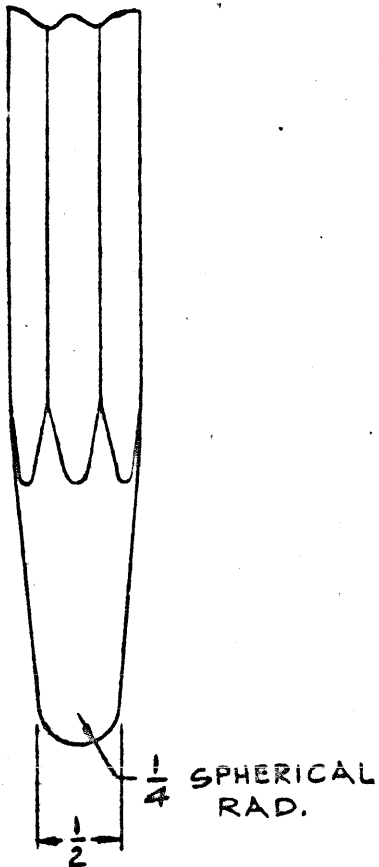
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OF TEE WELDMENT TOE



ENLARGED VIEW
OF TEE WELDMENT TOE

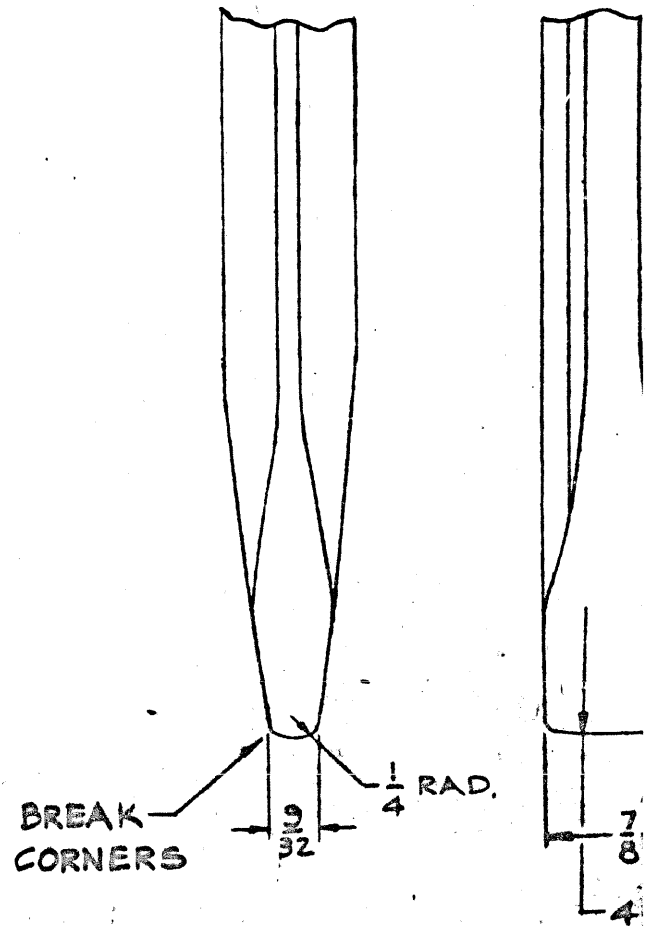


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CONTOURING TOOL

2

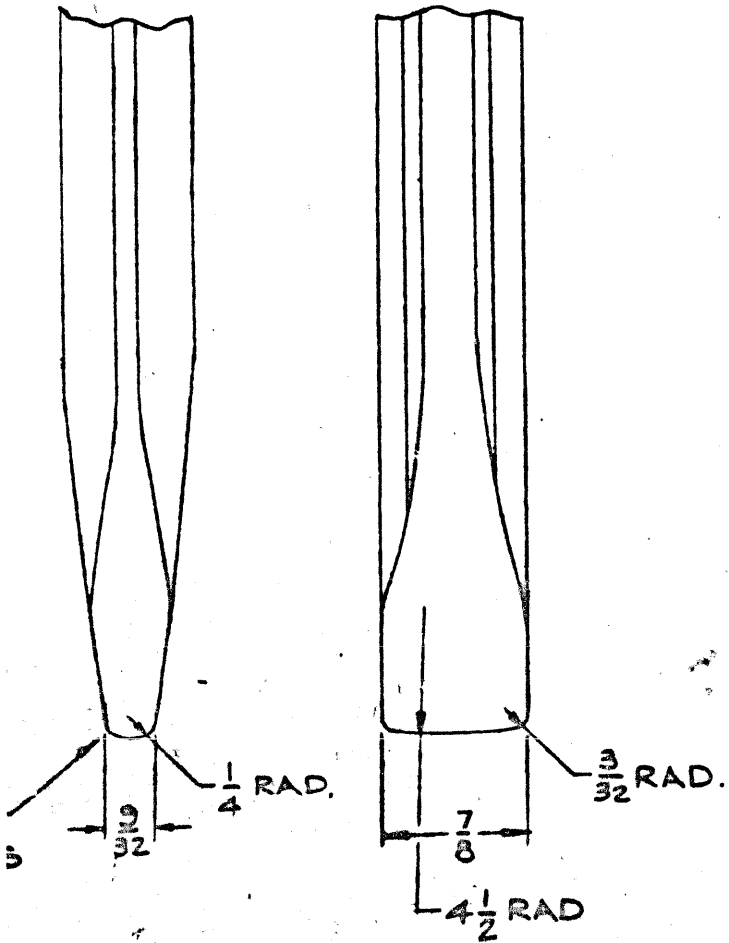


DRESSING TOOL

3

ENLARGED VIEW
OF TEE WELDMENT TOE

4



DRESSING TOOL

3

5

INSTRUCTIONS

I EQUIPMENT:

- (a) 90 PSI - AIR SUPPLY
- (b) PNEUMATIC HAMMER, FED. SPEC. 00-H-116a, SIZE
- (c) CONTOURING TOOL } CHISEL BLANK, HARDENED
- (d) DRESSING TOOL }

