A Short Thesis

on Arc-Welding

by

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June 7, 1927.

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During the past few years the attention of architects,engineers and others engaged in or connected with the building industry has been attracted to the possibilities of the application of welding processes to the joining of structural members. As oxy-acetylene welding was developed before electric arc welding became perfected it was only natural that the gas torch should be first considered. It developed however on examination of the two processes that while acetylene welding gave better results in most cases it was only in the hands of experts that it could consistently outscore the arc as a welding medium. Arc-welding has the advantage over the acetylene process,where each individual operator must use his own judgement as to the proper flame,in that a squad of arc-welders can work under the direction of a single expert supervisor who accepts the responsibility of fixing the current value and of determining the proper size of welding rod to be used on any given type of work.

In order to obtain a little first-hand information on arc-welding, it was decided that a few samples be worked up and submitted to standard tensile tests. Mr. Frinke, of the McClintic Marshall Steel Fabricating Company located in Los Angeles and Pittsburg, very kindly gave us a good deal of valuable assistance by lending us his personal files on arc-welding and also by furnishing us an unlimited number of samples. Though his welder was kept busy working overtime on the fabrication of structural steel members for the Los Angeles City Hall then being fabricated in the company's shops, he managed to make our samples as fast as we could test them. We are indeed greatly indebted to Mr. Frinke and to the McClintic-Marshall Co. for their hearty and willing cooperation.

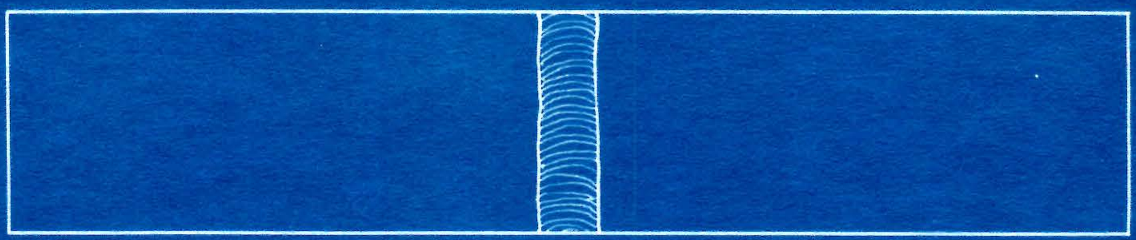
As is usual with a thesis of this type an insufficient number of tests was made, both as concerns variety and as concerns extent. Some of our conclusions are therefore based on rather insufficient data and this must at all times be kept in mind.

In general the welds tested showed a structure that was disappointing. In many cases slag and gas pockets cut down the area of cross-section as much as twenty per cent. In other cases the area of effective cross-section was materially decreased by rusty test pieces.This was especially true on the lap and side welds.In the future the difficulty arising from porous welds will undoubtedly be solved but until this time comes it is difficult to tell a good weld without testing it to failure. The Westinghouse Company is at present developing a process they believe will revolutionize arc-welding. They call the process the atomic hydrogen torch. Regular molecular hydrogen passes through an auxiliary arc and is converted into atomic hydrogen. This is then directed at the hot metal in the immediate vicinity of the welding torch where it reforms to molecular hydrogen with the liberation of a great quantity of heat. The molecular hydrogen combines with the oxygen of the air and provides an enveloping flame that has the effect of producing a reducing atmosphere and thus reducing oxidation.

Our first tests were made on a set of butt welds in order to determine the proper method of scarfing the pieces to be joined. We tested double

