SPRINGFIELD ARMORY

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Report Title: Tensile and Impact Properties of Investment-Cast Steels

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Project Title: Engineering of Application of Cast and Powdered Metal Processes to the Manufacture of Small Arms

Preparing Agency: Springfield Armory, Springfield, Mass.

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ABSTRACT

An investigation was made to determine tensile and impact properties of investment-cast steels used for small arms components. Tensile bars of 1/4-inch diameter were cast to finished dimensions. Impact bars were cast to allow for the machining of standard Charpy V-notched specimens. All tensile and impact specimens of each steel were heat-treated simultaneously and tempered at selected temperatures so that four levels of hardness could be obtained. Test results indicated that consistent and reproducible mechanical properties can be obtained for cast components when the castings are adequately gated and heat-treated.

CONTENTS

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SUBJECT

Tensile and impact properties of investment-cast, 0.40 per cent carbon, low alloy steels were investigated.

OBJECT

The object of this investigation was to obtain data to determine the specific tensile and impact properties for investment-cast steels generally used at Springfield Armory for small arms weapon components.

CONCLUSIONS

1. Results of the tensile and impact tests performed on the investment-cast steels investigated indicate that consistent and reproducible mechanical properties can be obtained for cast specimens when adequately gated and heat-treated.

2. The cast 4140 tensile specimens exhibited the highest tensile and yield strengths with the highest hardnesses after tempering at the selected temperatures; the 8740 steel specimens exhibited the lowest tensile properties primarily due to the lower hardness.

3. At comparable hardness levels up to approximately Rc 45, 4340 cast steel displayed the greatest resistance to impact and 4640 steel the least resistance. A noticeable decrease in impact resistance occurred in the specimens tempered at 600°F, the blue-brittle tempering range for the steels investigated.

4. Comparison of the strength of wrought steels having basically the same composition as that of the cast specimens is shown in Table VII. A direct comparison of the cast and wrought materials is not given because of differences in directionality of the material, chemical composition, gage lengths, and diameters of test specimens. The lack of sufficient data on impact and tensile properties of the wrought compositions in the transverse direction prevented a more thorough evaluation. Because of the isotropic character of the castings, a more favorable relationship of longitudinal properties to transverse properties could be expected.

1. PROCEDURES

a. Patterns

Wax was used as the pattern material for the investment castings. A slight modification at the gated end of the Charpy bar was made to promote desirable directional solidification in the castings.

b. Gating

Sketches of the gating used for the tensile and Charpy test specimens are shown in Figures 1 and 2. Radiographic examination of the first group of test bars cast indicated that the castings were sound and adequately gated.

c. Casting Techniques

Each heat consisted of 15-1/2 pounds of wrought bar stock melted in an induction furnace. Cast iron shot, ferromanganese, ferrosilicon, calcium silicon, and aluminum were added to the heats to compensate for melting losses and for deoxidation. Pouring temperatures ranged from 2950°F to 2975°F. Mold temperatures were held at 1600°F.

d. Heat-Treatment

All test bars were given a carbon-restoration treatment before final heat-treatment. Final heat-treatment consisted of heating the test bars in a neutral salt bath followed by oil-quenching and tempering for one hour at the desired temperatures. The austenitizing temperatures used for each of the steels were as follows:

(1) 4640 1475°F

(2) 4340 1500°F

(3) 4140 1550°F

(4) 8640 1525°F

(5) 8740 1525°F

2. RESULTS

a. Chemical Composition

The results obtained from the analyses of one impact bar taken from each melt are given in Table I. The heat designated as 8740 is, in reality, 8640 steel due to its low molybdenum content. The composition of the heat of 4140 steel was at the upper end of the permissible range for alloying elements. Except for the 8740 steel, all of the cast compositions were comparable to the analysis specified for the wrought composition in Federal Standard 66. The silicon content of the castings ranged from 0.41 to 0.48 per cent. This silicon content is well within the 0.20 to 0.80 per cent specified at the Armory for the cast compositions.

b. Hardness

Hardness readings on individual specimens are included in Tables II through VI of the test results. A minimum of three readings were taken on the machined surfaces of both the tensile and impact specimens.

c. Impact Tests

All of the Charpy test bars were finish-ground and notched after final heat-treatment to meet the dimensional requirements of the standard V-notched specimen (Figure 3). Results of impact tests conducted at room temperature are listed in Tables II through VI. Comparison of the impact strength of the cast steels tempered at the selected temperatures is shown in Figure 4.

d. Tensile Tests

The threaded ends of the cast tensile bars, shown in Figure 3, were cleaned with a threading die to eliminate slight irregularities and globules of metal in the cast threads. Testing of the specimens was conducted on an Instron tensile testing machine equipped with recorder. Yield strength was obtained with 0.2 per cent offset. Results of the tensile tests are given in Tables II through VI. Tensile and yield strengths of the cast and the wrought materials, at the same hardness levels, are compared in Table VII. The values expected for the wrought materials are taken from the longitudinal direction.

The higher values obtained with some of the cast bars as compared with similar wrought compositions can be attributed to the smaller size of the cast bars. A more thoroughly quenched microstructure could be expected in the cast specimens of smaller diameter. Slight variations in the chemical compositions could also have some influence on the results.