II PROCEDURE:

- (a) DIRECT CONTOURING TOOL ② AS SHOWN IN ①
- (b) FOLLOW TOE OF WELD AT A SPEED OF 15 INCH APPROXIMATE CONTOUR. SHOWN IN ④
- (c) DIRECT DRESSING TOOL ③ AS IN ① ABOVE, THIS REMOVE SPHERICAL IMPRESSIONS OF CONTOUR

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ALTERATIONS

NASL PEENING
 PROCEDURE FOR THE IMPROVEMENT
 OF FATIGUE PROPERTIES.
 (AS SHOWN FOR STEEL WELDMENTS)

U.S. NAVAL APPLIED SCIENCE LABORATORY
 U.S. NAVAL BASE, BROOKLYN, NEW YORK, 11201

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DATE 13 JAN. 1964

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 CHECKED BY G. GIRAGOSIAN
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 IN CHARGE C. SHARP

APPROVED _____ DATE 1/19/64
S. Colonna
 INDUSTRIAL DEPARTMENT HEAD

APPROVAL LETTER

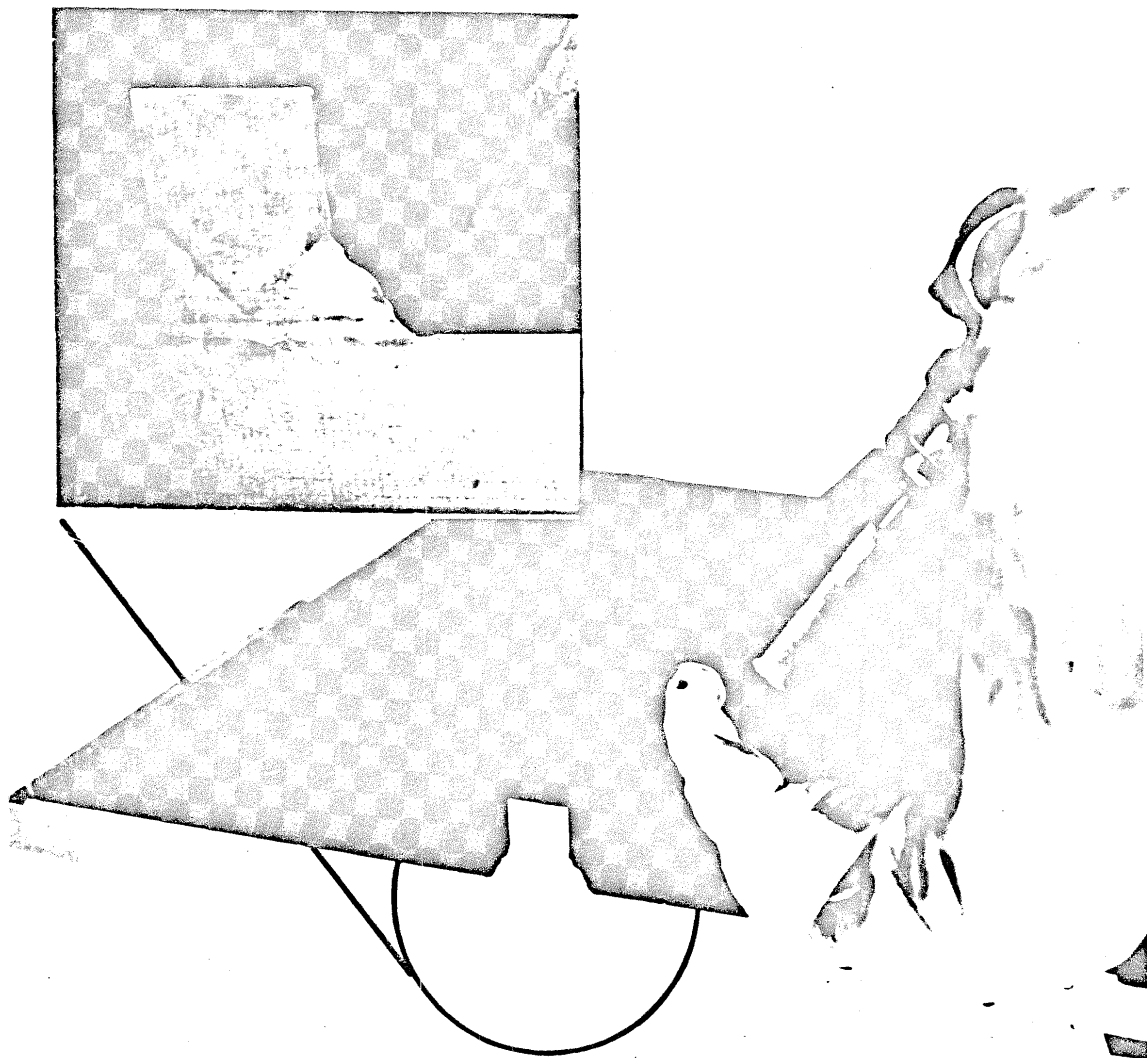
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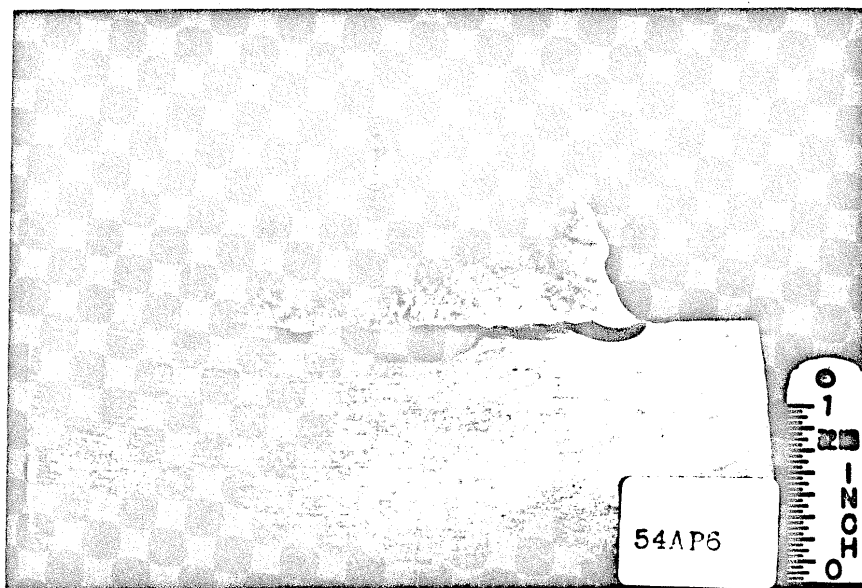
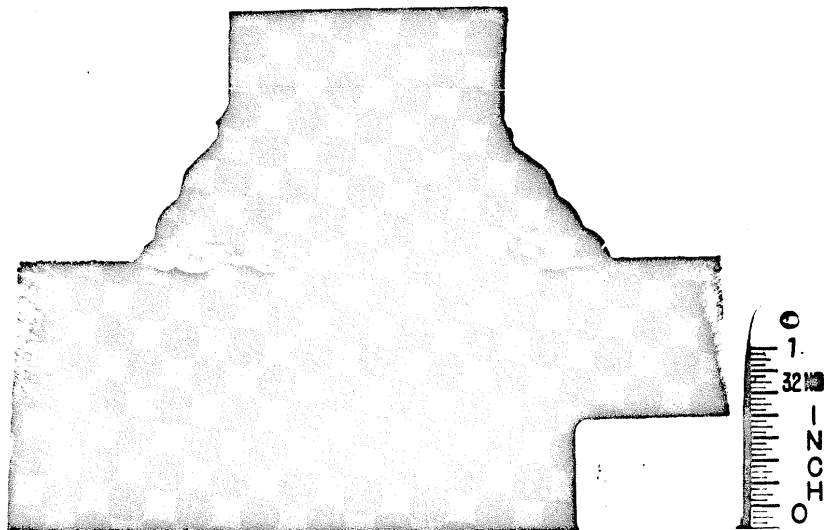


