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Materials (8)
Iron and Alloys (9)

20139

Steel - Brazing (90395.5); Steel -
Heat treatment (90396.5); Steel alloys - Strength
(90408)

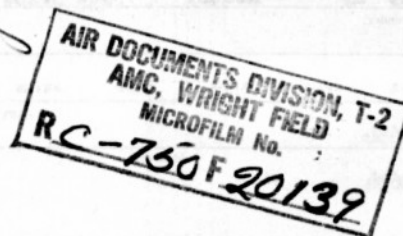
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Effect of a copper brazing temperature cycle and subsequent heat-treatments on
the mechanical properties of some aircraft steels

Royal Aircraft Establishment, Farnborough, Hants

24.Brit. Eng. Reestr. Reestr. May '47 55 tables, graphs, drugs

Tests have been made to determine the effect of copper brazing and subsequent heat-treatments on the tensile, impact and fatigue properties of a number of heat-treated steels, weldable low-alloy steels and plain carbon steels. All the steels suffered some reduction in properties as a result of the brazing process although in the case of the hot rolled and normalized plain carbon steels only the impact resistance was appreciably affected. With the exception of one material, whose properties were obtained by cold working, the original properties of the steels could be restored by an appropriate post-brazing heat-treatment.



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WRIGHT FIELD, DAYTON, OHIO

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Report No. Met.18

May, 1947.

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Effect of a copper brazing temperature cycle and subsequent heat-treatments on the mechanical properties of some aircraft steels.

by

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SUMMARY

Tests have been made to determine the effect of copper brazing and subsequent heat-treatments on the tensile, impact and fatigue properties of a number of heat-treated steels, weldable low-alloy steels and plain carbon steels. All the steels suffered some reduction in properties as a result of the brazing process although in the case of the hot rolled and normalised plain carbon steels only the impact resistance was appreciably affected. With the exception of one material, whose properties were obtained by cold working, the original properties of the steels could be restored by an appropriate post-brazing heat-treatment.

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1. Introduction

Outside the aircraft industry the copper brazing process has been mainly used for joining small pressed or turned parts made from mild steel. Tests have shown that the joints produced are surprisingly strong and the satisfactory behaviour of the parts in service indicates that the effect on the mechanical properties of the steel of heating to the high temperature (about 1100°C) necessary for brazing, is so small as to be unimportant in the usual applications. When the process began to be used for making aircraft parts its range of application was extended to include the joining of parts made from weldable low alloy steels. Joints in these materials were found to have about the same strength as joints in mild steel, and it was inferred that the effect of the brazing temperature cycle on the mechanical properties of these steels would be similar to that of welding, which was already known. Steels whose high tensile strengths are obtained by hardening and tempering were tentatively regarded as unsuitable for copper brazing because it was clear that the brazing temperature cycle would nullify any prior heat-treatment, and it was not known whether the properties of such steels could be restored by re-heat-treatment, and if such a treatment were successful what its effect would be on the strength of the joint.

In order to provide information on these points, which, if favourable, would allow designers to specify high tensile steels for parts to be made by copper brazing, and also to provide more precise data concerning the effect of the process on carbon and weldable low-alloy steels, a two part investigation was started. The aim of the first part, with which this report is concerned, was to determine the effect of a copper brazing temperature cycle and subsequent heat-treatments on the tensile, impact and fatigue properties of a range of aircraft steels; and the aim of the second part, which will be reported later was to determine the effect of post-brazing heat-treatments on the strength of joints in these steels, and on the degree of intercrystalline penetration of copper into the steels.

2. Steels tested

These are shown in Table I. The bar materials were all 1 in. diameter, the tube materials 1" o.d. x 12G., and the strip was 16G.

3. Details of tests

Tensile, Izod impact and Wöhler fatigue tests were made on the bar materials in each of the following conditions (a) as received (b) after being passed through a copper brazing furnace and (c) after being passed through the furnace and then heat-treated in one or more ways. Tensile and flattening tests were made on the tube materials and tensile and bend tests on the strip material, in each of these conditions.

3.1 Tensile tests

For these, round test pieces having the dimensions of Test Piece C of B.S.18 were machined from lengths of bar in the various conditions. The ends were screwed with a 7/8 in. B.S.F. thread for attachment to the self aligning shackles of the testing machine. The tube specimens were 18 in. long, they were tested with wedge grips the ends being plugged. For tests on the strip material, Test Piece A of B.S.18 was

used, the width of the $2\frac{1}{2}$ in. parallel length being $\frac{1}{2}$ in. The ends were drilled to take pins for attachment to shackles. Duplicate tests were made in all cases, values of 0.1%, 0.2% and 0.5% proof stresses, ultimate tensile stress and percentage elongation on an appropriate gauge length being determined.

3.2 Izod impact tests

These were made in duplicate on standard J notch, 10 m.m. square test pieces (B.S.131) machined from lengths of bar which had received the various treatments described.

3.3 Wöhler fatigue tests

For each of the bar materials ten 5 in. lengths were obtained in each of the conditions investigated and from these Wöhler test pieces having the dimensions shown in Fig.1 were machined. These were tested at various stresses to obtain data for a stress-endurance curve from which the fatigue limit was determined.

3.4 Flattening and bend tests

As the specifications for the tube materials call for flattening tests such tests were made on material in each of the conditions tested, the testing procedure laid down in the specification being followed. Similarly single and reverse bend tests were made on specimens from the strip material.

4. Temperature cycling and heat-treatments

Sufficient short lengths of bar, tube and strip for tests in the 'as brazed' and 'as brazed and heat-treated' conditions were passed through a conveyor type brazing furnace spaced at intervals along the belt between charges of production parts. The speed of the belt was 0.4 ft./min. and the times spent in the preheating, brazing and cooling zones were 17, 17 and 55 minutes respectively. The charge reached a maximum temperature of 1110°C just before passing into the cooling chamber.

Details of the various post-brazing heat-treatments used are given in Table II.

5. Metallographic examination

Sections taken from a number of the broken tensile test pieces were examined microscopically. In the 'as brazed' condition the structures of the steels examined were of two types, the plain carbon steels (B.S.S.15 and S6) had coarse ferrite-pearlite structures and the alloy steels (D.T.D.188A and B.S.S.811) had coarse acicular structures. In all specimens the coarse structures were completely refined by the post-brazing heat-treatments.

6. Results and Conclusions

The results of the fatigue tests are given in detail in Table XII - XXVIII and are shown in the form of stress-endurance curves in Figs.2 - 6. The fatigue limit values derived from these curves are included in Tables III - XI each of which summarizes the results of all the tests made on a particular material and also gives the main specification requirements for that material. The conclusions derived from the results are discussed below.

