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NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

WELDING TEST 206
PHYSICAL CHARACTERISTICS OF WELDED LONGITUDINAL SEAMS

~~CONFIDENTIAL~~ 15

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March 1943 Report R-129

PERSONNEL

This test was conducted by J.W. Day, Assistant Mechanical Engineer, with the assistance of the personnel of the Materials Testing Laboratory of the Taylor Model Basin. The report was prepared by Mr. Day, but responsibility for the comment rests with Commander W.P. Roop, USN.

WELDING TEST 206

PHYSICAL CHARACTERISTICS OF WELDED LONGITUDINAL SEAMS

ABSTRACT

The effects of longitudinally welded seams and webs on large steel tensile specimens were investigated. Some interesting data were obtained on the nature and mode of propagation of rupture in the specimens. These data were secured by means of a motion picture camera. The value of energy absorbed was computed for each specimen. Longitudinal weld and web metal had little effect on the strength of medium steel, but a moderate reduction in ductility resulted. The strength of high tensile and of special treatment steel was reduced slightly by the presence of longitudinal weld and web metal, but there were erratic variations in the ductility of these steels. The medium steel specimens absorbed more energy than did the high tensile and special treatment steel specimens. However, this difference was less pronounced where the high tensile steel and special treatment steel specimens had medium steel welded webs.

INTRODUCTION

In a previous test at the David W. Taylor Model Basin (1)* it was found that the welding of transverse webs of medium steel (MS) to tensile specimens of special treatment steel (STS) with Grade IV electrodes** did not affect the strength of the special treatment steel. In the same test it was found that welding longitudinal MS webs to STS specimens with Grade IV electrodes did not detract more than 10 per cent from the strength of the special treatment steel, and later (2) evidence was obtained that STS specimens in which the welded web and weld metal were machined off before test were actually strengthened by such treatment.

Tests (3) on high tensile steel (HTS) specimens of high width-thickness ratio with butt-welded transverse joints of Grade EA electrode showed that these joints can be expected to develop a strength equal to that of the plate. Additional tests of HTS tensile specimens with longitudinal welded seams (4) indicated that the strength of the specimens was not appreciably affected by the welded seams.

All these tests were made on large specimens like those shown in Figure 1, which were wide enough so that plastic flow in the transverse section in which failure occurred was almost wholly in thickness and not much

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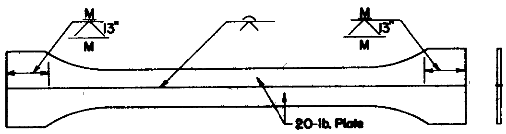
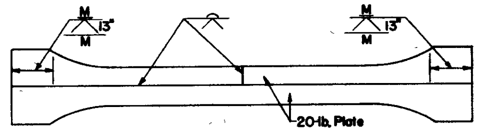
* Numbers in parentheses indicate references on page 14 of this report.

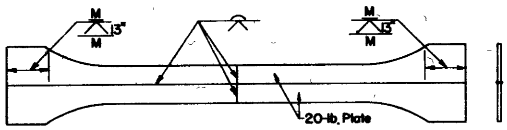
** Grade IV electrodes contain 25 per cent chromium and 20 per cent nickel.



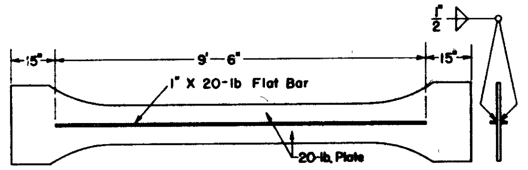
Type A Assembly	Area sq in	Photograph Figure
A-S	4 15	32
A-H	5 71	7-25
A-M	7 88	3-15



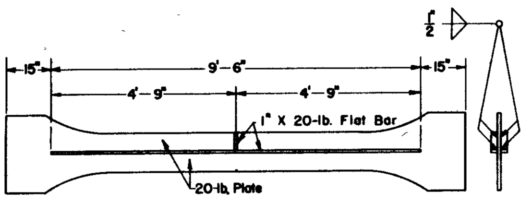
Type B Assembly	Area sq. in.	Photograph Figure
B-S	4.12	33
B-H	5.84	8-26
B-M	8.08	16-17



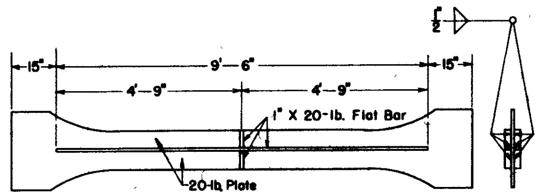
Type C Assembly	Area sq. in	Photograph Figure
C-S	4.16	34
C-H	5.90	9-27
C-M	8 04	4-18-19



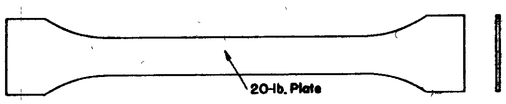
Type D Assembly	Area sq. in.	Photograph Figure
D-H	5.88	28
D-M	8.64	20-21



Type E Assembly	Area sq. in.	Photograph Figure
E-S	4 71	35
E-H	5 88	29
E-M	8 53	5-22



Type F Assembly	Area sq in	Photograph Figure
F-S	4.70	36
F-H	5.83	10-30
F-M	8.47	6-23



Base Metal Control Specimen

Type G Assembly	Area sq. in.	Photograph Figure
G-S	4 13	37
G-H	5.89	11-31
G-M	7.92	24

Figure 1 - Sketch showing Structure of Assemblies and Classification of Types

Each type, except Type D, is represented by three specimens, designated as S, H, and M to indicate special treatment steel, high tensile steel, and medium steel, respectively. Widths varied with materials as shown in Figure 2 to give suitable values of total breaking load. Specimen S is welded with Grade IV electrode and Specimens H and M are welded with Grade EA electrode.

in width. The purpose of such specimens is to obtain test conditions simulating those of ship plating in service more closely than is possible in the usual tensile test specimen of small size and low ratio of width to thickness of section.

The present test was authorized (5) to supplement these preliminary tests (4); it covers the effects of the welding of transverse joints or butts, of transverse webs, and of longitudinal seams and webs, all on MS, HTS, and STS plate. The added metal was left in place as in a previous test (1).

SPECIMENS, APPARATUS, AND TEST PROCEDURE

Twenty tensile specimens, all cut from 20-pound plate, were tested. They were divided into seven groups of which Types A, B, and C had welded seams, and Types D, E, and F welded webs. Type G specimens were not welded and served as control specimens. Grade IV electrodes were used in welding the STS specimens, and Grade EA electrodes on the HTS and MS specimens. The webs were of medium steel on all specimens. Details of fabrication and classification of the various assemblies are indicated in Figures 1 and 2.

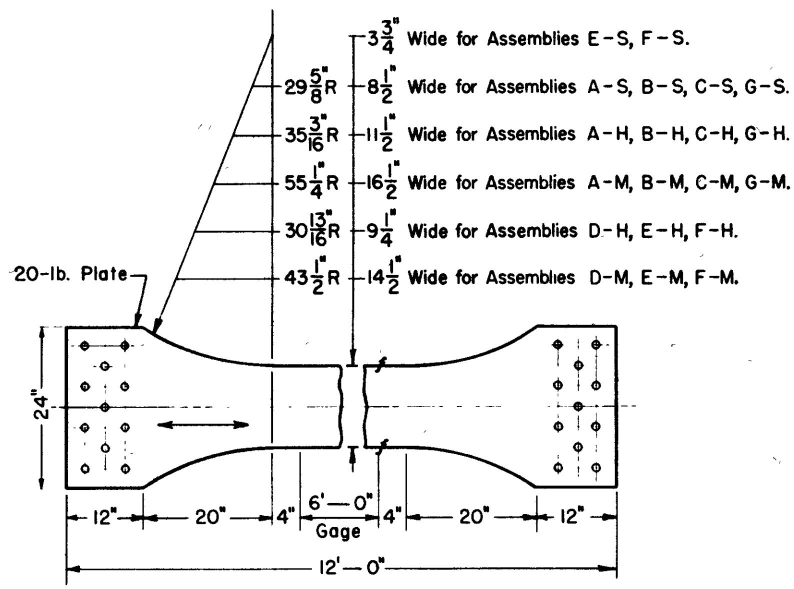


Figure 2 - Details of all Specimens

Holes were drilled in the ends of the specimens to permit bolting them to the pulling heads. Transverse lines were scribed at 5-inch intervals over the length of the gage section of each specimen to facilitate measurement of elongations in the ruptured sections.

The specimens were tested to destruction in the 600,000-pound Baldwin-Southwark hydraulic testing machine at the Taylor Model Basin. Motion pictures were made of each specimen as it was about to rupture, in an attempt to record the beginning and the mode of propagation of failure. The exposures were made at the rate of 16 per second.

Elongations after rupture were measured over 10-inch bases for a total of 60 inches on each specimen, and the mode of failure and condition of the ruptured surfaces were noted after each test.

RESULTS

Data compiled from the test are included in Table 1. Figures 3 to 11 inclusive show selected motion picture photographs (not in all cases successive frames) of the specimens as rupture developed. Elongation, showing its axial distribution on the centerline, is exhibited in Figures 12 to 14 inclusive, in Appendix 1. Views of the specimens after test are shown in Figures 15 to 37 inclusive.

TABLE 1

Strength of Plates with Welded Longitudinal Seams

Specimen Shape Type and Mark	Minimum Plate Section*		Strength lb. per sq. in.		Elongation in 60-inch Base Length		Ultimate Strength** per cent	Energy Absorbed lb-in/in.*	Location of Break (showing Contractions, etc., Exaggerated)
	Thick.-in.	Area-in.*	Yield	Ultimate	inches	per cent			
A-M	0.478	7.88	33,500	51,800	5.16	8.58	92.1	4,250	A-M
B-M	0.489	8.08	35,900	61,900	9.20	15.34	110.0	8,850	B-M
C-M	0.487	8.04	34,700	59,800	11.71	19.52	106.3	10,450	C-M
D-M	0.480	8.64	43,600	61,000	2.95	4.92	108.3		D-M
E-M	0.485	8.53	38,100	61,800	8.53	14.20	109.8	7,630	E-M
F-M	0.481	8.47	-	60,900	9.48	15.80	108.2	8,560	F-M
G-M	0.480	7.92	33,300	56,300	15.59	25.95	100.0	13,880	G-M
A-H	0.497	5.71	60,300	82,500	7.15	11.92	98.9	8,950	A-H
B-H	0.509	5.84	-	80,800	4.16	6.92	96.9	4,700	B-H
C-H	0.513	5.90	60,000	77,500	3.32	5.53	92.9	4,130	C-H
D-H	0.500	5.88	-	85,400	8.54	14.23	102.4	8,970	D-H
E-H	0.500	5.88	-	86,200	7.54	12.58	103.3	8,880	E-H
F-H	0.495	5.83	61,100	85,800	6.60	11.01	102.7	7,050	F-H
G-H	0.513	5.89	62,200	83,400	8.97	14.94	100.0	11,080	G-H
A-S	0.488	4.15	-	111,300	3.11	5.18	95.4	5,175	A-S
B-S	0.483	4.12	-	104,300	0.86	0.68	89.4	1,250	B-S
C-S	0.489	4.16	-	99,700	0.48	0.80	85.5	636	C-S
E-S	0.484	4.71	-	108,500	6.15	10.24	95.2	8,450	E-S
F-S	0.489	4.70	-	108,600	6.48	10.79	88.0	8,740	F-S
G-S	0.488	4.13	-	116,600	4.46	7.43	100.0	6,420	G-S

* NOTE: In the case of specimens without longitudinal webs, nothing is added for the welds.
** Referred to the control specimen.