Single scarf

Double scarf

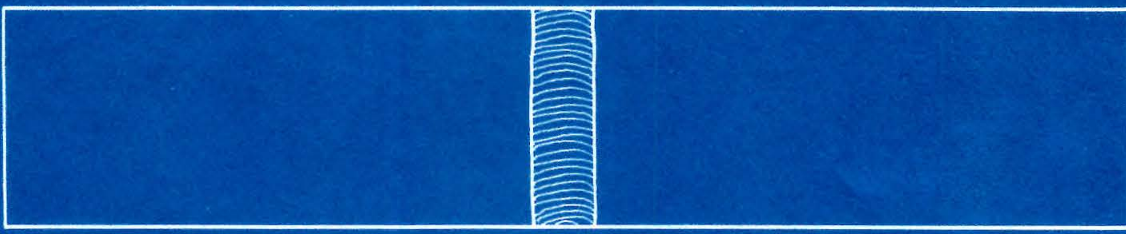


NO	SIZE	WELD	SCARF	MAX. STRESS	STRESS IN #/□"	STRUCTURE	FAILURE
1	2"×1/2"	BUTT	SINGLE	43300#	43300	M.C.	T. 100%
2	"	"	"	BROKE IN	FLEXURE	TEST	
3	"	"	"	47700	47700	M.C.	T.60%-S.40%
4	"	"	"	47100	47100	"	T. 100%
5	"	"	"	38000	38000	"	T.90%-S.10%
6	"	"	"	40050	40050	"	T. 100%
7	"	"	"	59500	FAILED OUT	SIDE WELD	
8	"	"	"	49250	49250	M	"
9	"	"	"	43100	43100	"	"
10	"	"	"	40300	40300	C	"
11	"	"	"	36000	36000	"	"
12	"	"	"	46600	46600	M	"
13	"	"	"	56400	FAILED OUT	SIDE WELD	
14	"	"	"	49500	49500	M.C.	"
15	"	"	"	36700	36700	C	"
16	"	"	"	47800	47800	"	"
17	"	"	"	46300	46300	"	"
18	"	"	"	52300	52300	M.C.	"

Note-Test pieces were all torch scarfed.

Single scarf

Double scarf



NO	SIZE	WELD	SCARF	MAX.STRESS	STRESS IN #/□"	STRUCTURE	FAILURE
19	3"×½"	BUTT	*SINGLE	59050#	39400	M.C.	T.100%
20	..	..	* ..	48150	32100	M.	..
21	..	..	..	45350	30250	C.	..
22	..	..	..	57000	38000	M.C.	..
23	..	..	NONE	59200	39400	C.	..
24	..	..	..	57000	38000	C.	..
25	..	..	—	62000	41300	M.C.	..
26	3"×¼"	..	SINGLE	40050	53300	C	..
27	..	..	..	34550	46000	M.C.	..
28	..	..	..	35600	47500	C.	..
29	..	..	..	48700	65000	M.	..
30	..	..	..	38350	51100	M.C.	..
31	..	..	DOUBLE	38000	50700	M	T. 70%- S.30%
32	..	..	..	37300	49750	C.	..
33	..	..	..	44600	59500	M	T.80%- S-20%
34	..	..	..	34100	45500	..	T.85%- S.15%
35	..	..	..	43500	58000	M.F.	..
36	2"×¼"	..	..	25100	50200	M.C.	..
37	2"×1"	..	SINGLE	89500	44750	F.	..

*One half of test piece only scarfed.

Note. All test pieces were torch scarfed.

and single scarfed welds in two thickness of metal. In the thinner material it made very little difference in the ultimate strength of the specimens whether they were double scarfed of single scarfed. The thin welds were represented by 3x1/4 butt welds. The single scarfed welds averaged 52,600 #per Sq.In.,while the double scarfed quarter inch welds ran 52,700# per Sq.In.

In the case of the thicker butt welds represented by 2"x 1/2",2"x1"and 3"x1/2" test pieces a considerable difference was noted between single and double scarfed preparation. The double scarfed welds averaged a stress of 48,000# per Sq.In.,while the single scarfed ran some ten per cent less or an average of 43,400# per Sq.In.

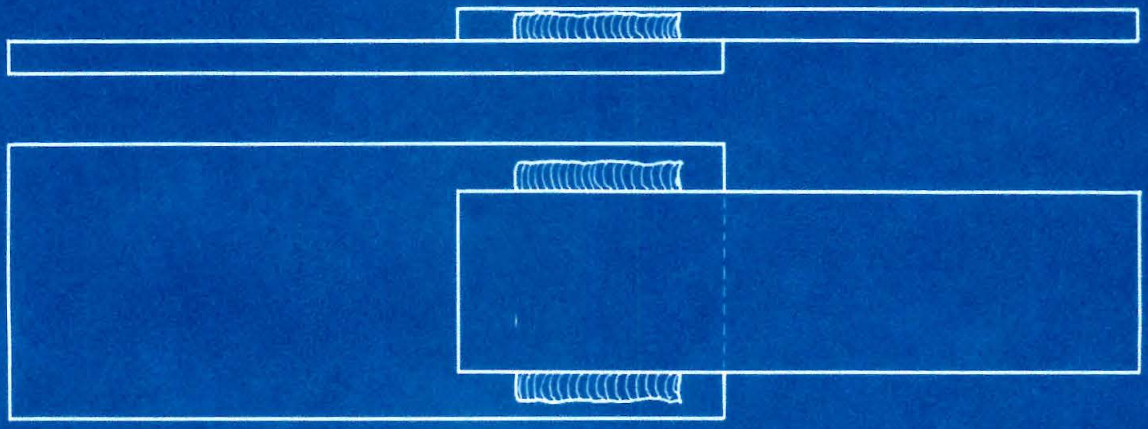
One cannot help but note that the thinner welds are apparently stronger per square inch than the thicker welds. While this is apparently true the increase of the unit stress is in a large part due to the following. The quarter inch welds invariably measured 5/16" through the welded portion,while the half inch welds were more nearly a 1/2" or 9/16" in thickness. Thus we see that the actual stress in the welds are 4/5 of 52,700# for the 1/4" welds and 8/9 of 48,100# for the 1/2" welds. In this light the quarter inch welds averaged 42,100# and the half inch averaged 42,600# per Sq.In. which after all is a negligible difference considering the extent of our tests and the wide variation of the results obtained from two similar test pieces.