Results of the comparison of tensile and yield strength of cast steels are shown in Figures 5 and 6.

2. RESULTS

e. Metallographic Examinations

Sections of the tensile test bars tempered at 800°F from each of the cast steels were examined for microstructure and for decarburization.

(1) Unetched. Inclusions in all of the specimens were of the globular oxide type. These were small and well distributed throughout the sections examined. A greater number were observed in the 4640 and 8640 steel specimens.

(2) Etched. The microstructure in all specimens consisted of fine, tempered martensite with faint traces of the original dendritic structure. Decarburization was not evident in any of the specimens examined.

APPENDICES

A - Figures (6)

B - Tables (7)

C - Distribution

APPENDIX A

Figures (6)

GATING USED FOR INVESTMENT CAST IMPACT BARS

18 CASTINGS PER MOLD - 3 ROWS OF 6 EACH

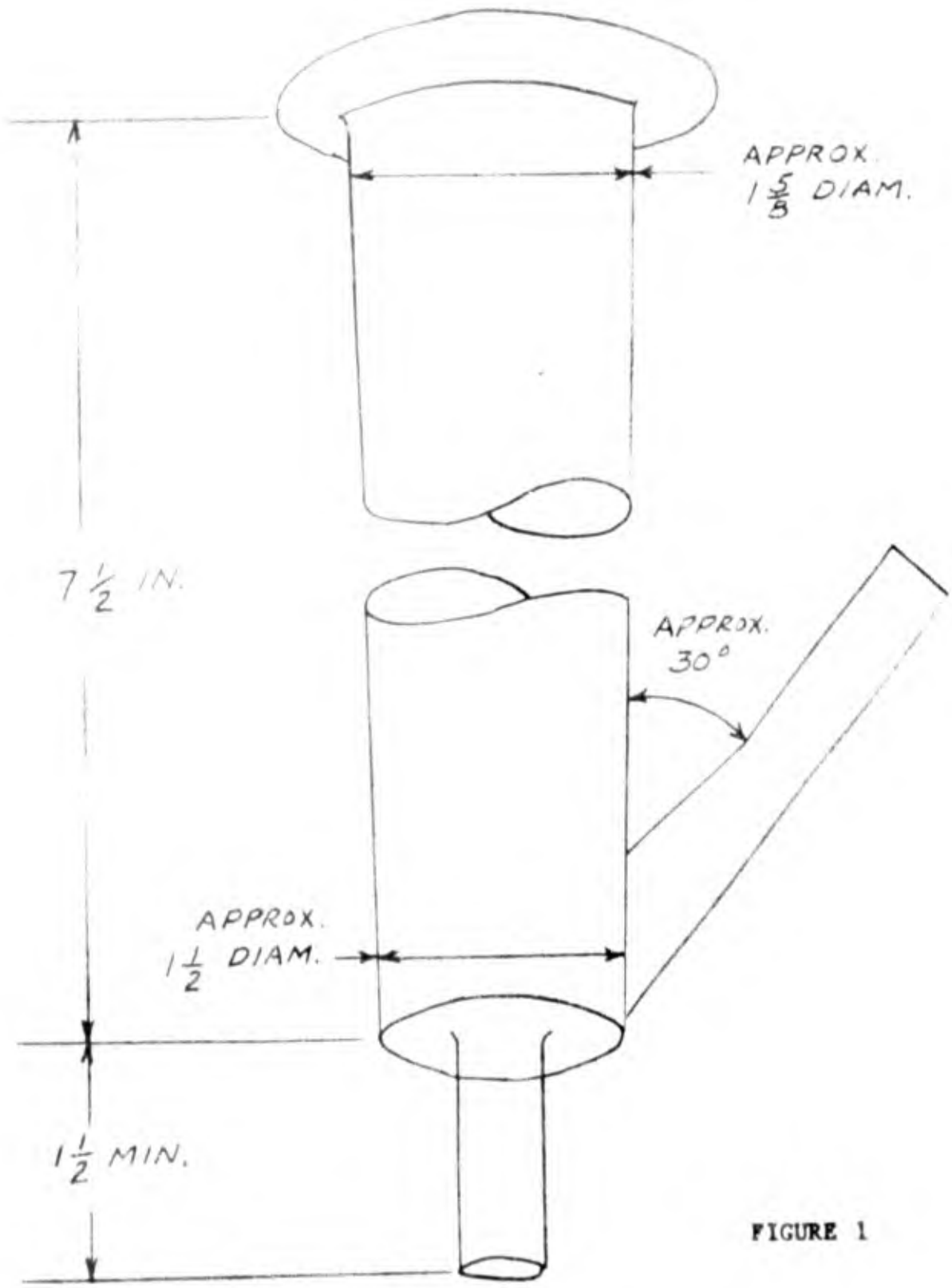


FIGURE 1

GATING USED FOR INVESTMENT CAST TENSILE BARS

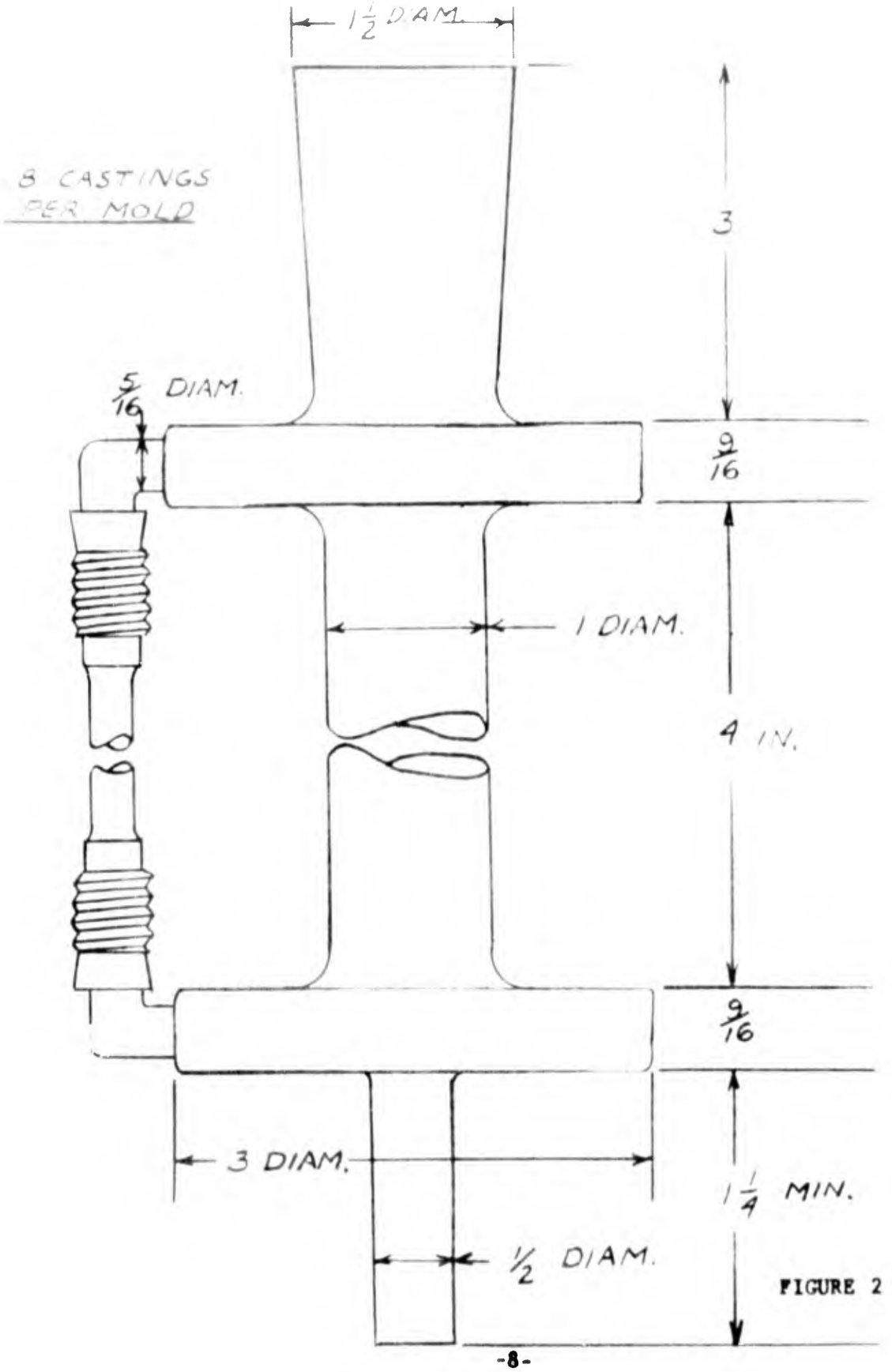


FIGURE 2

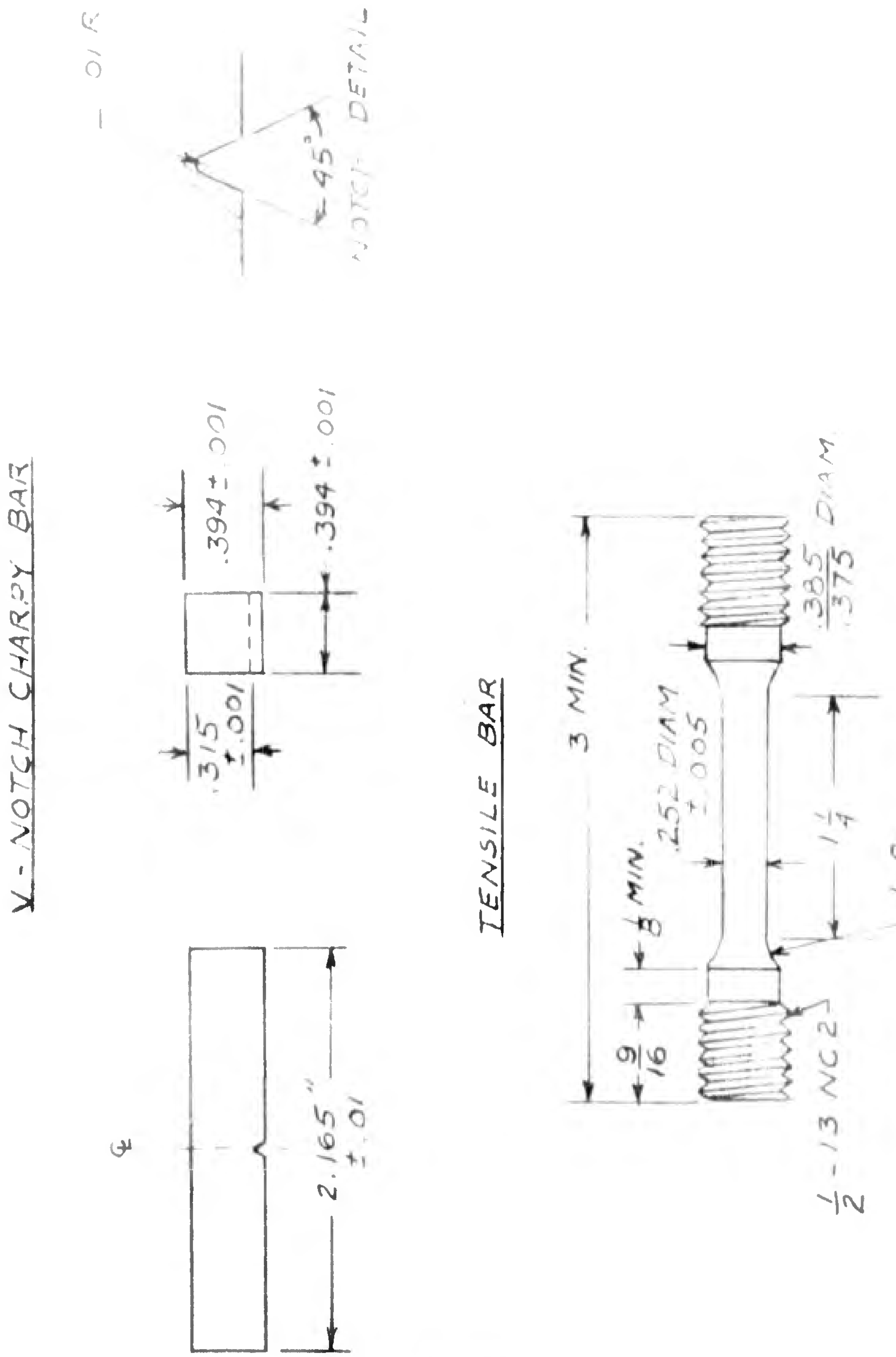
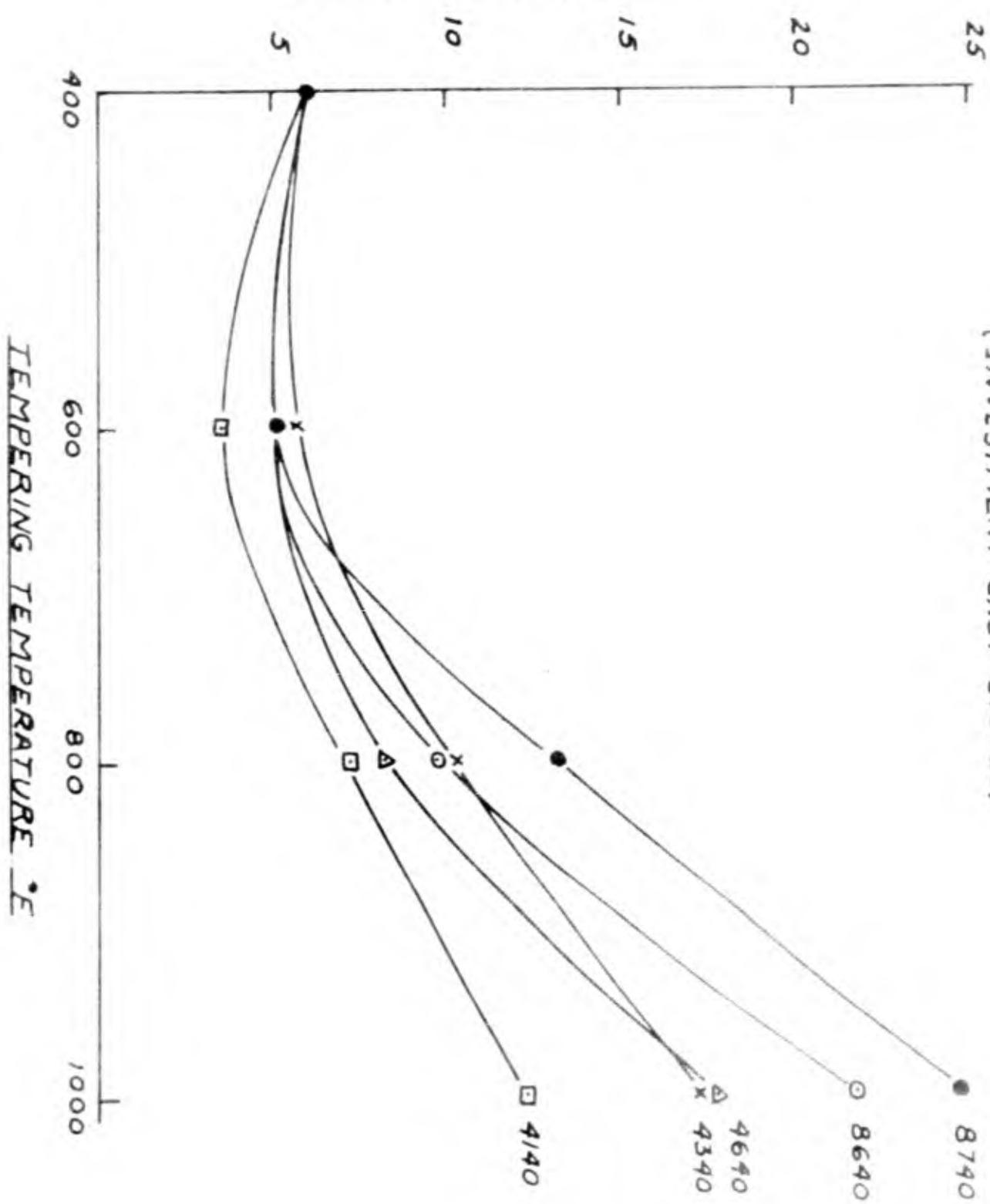