DISCUSSION

In considering any local section of a ship structure subjected to tension, it is well known that when the section fails rupture takes place without much plastic flow parallel to the surface of the plating, although the metal is characteristically ductile when tested as a small standard tensile specimen. This apparent brittle behavior is usually said to be due to the constraint offered by the adjacent material comprising the structure. It is thought that forcible prevention of transverse strain reduces plastic tensile flow.

(continued on page 9)

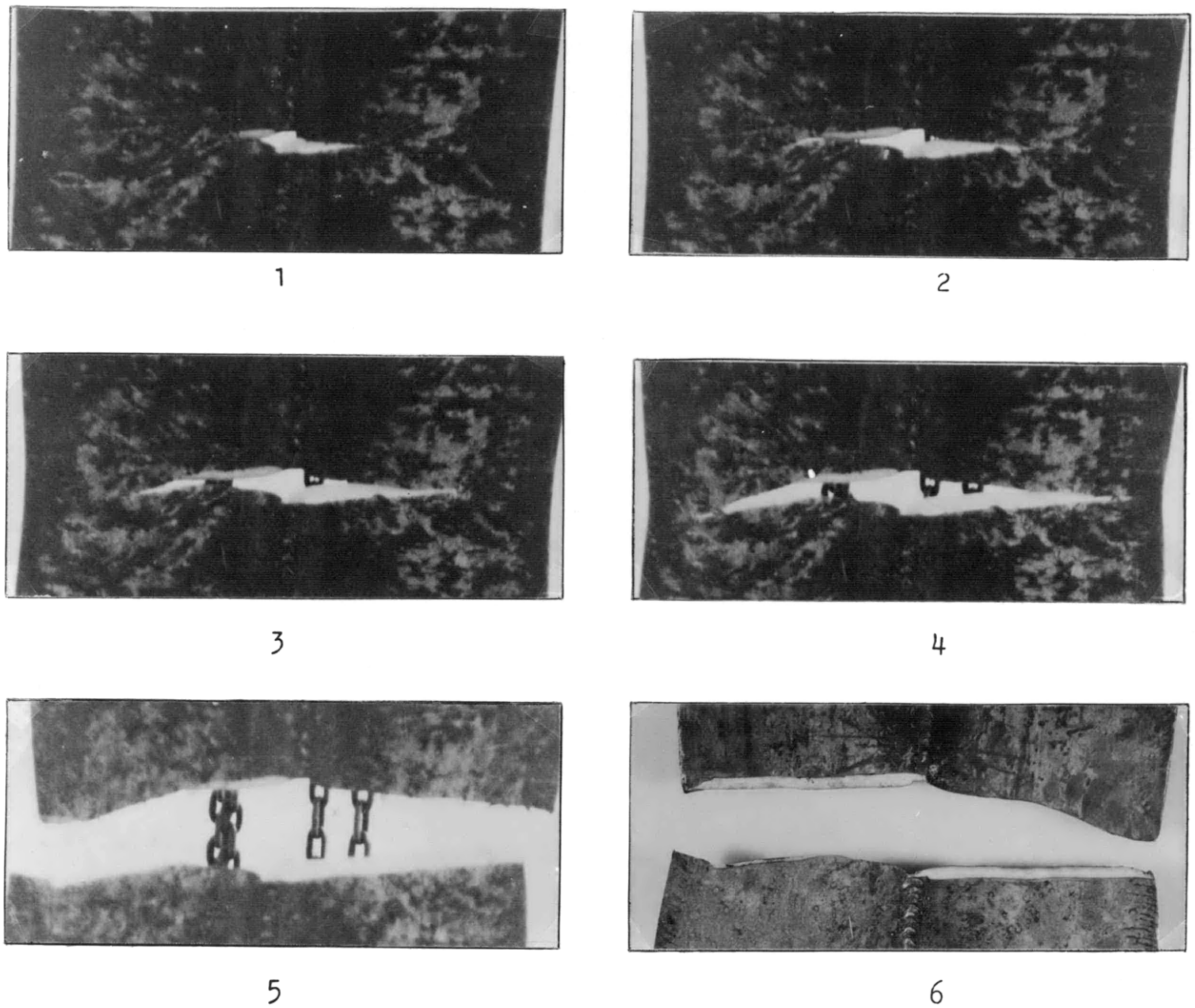


Figure 3 - Progressive Views of Failure of Medium Steel Specimen A-M

Longitudinal seam welded in MS plate with Grade EA electrode. Rupture started in the welded seam, then spread into the plate on both sides with approximately equal rapidity.

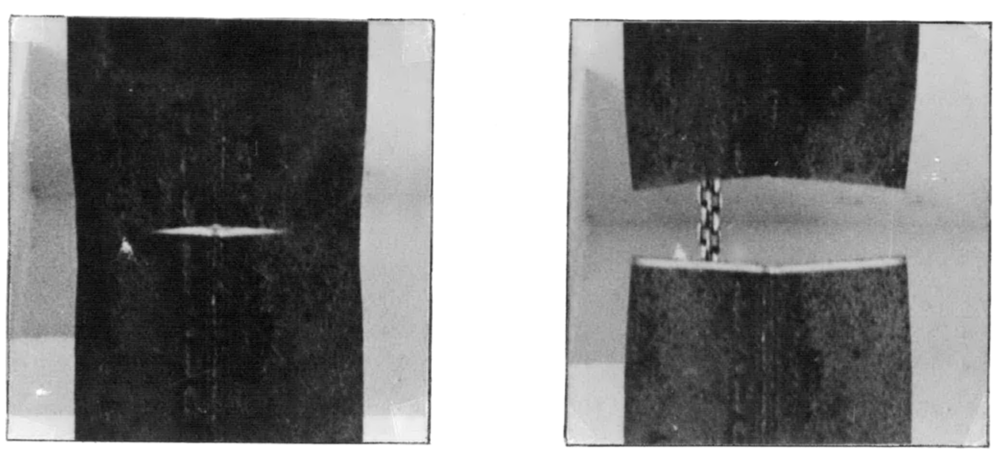


Figure 4 - Progressive Views of Failure of Medium Steel Specimen C-M

Longitudinal seams in MS plate welded with Grade EA electrode. The rupture started in the longitudinal seam about 3 feet from the transverse butt (see Figure 18). Lack of offset of separated parts shows freedom from eccentricity of loading.

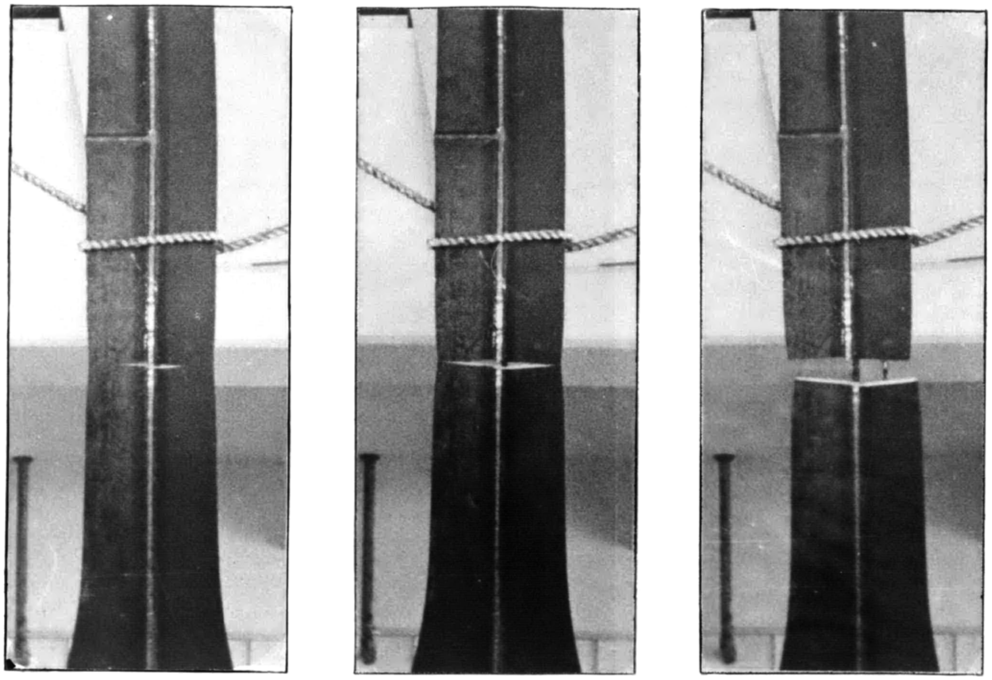


Figure 5 - Progressive Views of Failure of Specimen E-M

Longitudinal web and half-width transverse web of medium steel welded to MS plate with Grade EA electrode. The fracture started in the fillet welds alongside the web and spread simultaneously to the plate on both sides of the web. Note the reduced transverse contraction at the transverse web.

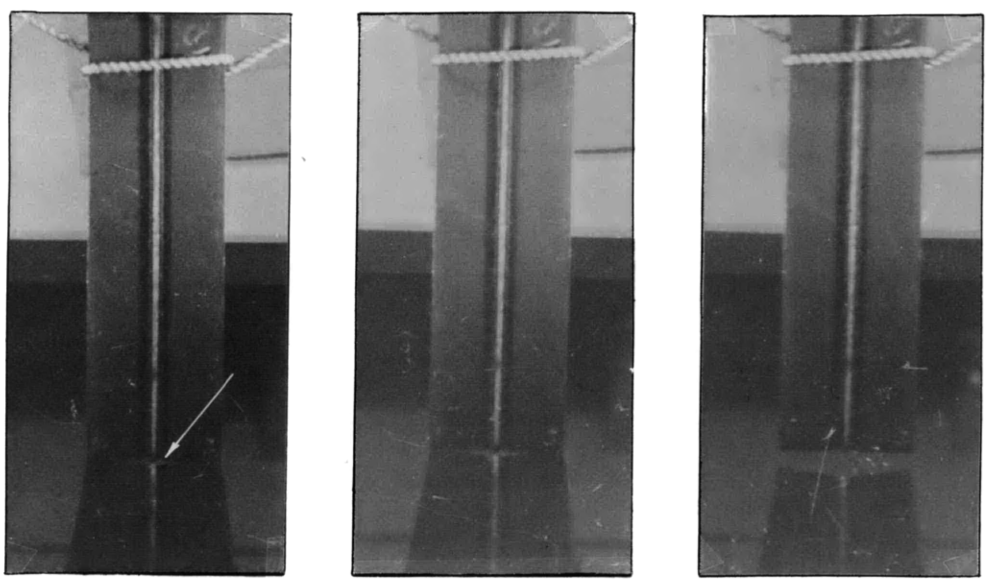
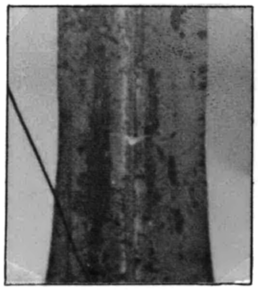


Figure 6 - Progressive Views of Failure of Specimen F-M

Longitudinal and transverse webs of medium steel welded to MS plate with Grade EA electrode. The arrow in the view at the left indicates the start of the fracture at the fillets. Note again the reduced transverse contraction at the transverse webs.