It was intended that a series of tests be run to determine the efficacy of torch cut scarfs as compared with sheared scarfs. Due to a misunderstanding we received all torch cut specimens and were therefore unable to run this test which would have provided some valuable data for future construction in the field. That is an oxy-acetylene torch can be used to cut members in the field in preparation to joining them by arc-welding.

Though we cannot say that torch cut specimens are weaker than sheared pieces we can safely say from our data that welds on torch cut specimens show definite planes of weakness along the scarfs. That is, practically 75% of the specimens tested failed in a fracture that showed from 15 to 25% of the effective area along the torch cut scarfs. Twenty per cent of the remaining 25% showed from 5 to 15% exposed scarf. On three test pieces practically the whole break occured along the scarf. While these pieces were not noticeably below the average it is safe to say that unless the slag remaining from the cutting process is not removed the possibility of obtaining the strongest weld is much reduced. Practically all of this slag can be removed by a light hammering and the brushing thoroughly with a stiff wire brush.

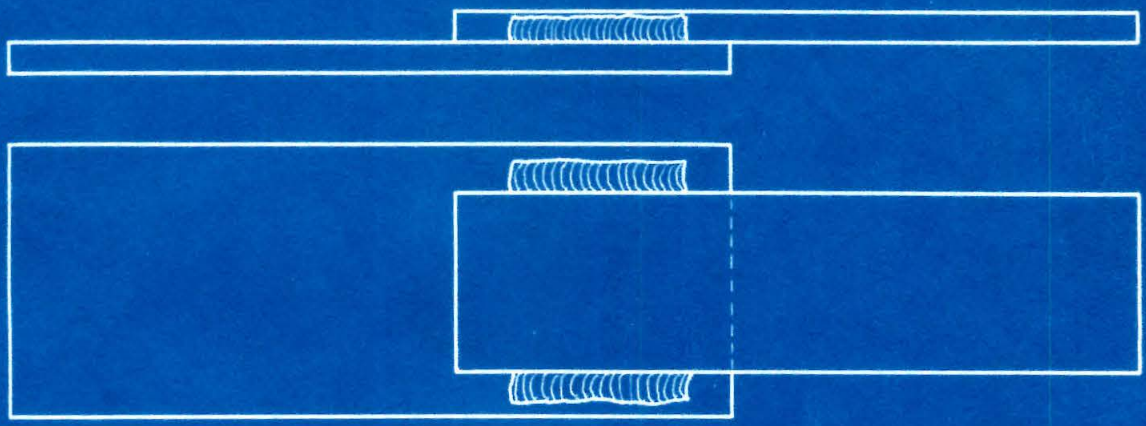
The next set of tests were designed to test the strength of a welded bead under stresses along the axis of the bead and perpendicular to the axis of the bead, and to determine the difference of strength if the strengths are different. For this the lap welds shown in table III were tested and likewise the side welds shown in table IV. The side welds seemed to fail in shear of the bead and fairly consistent results were obtained. The twenty-four samples average 8900# per linear inch of 3/16" bead. The thickness and width of the test pieces seemed to have very little effect on the strength of the side welds.

The lap welds in general averaged some what higher in strength. There was a noticeable difference in the strength when 1/2" pieces were used and when 1/4" test pieces were used. The 1/2" pieces gave an average of 15,100# per lin. in. for 3/16" bead. The 1/4" test pieces gave



