A REPORT ON THE TESTING OF ELECTRIC WELDS

by

F. L. McNair, B.S.
and
C. W. Vaughan, Jr., B.S.

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Introduction

This thesis was prepared as a result of the growing interest in, and the increasing importance of, electric welding as applied to many types of manufactured products. Although the art of electric welding is comparatively new, great steps have been taken in its adaptation to industry. As yet the process is underdeveloped, and no information is available whereby one may know with certainty the behavior to expect from a welded joint.

The composition of the metal to be welded, the composition of the welding rod, and the method used in welding are but a few of the factors which determine the ultimate strength and behavior of an electrically welded specimen. Far from claiming the credit for a comprehensive report on electric welding, the authors of this thesis admit that it of necessity is limited in its treatment of the subject.

Both steel and wrought iron specimens were tested, the steel specimens ranging from 0.2 to 0.5 per cent carbon content. At first the investigation

embraced lap-welded and butt-welded joints, but because of the fact that properly made lap-welds never break in the weld, and hence give no indication as to the strength of the weld, this type was abandoned, and all V-type butt-welds were used. All of the welds, with a few exceptions which will be mentioned later, were tested in tension, their tensile strength being used as an indication of their ultimate strength.

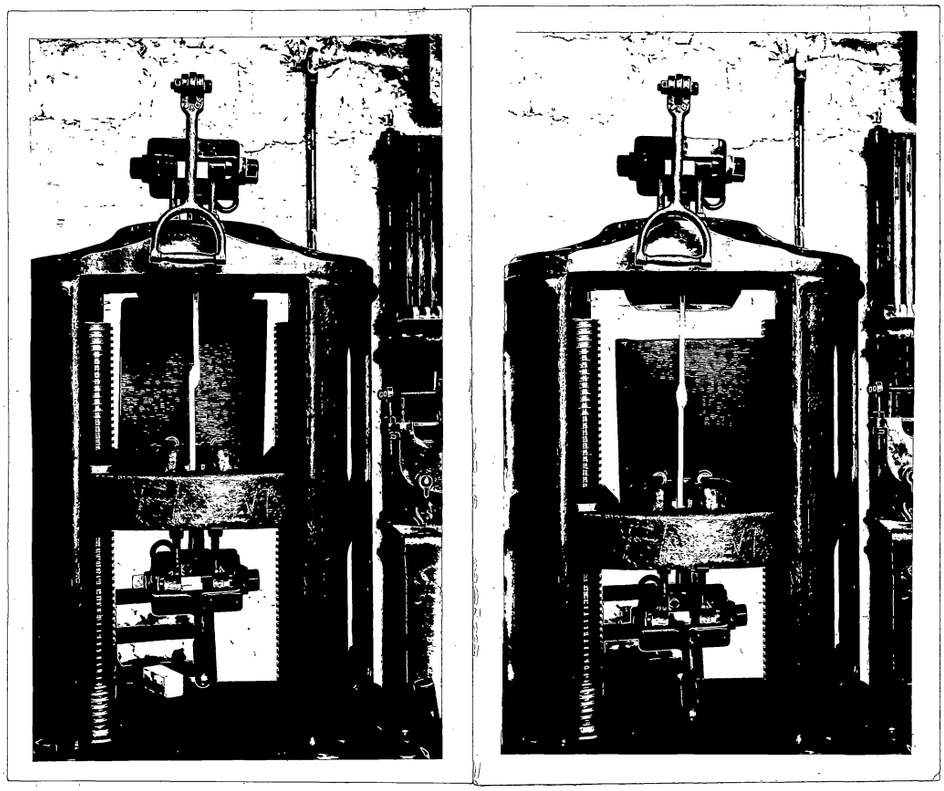
The Tinius Olsen strain gage was used in obtaining the elongations of the specimens. In the tables which follow, the values in the deformation column will be expressed in Tinius Olsen units, each unit being 0.0003333 of an inch. If the value in the deformation column were 2.3 and this value were desired in inches, the conversion factor 0.0003333 should be multiplied by 2.3, giving 0.00076659 inches as a result.

The welding was done with a Lincoln Stable Arc Welder. During the welding operations the voltage was kept at 60 and the amperage was about 150.

Most of the welded specimens discussed in this thesis were prepared in the shops of the Virginia Polytechnic Institute by Mr. M. B. Smith, Shop Super-

intendent. From Mr. W. G. Conner, Director of the V. P. I. shops, under whose supervision this thesis was prepared, much valuable information and advice was obtained. Dr. W. E. Barlow, head of the V. P. I. Metallurgical Department, rendered invaluable assistance in metallographical investigations. The Virginia Bridge and Iron Company of Roanoke, Virginia, very graciously supplied a number of welded specimens which were prepared in their own shops. To the gentlemen and to the company named above the authors wish to extend their sincere appreciation.

Figure 1 shows the method of testing a specimen in the Riehle testing machine.



(a) Specimen in machine before application of load.

(b) Specimen pulled into line of applied force.

Lap Welds

Figure 1

The following sketch will help to explain the method of making measurements with the strain gage:

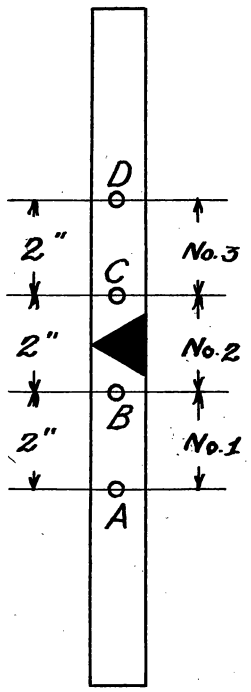


Figure 2

The punch-mark holes, indicated by A, B, C, and D, were punched two inches apart and the readings were numbered as shown. Both sides of the specimen were punch-marked, and the average of the readings over two correspondingly opposite lengths was used as the final value of the deformation over that particular length under test. This same procedure was followed

with all the specimens of which deformation was observed except the lap-welds.