6.1 B.S.S.15 Bar

This material was included in the tests as a substitute for B.S.S.S21 ('20' carbon steel suitable for welding) which was in short supply at the time the tests were started. The results given in Table III show that the tensile properties were not appreciably affected by brazing, the Izod value was apparently lowered, as would be expected, but the effect seems unimportant in view of the variability of the 'as received' bar. Normalising improved the Izod value. Water quenching from the brazing temperature nearly doubled the tensile strength but caused a serious reduction in the percentage elongation and Izod values. In this condition the structure of the steel consisted of martensite with very small amounts of ferrite and troostite at the boundaries of the pre-existing coarse grained austenite.

6.2 B.S.S.4S1 Bar

As the properties of this material are obtained by cold working, brazing had a marked effect, the tensile and proof stresses being lowered well below specification requirements. Also, as would be expected, the original properties were not restored by normalising, and in view of the wide range of carbon content permitted by the specification it is very unlikely that this steel would in practice be considered suitable for hardening and tempering.

6.3 B.S.S.3S6 Bar

The ultimate tensile stress, proof stress and percentage elongation values conformed to specification requirements after brazing but the Izod values were low. Satisfactory impact properties were obtained by re-normalising, and a general improvement in properties was secured by full heat-treatment.

6.4 D.T.D.188A Bar

The tensile and Izod values, particularly the latter, were lowered by brazing. Because the temperature (660°C) at which the re-heat-treated specimens were tempered was too high, the ultimate tensile stress and proof stress values obtained for these specimens fell short of specification requirements but it is clear that by the use of a lower tempering temperature the original properties could have been fully restored.

6.5 B.S.S.4S11 Bar

The rate of cooling from the brazing temperature was sufficiently rapid to cause partial hardening so that the 'as brazed' tensile strength was high. However, the proof stresses, percentage elongation and Izod values were lowered so much that the material would obviously not be suitable for service in this condition. By adjustment of the brazing cycle it might be possible to increase the rate of cooling sufficiently to give complete hardening and so make it possible to obtain specification tensile properties by means of a post-brazing tempering treatment only, but low Izod values would still be obtained. Full specification properties were restored by complete re-heat-treatment after brazing.

6.6 B.S.S.3T26 Tube

In the 'as brazed' condition the properties were within the expected range for softened tubes.

6.7 B.S.S. 2T45 Tube

The properties of this material are obtained partly by cold working. The ultimate tensile stress, and the proof stresses more so, were reduced below specification requirements by brazing but were restored by hardening and tempering.

6.8 D.T.D. 347 Tube

Here again the original properties are obtained by cold working and consequently they are impaired by the brazing cycle. The ultimate tensile stress was reduced to about the same value as by welding but the proof stresses were more seriously reduced. Full specification properties were restored by hardening and tempering after brazing.

6.9 D.T.D. 124A Strip

This was received in the softened condition. After brazing the properties were much the same, that is they were well below those required for hardened and tempered material; but full specification properties were obtained by hardening and tempering after brazing.

Attached: Mat. 2451 - 2455. MT. 7977/1
Tables I - XXVIII

Circulation:

C.S. (A)
P/D.T.D. (A)
D.A.R.D.
D.D.A.R.D. (Mat) (Action copy + 1)
R.T.P./T.L.B. (100)
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D.D.R.A.E.
Structures Dept.
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TABLE I
Details of steels tested

Form	Specification	Type	Specified tensile strength - tons/sq.inch.
Bar	B.S.S.15	Structural steel	28 - 33
	B.S.S.431	Carbon steel-cold drawn	35 - 45
	B.S.S.386	" " -normalised	35 - 45
	D.T.D.188A	Manganese-molybdenum steel	55 - 65
	B.S.S.4311	Nickel-chromium steel	55 - 65
Tube	B.S.S.3T26	Carbon steel	20 min.
	B.S.S.2T45	Carbon-manganese steel	45 min.
	D.T.D.347	Chromium-molybdenum steel	50 min.
Strip	D.T.D.124A	Carbon manganese steel	40 - 55 0.1% Proof Stress

TABLE II
Details of heat treatments applied after brazing

Material specification	Normalising	Hardening and tempering
B.S.S.15	Air cooled from 860°C.	Water quenched from brazing temperature
B.S.S.431	Air cooled from 860-870°C.	-
B.S.S.386	Air cooled from 860°C.	Oil quenched from 850°C. tempered at 600-610°C. and quenched in water.
D.T.D.188A	-	Oil quenched from 850°C. tempered at 660°C. and quenched in water.
B.S.S.4311	-	Oil quenched from 840°C. tempered at 610°C.
B.S.S.3T26	Air cooled from 870-880°C.	-
B.S.S.2T45	-	Oil quenched from 860°C. tempered at 550°C., and quenched in water.
D.T.D.347	-	Oil quenched from 880°C. tempered at 425-450°C. and quenched in oil.
D.T.D.124A	-	Oil quenched from 860°C. tempered at 550°C. and quenched in water.

TABLE III
Summary of test results and specification requirements for Bar to
B.S.S. 15 (Structural Steel)

Condition	Test No.	U.T.S. -t/in ²	Proof stresses - t/in ²			Elongation - % on 4√A	Izod -ft.lb.	Fatigue limit - $\frac{1}{2}$ t/in ²
			0.1%	0.2%	0.5%			
As received	1	32.9	19.05	19.05	19.05	33	57,64,59	16.7
	2	32.2	21.2	21.2	21.2	32	23,23,20	
As brazed	3	32.0	18.0	18.0	18.0	31	19,23,18	14.8
	4	32.5	19.0	19.0	19.0	30	23,23,17	
Brazed and normalised	5	32.8	21.0	21.0	21.0	32	29,26,30	15.04
	6	32.6	21.0	21.0	21.0	32	36,28,27	
Water quenched from brazing temp.	7	61.2	30.4	37.5	44.1	5	6, 4, 4	20.1
	8	60.0	30.6	38.2	-	5	3, 4, 5	

Specification requirements

To be made from Acid Open Hearth, Basic Open Hearth or Acid Bessemer steel with > 0.06% S and
 > 0.06% P.
 Tensile strength 28 - 33 t/in².