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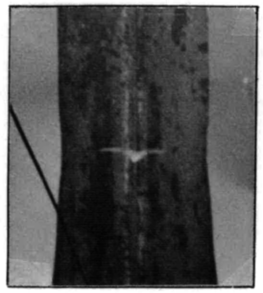

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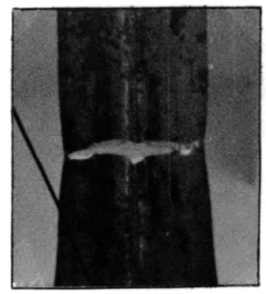

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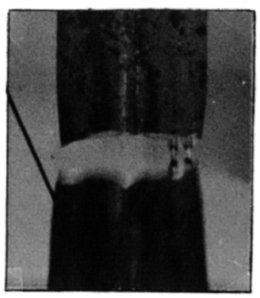

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Figure 7 - Progressive Views of Failure of Specimen A-H

HTS plate with longitudinal seam welded with Grade EA electrode.

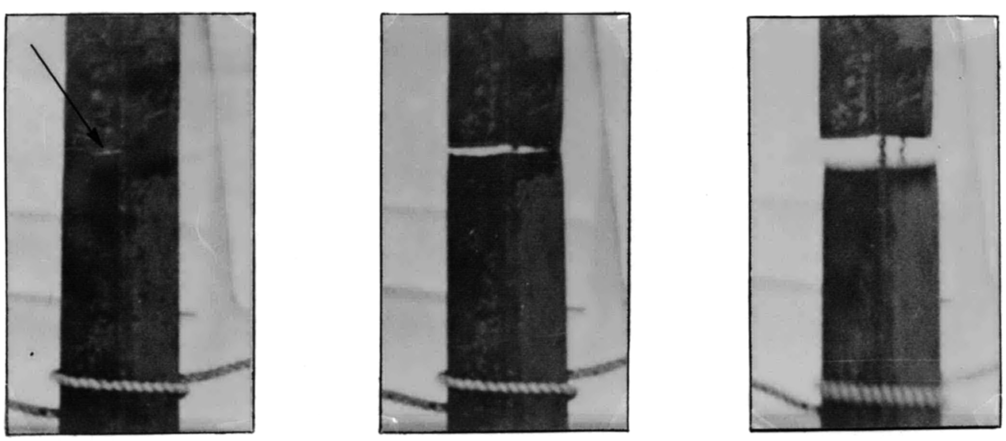


Figure 8 - Progressive Views of Failure of Specimen B-H

HTS plate with longitudinal seam and half transverse butt welded with Grade EA electrode. The arrow in the view at the left indicates start of the rupture in the transverse weld. Eccentricity of plastic flow, entirely absent in Figure 4, is especially marked here; it may be associated with off-center start of rupture.

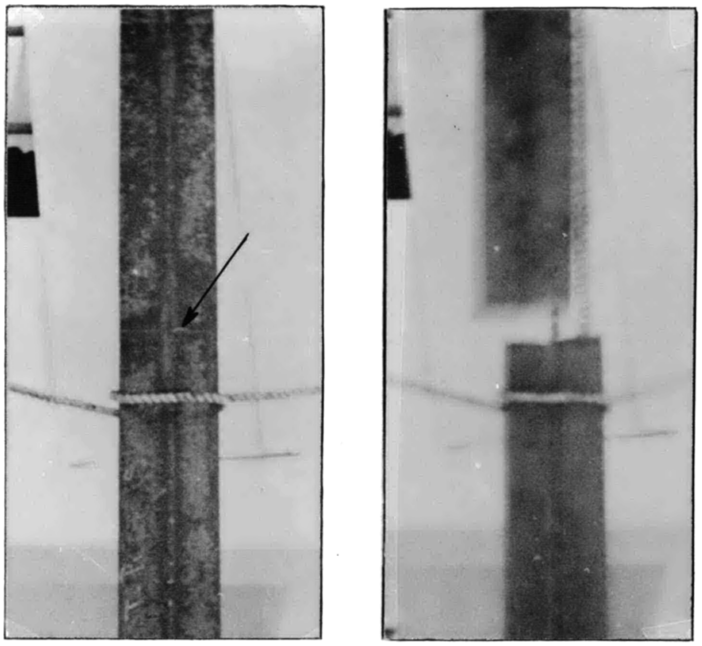


Figure 9 - Views of Failure of Specimen C-H

Longitudinal seam and transverse butt in HTS plate welded with Grade EA electrode. The arrow in the view at the left indicates start of the rupture in the transverse weld. Eccentric plastic flow is pronounced.

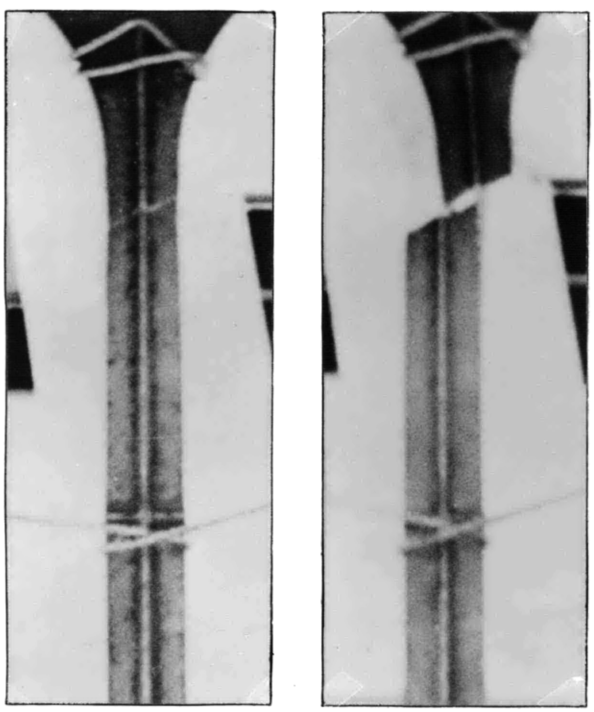


Figure 10 - Views of Failure of Specimen F-H

Longitudinal and transverse webs of medium steel welded to HTS plate with Grade EA electrode. In the view at the left rupture appears to have started near the web, since the tear is widest at that point. Eccentricity of plastic flow is very pronounced. Diagonal fracture indicates predominance of shear over tensile action.

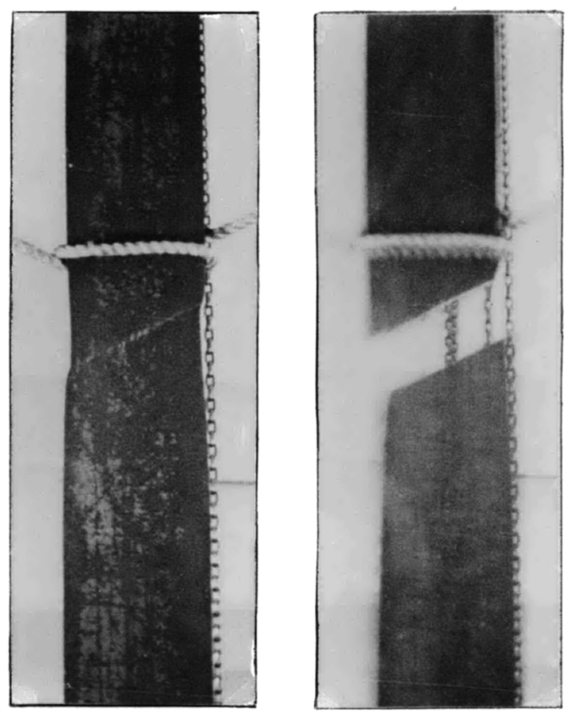


Figure 11 - Views of Failure of Specimen G-H

Unwelded control specimen of high tensile steel, in process of failing by shear rupture. The exposure at the right followed that at the left after 1/16 second.

MEDIUM STEEL SPECIMENS, A-M TO G-M

Ultimate strength of the MS specimens, as shown in Table 1, shows only moderate variation from A-M to G-M. The average for A-M, B-M and C-M equals that for G-M within experimental error limits. Elongation, though rather erratic in the welded specimens, was notably less in A-M, B-M and C-M than in the control or pilot Specimen G-M.

Specimen D-M failed in the section beyond the longitudinal webs as shown in Figure 18. It was decided, therefore, to reduce the area of the longitudinal webs to prevent similar failure in other specimens which would have defeated the purpose of the tests. In the case of all other MS specimens with webs, the outer half-width of the web was cut away, reducing the web depth to 1 inch. The cutting was done by a hand torch and the edges of the webs were left slightly irregular. It is possible that these rough edges decreased slightly the ultimate strength of some of the specimens.

All the MS specimens behaved in the same way; the photographs (indexed in Figure 1) confirm this. Thus consider Specimen A-M, Figure 3, a typical example of the failure of a longitudinal welded seam. The rupture starts on the centerline; it has long been known that this is the usual case, but its significance is not yet fully understood. That region is less ductile than the adjacent plate owing in part to the presence of the weld and in part to the constraint offered by the considerable width of the adjacent plating. As the rupture progresses into the metal on either side of the weld, both of these actions become less effective; in particular the constraint diminishes, and the familiar necking effect found in small specimens appears. Examination of the specimen after failure is enough to confirm this statement, since the rupture is wider at the centerline than at the edges, where more plastic flow occurred.

It is significant that Specimen C-M, shown in Figure 4 in the act of rupture, did not break at the transverse (butt) weld; on the contrary the welded butt resisted transverse contraction, as clearly shown in Figure 18, in Appendix 1. This suggests that the effect of the welded butt in reinforcing the section against necking was enough to offset any other sources of weakness in the weld; the weld resisted up to the necking point, and after necking started elsewhere it caused sufficient concentration of stress to bring about failure.

Figures 17 and 19 show similar ruptures in Specimens B-M and C-M at some distance from the transverse weld. The fact that the fracture of specimens with a transverse weld occurs at a distance from the transverse weld has been observed in previous tests (2).

Specimens D-M, E-M and F-M included in the section a flat-bar longitudinal web stiffener on each side at the centerline. The total area was increased only slightly, since the width of the plate was cut down to allow approximately for the area of the webs. The end connections of the stiffener were adequate (except in D-M) so that the webs presumably carried their share of the total load. It has usually been considered that such sharing of load was a sufficient condition of good design, and the equality of strength in B-M, C-M, E-M and F-M confirms this.

In D-M, failure was determined by concentration at the end of the web, as shown in Figure 21 by the greater width of opening at the centerline, and the radial disposition of elongated bolt holes. The ultimate strength is about as in the other specimens, but the energy value of 2.5 inch-kips per cubic inch is unduly low and is considered invalid.

The curves of elongation, pages 15 to 17, reveal important differences between the different specimens. The energy absorbed in Specimen G-M is 13,880 inch-pounds per cubic inch, in B and C notably less, and in E and F still smaller. This can be ascribed to the deferred necking in G-M, which did not begin until after the whole specimen had suffered elongation of about 20 per cent. The circumstances which determine the onset of necking are not known, but they must be related with presence of welds and perhaps also with the width-thickness ratio.

Energy absorption is discussed further in Appendix 2.

SPEED OF RUPTURE

Most of the MS specimens ruptured at a relatively slow speed so that several pictures of the process could be secured. As a rule MS specimens ruptured at a slower rate than the HTS specimens and considerably slower than the special treatment steel.

The speed of propagation of rupture in the STS specimens was too great to record by means of the photographic equipment used, even at the slowest possible rate of loading.

HIGH TENSILE STEEL SPECIMENS, A-H TO G-H

While Specimens A-M and A-H, Figures 3 and 7, were almost identical in action, the other HTS specimens, Figures 8, 9, and 10 show more variation than those in Figures 4, 5, and 6. Rupture occurred in the transverse weld in B-H and C-H. Off-center starts appear in B-H and C-H, Figures 8 and 9, eccentric plastic flow in D-H, E-H, F-H, Figure 10, and G-H, Figure 11, and shear-type rupture F-H and G-H, Figures 10 and 11.