V-NOTCH CHARPY BAR
45°
.394 ± .001
.394 ± .001
.315 ± .001
2.165" ± .01
TENSILE BAR
3 MIN.
.252 DIAM ± .005
1 1/4
1/4 R
1/8 MIN.
9/16
.385/.375 DIAM
1/2 - 13 NC 2

FIGURE 3

FIGURE 4

ROOM TEMPERATURE CHARPY V NOTCH IMPACT STRENGTH

(INVESTMENT CAST STEELS)



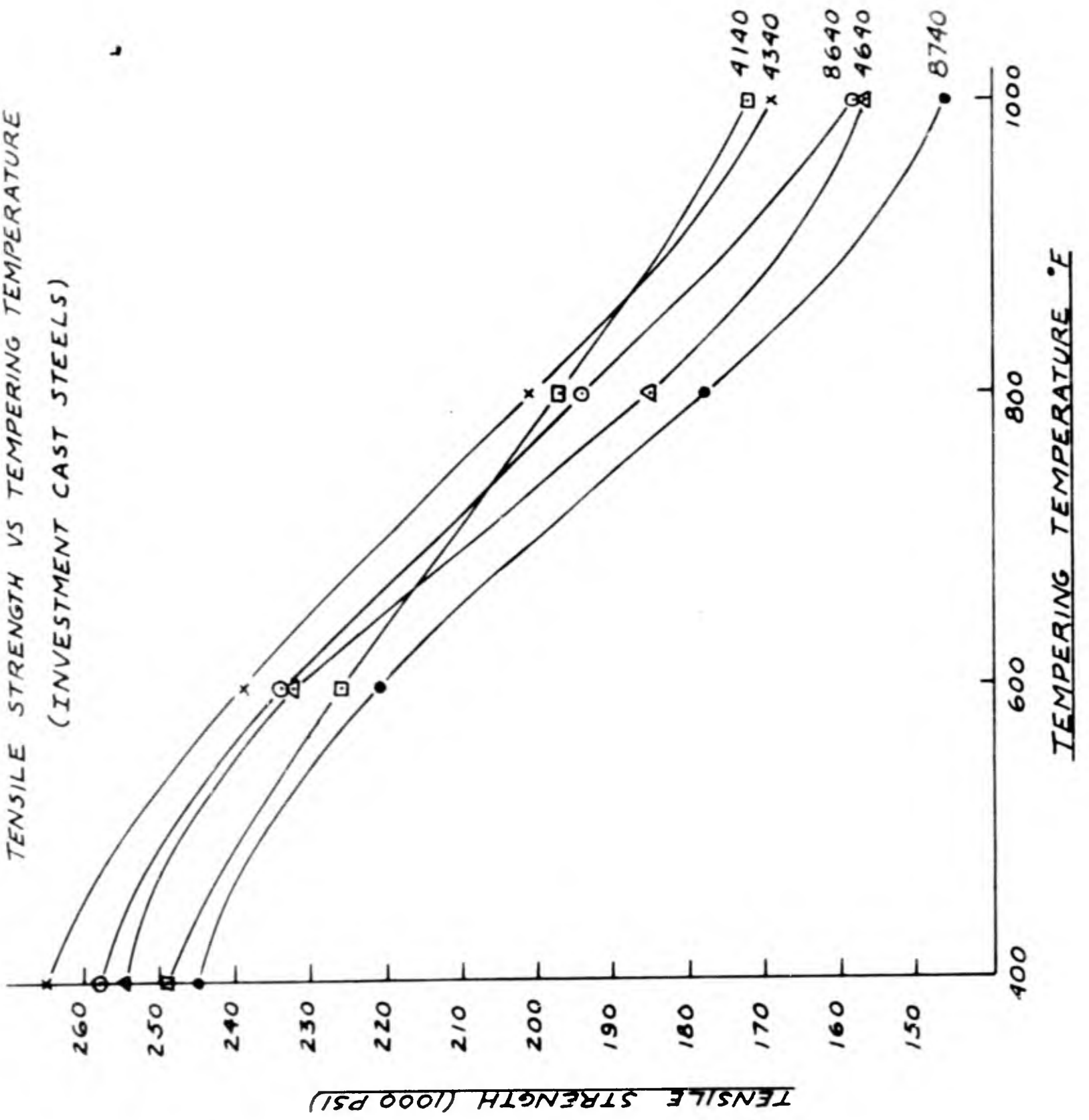

TENSILE STRENGTH VS TEMPERING TEMPERATURE
(INVESTMENT CAST STEELS)
4140
4340
8640
4690
8740
1000
800
600
400
TEMPERING TEMPERATURE °F
260
250
240
230
220
210
200
190
180
170
160
150
TENSILE STRENGTH (1000 PSI)

FIGURE 5

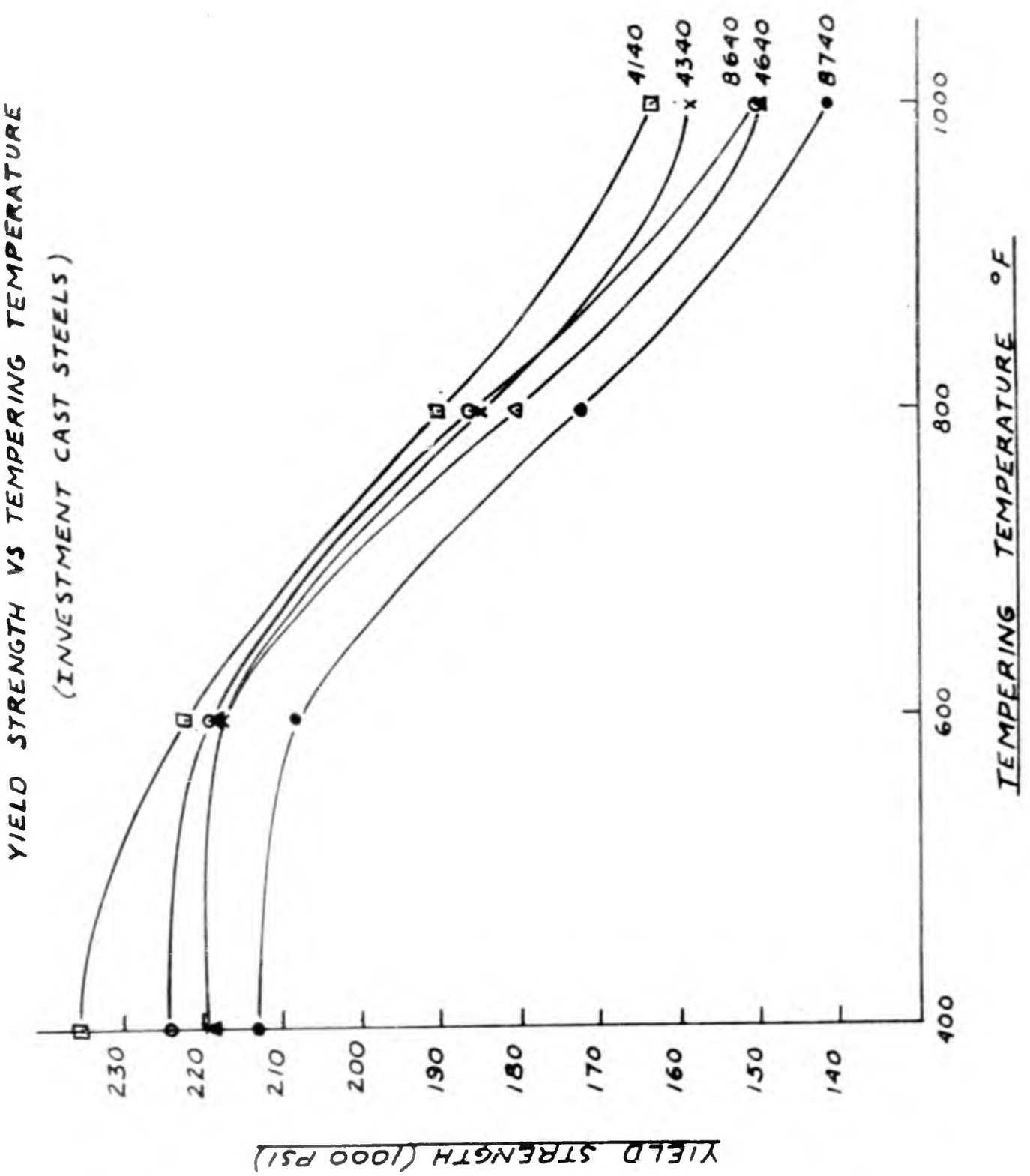

YIELD STRENGTH VS TEMPERING TEMPERATURE
(INVESTMENT CAST STEELS)
4140
4340
8640
4640
8740
YIELD STRENGTH (1000 PSI)
230
220
210
200
190
180
170
160
150
140
TEMPERING TEMPERATURE °F
400
600
800
1000

FIGURE 6

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APPENDIX B

Tables (7)

CHEMICAL ANALYSES OF MELTS

STEELS

ELEMENTS	4140	8640	4640	8740	4340
CARBON	.38 PERCENT	.40 PERCENT	.38 PERCENT	.43 PERCENT	.43 PERCENT
MANGANESE	.84	.77	.86	.72	.72
SILICON	.41	.41	.48	.45	.45
SULFUR	.021	.020	.027	.020	.015
PHOSPHOROUS	.009	.022	.024	.010	.010
CHROMIUM	.90	.53	.16	.49	.73
NICKEL		.49	1.64	.72	1.78
MOLYBDENUM	.25	.21	.30	.16	.28

WEIGHT OF CHARGE - 15.5 LBS.