TABLE IV

Summary of test results and specification requirements for Bar to
B.S. 431 (35-45 ton carbon steel)

Condition	Test No.	U.T.S. - t/in ²	Proof stresses - t/in ²			Elongation - % on 4 $\frac{1}{4}$ A	Izod - ft. lb. 24, 23	Fatigue limit - $\frac{1}{2}$ t/in ²
			0.1%	0.1%	0.2%			
As received	1	39.9	34.5	36.8	38.8	17.5	24, 23, 20	19.05
	2	38.8	34.3	36.3	38.1	18	24, 23	
As brazed	3	30.7	16.65	16.65	16.65	37	57, 53, 64	14.5
	4	30.9	17.0	17.0	17.0	35.5	56, 51, 62	
Brazed and normalised	5	31.2	19.15	19.43	19.43	36	73, 79, 79	14.25
	6	32.3	19.22	19.32	19.43	38	79, 80, 84	

Specification requirements

Percentage composition						U.T.S. - t/in ²	0.1% Proof stress - t/in ²	Elongation - % on 4 $\frac{1}{4}$ A	Izod - ft. lb.
C	Si	Mn	S	P	Pb				
0.10-0.40	> 0.35	0.5-0.9	> 0.05	> 0.05	> 0.3	35-45	< 21	< 15	< 20

TABLE V

Summary of test results and specification requirements for Bar to
 B.S.S. 356 (10% carbon steel - normalised)

Condition	Test No.	U.T.S. -t/in ²		Proof stresses - t/in ²		Elongation - % on 4 $\frac{1}{4}$	Isod -ft.lb.	Fatigue limit - $\pm$ t/in ²
		0.1%	0.2%	0.1%	0.2%			
As received	1	42.5	26.5	26.7	26.8	30	17,16,16	22.5
	2	40.2	26.0	26.1	26.2	33	14,15,14	
As brazed	3	45.0	24.10	24.45	24.75	25	3,3,4	20.15
	4	44.7	23.35	23.55	24.95	26.5	7,5,5	
Brazed and normalised	5	44.7	28.6	28.9	28.9	28	14,13,13	20.4
	6	44.1	28.15	28.4	28.5	28	14,13,13	
Hardened and tempered after brazing	7	48.7	31.95	31.95	31.95	27	31,29,30	24.0
	8	47.3	31.95	31.95	31.95	28	25,31,25	

Specification requirements

C	Percentage composition				U.T.S. -t/in ²	0.1% Proof stress - t/in ²	Elongation - % on 4 $\frac{1}{4}$	Isod -ft.lb.
	Si	Mn.	S	P				
0.35-0.45	>0.3	>1.2	>0.05	>0.05	35-45	4 20	4 20	4 10

TABLE VI
Summary of test results and specification requirements for Bar to
D.T.D. 188A (55-65 ton Mn - Mo steel)

Condition	Test No.	U.T.S. - t/in^2	Proof stresses - t/in^2		Elongation - % on 4 $\sqrt{A}$	Isod - ft.lb.	Fatigue limit - $\pm t/in^2$
			0.1%	0.2%			
As received	1	56.1	38.2	44.0	22.5	88,85,95	25.5
	2	56.1	37.5	42.8	23	89,87,92	
As brazed	3	52.0	30.5	34.7	20	6,7,8	24.0
	4	52.0	31.1	35.3	20	8,5,5	
Hardened and tempered after brazing	5	52.4	42.6	42.6	26	104,104,106	27.0
	6	52.0	42.6	42.6	25	102,104,114	

Specification requirements

Percentage composition						U.T.S. t/in^2	0.1% Proof stress - t/in^2	Elongation - % on 4 $\sqrt{A}$	Isod - ft.lb.
C	Si	Mn	S	P	Mo				
0.25-0.40	0.35	1.30-1.80	0.05	0.05	0.20-0.55	55-65	43	18	40

TABLE VII

Summary of test results and specification requirements for Bar to
B.S.S.4311 (52-65 ton Ni-Cr steel).

Condition	Test No.	U.T.S. - t/in^2	Proof stresses - t/in^2			Elongation - % on 4 $\sqrt{A}$	Isod - ft. lb.	Fatigue limit - t/in^2
			0.1%	0.2%	0.5%			
As received	1	59.6	56.5	56.6	57.0	26	72,74,72	31.5
	2	58.0	54.4	54.6	55.0	25	76,64,74	
As brazed	3	65.4	35.8	41.6	43.8	18	12,13,10	29.0
	4	70.2	33.0	38.6	45.8	16	11,9,8	
Hardened and tempered after brazing	5	62.1	55.3	55.7	55.7	23	76,80,76	29.9
	6	62.0	55.2	55.4	55.6	23	92,79,83	

Specification requirements

Percentage Composition										U.T.S. - t/in^2	0.1% P.S. - t/in^2	Elong. - % on 4 $\sqrt{A}$	Isod - ft. lb.
C	Si	Mn	S	P	Ni	Cr	V	Mo	W				
0.25 -0.35	0.30	0.45 -0.70	0.05	0.05	2.75 -3.75	0.50 -1.0	0.25	0.65	1.0	55-65	43	18	40

TABLE VIII
Summary of test results and specification requirements for Tube to B.S.S. 726 (20 ton steel tubes suitable for welding)

Condition	Test No.	U.T.S. 2 - $\frac{t}{in}$	Proof stresses - $\frac{t}{in^2}$			Elong. - % on $\frac{1}{2}in$	Flattening test - inside gap for cracking	
			0.1%	0.2%	0.5%		2t	2t
As received	1	42.8	41.2	42.2	42.8	36	21	Closed - no cracks
	2	30.2	28.0	29.0	29.5	41	-	"
As brazed	3	24.5	14.4	15.3	-	40	-	"
	4	24.3	14.8	15.6	-	76	58	2t
Normalised after brazing	5	23.0	15.2	15.3	15.6	72	55	2t
	6	24.5	17.2	17.3	17.5			

Specification requirements

Percentage composition			Flattening tests	
C	S	P	Half-hard (normal) condition	Soft condition
			Close to internal gap = 3t without cracking	Close completely without cracking
0.20	0.05	0.05		

No tensile test is specified but the following values are given for information only:-

0.2% proof stress $4 \frac{11}{16} \frac{t}{in^2}$
 Ultimate tensile stress $20 \frac{t}{in^2}$

TABLE IX

Summary of test results and specification requirements for Tube to
B.S.S. 274.5 (4.5 ton steel tubes suitable for welding)

Condition	Test No.	U.T.S. - t/in^2	Proof stresses - t/in^2		Elongation - % on 4"			Flattening test - inside gap for cracking
			0.1%	0.2%	1"	2"	4"	
As received	1	49.2	48.5	48.7	28	18 $\frac{1}{2}$	12	0.52"
	2	49.2	48.5	48.7	26	17 $\frac{1}{2}$	11 $\frac{1}{2}$	0.52"
As brazed	3	44.5	25.8	29.5	37	25	18	0.50"
	4	44.0	25.3	29.2	39	27	20	0.50"
Hardened and tempered after brazing	5	58.0	-	-	25	17 $\frac{1}{2}$	12	0.31"
	6	57.5	53.5	53.5	25	19	12 $\frac{1}{2}$	0.31"

Specification requirements

Percentage composition					U.T.S. - t/in^2	0.2% P.S. - t/in^2	Flattening test
C	Si	Mn	S	P			
0.26	0.35	1.75	0.05	0.05	45	40	Close to internal gap = 0.53" without cracking

* $\leq 30 t/in^2$ after welding.