The ultimate strength of Specimens A-H, B-H, and C-H averages nearly 4 per cent less than that of the pilot Model G-H. The models with webs show increased strength which may be in part attributed to the assumptions involved in calculating the ultimate load carried by the different elements.

In determining the allowance to be made for contribution of MS webs and weld fillets to total resistance to load, an arbitrary choice is necessary with respect to the manner in which this is done, as explained in pages 1 and 2, Reference (1). In brief, the three different kinds of metal are assumed to contribute to ultimate load in proportion to their areas and ultimate strengths. The higher ductility of webs and welds makes this assumption plausible, though all such considerations are open to doubt in the plastic range; the action is also affected by transverse constraints. If gross load were divided by gross area, strength would appear to be lower than the tabulated values and nearly equal to that of G-M.

Still photographs of the fractures, Figures 25 to 30, also show somewhat more irregular fractures than in the MS specimens. The necking and the excess of separation on the centerline over the edges are also variable, these being greater in A-H, D-H, and E-H than in B-H, C-H, F-H, and G-H.

Elongation is generally less than in the MS specimens, but not so adversely affected by the welding. Specimen D-H actually shows as much elongation as the control Specimen G-H. Distribution of elongation is subject to as much and as erratic variation as in MS specimens. Energy absorption is a maximum, as before, in the pilot Specimen G-H. The order of the others, however, is not the same as in the MS specimens. Values are generally lower than in medium steel as the loss of ductility outweighs the gain in yield point, but A-H is a striking exception.

The suggestion that width-thickness ratio as well as welding influences ductility is less secure in the case of high tensile steel than medium steel. But strength of HTS specimens is in all cases larger than that of medium steel by a wide and safe margin.

SPECIAL TREATMENT STEEL SPECIMENS A-S TO G-S

The differences between medium steel and high tensile steel are roughly paralleled by those between high tensile steel and special treatment steel. In the case of special treatment steel the speed of rupture was too fast to catch with the framing speed, 16 per second, in the camera used. But so far as the still photographs can show them, all the irregularities noted in special treatment steel may be seen in Figures 32 to 37 of Appendix 1.

Ultimate strength in A-S, B-S, and C-S is down 10 per cent from that of G-S, and in E-S and F-S by nearly the same amount, all calculated as explained for high tensile steel. Gross load divided by gross area in E-S and F-S gives very low values, since the area of the webs is nearly half the total. Elongation is in all cases low, almost zero in B-S and C-S, but erratic, exceeding that of the control Specimen G-S in specimens with longitudinal webs, E-S and F-S. This last might be attributed to the high ductility of the MS webs, and it suggests use of MS webs to increase energy absorption in special treatment steel.

The control Specimen G showed normal behavior, but it took less energy than G-H, and still less than G-M. The energy absorbed by the welded STS specimens is also appreciably lower than that absorbed by either the HTS or MS specimens. However, the welded specimens had a relatively small width-thickness ratio and may not indicate the amount of energy that plating of the same thickness would absorb when built into a continuous structure.

The present tests differ from those previously reported for special treatment steel (2), in which all added metal, weld or web, was machined off before test. In that test the change in ultimate strength was small. In the present case, where added metal was left in place, definite reductions in strength occurred. It is possible that these reductions are not real but result from the arbitrary method of assuming load distribution over the cross section.

This comparison, however, again suggests the idea that loss in strength may be as much a matter of geometrical form as of metallurgical effects of welding.

CRITIQUE OF THE PRESENT TEST

The variation of physical properties with dimensions and proportions of the specimen has had elaborate study (6) (7) (8) from which the conclusion was long since drawn that ultimate strength is a quantity not directly dependent on such parameters. Moore says: "The shape of a cross-section does not markedly affect any of the results of a tension test"; and Templin: "For variations in width-thickness ratio from 1 to 45 . . . . no effects on tensile strength and yield point values are observed."

The use of wide and expensive specimens nevertheless continues; the reason for this doubtless lies in the belief that the nearer a test specimen comes to reproducing the conditions of constraint under which the steel is loaded in service, the more confidence may be felt in the test results.

The grounds for this belief deserve careful consideration. In particular, the part played by plastic action of the metal has an importance which is hidden when design is based entirely on ultimate tensile strength.

The fact that ultimate tensile strength is not sensitive to changes in width-thickness ratio is evidence that the tensile test on small specimens does not offer a sufficient characterization of the properties of the steel.

A ship structure is not in fact, like a bridge, intended only to resist a specified load; its function is largely also to absorb and dissipate, or in some other way neutralize, the damaging effects of energy, whether applied by ordinary action of the sea, by grounding or collision, or by enemy attack.

From this point of view the great and unexplained differences in energy absorption in the different specimens of the present test present a problem which must be solved, but for which the present data offer no solution. It is not possible to determine whether these differences were caused by the effects of welding on the metal, by the wide variations in sectional profiles, or by some uncontrolled feature.

The only way to resolve these difficulties lies in the better understanding of plastic action; that is the hard but the necessary path to follow. Since plastic flow always precedes rupture, ultimate strength should in some way be related to plasticity. The specimen has a choice as to place of rupture and also as to extent of general plastic flow before necking begins, but the maximum load appears not to be affected by this choice. It is even more uncertain what determines the value of load at rupture.

In an assembled structure, however, local conditions govern location of the rupture point; overload may cause either a catastrophic progression to complete failure or a simple redistribution of stress through plastic adjustment. The latter choice occurs in most cases of service failure, even when it occurs mainly through instability.

The tensile test is finally catastrophic in nature, after a period of plastic adjustment, even in such wide specimens as are seen in the present tests. Even such wide specimens, therefore, fail to reproduce fully the conditions of service failure.

However service conditions are approached in the wide specimen with respect to the establishment of biaxial stress distribution. The nature of the consequences of this is still obscure, but more complete knowledge of energy relations is sure to be of benefit.

CONCLUSIONS

Additions of weld and web metal laid-in longitudinally as in these tests have little effect on strength but reduce ductility moderately in medium steel.

In high tensile steel a slight loss of strength occurs, combined with erratic ductility. Special treatment steel acts like high tensile steel in this respect.

A number of circumstances point to the suggestion that the plastic flow before failure of the specimens tested is affected by width-thickness ratio as well as by metallurgical consequences of the welding operation.

Special treatment steel loses a little strength by welding, contrary to the earlier conclusion (2) where it was found that welding medium steel to special treatment steel with Grade IV electrodes increases the ultimate strength of the special treatment steel slightly.

The ductility of STS plates is increased considerably when MS webs are welded to them with Grade IV electrodes.

Large and unexplained differences in energy absorption in different specimens occur.

REFERENCES

(1) "Welding Test 171 - Effects of Welding on the Properties of STS," EMB Test Report R-110, August 1939.

(2) "Welding Test 171-A - The Effect of Welding on the Physical Properties of Special Treatment Steel," TMB Test Report R-121, April 1941.

(3) "Welding Test 180 - High Tensile Steel - The Tensile Strength of Welded Joints with High Width-Thickness Ratios," EMB Test Report R-113, December 1939.

(4) "Welding Test 206 - Physical Characteristics of Welded Longitudinal Seams - Preliminary Investigation," TMB Test Report R-122, April, 1941.

(5) Bureau of Ships letter QP/W and C-(4)-(5)-(DW) received 12 December 1940 to Commandant, Navy Yard, Norfolk, and Director, David W. Taylor Model Basin.

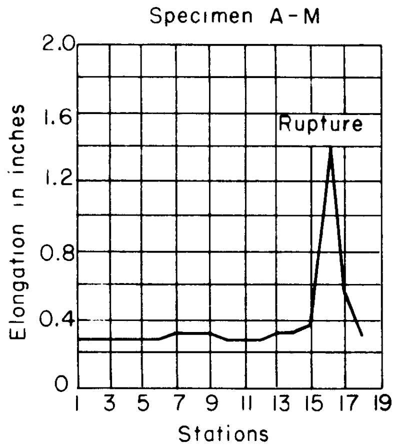
(6) "Tension Tests of Steel with Test Specimens of Various Sizes and Forms," H.F. Moore, Proceedings A.S.T.M. Vol. 18, 1918, Part I, pp. 403 to 421.

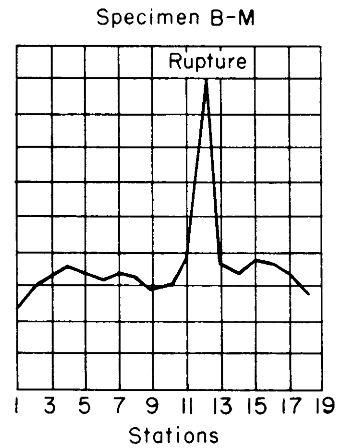
(7) "Effects of Size and Shape of Test Specimens on the Tensile Properties of Sheet Metals," R.L. Templin, Proceedings of the Twenty-Ninth Annual Meeting, A.S.T.M. Vol. 26, 1926, Part II, pp. 378 to 398.

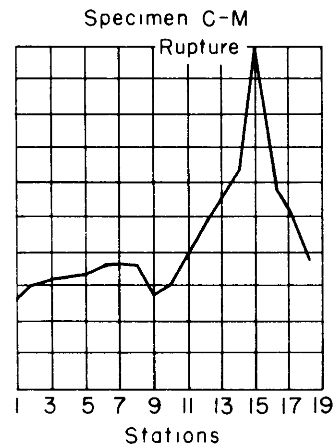
(8) "The Influence of the Width of the Specimen upon the Results of Tensile Tests of Mild Steel and Rolled Copper," T.H. Beare, W. Gordon, Engineering, September 9, 1921, pp. 389 to 391.

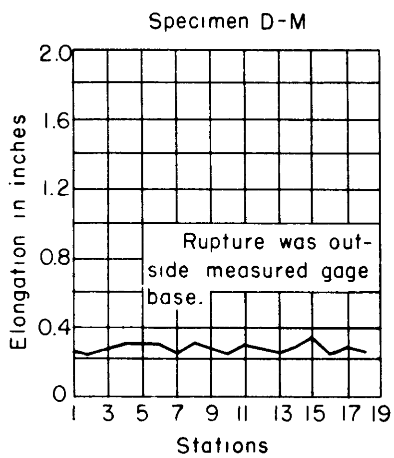
(9) "Properties of Medium Steel at High Rates of Loading," TMB Report 503, to be published.