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Figure 2 - Mechanical Peening Technique Showing Position of Tool Relative to Fillet Toe of 1-1/2" Thick HY-80 Tee-Weldment

Photo L19713-1

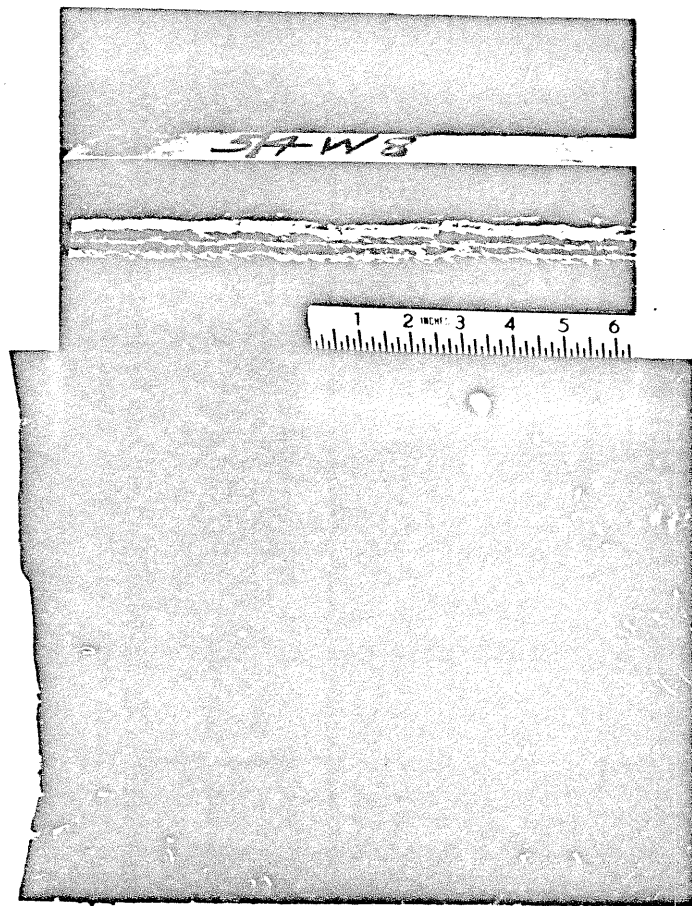


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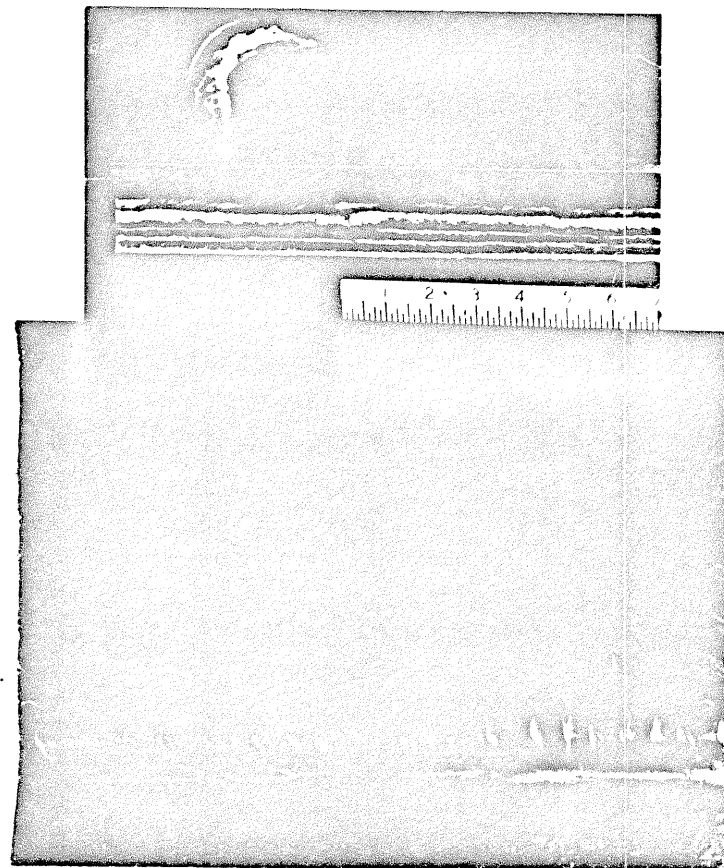
Lab. Project 9300-1
Progress Report 1