TABLE I
Summary of test results and specification requirements for Tube to D.T.D. 347
(50 ton Cr-Mn steel tubes suitable for welding)

Condition	Test No.	U.T.S. ² - t/in ²	Proof stresses - t/in ²			Elong - % on			Flattening test - inside gap for cracking
			0.1%	0.2%	0.5%	1"	2"	4"	
As received	1	55.2	50.3	51.0	51.8	20	15	7 1/2	0.70"
	2	57.2	53.1	53.3	55.4	20	15	8	0.68"
As brazed	3	45.0	25.7	29.8	34.6	37	24	17	0.10"
	4	45.0	25.2	29.1	32.5	38	23	16	0.10"
Hardened and tempered after brazing	5	77.0	71.5	72.9	74.2	20	11	7	0.52"
	6	76.0	71.0	72.6	74.3	15	8	4	0.52"

Specification requirements

Percentage composition							U.T.S.* - t/in ²	0.2% P.S. - t/in ²	Flattening test
C	Si	Mn	S	P	Cr	Ni			
0.26	0.30	0.8	0.05	0.05	0.8-1.2	0.5	50	45	Close to internal gap = 0.69" without cracking

* 45 t/in² after welding

TABLE XI
Summary of test results and specification requirements for Strip to
D.T.D. 124A (40-55 tons 0.1% Proof Stress carbon steel suitable
for welding)

Condition	Test No.	U.T.S. - t/in^2	Proof stresses - t/in^2			Elong. - % on 2"	Single bend test	Reverse bend test
			0.1%	0.2%	0.5%			
As received	1	31.7	21.4	21.5	21.8	26	No cracks	No cracks
	2	34.5	23.4	23.5	23.7	23		
As brazed	3	37.2	21.2	22.1	23.5	22	No cracks	No cracks
	4	37.4	21.2	22.0	23.2	22		
Hardened and tempered after brazing	5	52.7	45.9	46.6	47.2	12½	No cracks	No cracks
	6	52.0	45.7	46.4	47.3	12½		

Specification requirements for hardened and tempered strip

Percentage composition						0.1% P.S. - t/in^2	Single bend test	Reverse bend test
C	Si	Mn	S	P	Ni			
0.18- 0.26	△ 0.30	1.35 - 1.75	△ 0.05	△ 0.05	△ 0.4	40-55	No cracks on bending through 180° over $r = t$	No cracks on bending twice through 180° over $r = 3t$.

TABLE XII

Results of Wohler Fatigue Tests on Bar to
B.S.B. 15 in the As Received Condition

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - x 10 ⁶ cycles	Remarks
B 19	20.0	0.241	Broken
20	17.9	0.764	"
21	16.9	1.543	"
23	16.55	39.909	Not broken
24	17.4	2.819	Broken
25	16.75	43.107	Not broken
26	16.84	1.826	Broken
27	16.76	1.560	"
28	16.80	1.800	"

TABLE XIII

Results of Wohler Fatigue Tests on Bar to
B.S.B. 15 in the As Brazed Condition

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - x 10 ⁶ cycles	Remarks
B 29	16.55	1.782	Broken
30	15.0	5.075	"
31	14.55	32.407	Not broken
32	15.75	3.206	Broken
33	14.75	29.006	Not broken
34	14.89	32.464	" "
35	17.25	1.363	Broken
36	18.60	0.582	"
37	14.90	5.419	"
38	14.78	35.064	"

TABLE XIV

Results of Wohler Fatigue Tests on Bar to
B.S.S.15 Normalised after Brazing.

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
B 49	17.25	0.687	Broken
50	16.05	5.304	"
51	15.50	5.428	"
52	15.04	30.307	Not broken
53	16.65	0.980	Broken
54	15.30	4.002	"
55	18.30	0.348	"
56	15.15	5.178	"
57	15.00	23.674	"

TABLE XV

Results of Wohler Fatigue Tests on Bar to B.S.S.15
Quenched after Brazing

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
B 39	28.20	0.112	Broken
40	26.10	0.319	"
41	23.84	0.520	"
42	22.00	0.968	"
43	20.10	26.257	Not broken
44	21.60	1.428	Broken
45	21.30	3.022	"
46	20.10	45.048	Not broken
47	21.04	1.552	Broken
48	20.46	3.277	"

TABLE XVI

Results of Wöhler Fatigue Tests on Bar to
B.S.S.481 in the As Received Condition

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
Sl W-1	17.4	43.298	Not broken
2	19.0	37.749	" "
3	19.85	2.304	Broken
4	20.75	1.031	"
5	19.05	46.189	Not broken
6	19.60	2.134	Broken
7	19.20	13.564	Broken
8	19.45	1.514	"
9	19.35	6.461	"
10	19.10	2.755	"
11	19.10	1.790	"

TABLE XVII

Results of Wöhler Fatigue Tests on Bar to
B.S.S.481 in the As Brazed Condition

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
Sl A W1	15.96	0.572	Broken
2	16.55	0.526	"
3	14.23	5.589	"
4	15.05	1.074	"
5	17.15	0.419	Not broken
6	14.5	35.590	Broken
7	14.85	3.995	"
8	14.78	3.615	"
9	14.60	4.692	"
10	14.60	9.162	"

TABLE XVIII

Results of Wöhler Fatigue tests on Bar to
B.S.S.-431 Normalised after Brazing

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - x 10 ⁶ cycles	Remarks
SLN W 1	17.10	0.753	Broken
2	18.00	0.370	"
3	16.05	0.846	"
4	15.00	2.339	"
5	14.40	6.581	"
6	14.10	34.268	Not Broken
7	14.25	32.946	" "
8	14.28	12.157	Broken
9	14.55	35.369	Not Broken
10	14.40	34.701	" "