ADDITIONS -
CAST IRON
FERRO MANGANESE
FERRO SILICON
CALCIUM-SILICON
ALUMINUM

TABLE I

RESULTS OF TESTS ON 4140 INVESTMENT CAST SPECIMENS

BARS NO.	TEMPERING TEMP	HARDNESS Rc	IMPACT STRENGTH	TENSILE STRENGTH	YIELD STR. .2% OFFSET	PERCENT ELONGATION	PERCENT REG. AREA
1	400 °F	54 - 55	6 FT. LBS.	249 000 psi	234 000 psi	1.0	7.1
2	"	53.5 - 55	5.5	249,000	235 500	—	7.1
3	"	54 - 55	6	252,000	—	—	4.8
4	"	54.5 - 55	6	237,000	—	1.0	6.2
5	600 °F	50 - 51.5	3	224,000	—	.5	7.9
6	"	50.5 - 52	3	214 000	—	1.5	7.9
7	"	50 - 51	4	231 000	219 000	.5	—
8	"	50 - 51	4	237 000	226.100	.5	5.0
9	800 °F	44 - 46	6	196 000	189 000	1.7	10.9
10	"	45 - 46	7	197 000	189 000	2.3	8.7
11	"	44.5 - 45	7.5	196 000	191 000	1.6	8.7
12	"	44.5 - 46	7.5	199 000	190 500	1.5	10.1
13	1000 °F	39.5 - 41	12	172 600	164 000	4.0	10.7
14	"	39.5 - 41	12.5	172 000	163 000	4.2	8.7
15	"	39 - 40.5	12	165 000	161 500	3.5	10.9
16	"	39.5 - 41	12	170 000	163 000	3.4	12.3

RESULTS OF TESTS ON 4640 INVESTMENT CAST SPECIMENS

BARS No.	TEMPERING TEMP.	HARDNESS R_c	IMPACT STRENGTH	TENSILE STRENGTH	YIELD STR. .2% OFFSET	PERCENT ELONGATION	PERCENT RED. AREA
17	400 °F	46.5 - 49.5	6 FT LBS	252,000 PSI	217,500 PSI	2.4	6.2
18	"	47 - 49	5	252,000	217500	2.7	8.7
19	"	46 - 48	5.5	256,500	218400	2.7	9.4
20	"	46 - 49	7	260,000	219000	4.3	5.7
21	600 °F	43 - 46	4	235,200	216900	—	—
22	"	45 - 47	7	233,400	215400	2.7	8.7
23	"	44 - 47	4	232400	219300	2.0	10.1
24	"	46 - 47	5	234600	220800	3.3	10.7
25	800 °F	37.5 - 40	9	183000	177,600	3.4	12.3
26	"	39 - 41	8	184500	178800	3.9	13.7
27	"	38.5 - 41	8	187800	181500	4.2	10.1
28	"	40 - 41	8.5	186,900	180600	4.0	10.8
29	1000 °F	33 - 36	18	156000	150900	7.3	13.9
30	"	34.5 - 37	17	156600	150000	6.8	15.3
31	"	34 - 37	17	157,500	150900	7.0	11.5
32	"	35 - 36	18	157,500	151800	6.4	14.6

TABLE IV

RESULTS OF TESTS ON 8640 INVESTMENT CAST SPECIMENS

BARS No.	TEMPERING TEMP.	HARDNESS Rc	IMPACT STRENGTH	TENSILE STRENGTH	YIELD STR. .2% OFFSET	ELONGATION % IN 1 INCH	PERCENT RED. AREA
33	400 °F	47 - 50	6 FT LBS	259 500 PSI	222,000 PSI	3.6	5.6
34	"	47 - 51	6 "	259 500	225 000	2.2	5.5
35	"	49.5 - 51.5	6 "	256 500	223 500	2.3	9.4
36	"	47.5 - 53	5.5 "	258 000	226 500	2.4	8.5
37	600 °F	46.5 - 48	4.5	228 600	216 600	2.5	10.1
38	"	45.5 - 48	6.	233 400	219 000	2.5	9.4
39	"	45 - 48	7.	240 000	222 600	2.5	8.6
40	"	46.5 - 47	5.	233 400	219 000	2.6	9.4
41.	800 °F	40 - 43	10	194 400	184 500	4.3	13
42	"	39 - 41.5	11	195 600	187 500	3.8	10.8
43	"	39 - 41	9.5	195 500	184 800	2.7	12.3
44	"	38.5 - 42.5	9.	192 600	188 400	1.6	11.7
45	1000 °F	34 - 36	22	159 000	152 700	6.8	16.4
46	"	34 - 35	20.5	156 900	150 000	6.2	12.3
47	"	34.5 - 36	22	159 000	150 600	6.3	14.1
48	"	34 - 35	22	156 300	150 000	5.8	

