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DEVELOPMENT OF A HIGH STRENGTH
ISOTHERMALLY HEAT-TREATED NODULAR IRON
ROAD WHEEL ARM
CONTRACT No DAAE07-83-C-R051



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by _____

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PREFACE

This final report covers work done under Contract No DAAE07-83-C-R051, titled "Development of a High Strength Isothermally Heat-Treated Nodular Iron Road Wheel Arm." The report spans March 1983 through March 1985.

The contract was awarded to Hayes-Albion by the US Army Tank Auto-motive Command (TACOM). It was carried out under the technical direction of Michael Holly and later Avery H. Fisher, TACOM, Warren MI.

The project activities were under the technical guidance of A.R. Moore, experimental engineer, Hayes-Albion. The project was under the general direction of James Paternoster, technical director, Hayes-Albion Corp., Albion Division. Stress analysis and testing was under the direction of Lary Geer, corporate special projects engineer, Hayes-Albion Corp. Other areas of assistance were given by James Falconer, manager, tool engineering, Hayes-Albion and Nick Januszewski, sales engineer, Hayes-Albion Corp.

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1.0. INTRODUCTION

This final report was prepared by Hayes-Albion Corp. for the US Army Tank-Automotive Command under Contract No DAAE07-83-C-R051. It describes the redesign, material characterization, material selection, manufacture, and testing of a proposed road wheel arm for the M1 tank. The material selected is bainitic ductile iron (BDI). This material made by the casting process and heat-treatment, takes advantage of the toughness of bainite (acicular ferrite), the ability of the casting process to make a complex shape, and a 10 percent lighter than steel weight. A further advantage is its relatively low cost compared to a steel forging. The part is shown in Fig. 1-1.

2.0. OBJECTIVE

The main objective of the project was to supply a road wheel arm of equal or better performance than the existing one, with a weight and cost reduction. A secondary objective was to conduct an investigation into BDI to characterize its properties over a broad range.

3.0. CONCLUSIONS

A set of 14 road wheel arms were made and assembled. Dynamic tests on the design passed the 650,000 cycle specification, going beyond one million cycles. A 35 pound or 27 percent weight savings per arm was achieved, and based on figures obtained during the project, a considerable cost reduction can be effected.

Data were generated during the investigation and characterization phase to allow design calculations to be made with more confidence.

4.0. RECOMMENDATIONS

4.1. Design

Figures obtained during the static and dynamic tests indicate that further refinement of the design should be done. This involves a redistribution of metal from areas of low stress to areas of high stress. Such a change would not affect the overall weight but would increase the safety factor.

4.1.1. Material Characterization. The material was characterized using one austenitizing temperature (1650°F) throughout, varying the quench temperatures and times. Investigation should be made