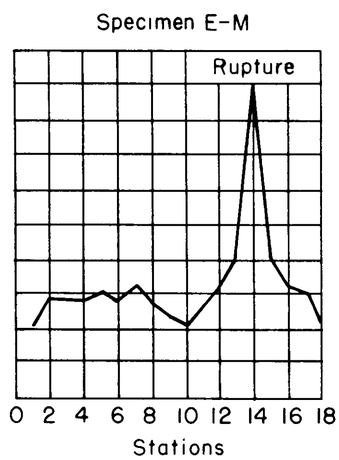
APPENDIX 1

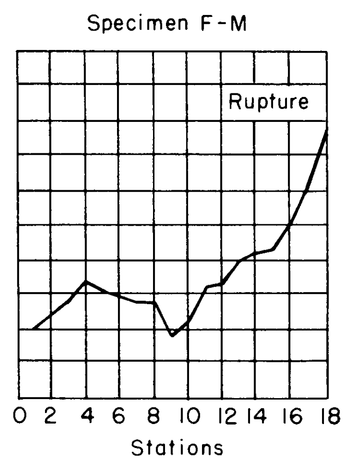












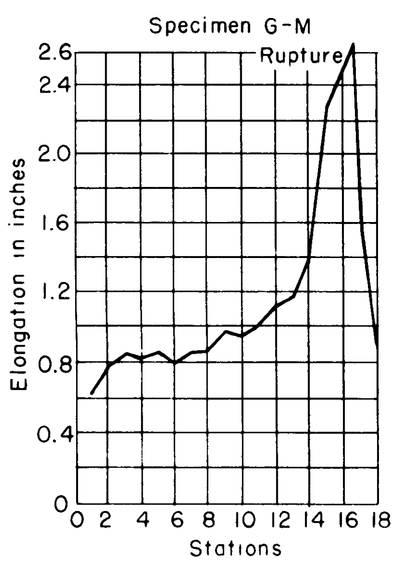
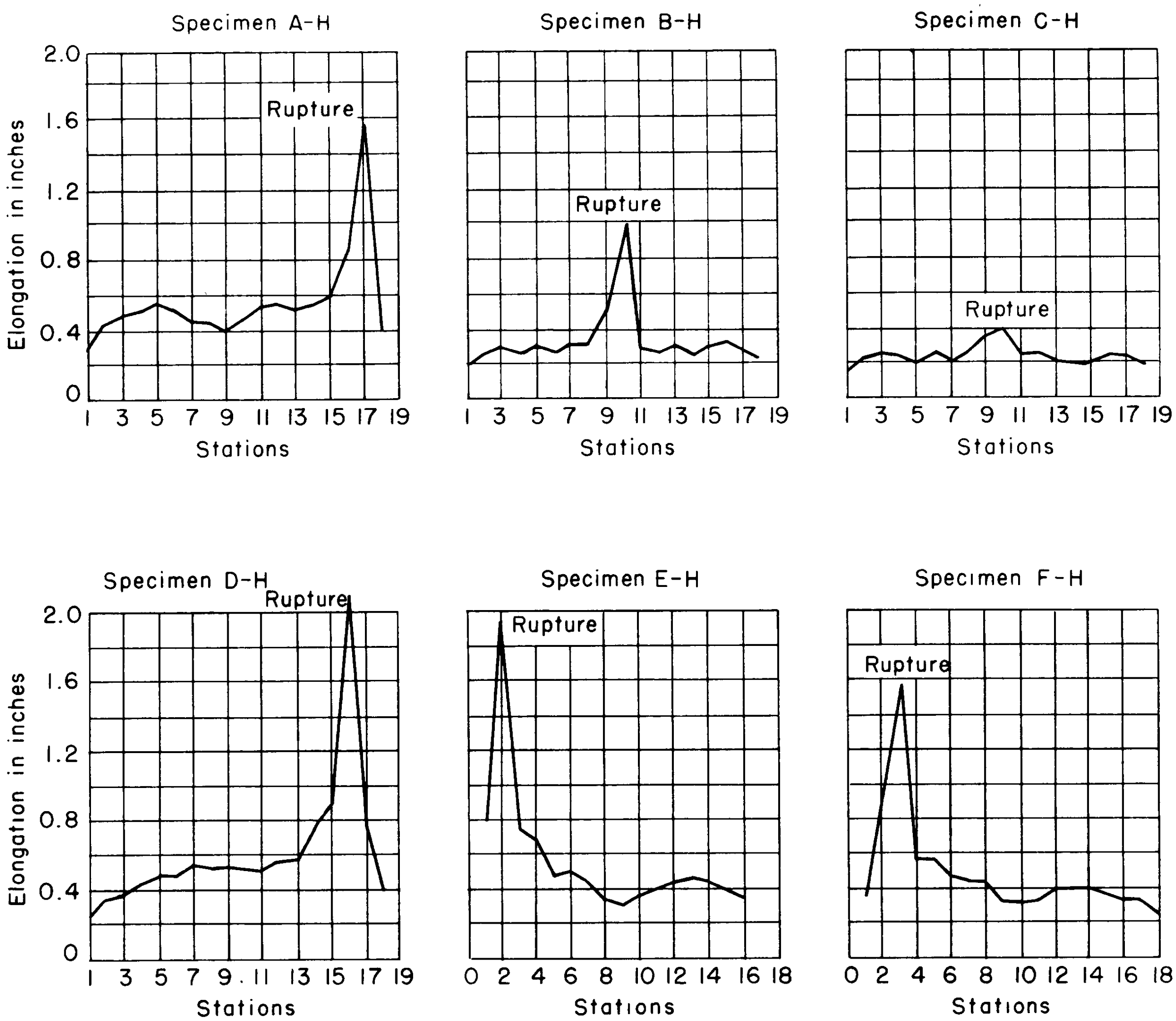


Figure 12 - Distribution of Average Axial Elongation in Medium Steel Specimens

Stations were spaced at 5-inch intervals over the specimens. Elongations are given in inches per 5-inch interval.



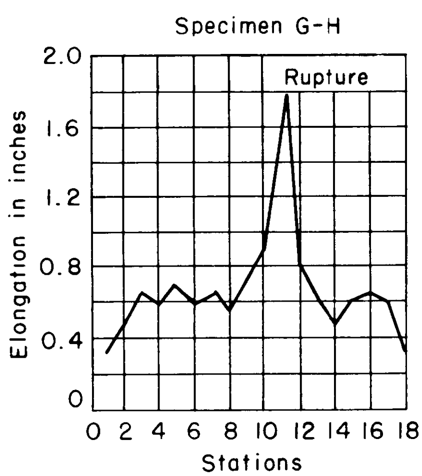


Figure 13 - Distribution of Average Axial Elongation in High Tensile Steel Specimens

Stations were spaced at 5-inch intervals over the specimens. Elongations are given in inches per 5-inch interval.

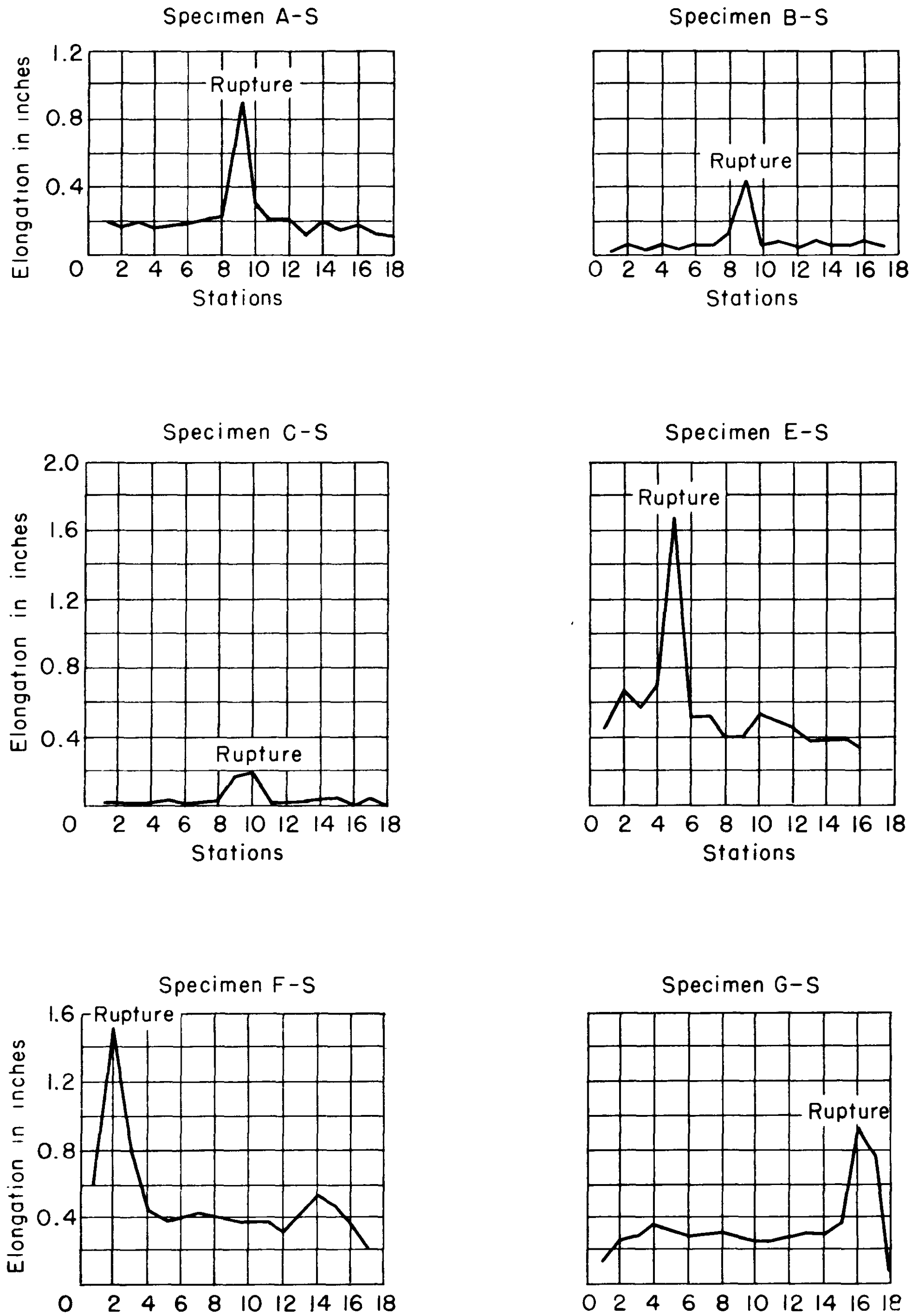


Figure 14 - Distribution of Average Axial Elongation in Special Treatment Steel Specimens

Stations were spaced at 5-inch intervals over the specimens. Elongations are given in inches per 5-inch interval.

Figure 15 - Medium Steel Specimen A-M after Test

Note the Lüders' lines at the edges of the plate and at the longitudinal seam to the right of the fracture.

Figure 16 - Medium Steel Specimen B-M at Half Transverse Butt after Test

Note the reduced transverse contraction of the edge of the plate adjacent to the transverse seam, and the strain lines near the junction of the welds.

Figure 17 - Medium Steel Specimen B-M after Test, showing Rupture Section

The transverse welded butt was about a foot from the rupture, just beyond the limits of the photograph.

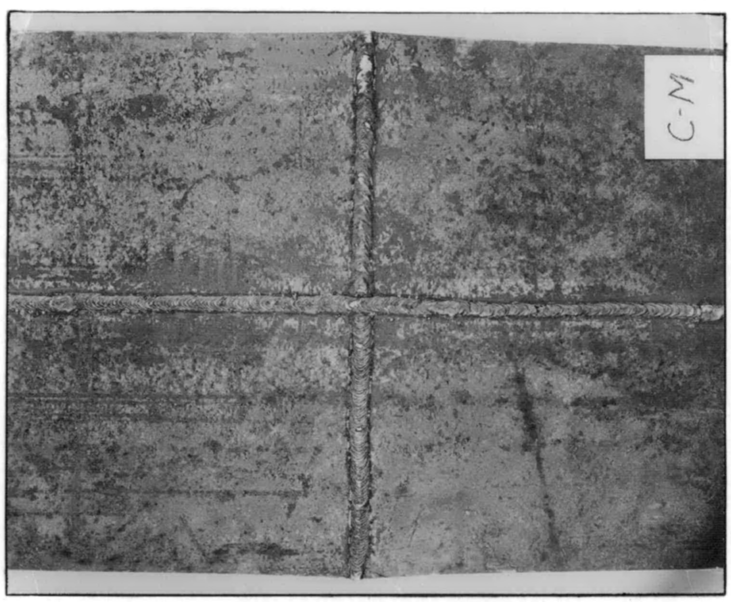


Figure 18 - Medium Steel Specimen C-M at Weld Intersection after Test

Note the diminished transverse contraction of the plate adjacent to the transverse butt.