Some of the specimens were cut to an exact section before testing them, others were cut and welded directly from stock sizes. In all cases dimensions will be given, but when stock size is used the word "stock" will follow the dimensions, thus indicating that measurements were not made with a micrometer, but were merely made with a steel rule.

Results

Series A indicates steel of about 0.2 to 0.3 per cent carbon content. Several unwelded specimens were first tested to determine the average yield point and maximum load. (With few exceptions, the maximum load was the same as the breaking load on welded specimens.) These specimens were steel strips $2\frac{1}{2}$x3/8 inches. The following nominal values were obtained by averaging the results of the several specimens:

Yield point ---------- 41,806 lbs./sq.in.
Maximum load --------- 57,731 lbs./sq.in.
Breaking load -------- 48,406 lbs./sq.in.

In the following tables the total deformation over a length of six inches is shown in tables No. 1; tables No. 2 show the sum of the deformations over each third of the six inches under test for all loads up to the yield point. All loads are in pounds per square inch, and deformations are in Tinius Olsen units as explained in the introduction.

The efficiency of a welded specimen is defined as follows:

$$\text{Efficiency} = \frac{\text{Unit breaking load of welded specimen}}{\text{Unit maximum load of unwelded specimen}}$$

Specimen A-5

Table No. 1

Unit Load	Deformation
0	0.0
3883	2.3
7766	3.5
11649	6.2
15532	9.6
19415	11.2
23298	13.8
27181	17.2
31064	19.2
35379	21.4
31896	24.2
29100	50.2
49514	Broke

Table No. 2

1	2	3
7.0	7.7	6.8

Butt-welded specimen.

Dimensions: 2.06"x.375"

Yield point = 35379 lbs./sq.in.

Efficiency = $\frac{49514}{57731}$ = 85.7%

Specimen A-6

Table No. 1

Unit Load	Deformation
0	0.0
3974	3.7
7948	6.3
11922	9.1
14896	12.8
19870	14.7
23844	17.8
27818	21.3
31792	28.4
37308	57.6
24377	Broke

Table No. 2

1	2	3
14.2	23.3	20.1

Butt-welded specimen.

Dimensions: 2.013"x.375"

Weld was found to contain a large number of blowholes.

Yield point = 37308 lbs./sq.in.

Efficiency = $\frac{24377}{57731}$ = 42.2%

Specimen A-8

Table No. 1

Unit Load	Deformation
0	0.0
3390	1.7
6780	4.1
10170	5.9
13560	8.8
16950	9.7
20340	11.0
23730	12.6
27120	15.3
30510	17.3
32022	18.3
31977	18.9
33559	20.4
50056	Broke

Table No. 2

1	2	3
6.4	7.8	4.1

Butt-welded specimen.

Dimensions: 1.98"x.447"

Yield point = 32022 lbs./sq.in.

Efficiency = $\frac{50056}{57731}$ = 86.7%

Specimen A-11

Table No. 1

Unit Load	Deformation
0	0.0
3200	1.9
6400	4.0
9600	6.1
12800	8.8
16000	10.6
19200	11.5
22400	12.9
25043	14.9
25600	16.8
26669	17.4
40271	Broke

Table No. 2

1	2	3
5.3	5.6	4.0

Butt-welded specimen.

Dimensions: 1.986"x.472"

Yield point = 25043 lbs./sq.in.

Weld contained numerous blowholes. Large areas were unwelded.

Efficiency = $\frac{40271}{57731}$ = 69.9%

Specimen A-12

Table No. 1

Unit Load	Deformation
0	0.0
3164	1.7
6328	3.3
9492	5.8
12656	7.8
15820	
18984	
22148	
62321	Max.
54251	Broke

Table No. 2

1	2	3
2.7	3.1	2.0

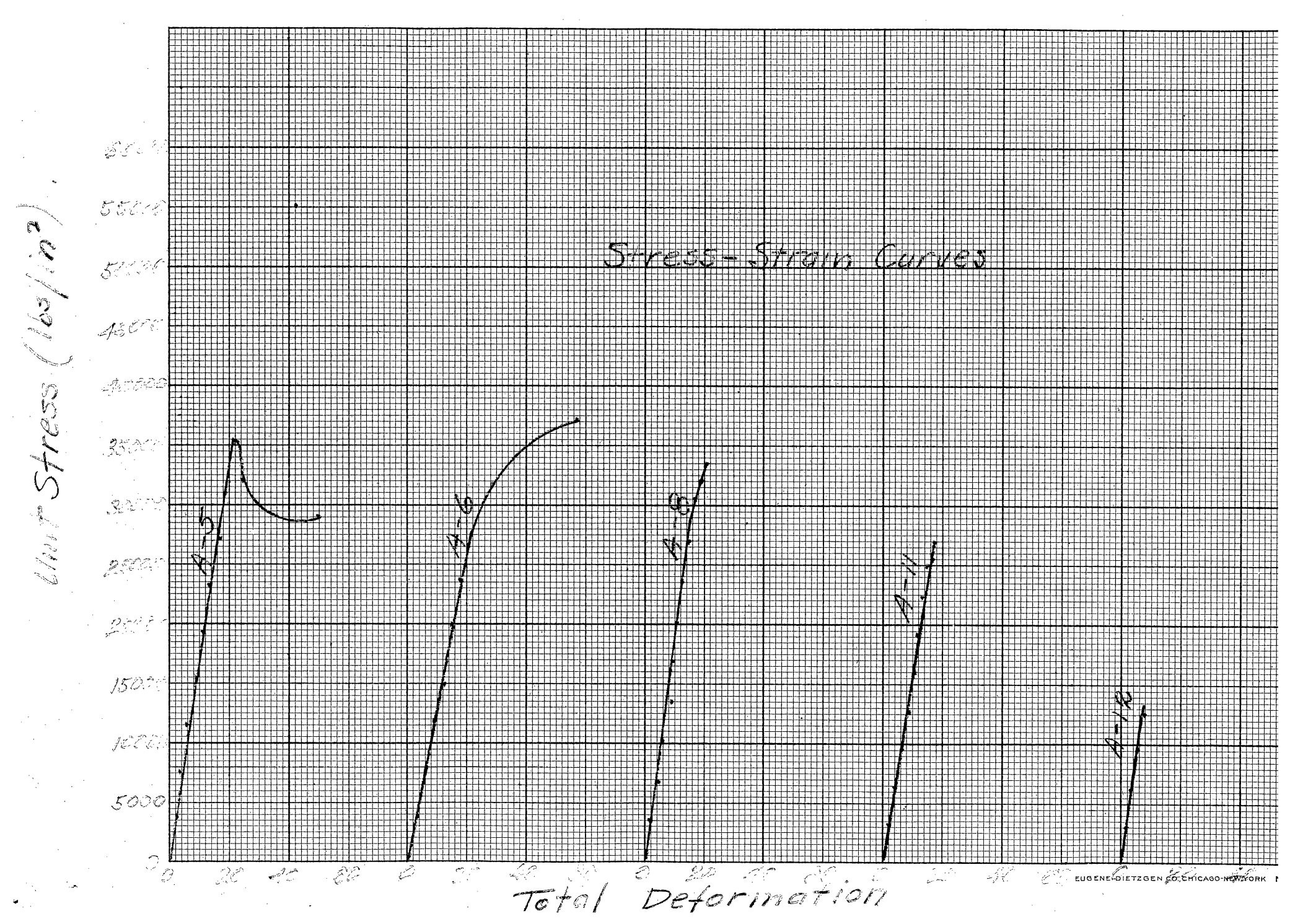
Butt-welded specimen.