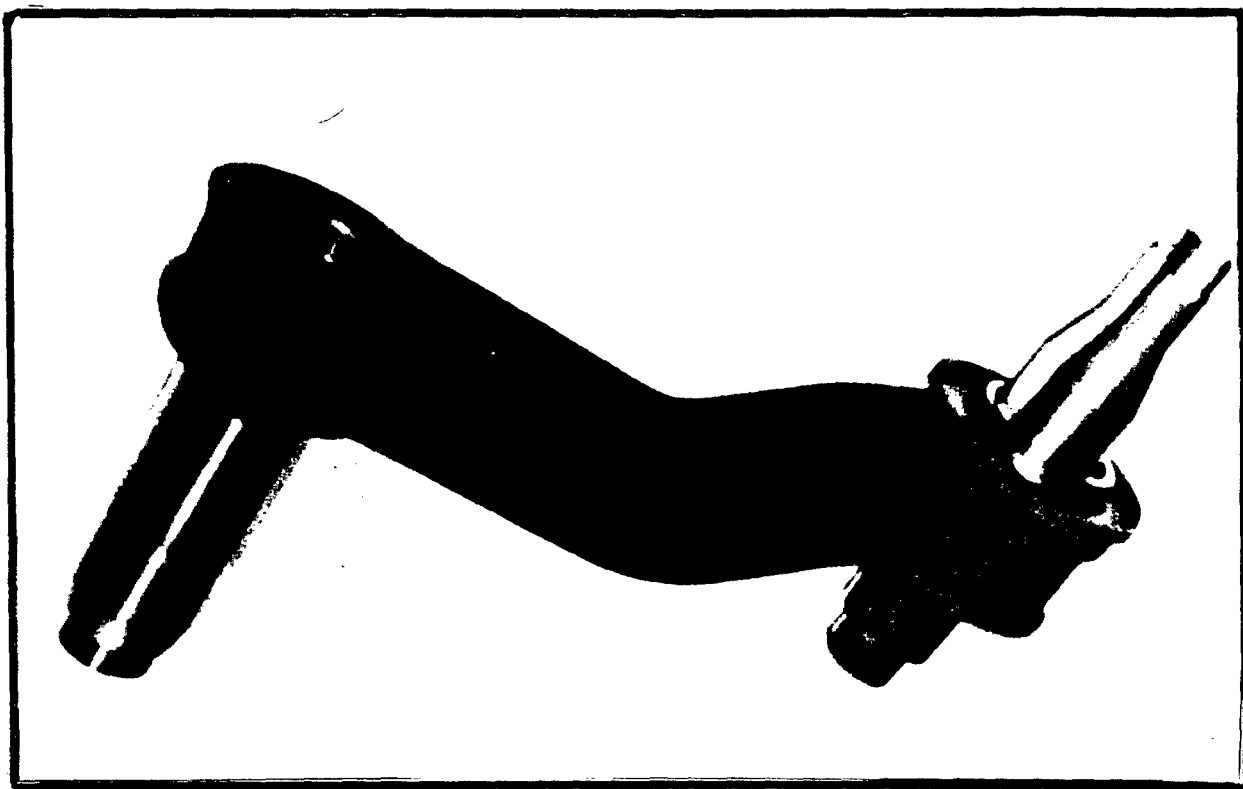


Fig 1-1. Isothermally Heat-Treated Nodular Iron Road Wheel Arm.

into varying the austenitizing temperatures as information on this comes to light.

4.1.2. Control. In the course of the investigation and testing, it was demonstrated that isothermally heat-treated nodular iron is quite notch sensitive. Every effort must be made to avoid grinding gouges on the outside of the casting. Likewise, no holes should be drilled in the casting for any reason. The manufacture of BDI is time-temperature-chemistry sensitive. Control must be close over these variables. Vendors bidding on future requirements should show that they routinely control their product metallurgically and that they can produce BDI to specification.

4.2. Further Recommendations

Castings made for this project had a ladle addition of Molybdenum (see Table 4-1a). It would be advantageous to further characterize the material through varying key elements such as carbon, silicon, copper, manganese, and molybdenum. An important field of study has been shown by the present project: the cause of notch sensitivity should be found and if possible methods of preventing it should be provided.

Two spacers on the assembly are presently made from forgings. These could be made from pearlitic ductile iron at much lower cost.

5.0. DISCUSSION

5.1. Background

Nodular or ductile iron is a readily available material whose manufacture is well understood by many foundries. In the as-cast condition, unalloyed nodular iron is made to several specifications (see Table 5-1). Alloyed primarily with copper, nickel, and molybdenum, it can be tailored to many specific applications in the normal to high temperature ranges. Unfortunately, it shares to a greater degree than specialty steels the tendency to lose strength at low temperatures. Isothermal heat-treatment not only improves the as-cast mechanical properties but significantly improves them at low temperatures to where they can compete with cryogenic steels.