TABLE XIX

Results of Wöhler Fatigue tests on Bar to
B.S.S. 586 in the As Received Condition

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - x 10 ⁶ cycles	Remarks
S6 W1	17.45	40.722	Not broken
2	22.5	36.564	" "
3	24.92	0.458	Broken
4	24.30	0.829	"
5	23.90	0.980	"
6	23.05	0.558	"
7	23.05	1.267	"
8	22.7	1.879	"
9	22.6	1.012	"
10	22.3	26.762	Not Broken

TABLE XX

Results of Wohler Fatigue Tests on Bar to
B.S.S. 386 in the As Brazed Condition

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
S6A W1	23.3	0.234	Broken
2	22.32	0.303	"
3	21.5	0.881	"
4	20.97	1.205	"
5	20.15	34.260	Not broken
6	20.52	1.692	Broken
7	20.28	2.718	"
8	20.20	6.460	"
9	20.16	3.873	"

TABLE XXI

Results of Wohler Fatigue Tests on Bar to
B.S.S. 386 Normalised after Brazing

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
S6 NW1	22.90	0.490	Broken
2	22.00	0.542	"
3	21.08	1.909	"
4	20.54	4.049	"
5	21.44	3.810	Not Broken
6	20.10	22.367	" "
7	20.20	29.048	" "
8	20.46	15.157	Broken
9	20.32	37.161	Not Broken
10	20.40	35.434	" "

TABLE XXII

Results of Wöhler Fatigue Tests on
B.S.S. 386 Bar Hardened and Tempered
after Brazing

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
S6T W1	24.30	0.646	Broken
2	23.16	31.510	Not Broken
3	23.70	37.027	" "
4	25.00	0.116	Broken
5	24.74	0.912	"
6	24.00	32.380	Not Broken
7	24.30	1.431	Broken
8	24.14	1.105	"
9	24.08	2.290	"
10	24.00	35.429	Not Broken

TABLE XXIII

Results of Wöhler Fatigue Tests on D.T.D.188A
Bar in the As Received Condition.

Specimen No.	Semi-range of stress - tons/sq.in.	Endurance - $\times 10^6$ cycles	Remarks
C 15	31.0	0.917	Broken
16	28.6	0.152	"
17	26.0	0.341	"
18	24.0	17.049	Not Broken
19	25.1	34.365	" "
20	25.65	0.483	Broken
21	25.43	38.993	Not Broken
22	25.50	40.306	" "
23	25.65	8.715	Broken
24	26.0	44.515	Not Broken

TABLE XXIVResults of Wöhler Fatigue Tests on Bar to D.T.D.188A
in the As Braced Condition

Specimen No.	Semi-range of stress - tons/sq. in.	Endurance - $\times 10^6$ cycles	Remarks
025	25.20	1.147	Broken
26	24.60	1.682	"
27	24.00	25.402	Not broken
28	24.30	2.522	Broken
29	24.14	7.026	"
30	26.10	0.560	"
31	27.00	0.642	"
32	28.00	0.354	"
33	24.08	29.789	Not broken
34	24.08	2.794	Broken

TABLE XXVResults of Wöhler Fatigue Tests on Bar to D.T.D.188A
Hardened and Tempered after Bracing

Specimen No.	Semi-range of stress - tons/sq. in.	Endurance - $\times 10^6$ cycles	Remarks
035	24.00	25.104	Not broken
36	25.04	30.348	"
38	30.00	0.222	Broken
39	29.10	0.398	"
40	27.00	39.327	Not broken
41	27.60	0.491	Broken
42	27.30	0.424	"
43	27.17	0.785	"
44	27.00	13.106	Not broken

TABLE XXVI

Results of Wöhler Fatigue Tests on Bar to B.S.S.4S11
in the As Received Condition

Specimen No.	Semi-range of stress - tons/sq. in.	Endurance - $\times 10^6$ cycles	Remarks
S11 W1	28.2	13.777	Stopped
2	29.1	31.923	Not broken
3	34.3	0.460	Broken
4	32.0	1.292	"
5	31.0	34.047	Not broken
6	31.5	36.292	"
7	31.6	1.115	Broken
8	31.7	0.938	"
9	31.5	37.090	Not broken
10	32.85	0.502	Broken

TABLE XXVII

Results of Wöhler Fatigue Tests on Bar to B.S.S.4S11
in the As Brazed Condition

Specimen No.	Semi-range of stress - tons/sq. in.	Endurance - $\times 10^6$ cycles	Remarks
S11 AW1	38.45	0.090	Broken
2	37.10	0.337	"
3	36.10	0.189	"
4	35.05	0.190	"
5	33.10	0.502	"
6	32.00	0.948	"
7	31.30	0.769	"
8	30.75	1.503	"
9	29.20	1.560	"
10	30.50	1.368	"
11	28.00	31.227	Not broken
12	28.50	25.459	"
13	28.90	35.010	"
14	29.04	36.851	"
15	29.36	30.805	"
16	30.00	6.744	Broken

TABLE XXVIII

Results of Wöhler Fatigue Tests on Bar to B.S.S.4S11
Hardened and Tempered after Brazing

Specimen No.	Semi-range of stress - tons/sq. in.	Endurance - $\times 10^6$ cycles	Remarks
S11 TW1	29.50	32.857	Not broken
2	33.15	0.578	Broken
3	32.28	1.916	"
4	31.56	0.610	"
5	30.56	2.553	"
6	30.08	6.601	"
7	30.00	4.248	Not broken
8	29.80	33.793	Broken
9	34.45	0.381	

FIG.2.