Figure 19 - Medium Steel Specimen C-M after Test

The rupture occurred about 3 feet from the transverse welded butt.

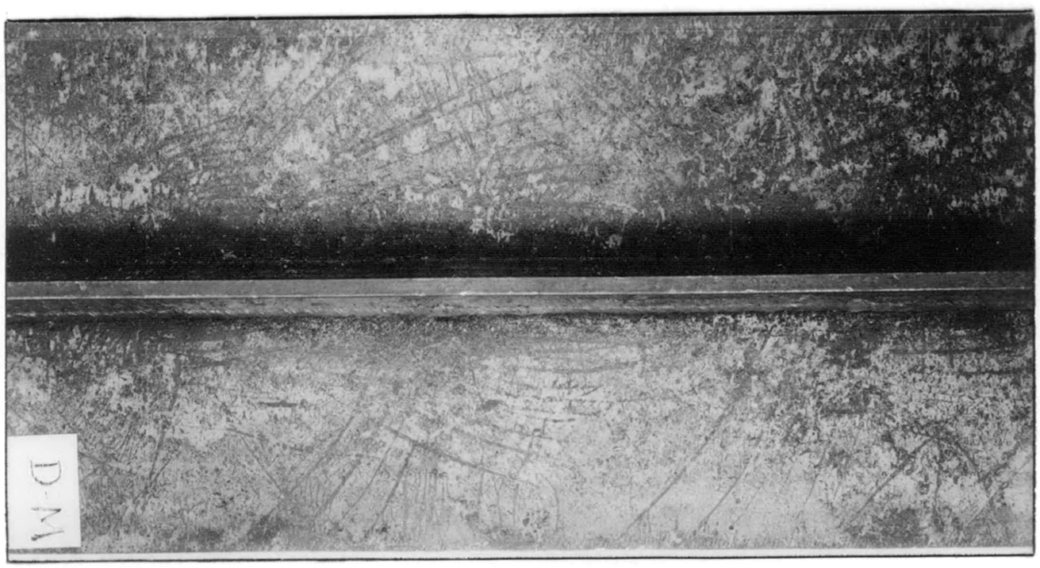


Figure 20 - Lüders' Lines on Medium Steel Specimen D-M after Test

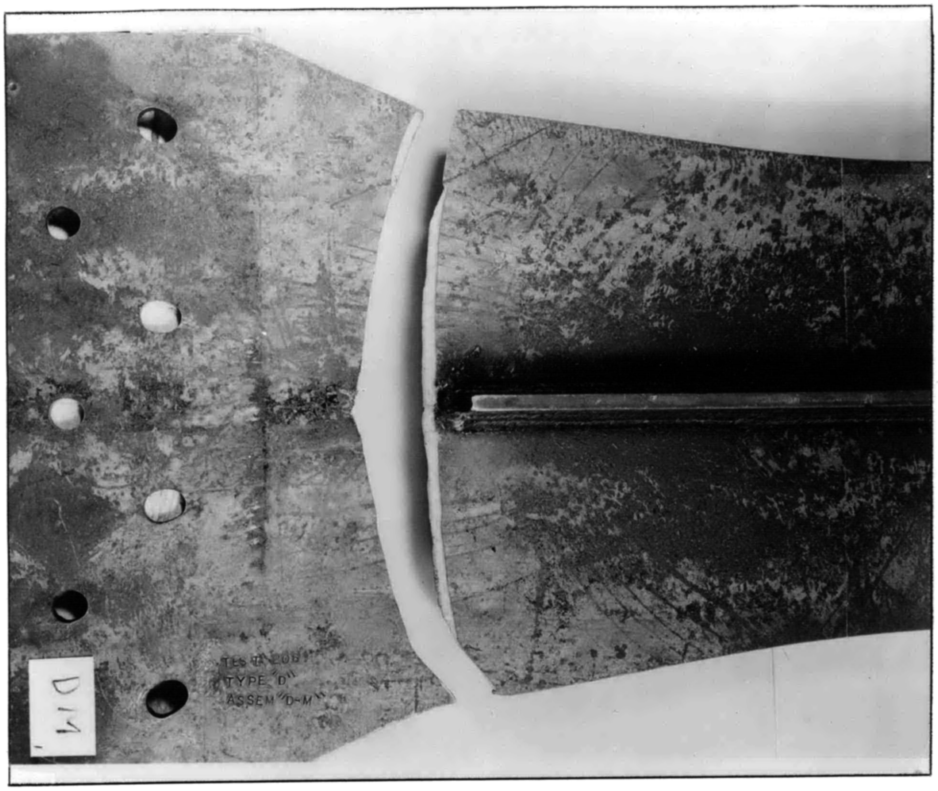


Figure 21 - Medium Steel Specimen D-M after Rupture

Note the elongation of the bolt holes. The webs were reduced in width in subsequent specimens from 2 inches to 1 inch.

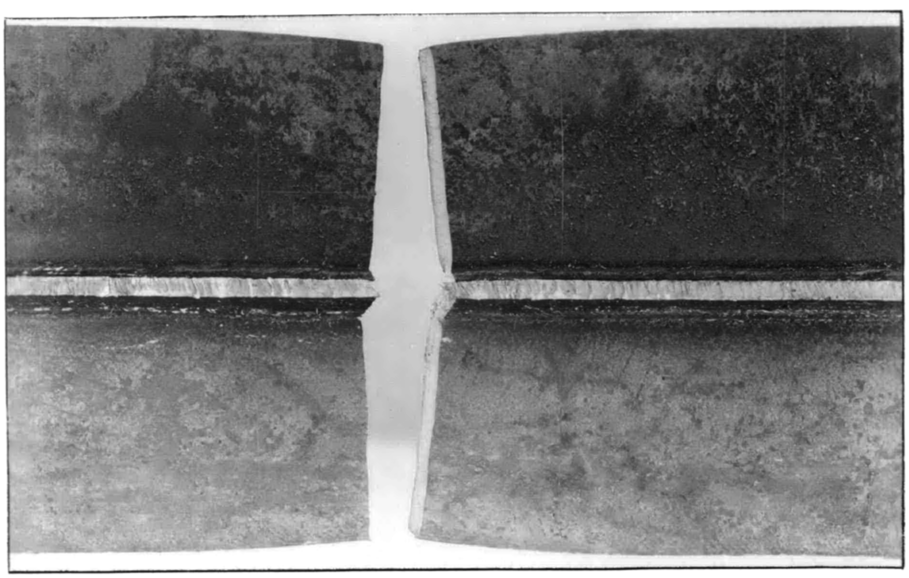


Figure 22 - Medium Steel Specimen E-M after Test

There was a small slag inclusion in one of the fillet welds at the point of fracture.

Figure 23 - Medium Steel Specimen F-M after Test

The greater separation of the rupture surfaces at the webs illustrates the lower ductility of the section at the welds.

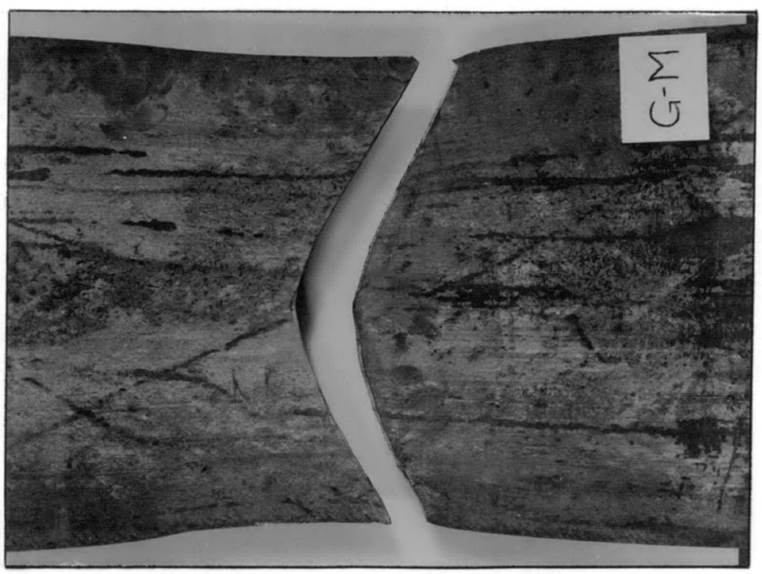


Figure 24 - Fracture in Medium Steel Control Specimen G-M

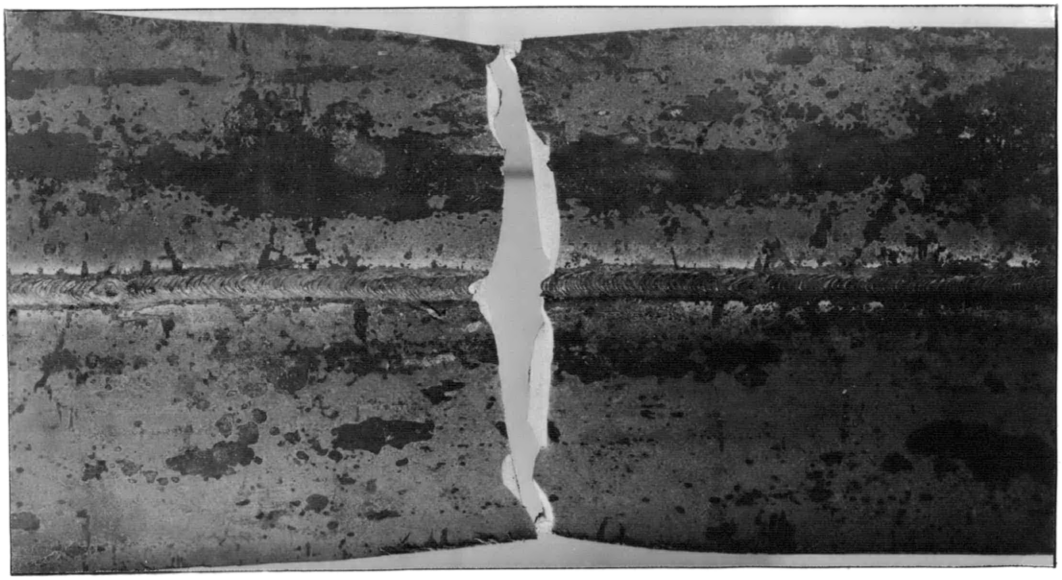


Figure 25 - High Tensile Steel Specimen A-H after Test

The rupture started in the weld.

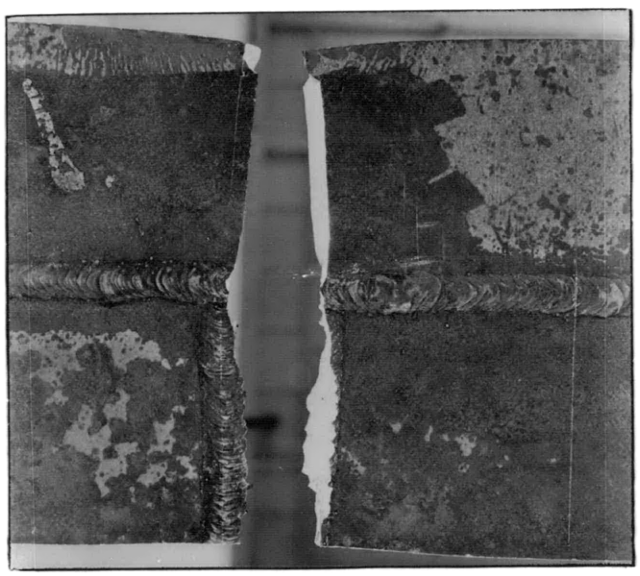


Figure 26 - High Tensile Steel Specimen B-H after Test

The rupture started in the transverse weld near the junction with the longitudinal weld.