Figure 3 - Macro-Section of As-Welded (Top) and Mechanically Peened (Bottom)
Specimens Taken From 1-1/2" Thick HY-80 Tee-Weldments

Photo L19713-2



As-Welded



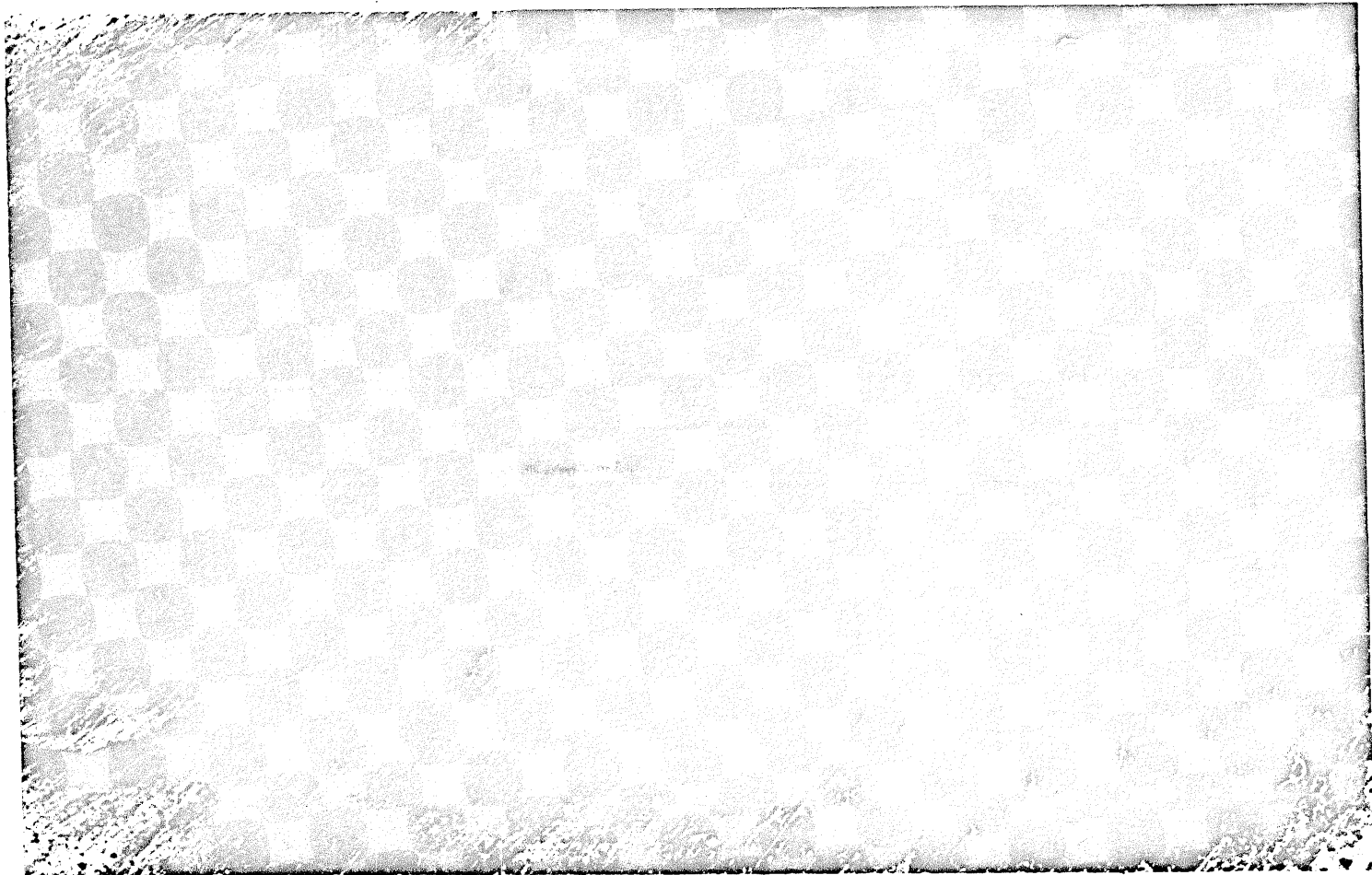
Mechanically Peened

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Progress Report 1

Figure 4 - Appearance of Fillet Toe of 1-1/2" Thick HY-80 Tee-Weldments

Photo L19713-3



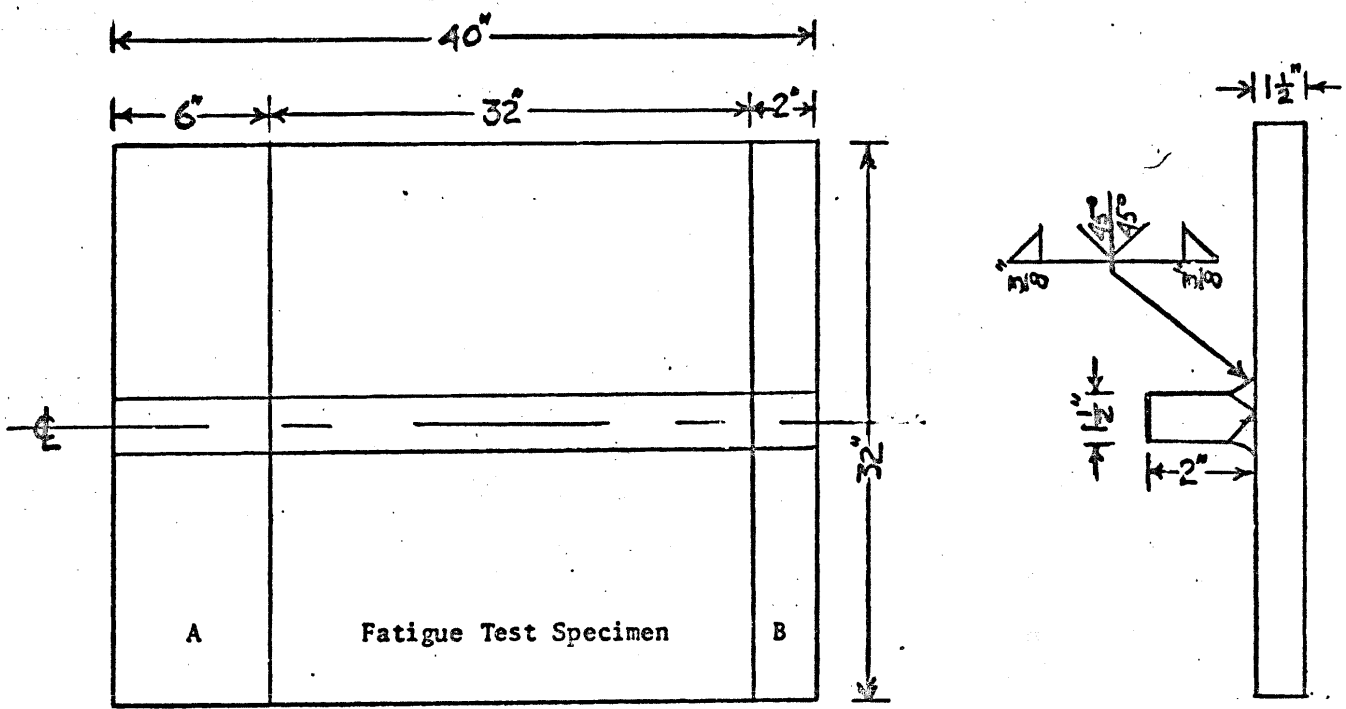
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Progress Report 1