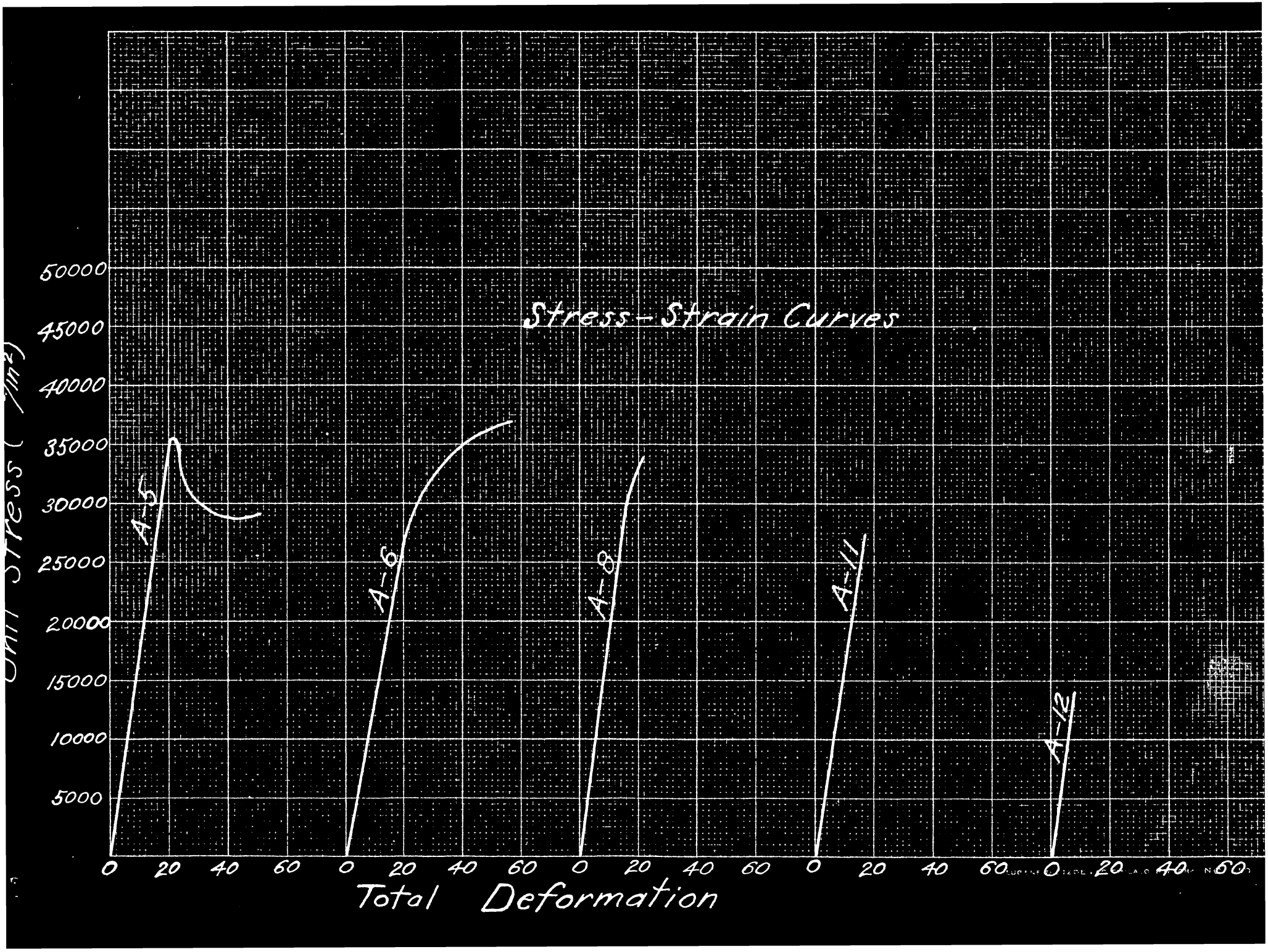
Dimensions: 1.996"x.475"

Yield point: Undetermined.

Efficiency $= \frac{54251}{57731} = 94.1\%$

Series B indicates steel of about 0.2 to 0.3 per cent carbon content. The specimens were welded as in series A, and then heated in a forge to a bright red heat (about 800°C.). The specimens were then cooled in a lime pit. The following tables have the same significance as in the foregoing series.