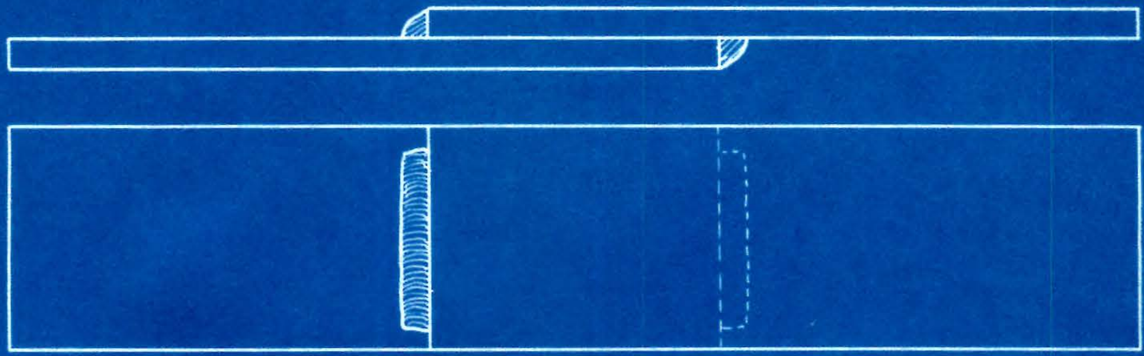
NO	SIZE	MAX. STRESS	LENGTH OF BEAD	HEIGHT OF FILLET	STRESS #/" BEAD
1	3"x½"-1"x½"	14500	2"	.20"	7250
2	"	13200	"	"	6600
3	"	16250	1.75"	"	9270
4	"	18100	2"	"	9050
5	"	14000	1.75"	"	8000
6	"	18900	2"	.25"	9450
7	3"x½"-2"x¼"	18700	"	.20"	9350
8	"	18700	2.25"	"	8300
9	"	20300	"	"	9000
10	"	17800	2.13"	"	8350
11	"	20000	2"	"	10000
12	"	17500	1.75"	"	10000

Note. 1- Pieces failed in shear.
2- Pieces were shear cut.



NO	SIZE	MAX. STRESS	LENGTH OF BEAD	HEIGHT OF FILLET	STRESS #/" BEAD
13	3"x½"-2"x½"	20000#	2"	.20"	10000
14	"	18250	1.9"	"	9600
15	"	21000	2.3"	"	9200
16	"	20000	2"	"	10000
17	"	22000	1.8"	.25"	12200
18	"	21000	2"	.20"	10500
19	3½"x½"-1½"x½"	27300	3"	"	9100
20	3"x½"-1½"x½"	26400	2.8"	.25	9420
* 21	3"x½"-1½"x¼"	20740	3.5"	"	5920
22	"	20700	"	"	5900
23	3"x¼"-1½"x½"	29300	3.8"	.20"	7700
24	"	24300	3"	"	8100

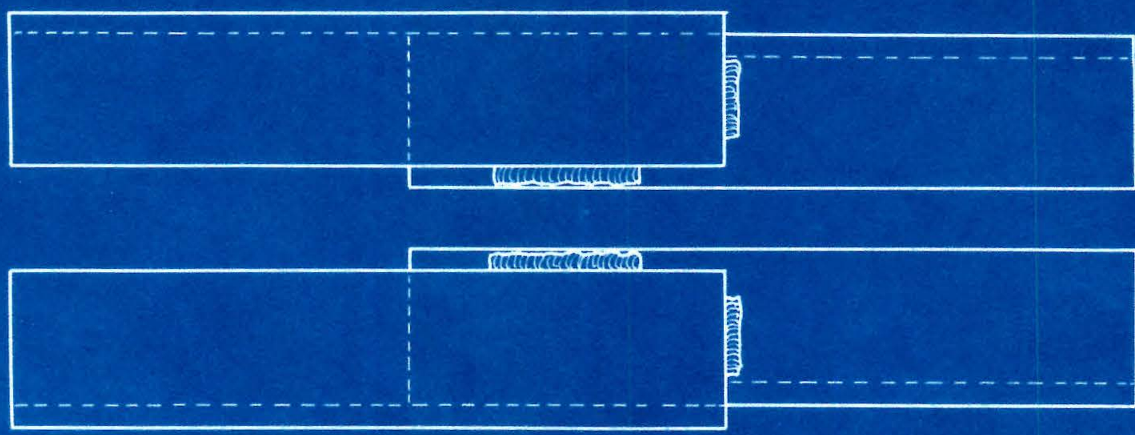
* Failed outside of weld.



NO	SIZE	MAX. STRESS	LENGTH OF BEAD	STRESS/" BEAD	HEIGHT OF FILLET	STRUCTURE
1	2" x 1/4"	20750#	2.2"	9850#	3/16"	F.
2	"	19600	2.1"	9330	"	M
3	"	14250	2.25"	6330	1/8"	"
4	"	17500	"	7770	3/16"	F
5	"	21000	2"	10500	"	M
6	"	17500	"	8750	"	F
7	"	25100	"	12550	"	C.
8	2" x 1/2"	21500	1.8"	11930	"	M.
9	"	18650	1.1"	17000	1/4"	"
10	"	24250	1.4"	17300	3/16"	F
11	"	22500	1.5"	15000	"	M.C.
12	"	30400	2"	15200	1/4"	C.
13	"	26100	1.8"	14500	3/16"	F.
14	2" x 1"	57300	2.5"	23000	3/8"	"
15	3 1/2" x 3 1/2"	43350	3"	14450	1/4"	M.

an average of 10,100# per linear inch for a 3/16" bead. Thus we see that the thickness of the material affects the strength of a lap weld and does not have any effect on a side weld. Moreover the lap weld is in general stronger than the side weld.