Figure 5 - Typical Mechanically Peened Profile Obtained on 1-1/2" Thick HY-80 Tee-Weldment. Arrows Indicate Extent of Metal Movement and Contouring.

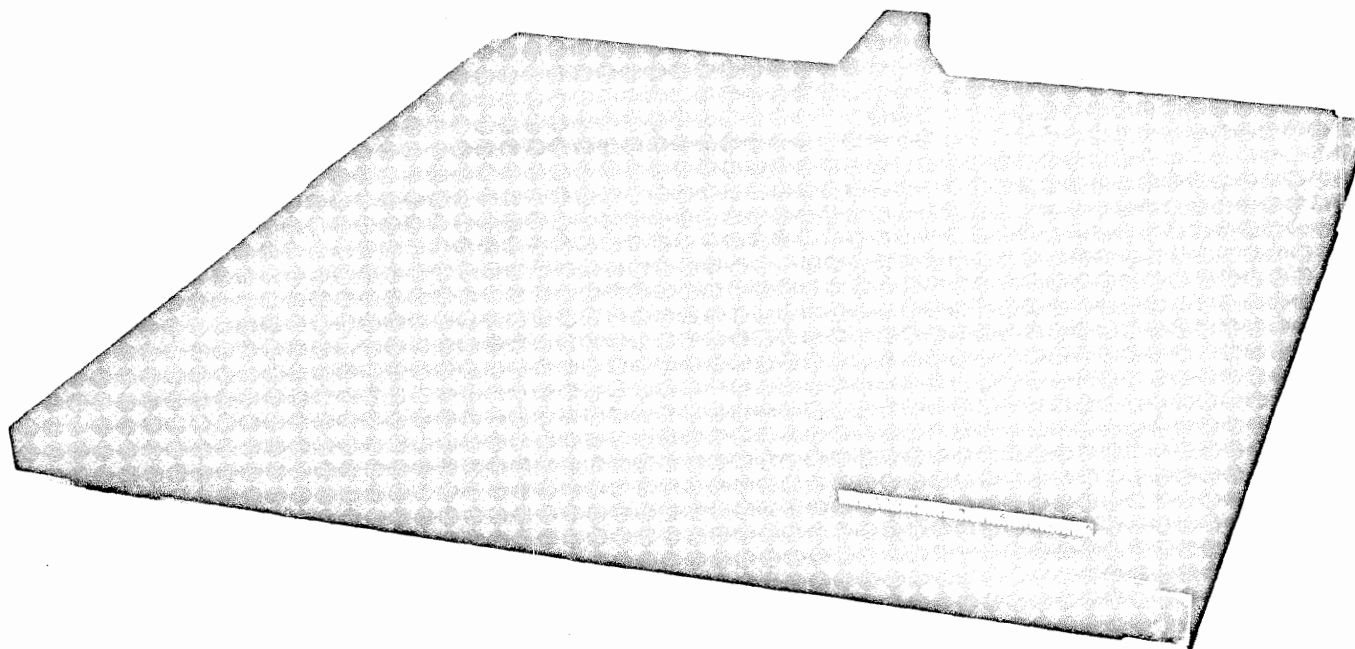
Photo L19713-4



A - Specimen for other related fatigue work.

B - Section for Macro specimen

Figure 6 - Tee-Weldment Showing Specimen Layout



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Progress Report 1

Figure 7 - Finished Machined, 1-1/2" Thick, HY-80 Tee-Weld-
ment Fatigue Specimen (29-5/8" Wide x 32" Long)