Stress-Strain Curves
Unit Stress (lbs/in²)
Total Deformation
5000
EUGENE DIETZGEN CO. CHICAGO-NEW YORK


Stress-Strain Curves
Unit Stress (lbs/in²)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
A-5
A-6
A-8
A-11
A-12
0
20
40
60
Total Deformation

Specimen B-2

Table No. 1

Unit Load	Deformation
0	0.0
4065	2.8
8130	8.6
12195	11.5
16260	13.2
20325	16.3
21802	17.1
25596	20.2
34146	41.5
47425	Broke

Table No. 2

1	2	3
7.4	5.3	4.4

Double "V" butt-weld.

Dimensions: 1.585"x.466"

Yield point = 21802 lbs./sq.in.

Portion of weld very good.
About half the area was oxidized.

Efficiency = $\frac{47425}{57731}$ = 82.1%

Specimen B-3

Table No. 1

Unit Load	Deformation
0	0.0
4354	3.6
8708	6.8
13062	10.8
17416	15.3
20798	17.8
25138	28.2
28156	
29026	Broke

Table No. 2

1	2	3
3.5	8.9	5.4

Single "V" butt-weld.

Dimensions: 1.569"x.439"

Yield point = 20798 lbs./sq.in.

Metal badly burned.

Efficiency = $\frac{29026}{57731}$ = 50.2%

Specimen B-4

Table No. 1

Unit Load	Deformation
0	0.0
3778	2.5
7556	5.8
11334	8.7
15112	11.9
18890	14.2
22040	17.3
22668	18.0
23300	18.1
29156	26.6
32846	
52897	Broke

Table No. 2

1	2	3
5.2	8.0	4.9

Single "V" butt-weld.

Dimensions: 1.588"x.50"

Yield point = 23300 lbs./sq.in.

Broke along plane between weld and parent metal.

Efficiency = $\frac{52897}{57731} = 91.6\%$

Series C indicates steel of about 0.2 to 0.3 per cent carbon content. The welded joints were prepared under different conditions of voltage and amperage. The values for these two factors will be given with each specimen.

Specimen C-1

Table No. 1

Unit Load	Deformation
0	0.0
3750	2.2
7500	5.3
11250	7.3
15000	9.7
18750	12.5
21250	14.4
22500	15.3
32250	24.0
35687	41.1
45000	Broke

Table No. 2

1	2	3
4.5	4.1	6.7

Double "V" butt-weld.
Dimensions: 1.650"x.486"
Yield point = 22500 lbs./sq.in.
60 volts.
120 amperes.
1/8" welding rod.
About 50% of weld was oxidized.
Efficiency = $\frac{45000}{57731} = 77.9\%$

Specimen C-2

Table No. 1

Unit Load	Deformation
0	0.0
3614	2.3
7228	5.5
10842	6.7
14456	9.6
18070	11.4
21684	14.0
23518	16.2
32012	23.0
34939	34.9
42470	Broke

Table No. 2

1	2	3
3.9	7.3	5.0

Double "V" butt-weld.
Dimensions: 1.650"x.503"
Yield point = 23518 lbs./sq.in.
60 volts.
120 amperes.
1/8" welding rod.
About 50% of weld was oxidized.
Efficiency = $\frac{42470}{57731} = 73.5\%$

Specimen C-3

Table No. 1

Unit Load	Deformation
0	0.0
3750	2.1
7500	6.7
11250	8.9
15000	11.2
18750	13.3
22500	15.3
25587	17.0
35000	22.2
35412	
47237	Max.
44525	Broke

Table No. 2

1	2	3
5.0	7.1	4.9

Single "V" butt-weld.
Dimensions: 1.619"x.493"
Yield point = 25587 lbs./sq.in.
60 volts.
200 amperes.
5/32" welding rod.
Numerous blowholes.
Good otherwise.

Efficiency $= \frac{44525}{57731} = 77.1\%$

Series D is composed of single "V" butt-welds in which the angle of the "V", or champher angle, was varied from 45° to 90°. In this series the specimens were not cut to an exact section, but the welded joint was shaped to the approximate size of the parent metal. The material used was wrought iron. The angle of the "V" was 90° in specimens D-3 to D-16 inclusive, 60° in specimens D-17 to D-21 inclusive, and 45° in D-22 and D-23.

Series D

Wrought Iron
Dimensions; 2"x½" stock.

No.	Yield Point	Breaking Load	Efficiency	Remarks
D-3	28000	45250	79%	Very good weld.
D-4	28580	42100	74	Slightly oxidized.
D-5	25000	43060	75	Fair.
D-6	28200	44960	79	Very good.
D-7	27040	36000	63	About 30% unwelded.
D-8	26080	42180	74	Fair.
D-9	26600	39600	69	Fair.
D10	27670	41920	73	
D11	28700	45000	79	Gave away gently.
D12	26760	34170	60	Large areas burned & unwelded.
D13	28170	43760	77	Good.
D14	25800	42000	74	Good.
D15	29750	37200	65	30% burned and unwelded.
D16	25620	40000	70	
D17	30000	37550	66	½ good, other ½ poor.
D18	29000	37620	66	
D19	28800	37190	65	
D20	28300	40000	70	Good.
D21	28780	34800	61	Burned and unwelded.
D22	27000	40500	71	
D23	27700	37000	65	Burned and unwelded.

Several unwelded specimens of the wrought iron used in this series were tested and the following average results were obtained:

Yield point ---------- 27235 lbs./sq.in.
Maximum load --------- 56940 lbs./sq.in.
Breaking load -------- 44915 lbs./sq.in.

The efficiencies given in the above table were obtained by the same formula as was used in the foregoing series.

The following series consists of welded specimens furnished by the Virginia Bridge and Iron Company. The letters P, R, and F have no special significance other than that of indicating different specimens of the same type of weld. The figures on the blue-prints show clearly the meaning of N1, N2, N3, etc., and their relation to the type of welding, and the dimensions of the specimens.