The next set of tests was to determine the proper method of joining angles. We could draw very few conclusions from our data because as the welds fâiled the weld tacks nearest the center of gravity of the system would give way first due to the concentration of stress in this section. Thus our average bead stress of 7,000# per linear inch of 3/16"bead neither agrees with our other data nor does it mean very much. The only conclusion to be drawn from this test is a quite obvious and logical one, namely that the proponderance of the weld metal should have been placed on the lap weld portion of the splice. In general then the weld metal must be proportionally placed around the axis of the applied forces.



NO	SIZE	MAX. STRESS	LENGTH OF BEAD	STRESS/in. BEAD	HEIGHT OF FILLET	STRUCTURE
1	2"x2"x1/4"	29000#	3.5"	8300#	3/16"	—
2	"	24500	3"	8170	"	M
3	"	27000	3.5"	7800	"	M.F.
4	"	21750	"	6170	"	"
5	"	28750	4"	7190	"	"
6	"	25250	3.5"	7210	"	"
7	"	23300	"	6650	"	"
8	"	25800	4"	6450	"	"
9	"	23000	3.75"	6130	"	"
10	"	29000	4"	7250	"	"
11	"	26150	3.75"	6970	"	"
12						
13						
14						
15						

In order to obtain information on which to base an opinion as to the stability of an arc-welded specimen under a large number of reversals four test pieces were subjected to a reversal of stress test. The test essentially consisted of subjecting the specimen to a constant bending moment and then revolving the specimen so as to reverse the stress on any given fiber once each revolution. Owing to the high speed at which the specimen turns it is essential that it be well machined, for any vibration introduces a whip in the weight producing the moment with a consequent impact.

The machine shop of the McClintic-Marshall Co. did a very good job on the specimens as only one of them showed any noticeable amount of vibration.

In order to obtain a value of stress that would permit the specimens to run over 100,000 revolutions and yet not to exceed 1,000,000 repetitions, which would take some ten hours, we took a value from a table by

NO	STRESS AT PERIPHERY #/□"	REPETITIONS	STRESS AT PERIPHERY #/□"	REPETITIONS
1	23000	1250	—	—
2	23000	100000	25600	13850
3	23000	100000	25600	26900
4	23000	100000	25600	58100

Moore and Seely that would break an unwelded structural steel specimen at 1,000,000 reversals. The table is given in the second part of the Proceedings of the American Society for Testing Materials for 1916 and is a curve solving the equation $S = \frac{B}{(1-Q)N^{\frac{1}{8}}}$ where S is the stress at the extreme fiber in pounds per square inch(computed by ordinary Mechanics of Materials formulas) corresponding to failure after N repetions of stress. Q is the ratio of minimum stress during one cycle of stress repetition to the máximum stress during the cycle, in our case Q -1 . B is a constant experimentially determined and is equal to 250,000 for ordinary structural steel. From this table a stress of 23,000# per sq.in. corresponds to 1,000,000 reversals of a structural steel specimen.

It can be readily seen from the table and from the formula that a small reduction in the intensity of stress greatly increases the number of repetitions possible. From the data of Moore and Seely it would appear that a 9% reduction of stress very nearly doubles the endurance. Since the test pieces showed flaws which reduce the effective cross-section and increase the stress and since the constant B for welded material should lie between gray cast iron and structural steel we expected the samples to run about 100,000 reversals.

Test piece number one was the first to go but it is safe to disregard this low value because of the poor character of the weld. Practically half of the break occurred along a torch cut scarf and showed no signs of weld penetration. The remaining three specimens were run through the hundred thousand mark and the the moment was increased from 23,000 to 25,600#. The pieces then averaged an additional 33,000 reversals which when translated back to to original stress would bring the average total to 190,000 repetions. This is quite good when one cōsiders that doubling the stress corresponds to a reduction of the reversals by 100 times. The samples would have undoubtedly gone to the 500,000 mark if the cross-sectional area had not been so reduced by slag deposits and gas bubbles. We did not run any unwelded specimens for a comparison as Moore and Seely have done a good deal of work on unwelded specimens and we are content to take their data as a standard

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