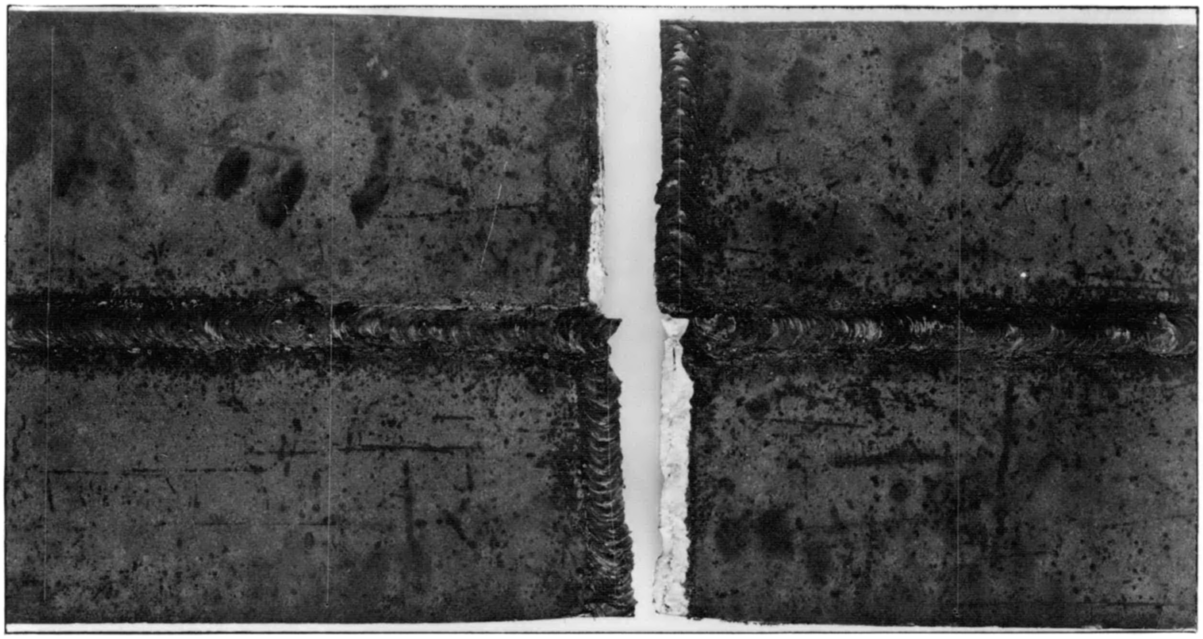


Figure 27 - High Tensile Steel Specimen C-H after Test

The rupture started in the transverse weld near the longitudinal weld.