5.1.1. Hayes-Albion made an unsolicited proposal to TACOM suggesting that BDI be investigated as a material suitable for tank road wheel arms. Mentioned in the proposal were the potential mechanical properties which could be in excess of 200,000 p.s.i. tensile strength, 180,000 p.s.i. yield strength and 10 percent elongation. These properties could be adjusted in the heat-treatment to produce optimum conditions for the application. Advantages cited were ease of manufacture, cost and weight reduction.

Table 4-1a. Chemistry of Contracted 14 Road Wheel Arms.

C	SI	MN	S	MG	CR	CU	CE	AL	SN	P	MO	NL	TI
3.76	2.38	0.33	0.008	N/A	0.042	0.16	0.001	0.0103	0.015	0.336	0.2602	0.019	0.0269

Table 4-1b. Chemistry of Metal Poured in Characterization Test Bars.

C	SI	MN	S	MG	CR	CU	CE	AL	SN	P	MO	NL	TI
3.76	2.29	0.3	0.011	N/A	0.052	0.10	0	0.0043	0.01	0.253	0.0079	0.013	0.019

Table 4-1c. Chemistry of Second Static Test Casting.

C	SI	MN	S	MG	CR	CU	CE	AL	SN	P	MO	NL	TI
3.7	2.32	0.35	0.009	N/A	0.058	0.17	0	0.0119	0.015	0.0257	0.4354	0.026	0.0217

Table 4-1d. Chemistry of Third static and Second Dynamic Test Specimen.

C	SI	MN	S	MG	CR	CU	CE	AL	SN	P	MO	NL	TI
3.79	2.45	0.34	0.011	N/A	0.052	0.19	0.002	0.007	0.014	0.0237	0.2596	0.034	0.0173

Table 4-1e. Chemistry of High Molybdenum Test bars.

C	SI	MN	S	MG	CR	CU	CE	AL	SN	P	MO	NL	TI
3.71	2.42	0.30	0.007	N/A	0.059	0.10	0.002	0.0106	0.014	0.0365	0.437	0.0253	0.0203

Table 5-1. Commercial Designations of Nodular Iron and Their Mechanical Properties.

Commercial Name	Tensile p.s.i.	Yield p.s.i.	Elongation percent
D4018	60,000	40,000	18
D4512	65,000	45,000	12
D5506	80,000	55,000	6
D7003	100,000	70,000	3
D9002	120,000	90,000	2

5.2. Rationale

Using BDI for a tank road wheel arm is a good application for the following reasons:

- o The material is readily available.
- o The material is less energy intensive than a forging.
- o The product is a critical member and, as a casting, would be in a lower energy state than a forging.
- o The material weighs approximately 10 percent less than steel.
- o through the casting process, the part can be redesigned to increase the section modulus, put material where it is needed, and by design, reduce weight.

5.3. Design

Design of the original road wheel arm was done by General Dynamics Corporation. It was designed in 4150H or 4340H forged steel hardened to Rc 35-39. The part is simply two hubs joined by an oval sectioned offset arm (see Fig 5-1). In redesigning the part in BDI, it was specified that the plan and elevation envelopes were not to be exceeded. No stress values were available. All that could be obtained was the weight of the vehicle at 60 tons. Using this dead weight, we then examined three possibilities:

- o The existing oval section.
- o An "I" beam section.
- o A box section.

These sections were surveyed in a comparative manner and the results shown in tables 5-2 and 5-3. APPENDIX A1 through A 16 contains the details on these calculations. For comparison reasons the stresses were calculated under the following assumptions: (1) A beam of constant cross-section 20 ins. long. (2) For bending stress about the X axis a 20,000 pound verticle load was used. (3) For bending about the Y axis a 5,000 pound load was used. (4) The shear stress calculations were performed using a pure torque of 245,000 in. pounds. These stresses are for cross-section comparison on only. This method was utilised based on the limited load and restraint information provided). These values are not to be construed to be actual in-field values. In Table 5-2 the existing section is first considered. The offset in the arm results in a torque being present as well as a bending moment. We must design particularly and with emphasis for