PHOTO L19713-5

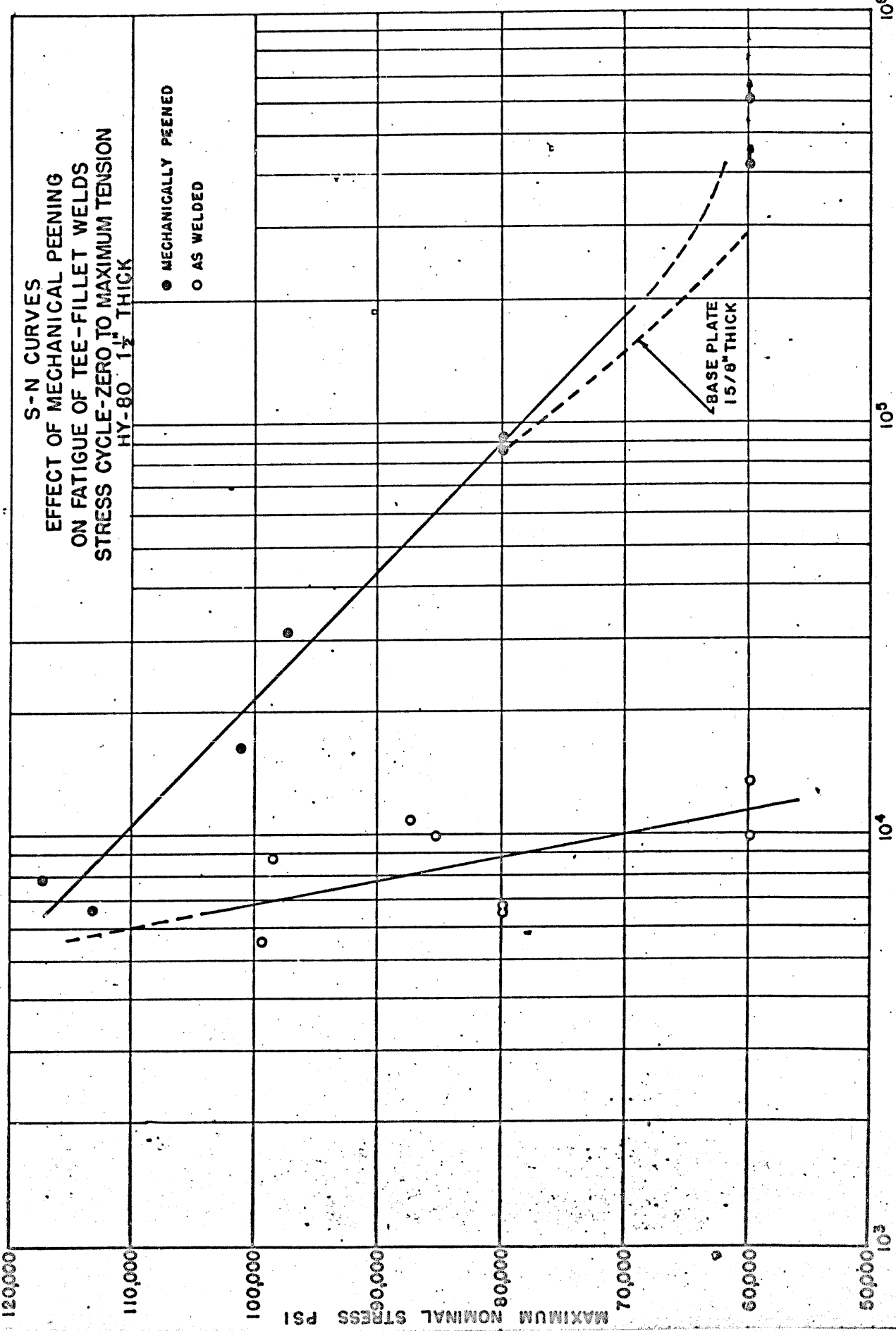
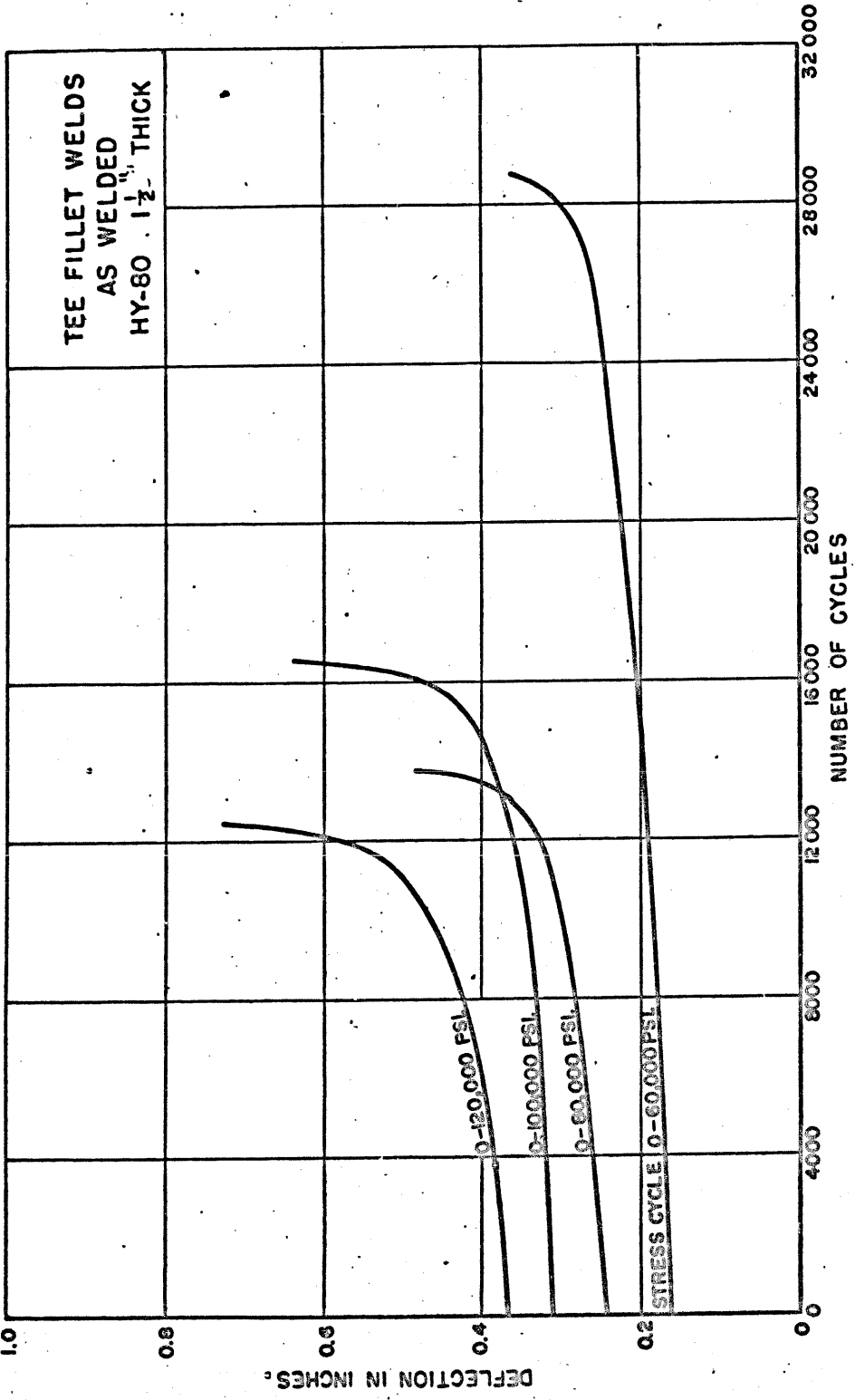