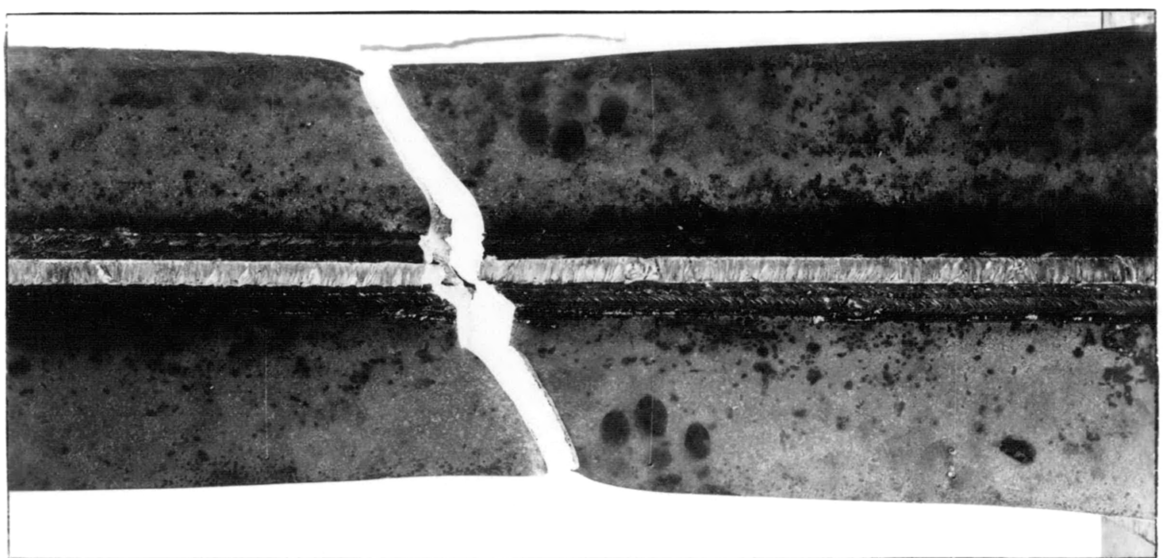


Figure 28 - High Tensile Steel Specimen D-H after Test

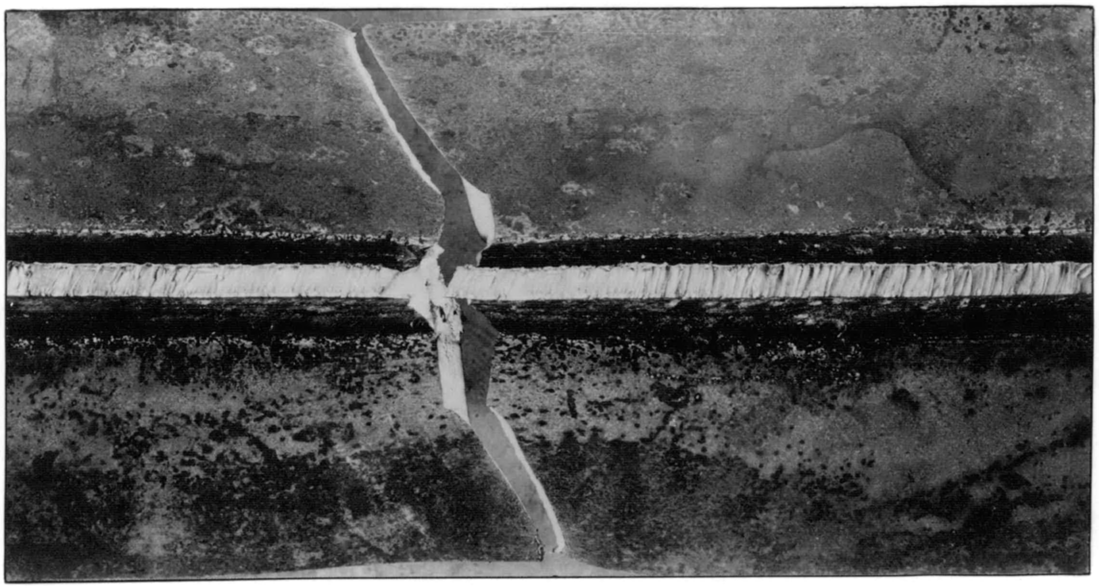


Figure 29 - High Tensile Steel Specimen E-H after Test

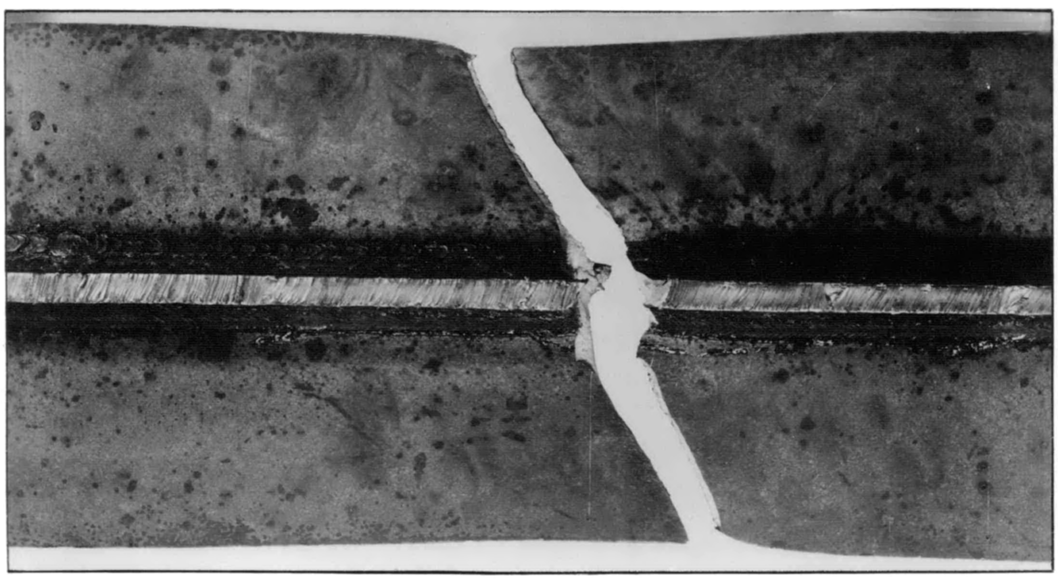


Figure 30 - High Tensile Steel Specimen F-H after Test

Figure 31 - High Tensile Steel Control Specimen G-H after Test

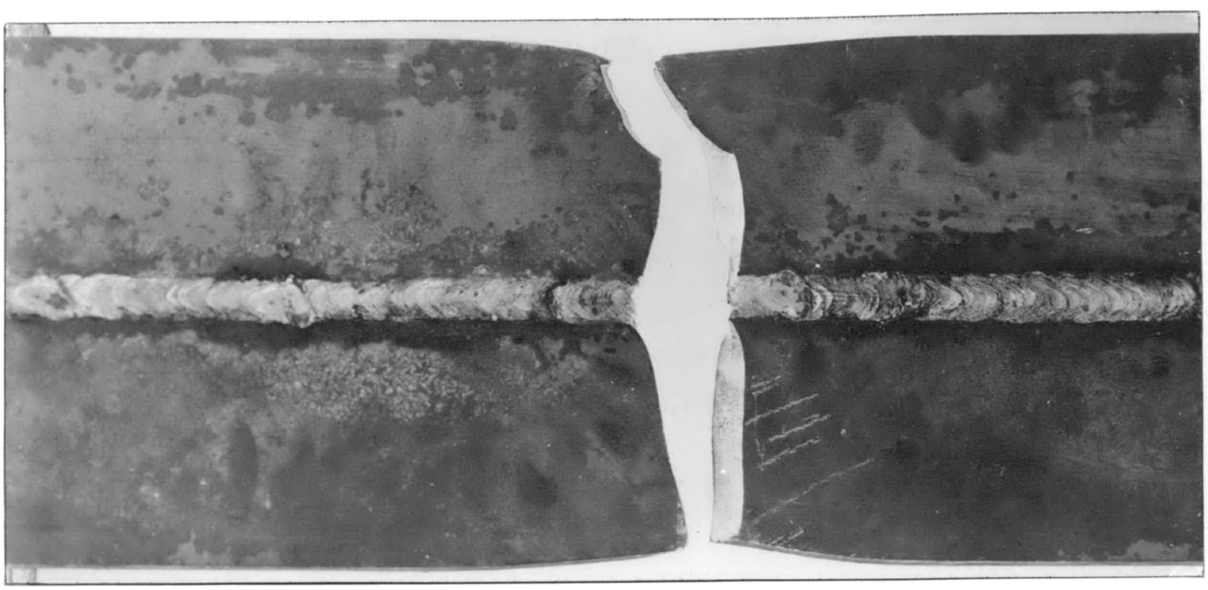


Figure 32 - Special Treatment Steel Specimen A-S after Test

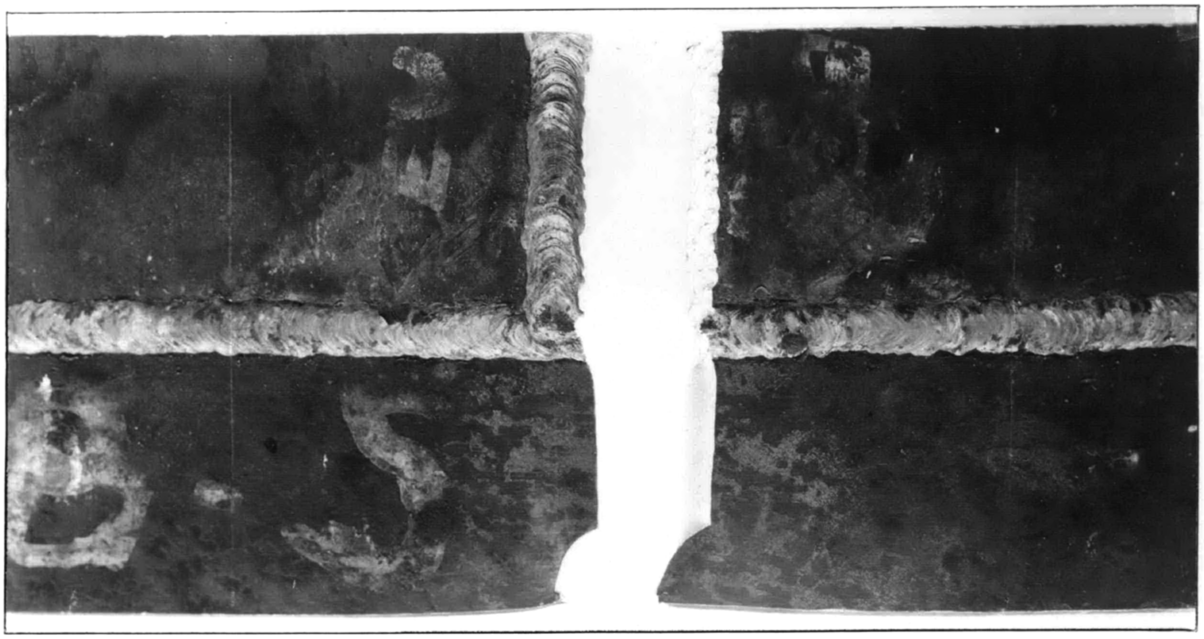


Figure 33 - Special Treatment Steel Specimen B-S after Test

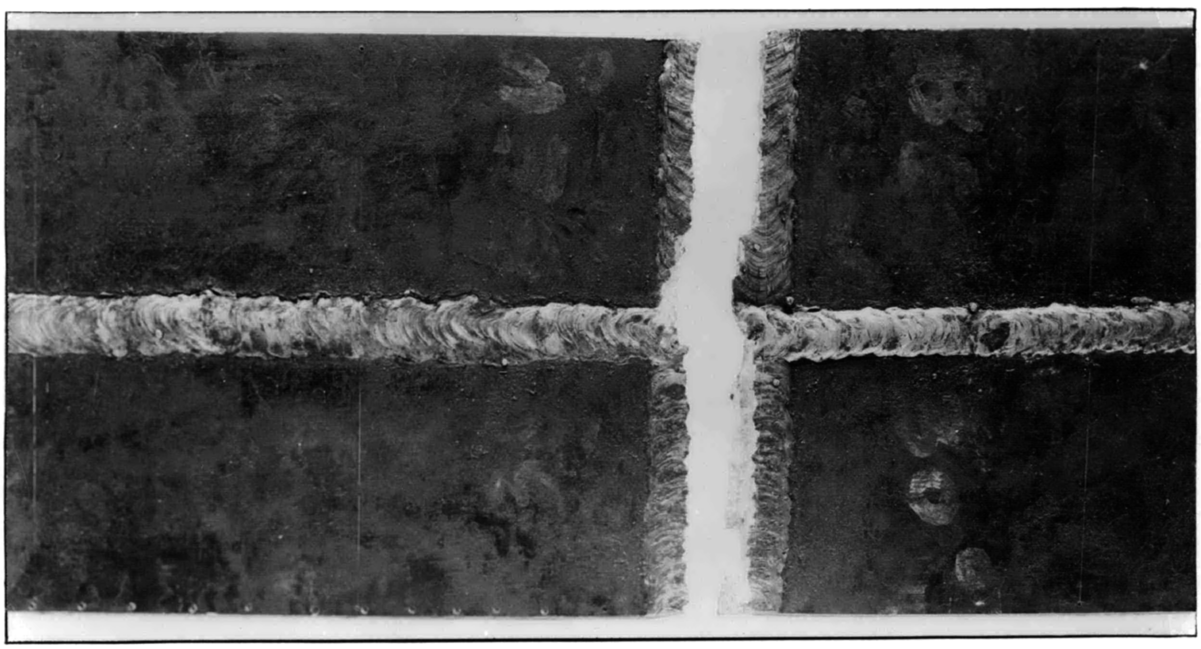


Figure 34 - Special Treatment Steel Specimen C-S after Test

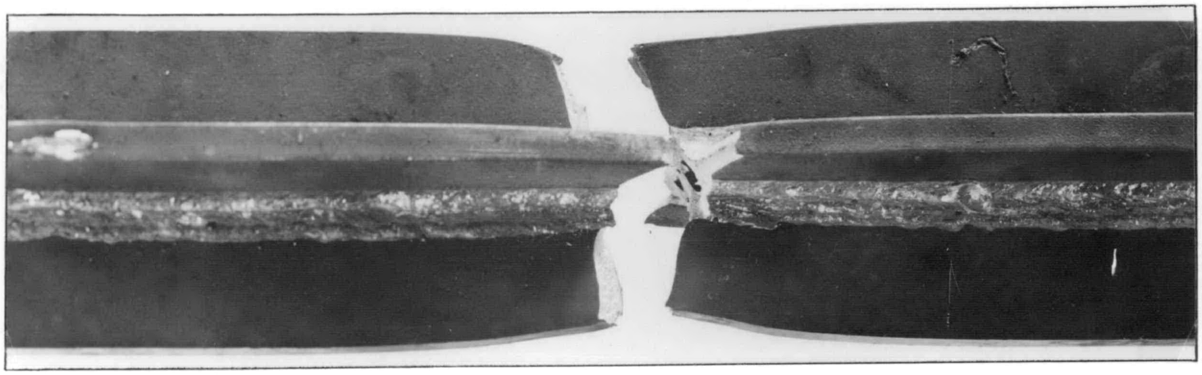


Figure 35 - Special Treatment Steel Specimen E-S after Test

The rupture started about 18 inches from the transverse web.

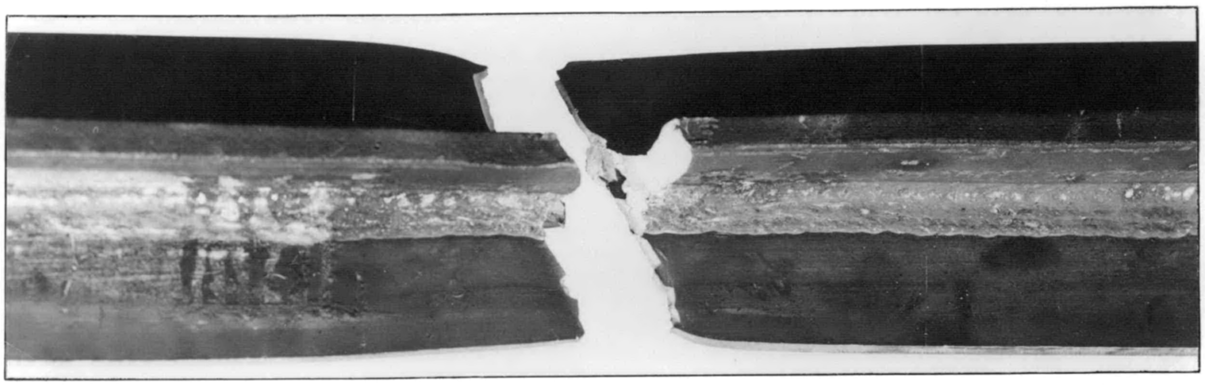


Figure 36 - Special Treatment Steel Specimen F-S after Test

The rupture occurred about 3 feet from the transverse web.

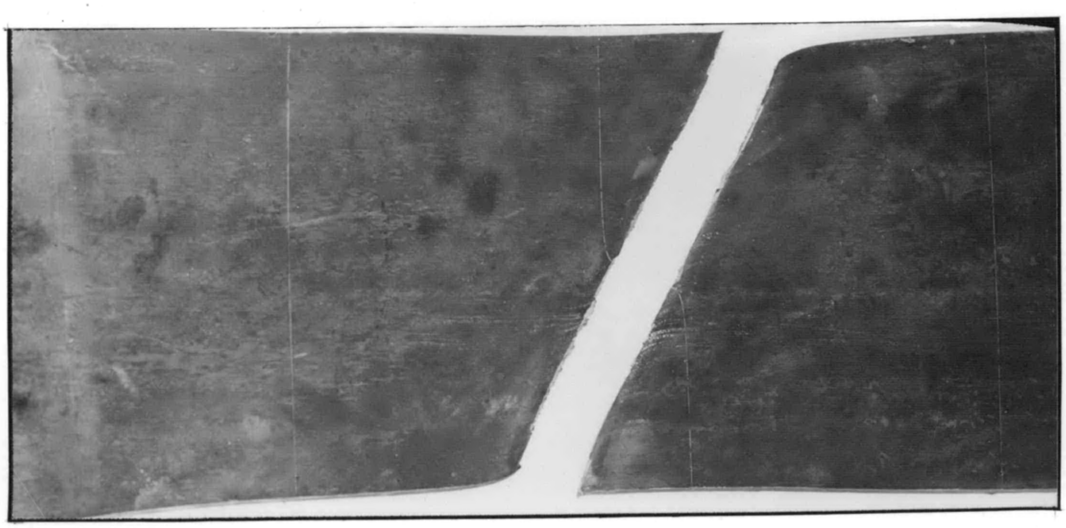


Figure 37 - Special Treatment Steel Control Specimen G-S after Test

APPENDIX 2

The inclusion of energy values in a report of this nature occurs for the first time in this case, and a brief explanation is offered herewith. Analysis of tensile test data in terms of energy is found desirable in connection with other work (9), especially impact tests, and in the present case it offers a more sensitive indicator of results obtained than the ultimate strength, which has formed hitherto the chief criterion of suitability of different structural assemblies.

Ductility is the word for the general property concerned, but instead of the arbitrary measure of ductility afforded by elongation in an arbitrary length, it is now proposed to use the energy absorbed per unit volume of metal. This measures the quality of the metal better than ductility alone, since it is increased by an increase in the stress which resists plastic flow as well as by the extent of the plastic flow.

The energy absorbed by a piece of steel, in inch-pounds per cubic inch of metal, is a number equally understandable when applied to a specimen of any size or form, even to an assembled structure, of which the specimens in this test are simple examples. It varies enormously, from the low average values of a few inch-kips per cubic inch obtained in a great extent of structure to very high values, even several hundred inch-kips per cubic inch, in the intensely worked metal adjoining a section of rupture.

The values quoted in Table 1 are rather crude averages, found by multiplying the overall elongation in the whole specimen by an estimated average load, and dividing by the volume of metal involved.

More refined calculations of energy absorption will be found in Reference (9). In particular, in addition to the data obtained in the present test, the load at rupture and the reduction in area at the rupture section should be measured in future work.