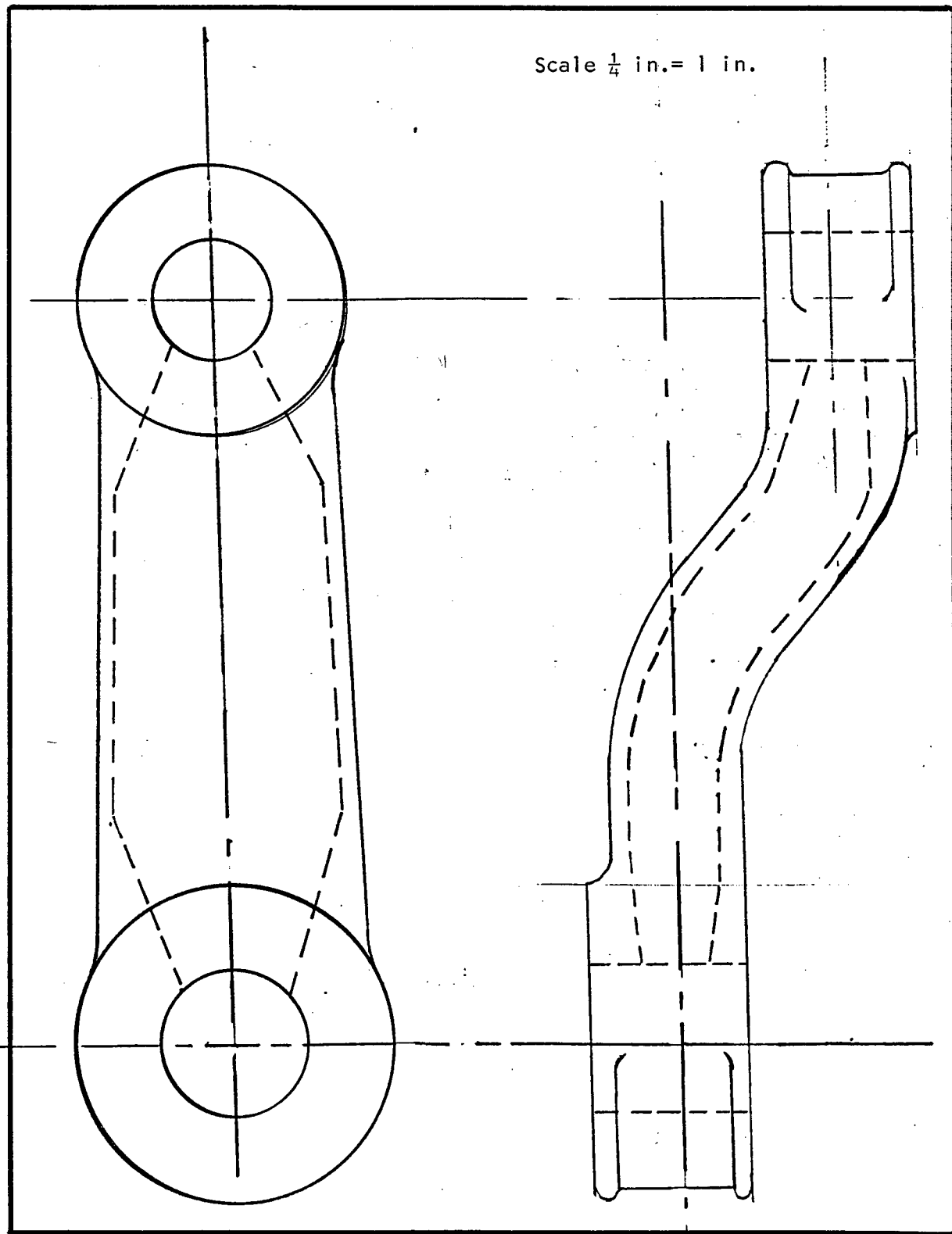


Fig. 5-1. Sketch of Cast Road Wheel Arm

5-2 Comparative Section Analysis and Corresponding Stresses of Arm Cross-Sections.
in Simple Bending.