FIGURE 8

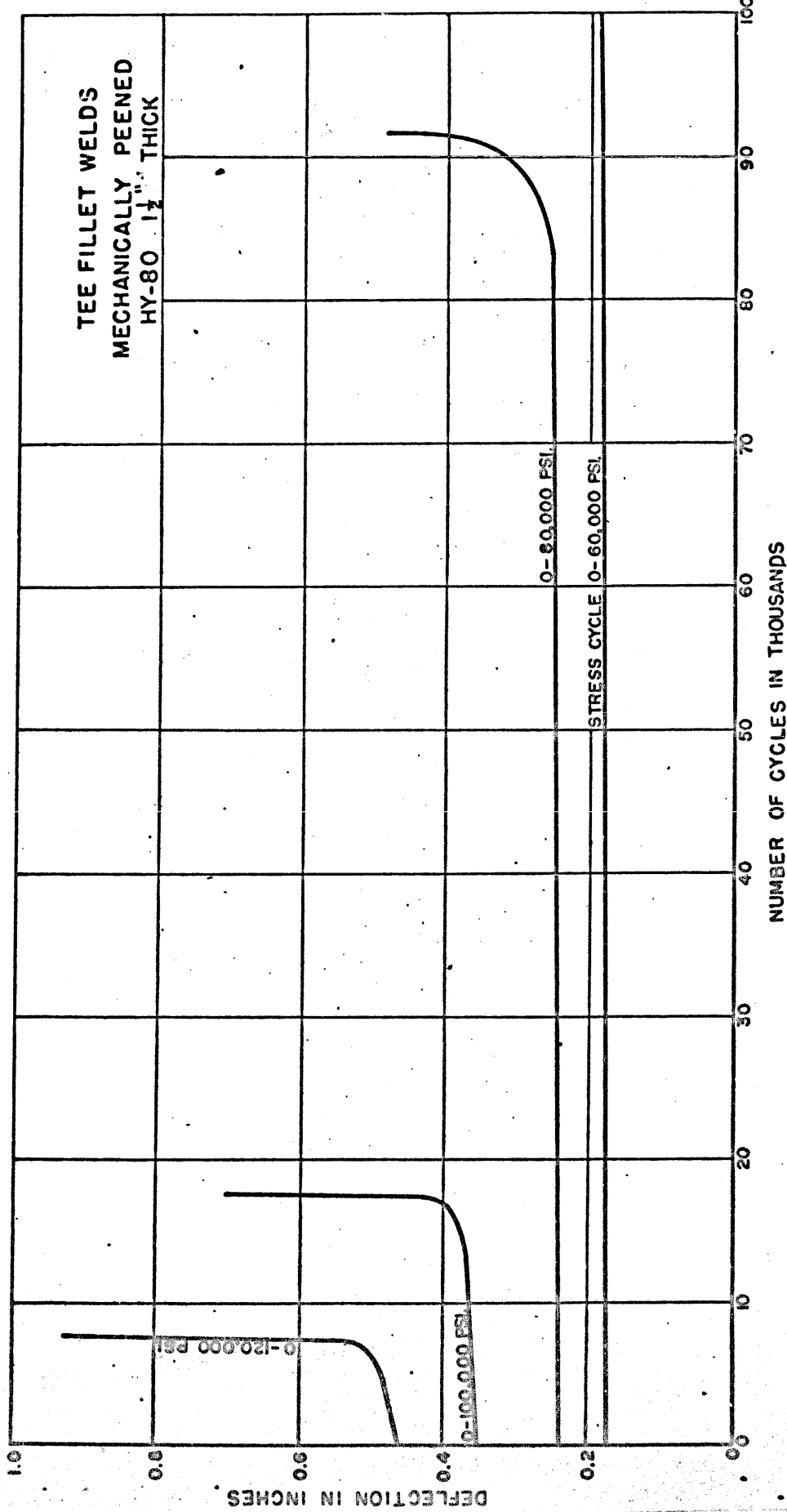


TEE FILLET WELDS
AS WELDED
HY-80 $1\frac{1}{2}$ " THICK

LAB. PROJECT 9300-1
PROGRESS REPORT I

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FIGURE 9 - CURVES SHOWING PROGRESSIVE INCREASE IN DEFLECTION AS CRACK PROPAGATED THROUGH THE CRITICAL SECTION OF PLATE TYPE SPECIMENS



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PROGRESS REPORT 1

FIGURE 10 - CURVES SHOWING PROGRESSIVE INCREASE IN DEFLECTION AS CRACK PROPAGATED THROUGH THE CRITICAL SECTION OF PLATE TYPE SPECIMENS

TABLE 1

CONDITIONS USED FOR MECHANICAL PEENING 1-1/2",
(NOMINAL) THICK HY-80 TEE WELDMENTS

Specimen No.	Travel Speed (inches/minute)		Total Treatment Rate (inches/min)
	Contouring	Dressing	
54AP-7	15.7	53.3	12.6
54AP-6	22.9	53.3	16.0
54AP-5	15.4	50.0	11.8
54AP-4	9.3	33.3	7.3
54AP-2	10.5	25.8	7.3
54AP-3	11.6	27.6	7.5
57AP-8	10.3	30.8	8.2
57AP-9	11.0	34.8	7.7
Average	13.3	38.6	9.8

Note: The above data is based on peening 20 linear inches
of weld per specimen.