Virginia Bridge and Iron Company's Specimens

Specimen	Yield Point	Breaking Load*	Remarks
PN1	39093	44546	
RN1	38666	47053	
FN1	37720	50133	Joint slightly reinforced.
PN2	38906	39466	
RN2	39040	56000	Very good.
FN2	39013	45626	
PN3	38733	46666	Joint slightly reinforced.
RN3	39066	44746	
FN3	**	29786	Small area unwelded.
PN4	**	24000	
RN4	**	26666	
FN4	**	25506	About 25% unwelded.
PN5	39520	59426	Good.
RN5	37133	57066	Broke outside joint.
FN5	38013	54666	

Continued on next page.

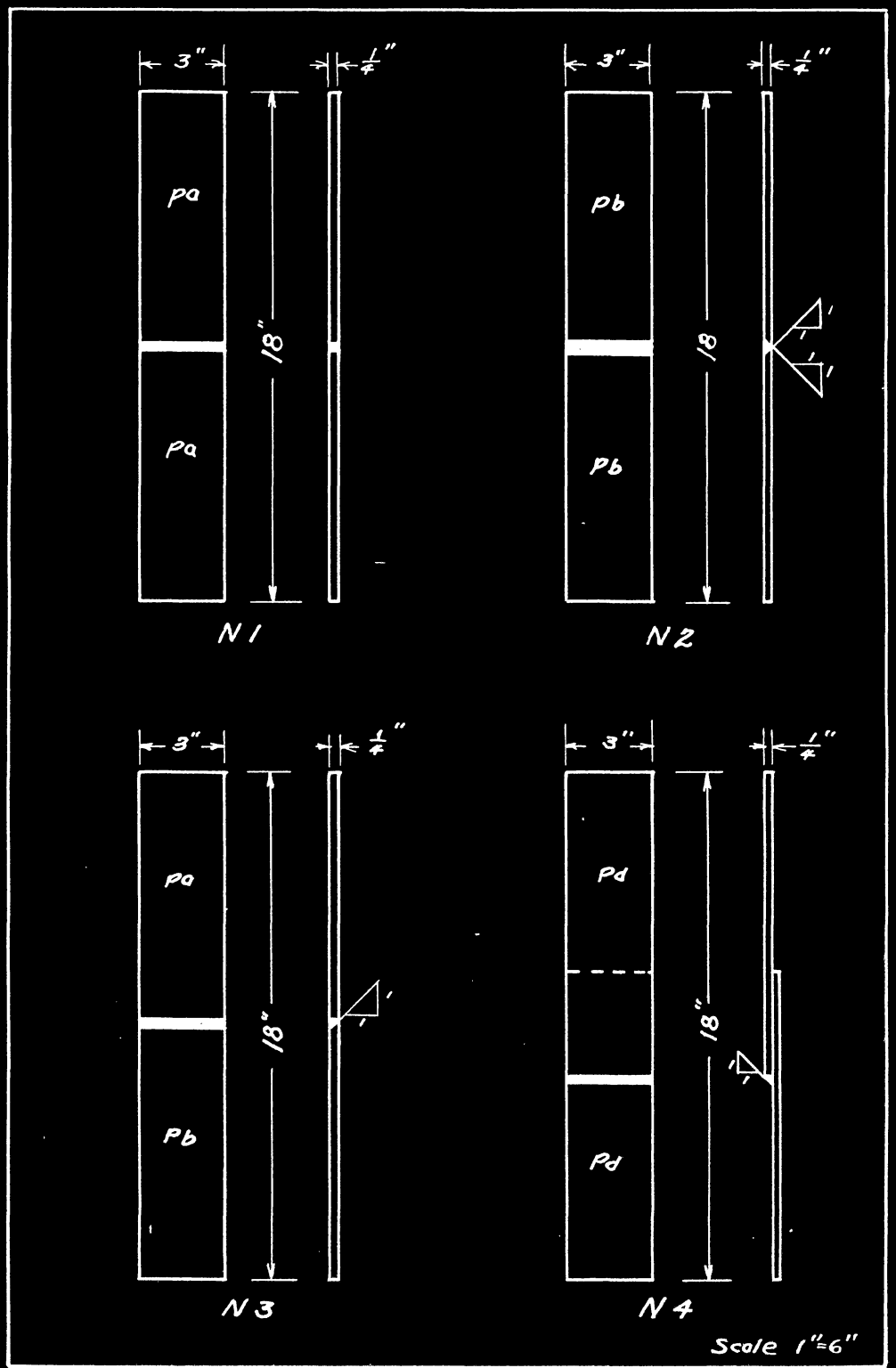
* All stresses are in pounds per square inch.
** Failed before reaching yield point.