Cross-Section Design	Area	I_x	I_y	J Polar Moment	Wt. lbs per in. Section	$\frac{A}{J}$	σ_x p.s.i.	σ_y p.s.i.
APPENDIX A3 Existing Oval Section	17.78	50.35	12.15	62.49	4.62	0.284	25,319	14,403
APPENDIX A4 1 Beam Sect.	9.341	53.53	5.97	59.5	2.42	0.157	24,285	29,313
APPENDIX A5	11.75	65.43	9.07	74.5	3.06	0.157	19,868	19,294
APPENDIX A6	13.0	60.78	7.17	68.0	3.38	0.191	21,388	24,407
APPENDIX A7	13.125	70.27	10.84	81.11	3.41	0.162	18,500	16,143
APPENDIX A8	15.75	72.95	11.70	84.65	4.10	0.186	17,820	14,957
APPENDIX A9	13.125	70.27	14.81	85.08	3.41	0.154	18,500	11,816
APPENDIX A10 Box Section	9.98	49.37	17.22	66.59	2.59	0.150	26,331	10,162
APPENDIX A11 9/16 in. Wall	10.93	52.96	18.24	71.2	2.84	0.153	24,546	9,594
APPENDIX A11 5/8 in. Wall								

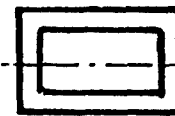
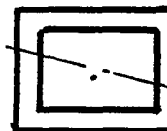
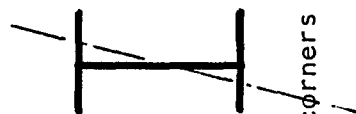


Table 5-3 Comparative Section Analysis and Corresponding Stresses of Arm Cross-Sections in Bending at 14 Degrees to Normal.

Cross-Section Design	Area	I_x	I_y	J Polar Moment	Wt. lbs per in. Section	$\frac{A}{J}$	σ_x p.s.i.	σ_y p.s.i.	p.s.i.
APPENDIX A12 Existing Oval Section	17.87	48.14	14.82	62.96	4.62	0.282	26,506	12,429	15,670
APPENDIX A13 I Beam Section 7/8 in. Flange 3/4 Webb	9.69	52.66	9.29	61.95	2.59	0.160	27,170	26,738	7,327
APPENDIX A14 *	10.94	50.93	20.27	71.2	2.84	0.154	26,506	11,408	11,604



* Assumes a half in. radius on outside corners

this torque as it is a crucial component of the stresses. For this reason the polar moment is of special interest. Having surveyed the present design cross-section we can regard that as a bogey because it is presently meeting the application. Other designs then should be measured against this design. The A/J column in the tables is simply a ratio of efficiency of material usage. The lower this value, the greater the efficiency. As can be seen from this data, a box section between 9/16 ins. and 5/8 ins. wall exceeds the oval section on all counts, is half the weight per design inch and has double the efficiency.

Table 5-3 considers the three basic shapes when acted upon by a bending moment applied at 14 degrees to normal (from information advanced by TACOM). Again the box section is clearly superior.

5.3.1 Using this information, a box section with an 0.625 in. wall was designed for the offset arm. Material was removed from around the end hubs where it appeared that these were over designed. (see Fig 5-1). The internal core for the box section is connected to the spindle hole cores so that a single core is used to make the complete casting.

5.4. Material Selection

5.4.1. Material Characterization. Concurrent with the design work, the issue of material characterization was worked on. Not only did this result in much needed information in general, but it also dictated the particular heat-treatment that would be used on the road wheel arms.