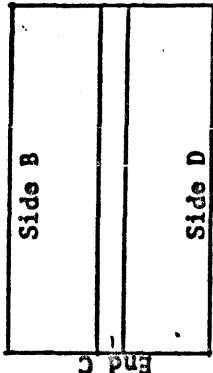
TABLE 2

SUMMARY OF FATIGUE RESULTS-TEE FILLET WELDS (AS-WELDED)

Specimen No.	Calculated Nominal Cyclic Stress (psi)		Average Thickness at Critical Section (in.)	Applied Uniform Pressure (psi)	Initial Deflection (in.)	Number of Stress Cycles to		10% Increase in Deflection	100% Increase in Deflection	Remarks
	Side B	Side D				First Observation of Crack	Side D			
53N1	60,000	59,950	1.485	227	0.176	4,100	4,300	13,500	28,590	Crack started on Side B 7-1/4" from A
54N2	59,700	60,000	1.493	229	0.177	5,000	3,300	9,900	22,620	Crack started on Side D 15-1/2" from C
53N3	79,600	80,000	1.489	303	0.245	1,600	1,200	6,700	13,750	Crack started on Side D 3" from C
54N4	80,000	79,800	1.501	309	0.234	1,100	2,500	6,500	12,830	Crack started on Side B 15-3/4" from C
53N5	85,500*	85,200	1.482	320	0.314	460	1,900	9,900	16,460	Crack started on Side B 1-1/2" from A
54N6	87,700*	88,000	1.487	334	0.337	800	500	10,900	17,760	Crack started on Side D 1" from C
53N7	99,600**	98,500	1.484	373	0.372	400	260	8,800	16,160	Crack started on Side B 1/2" from C
54N8	99,400**	99,800	1.502	384	0.365	600	250	15,500	12,180	Crack started on Side D 1-3/4" from C

* "Equivalent elastic stress" of 100,000 psi

** "Equivalent elastic stress" of 120,000 psi



End C
End D
End A

TABLE 3

SUMMARY OF FATIGUE RESULTS - TEE FILLET WELDS (MECHANICALLY PEENED)

	Side B
	Side D

Specimen No.	Calculated Nominal Cyclic Stress (psi)	Average Thickness at Critical Section (in.)	Applied Uniform Pressure (psi)	Initial Deflection (in.)	Number of Stress Cycles to		Remarks
					10% Increase in Deflection	100% Increase in Deflection	
	Side B	Side D			Side B	Side D	
54AP5	59,700	60,000	230	0.182	5,000	4,700	Subjected to 420,000 cycles still under test, did not reach 10% increase in deflection.
54AP6	59,930	60,000	229	0.179	10,000	5,000	Subjected to 603,000 cycles still under test, did not reach 10% increase in deflection.
54AP2	60,000	79,900	305	0.254	700	600	Crack started on Side D 1-1/2" from end C
54AP3	79,900	80,000	307	0.245	400	500	Crack started on Side B 2" from end C.
57AP8	97,500*	97,300	405	0.330	500	600	Crack started on Side B at several locations.
57AP9	101,300*	100,200	415	0.355	740	940	Crack started on Side B 4-1/2" from end C
54AP4	118,300**	117,800	455	0.480	500	280	Crack started on Side D 4-1/4" from end C
54AP7	113,400**	113,000	434	0.458	200	200	Crack started on both sides 12-1/2" from end A on Side B 3-1/2" from end A on Side D

* "Equivalent elastic stress" of 100,000 psi

** "Equivalent elastic stress" of 120,000 psi

TABLE 4

CHEMICAL ANALYSES AND MECHANICAL PROPERTIES OF HY-80 TEST PLATE

Chemical Analyses	Plate	Plate	Plate	Specification MIL-S-16216G
	053	054	057	
a. C	0.16	0.17	0.16	0.18 (max)
b. Mn	0.33	0.33	0.34	0.10 - 0.40
c. P	0.010	0.013	0.018	0.025 (max)
d. S	0.008	0.009	0.020	0.025 (max)
e. Si	0.27	0.27	0.22	0.15 - 0.35
f. Ni	2.68	2.75	3.02	2.00 - 2.25
g. Cr	1.71	1.68	1.57	1.00 - 1.80
h. Ti	0.007	0.002	0.002	0.02 (max)
i. Cu	0.05	0.05	0.13	0.25 (max)
j. Mo	0.48	0.48	0.45	0.20 - 0.60
k. V	0.00	0.002	0.000	0.03 (max)

Tensile Properties (1)

a. Yield Strength (Ksi) 0.2% Offset	78.2 (L)(2) 78.5 (T)(2)	82.3 (L) 85.0 (T)	86.1 (L) 84.6 (T)	80.0 - 95.0
b. Tensile Strength (Ksi) (3)	104.7 (L) 105.6 (T)	104.1 (L) 104.8 (T)	105.4 (L) 105.7 (T)	-
c. Elongation % in 2 inches	28.8 (L) 25.5 (T)	28.0 (L) 25.0 (T)	28.0 (L) 25.3 (T)	20
d. Reduction in Area (%)	75.2 (L) 64.5 (T)	75.4 (L) 65.8 (T)	73.0 (L) 65.3 (T)	55 (L) 50 (T)

Charpy V-Notch Properties

-120°F Test Temperature Average ft/lbs	104.5 (L) 53.5 (T)(3)	126.0 (L) 54.0 (T)(3)	82.5 (L) 43.3 (T)(3)	-120°F 50 ft/lbs
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L - Longitudinal

(1) Values represent the average of two test results.

(2) Considered in practical conformity to specification requirement.

(3) For information only. Not required by specification.

T - Transverse