RESULTS OF TESTS ON 8740 INVESTMENT CAST SPECIMENS

BARS NO.	TEMPERING TEMP.	HARDNESS Rc	IMPACT STRENGTH	TENSILE STRENGTH	YIELD STR. .2% OFFSET	ELONGATION % IN 1 INCH	PERCENT RED. AREA
49	400 °F	51 - 53	6.5 FT. LB	249 000 PSI	217500 PSI	1.8	7.1
50	"	51.5 - 52.5	6.	208500	–	1.2	7.1
51	"	52 - 52.5	6	240 000	214000	1.0	3.9
52	"	51 - 52	6	247500	222 000	1.2	8.1
53	600 °F	47 - 48	5.5	225000	208500	1.2	8.1
54	"	47 - 48	5	221 500	208500	1.7	8.1
55	"	47 - 48	5	218 000	208 500	-	-
56	"	47 - 48	4.5	219 000	–	1.0	7.1
57	800 °F	41 - 42	13	177 000	172 500	3.0	8.1
58	"	40 - 41.5	12.5	177 000	171 500	2.8	17.2
59	"	40 - 41	12	180,000	171500	3.2	17.2
60	"	40 - 41	13.5	180 000	172 500	3.0	11.2
61	1000 °F	33 - 35	23	148 500	141 000	6.5	12.3
62	"	34 - 35	24.5	148 500	140 500	5.0	17.4
63	"	34 - 35	25.5	144 000	142 500	3.5	18.7
64	"	34 - 35	25	146 000	140 500	4.0	23.

TABLE V

RESULTS OF TESTS ON 4340 INVESTMENT CAST SPECIMENS

BARS No.	TEMPERING TEMP.	HARDNESS Rc	IMPACT STRENGTH	TENSILE STRENGTH	YIELD STR. .2% OFFSET	ELONGATION % IN 1 INCH	PERCENT RED. AREA
65	400°F	52 - 53	6 FT LBS	174000 PSI	-	-	-
66	"	51 -53	7	268000	216000 PSI	2.0	8.1
67	"	52 -53	5.5	264000	222000	2.0	10.0
68	"	52.5 -53	6	264 000	216 000	2.0	8.6
69	600 °F	48 - 49	5.5	223500	217500	-	-
70	"	48 - 49	6	248 000	219000	2.0	12.3
71	"	48 - 48.5	5.5	234 000	216 000	1.6	6.2
72	"	48 - 49	5.5	249 000	220 500	2.5	6.2
73	800 °F	43 - 44	10	201 000	184500	3.8	12.3
74	"	43 - 44	10	200 500	184 500	5.0	15.3
75	"	43 - 43.5	10	201 500	185 000	4.5	11.0
76	"	43 - 44.5	10.5	202 500	186 000	4.8	12.3
77	1000 °F	38 - 38.5	17	168500	157 500	5.5	15.4
78	"	38 - 39.5	16	169 500	157 500	6.2	12.6
79	"	38 - 39	16.5	171 000	159 500	6.0	16.1
80	"	38 - 39	18	168000	159000	4.7	13.3

COMPARISON OF TENSILE AND YIELD STRENGTHS OF INVESTMENT CAST VS WROUGHT STEEL IN LONGITUDNAL DIRECTION

STEEL	TEMPERING TEMP.	AVERAGE HARDNESS	AVERAGE TENSILE STRENGTHS		AVERAGE YIELD STRENGTHS	
			INVESTMENT CAST (ACTUAL)	WROUGHT STEEL * (PUBLISHED)	INVESTMENT CAST (ACTUAL)	WROUGHT STEEL * (PUBLISHED)
8740	400°F	R_c 52	245 500 PSI	265 000 PSI	217 500 PSI	231 000 PSI
	600	47	220 875	230 000	208 500	212 000
	800	40	178 500	190 000	172 000	177 000
	1000	34	146 750	160 000	141 125	146 000
4340	400	52	265 300	266 000	218 000	225 000
	600	49	243 700	240 000	218 250	212 000
	800	43	201 300	198 000	186 250	182 000
	1000	38	169 250	168 000	158 375	152 000
8640	400	50	258 375	260 000	224 250	238 000
	600	46	233 860	230 000	219 300	212 000
	800	40	194 500	180 000	186 300	180 000
	1000	35	157 800	155 000	150 825	145 000
4640	400	48	255 100	240 000	218 100	216 000
	600	45	233 900	220 000	218 100	198 000
	800	40	185 500	180 000	179 625	167 000
	1000	35	156 900	160 000	150 900	142 000
4140	400	54	246 750	280 000	234 750	243 000
	600	50	230 700	250 000	222 550	229 000
	800	45	197 000	210 000	189 875	195 000
	1000	40	169 900	185 000	162 875	166 000

* .505 INCH DIAM., 2 INCH G.LENGTH TEST BARS

TABLE VII

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