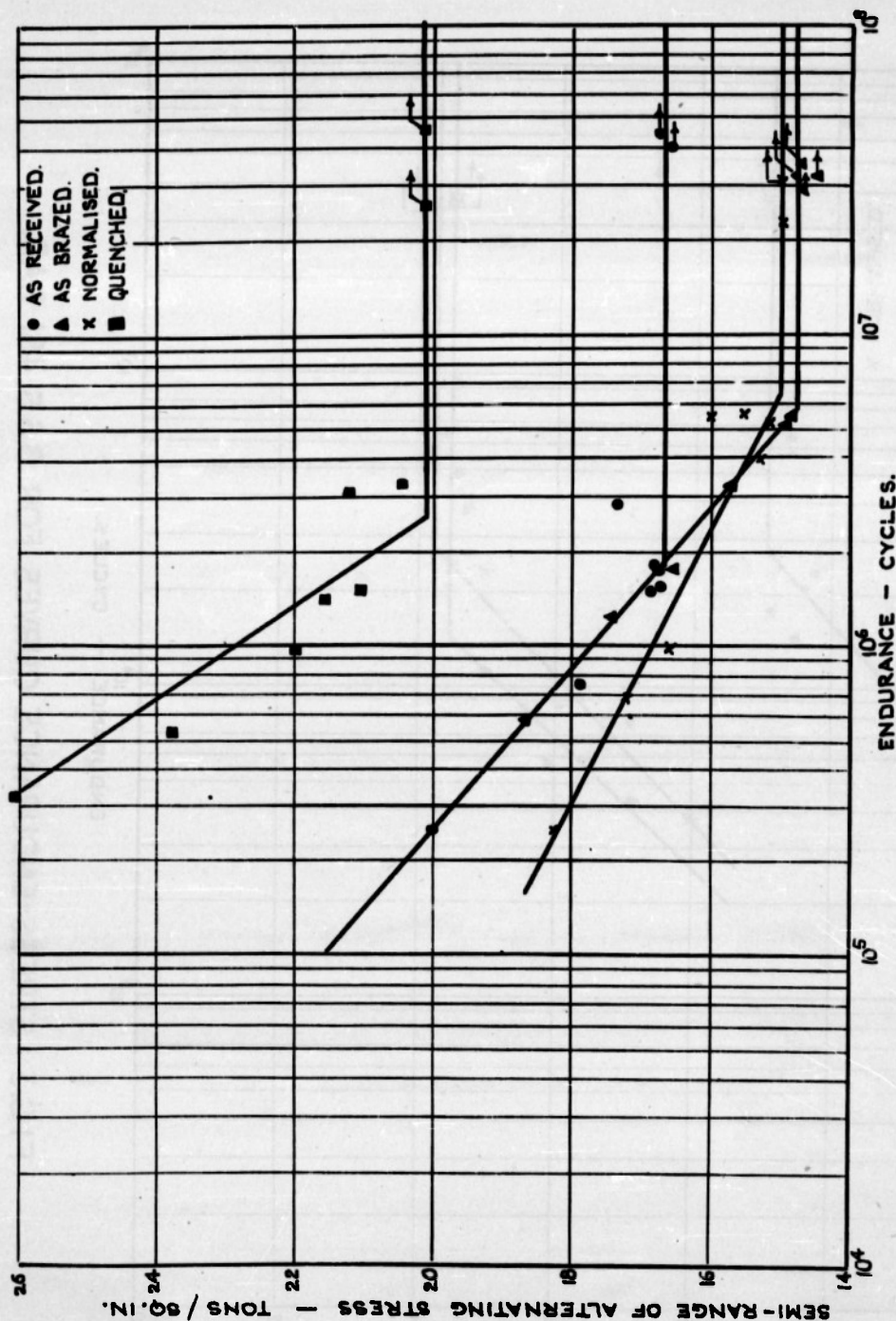


FIG.2 : STRESS-ENDURANCE CURVES FOR B.S.S. 15 BAR .

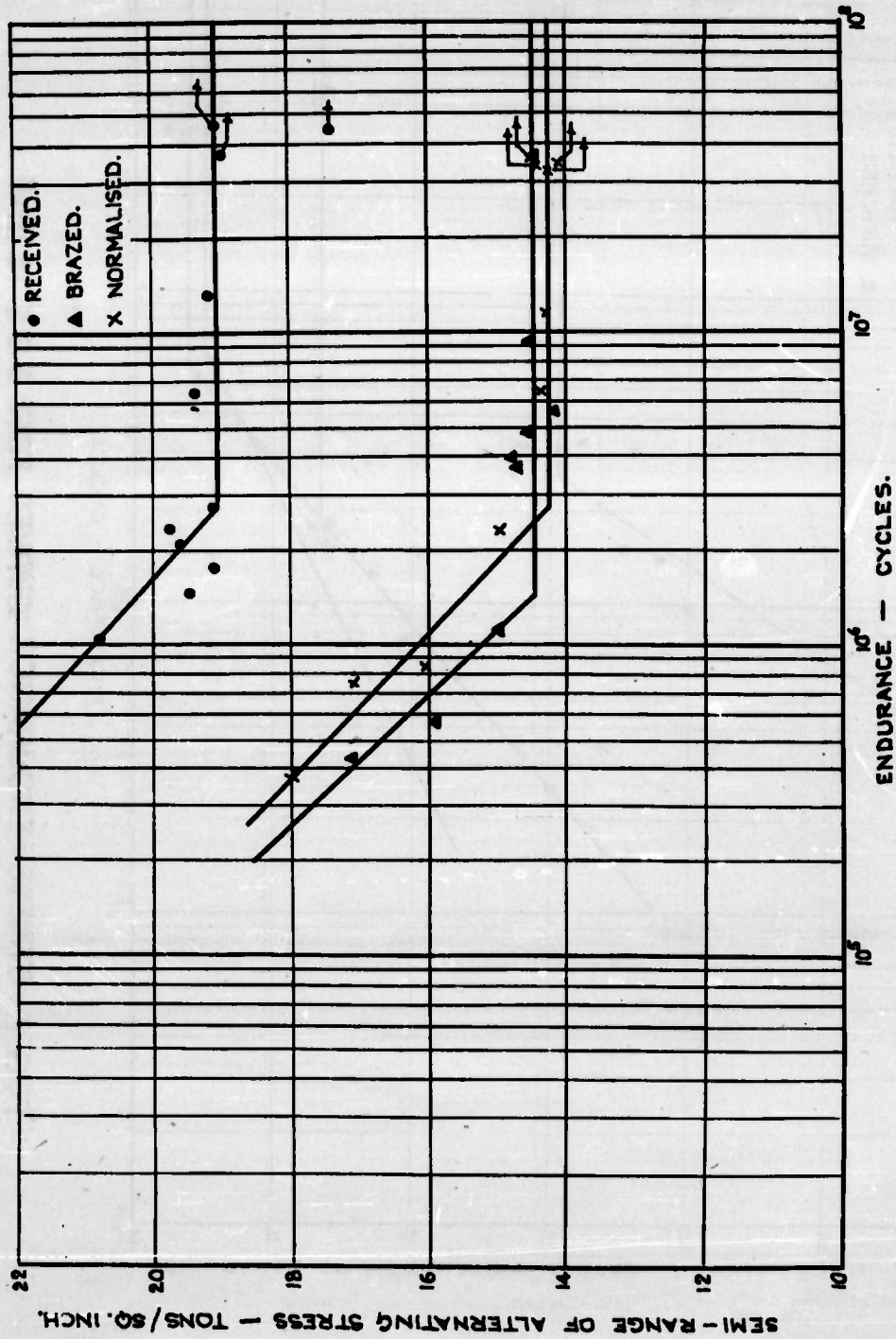


FIG.3 : STRESS-ENDURANCE CURVES FOR B.S.S. 4SI BAR.