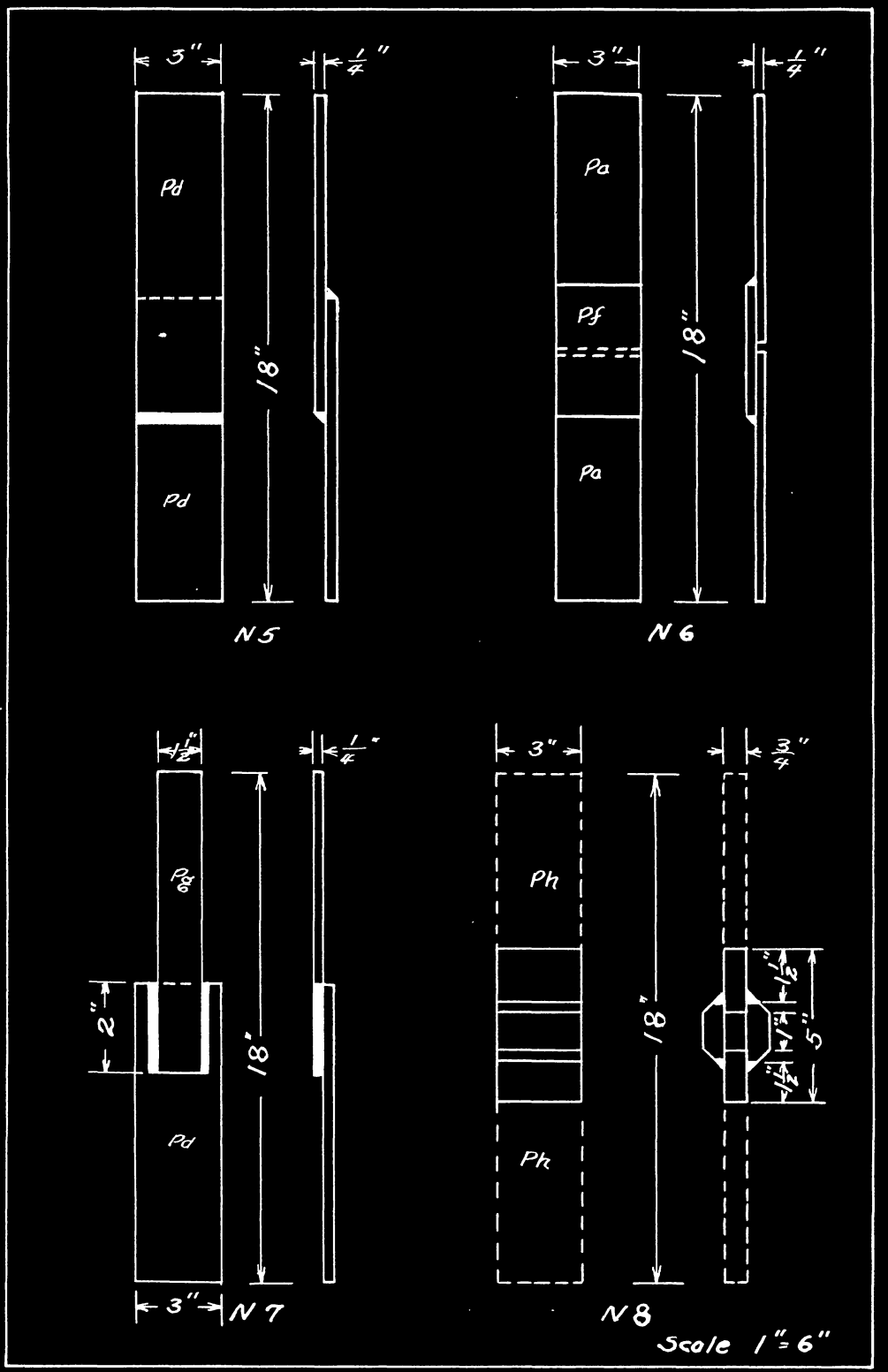
V. B. and I. Co's. Specimens (Continued)

Specimen	Yield Point	Breaking Load*	Remarks
PN6	**	21613	
RN6	**	25813	
FN6	**	20080	
PN7	37227	50427	Broke several inches from joint.
RN7	34611	50853	" " " " " .
FN7	34853	49147	Broke just above joint.
PN8	**	23111	Tested in compression.
RN8	**	27555	" " " .
FN8	**	27395	" " " .

* All stresses are in pounds per square inch.
** Failed before reaching yield point.

The welds of series E are oxy-acetylene welds which were prepared for an approximate comparison with electric welds. The steel is the same as that of series A, B, and C. Since the area of the welded joints was nearly the same as that of the parent metal, the welds were not machined. Specimens 1 to 5 inclusive were welded with chrome welding rod; specimens 6 to 9 inclusive were welded with iron welding rod.


3"
1/4"
Pa
Pa
18"
N1
3"
1/4"
Pb
Pb
18
N2
3"
1/4"
Pa
Pb
18"
N3
3"
1/4"
Pd
Pd
18"
N4
Scale 1"=6"


3"
1/4"
Pd
18"
Pd
N5
3"
1/4"
Pa
Pf
18"
Pa
N6
1 1/2"
1/4"
Pg
2"
18"
Pd
3"
N7
3"
3/4"
Ph
18"
Ph
1 1/2"
1 1/4"
1 1/4"
5"
N8
Scale 1"=6"

Series E

Dimensions: 2"x$\frac{1}{8}$" stock.

No.	Yield Point	Breaking Load	Efficiency	Remarks
E-1	28840	44300	77%	
E-2	26660	33290	58	Edge unwelded. Tore across.
E-3	28070	46140	80	Good.
E-4	36180	42490	73	High yield point.
E-5	29430	43330	75	
E-6	36350	43600	75	Porous weld.
E-7	35300	38530	67	Nearly 50% unwelded.
E-8	28200	45840	79	
E-9	29180	47160	81	Very good.

Metallographic Examination

For the metallographic examination five welds were selected, and the specimens were removed as shown in Figure 3. Since specimen A-7 was typical of the entire set of five, it alone was studied. This specimen was polished and etched, for thirty seconds, with a solution of 10% of nitric acid in water. Figure 4 shows the appearance of the etched surface of the specimen when examined with the naked eye. The letters on the sketch refer to areas or zones of different metallographic formations.

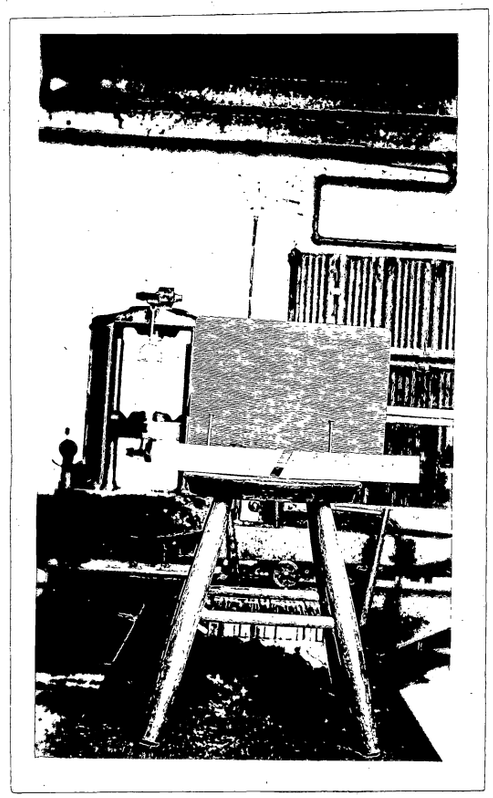


Figure 3

When examined under the microscope (x 90), the areas "b" showed the characteristic structure of low carbon steel, banded in a few places apparently as a result of rolling. Figure 5 shows the structure of the unaltered steel, or parent metal.