5.4.2. Characterization Method. Two hundred and fifty "keel block" tensile test bars and 500 charpy impact test bars were cast (see Fig 5-2). These were all cast in the same heat of iron with a routine ferritic iron chemistry, Table 4-1b. The reason for making them all from the same heat was to eliminate chemistry as a variable in this study. Since isothermally transformed nodular iron has a propensity to work harden because of the transformation of retained austenite to martensite at the interface, it was judged that machining the test bars after heat-treatment would skew the results. All bars were therefore machined prior to heat-treatment. The austenitizing temperature was maintained at 1650°F in every case and 25 tensile test bars and 50 charpy bars were processed at each quench temperature. The austenitized bars were quenched at temperatures from 400°F to 800°F in 50°F increments. After one hour in the salt, 5 bars each of tensile and 10 of charpy were removed and rinsed off in water. In this way, a profile was obtained over 4 hours quench-soak time at one hour intervals. Austenitizing time was maintained at 3 hours at temperature in every case. The tensile bars were then pulled and the results were recorded. The charpy bars, five notched and five unnotched were impacted and the results were recorded. These data are shown graphically in APPENDIX B. Selected photomicrographs are shown in APPENDIX C.

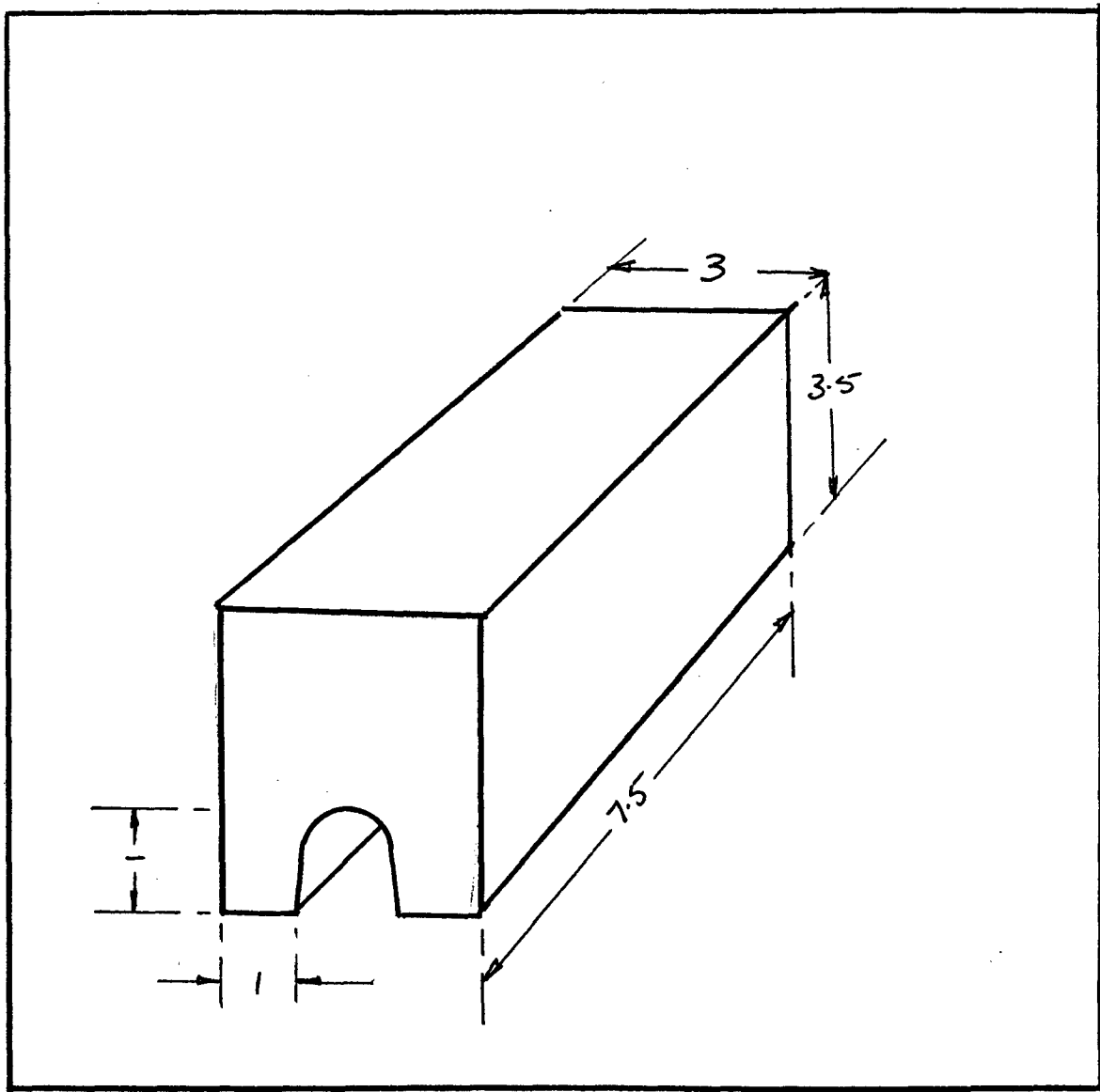


Fig. 5-2. Test Bar Keel Block. Test bars are cut from the two lower ribs and machined into standard $\frac{1}{2}$ in. diameter tensile bars.

5.4.3. Characterization at Temperature. The contract required that the material be characterized at temperatures from -60°F to 230°F . This was done by picking a quench temperature that resulted in an optimum of mechanical properties and processing 40 more tensile and 40 unnotched charpy bars at 700°F quench temperature. A thermocouple was welded to each bar and five bars were tensile tested or impacted at each temperature. The results of this study are shown in APPENDIX D. A sketch of the apparatus is shown in Fig 5-3.