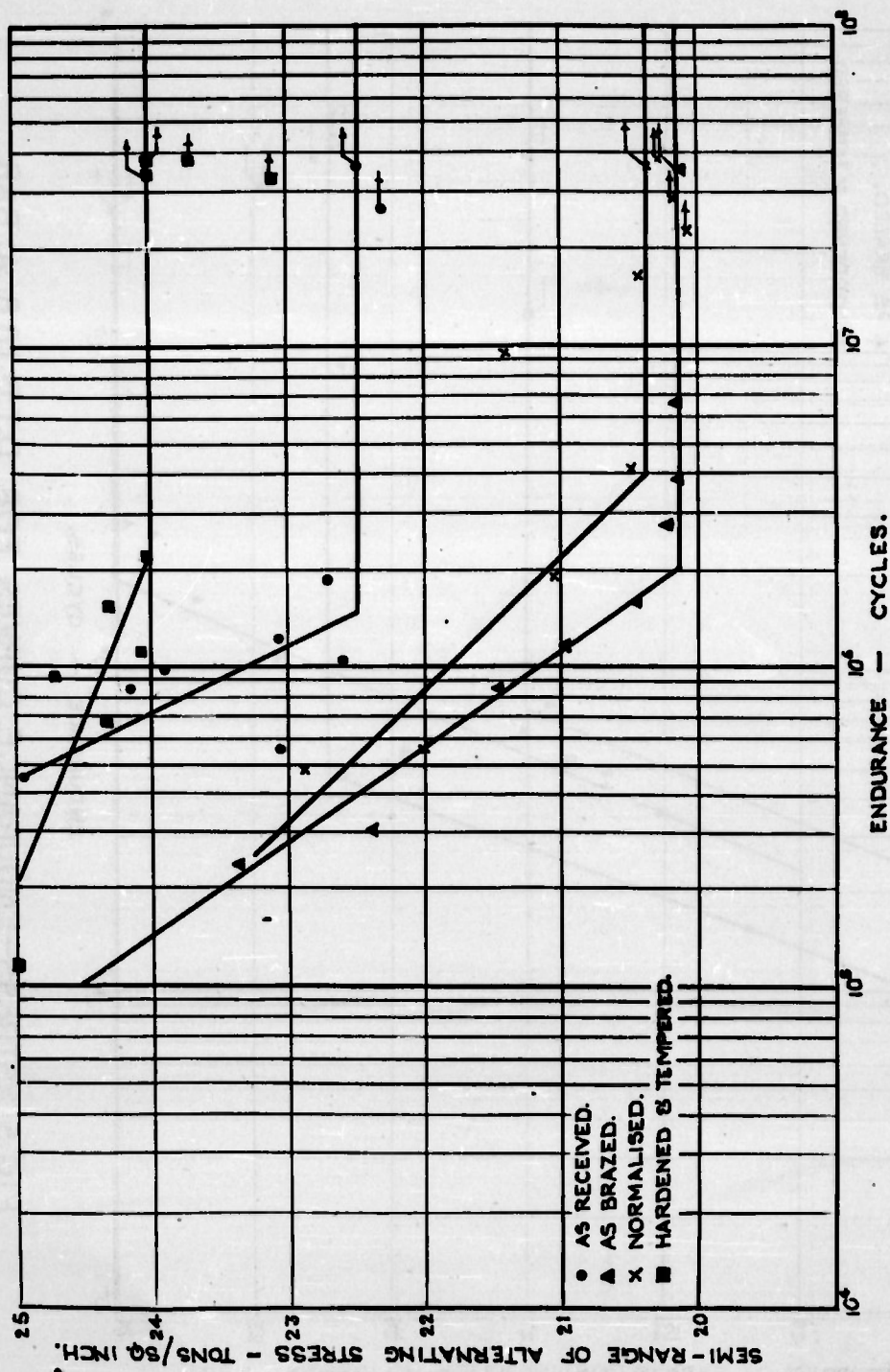


FIG.4 : STRESS-ENDURANCE CURVES FOR B.S.S.356 BAR.