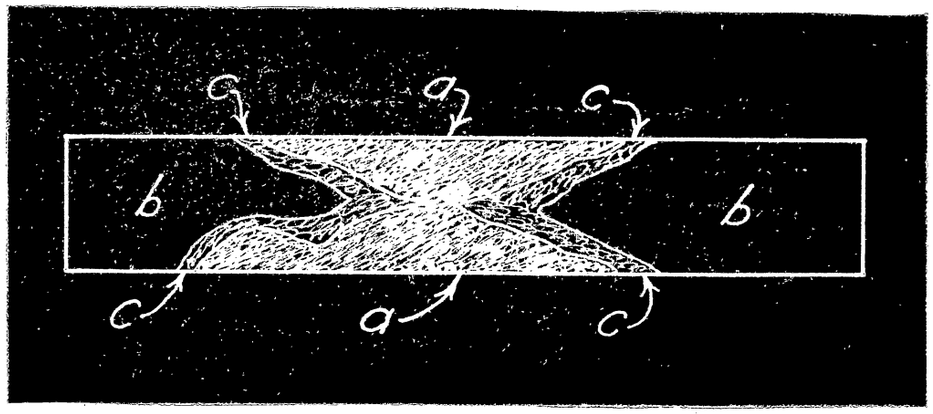


Figure 4

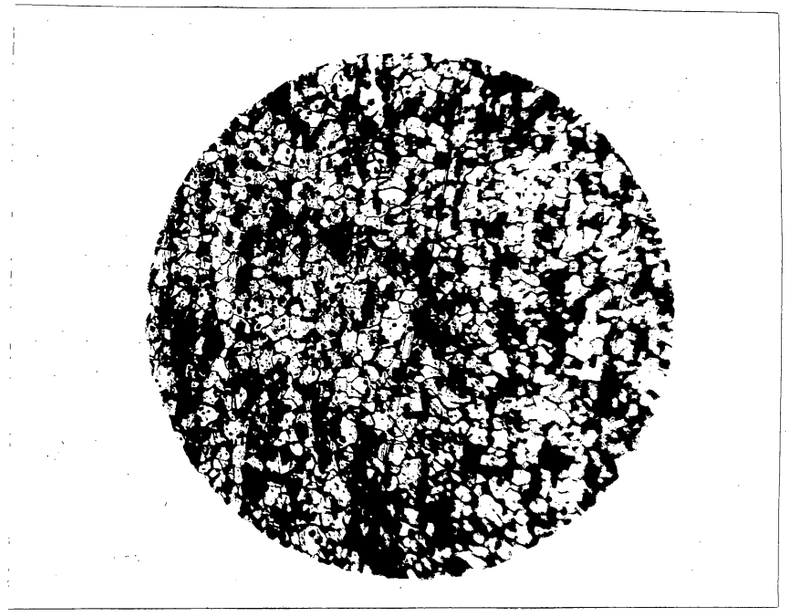


Figure 5

Area "b", showing unaltered steel or parent metal. (x 90)

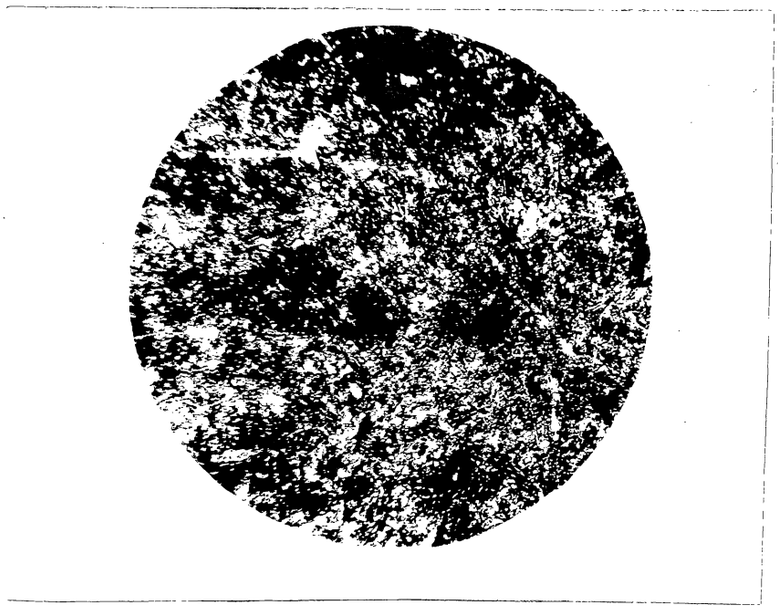


Figure 6

Area "a", showing structure of material added by welding rod. (x 90)

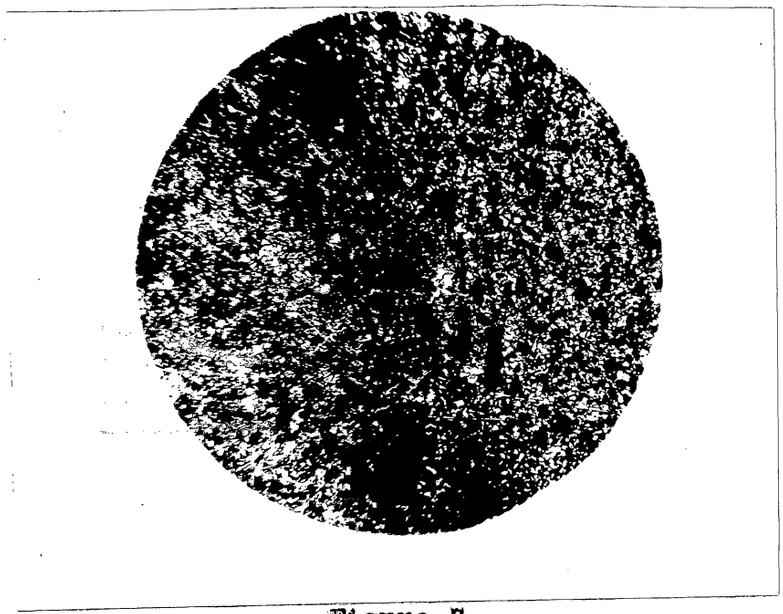


Figure 7

Junction between areas "a" and "c", separated by a band of sorbite. (x 90)