5.4.4. Additional Trials. In the course of this investigation, two other trials were made. One was to look at the effects of austempering a second time on a group of bars where a furnace failure had interrupted the process, and a second was to see what effect molybdenum might have on the qualities of the material (Table 4-1e). These results are shown in APPENDIX E.

5.4.5. Discussion of Results As might be expected, the lower quench temperatures result in test bars with higher hardness values, while the higher quench temperatures give test bars with lower values. Elongation values, however, are the reverse of this, reaching nearly 10 percent at the 700°F quench. Tensile strengths of over 200,000 p.s.i. are easily obtainable in the 550°F quenches but elongation at this level is barely 5 percent. These relationships are clearly shown in the bar chart, Fig 5-4. The effect of low or high ambient temperatures is minimal at the temperatures investigated, indicating that if nodular iron is to be used at temperatures to -60°F , it should be austempered in the 700°F range for best results and safety. The net result of this characterization is that isothermally heat-treated nodular iron can be tailored to many applications normally reserved for alloy steels and has cryogenic applications. On the negative side is the strong evidence, as indicated by the charpy notched bars, that the material is quite notch sensitive. Until a method can be found to minimize this problem, every effort must be made in design to eliminate sharp angles and other stress raisers in a component. It is also essential that in the course of manufacturing, machining or grinding notches into a part must be avoided at all costs. Reheat-treating parts does not appear to be advisable if optimum qualities are to be obtained. Even when austenitizing at the higher temperature of 1700°F , some loss in mechanical properties to the extent of 3-4 percent was found. The addition of 0.4 percent molybdenum seemed to have little effect except to make the point of optimum properties a little more critical with respect to time in the salt (at least in the standard test bar section). This is in contradiction to published literature.