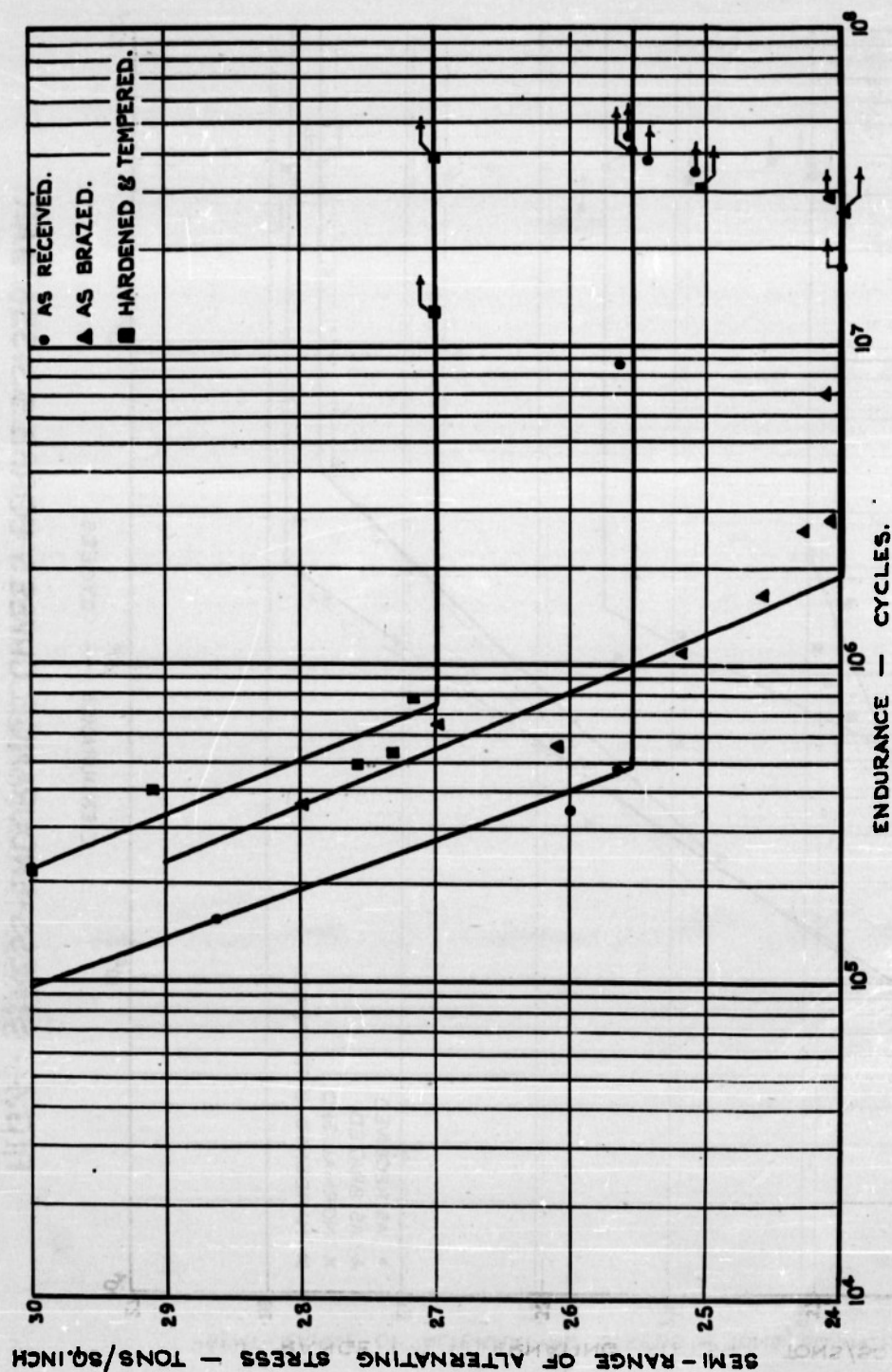


FIG. 5 : STRESS-ENDURANCE CURVES FOR D.T.D. 188 A BAR.

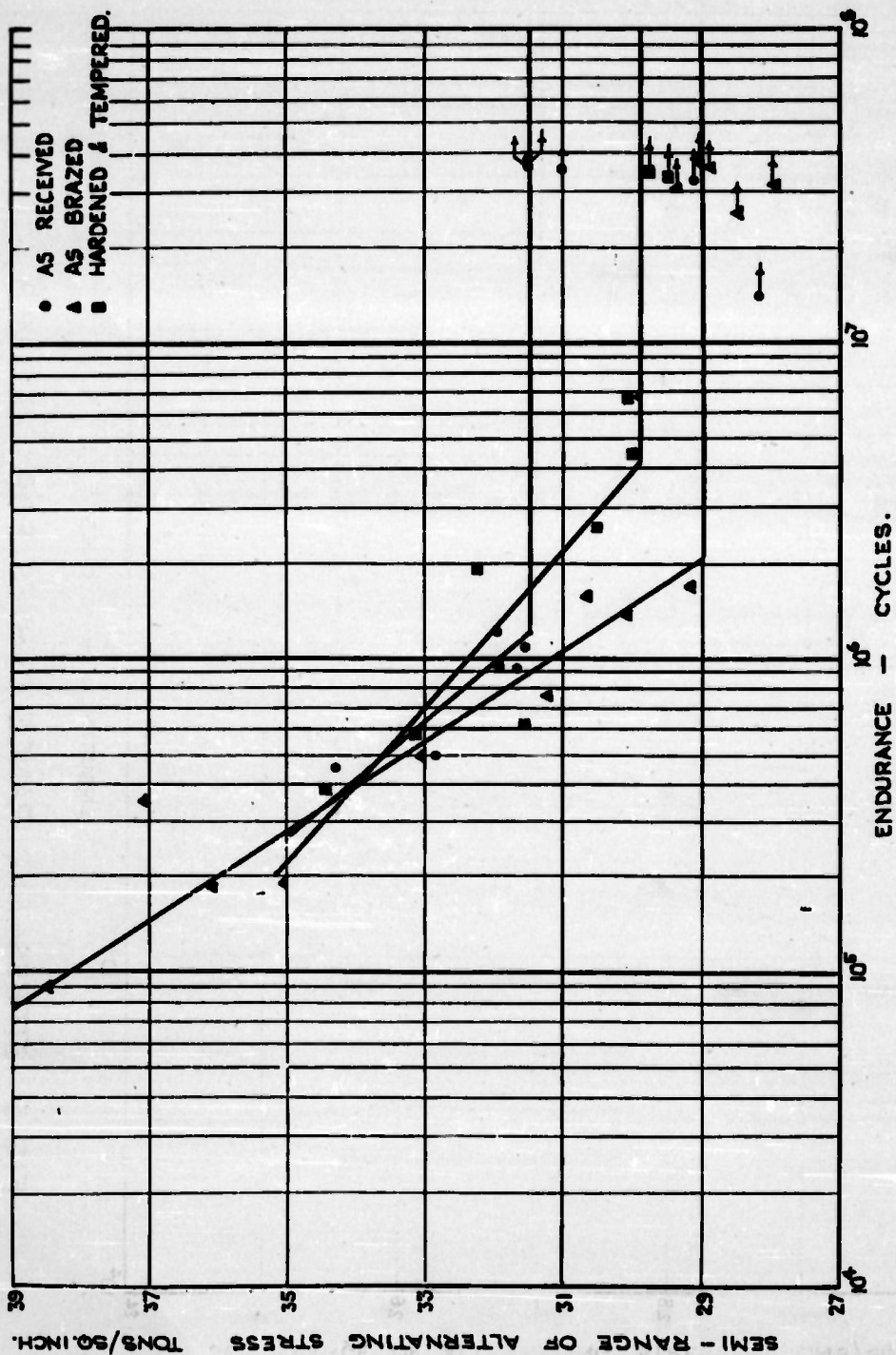


FIG. 6 : STRESS-ENDURANCE CURVES FOR B.S.S. 4SII BAR.

REEL - C

750

A.T.I.

2 0 1 3 9

EDIN FORM 60 A (13 MAR 47)

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DIVISION: Materials (8) 56

SECTION: Iron and Alloys (9) 5

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ABSTRACT

Tests have been made to determine the effect of copper brazing and subsequent heat-treatments on the tensile, impact and fatigue properties of a number of heat-treated steels, weldable low-alloy steels and plain carbon steels. All the steels suffered some reduction in properties as a result of the brazing process although in the case of the hot rolled and normalized plain carbon steels only the impact resistance was appreciably affected. With the exception of one material, whose properties were obtained by cold working, the original properties of the steels could be restored by an appropriate post-brazing heat-treatment.

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 AIR TECHNICAL INDEX

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