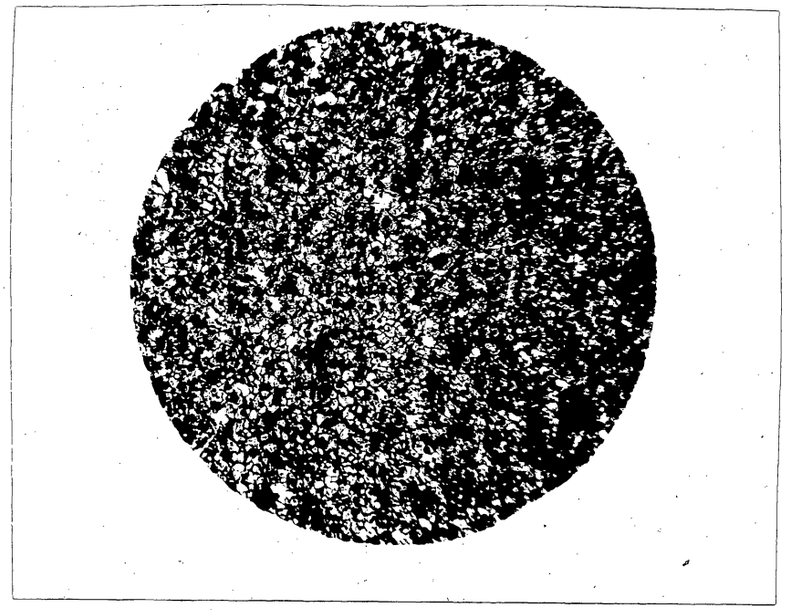


Figure 8

Area "c", showing structure of portion which was "heat-refined" (x 90)

The areas marked "a", in Figure 4, were composed almost entirely of sorbite or sorbitic pearlite. This constitution would naturally result from air cooling a comparatively small piece from a high temperature (within the Roberts-Austen diagram). Figure 6 shows the structure of the material supplied by the welding rod.

The "zones" or "fringes" marked "c" show both sorbite and some unaltered ferrite plus pearlite. The ferrite grains are much smaller than those in the unaffected area "b". This condition was evidently

due to the fact that in areas "c", the steel was heated to a temperature just above the critical range (i.e. just within Region IV of the R-A diagram), the grain size being accordingly "heat refined" in a very striking manner. The grains of ferrite are about one-twentieth the size of those of the unaltered ferrite. Figure 7 shows the junction of the two zones, "a" and "c", separated by the dark band of sorbite. Zone "a" is on the left of the sorbitic band, and zone "c" is on the right. Figure 8 shows the structure of zone "c". From a comparison of Figures 5 and 8, it may be seen that the grain size in the latter is approximately one-twentieth that in the former.

If a state of true metallic cohesion existed between "a" and "c", and between "c" and "b", and if the zone "c" (showing both "refined" grain and some sorbite) were wide enough and shaded off gradually from the pearlite-ferrite system to the system rich in tough sorbite, one would expect the weld to be as strong as the portions marked "b". But since these ideal conditions are never realized in practice, the weld always fails at the joint unless it is heavily reinforced.

Conclusion

Since an exhaustive study of welding was impossible (in the preparation of this thesis), the following conclusions should not be too fully relied upon, except as they give some approximate idea of the subject to which they are related.

The average efficiency of each group is as follows:

Electric Welds

Group A ----- 75%
" B ----- 74%
" C ----- 76%
" D
90° ----- 72%
60° ----- 66%
45° ----- 68%

Gas Welds

Group E
Chromium ---- 73%
Iron -------- 75%

It may thus be seen that the efficiencies of electric and oxy-acetylene welds vary but little.

In series A, tables No. 2 show that in some cases the elongation over the welded joint exceeds that over an equivalent length of parent metal. This phenomenon is probably due to the fact that the unit stress in the welded joint was greater than the unit stress in the parent metal for reasons which will be

explained later. These greater deformations do not necessarily indicate that the welding rod material is more ductile than the parent metal.

The difficulty in obtaining a weld whose efficiency is 100% is not due to the weakness of the metal supplied by the welding rod, but is caused by flakes of iron oxide which prevent a perfect union between the welding rod substance and the parent metal. In most cases, large areas were found to be unwelded, and hence the effective area was relatively small. As a consequence, the unit stress in the welded portion was exceedingly high, thus causing the specimen to break at the joint.

Since the welding rod forms one electrode in the welding operation, and because it is rapidly consumed, considerable difficulty is experienced in maintaining an arc of constant length. Any change in the arc length from the normal operating condition produces spongy welds.

In electric welding, especially, it must be remembered that the metal to be welded has to be raised from a low temperature to a welding temperature in a very short period of time, and in so doing, no accurate control over the welding temperature can

be maintained. In group B, an effort was made to heat-treat the welds, and although the grain size was decreased, the oxide inclusions were unaffected, and remained as formidable obstacles within the weld.

The development of a suitable apparatus which would enable the operator to maintain accurate control of the welding temperature, and at the same time prevent the formation of oxides, seems to be a plausible solution to the problem. The atomic-hydrogen arc-welding machine which has just been developed by the General Electric Company approaches this ideal apparatus. Oxygen, which in the "old style" of welding is one of the most subtle obstacles, is combined with a stream of hydrogen, and is so manipulated as to supplement the heat from a two-electrode arc. This type of machine has a very promising future.