5.5. Road Wheel Arm, Material Selection.

Using the material characterization data, a quench temperature of 650°F was selected for the redesigned road wheel arms. Although the 700°F temperature properties look better, it was thought that the mass of

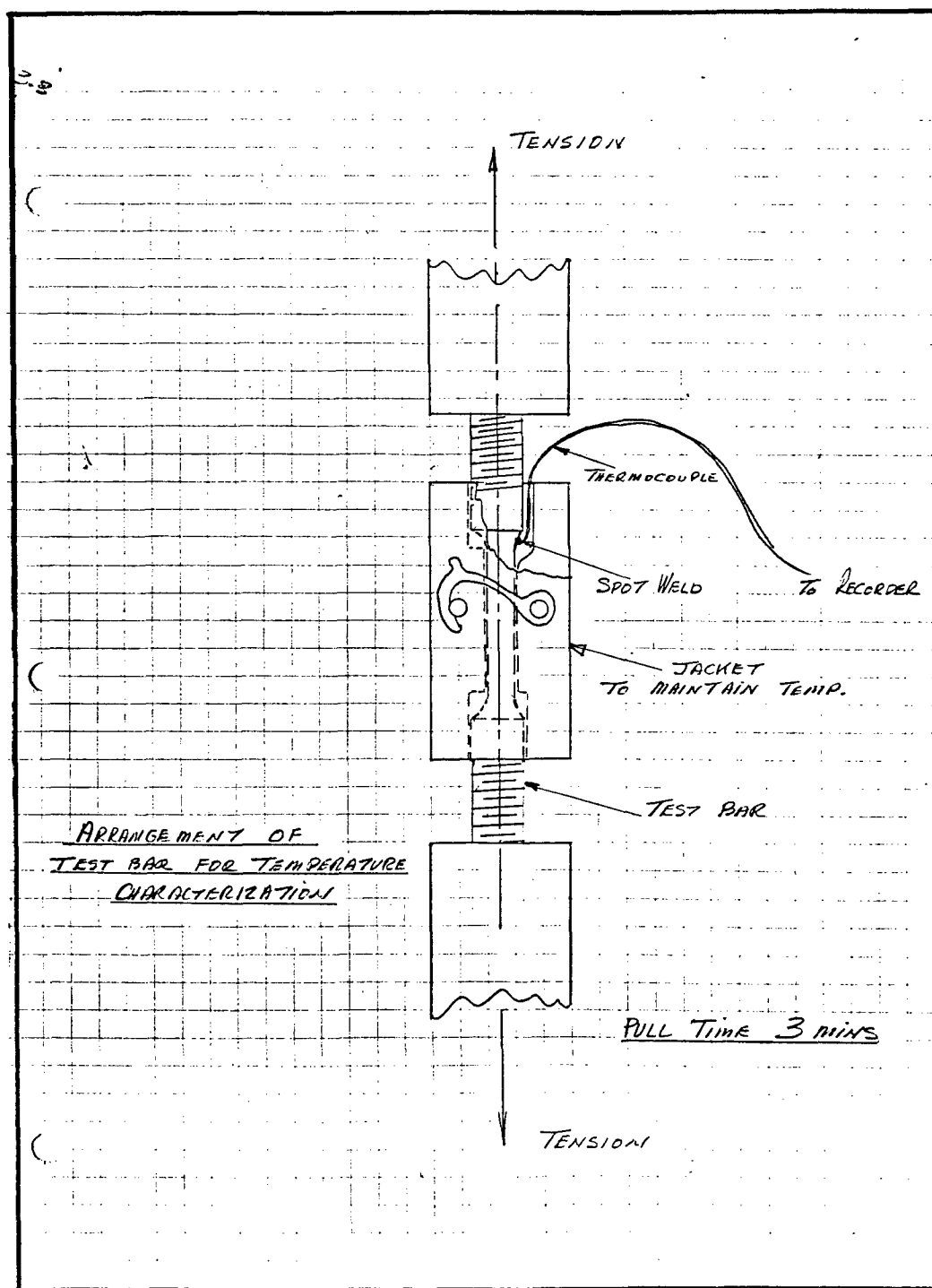


Fig. 5-3. Sketch Showing the Arrangement of Apparatus to obtain Temperature Characterization.

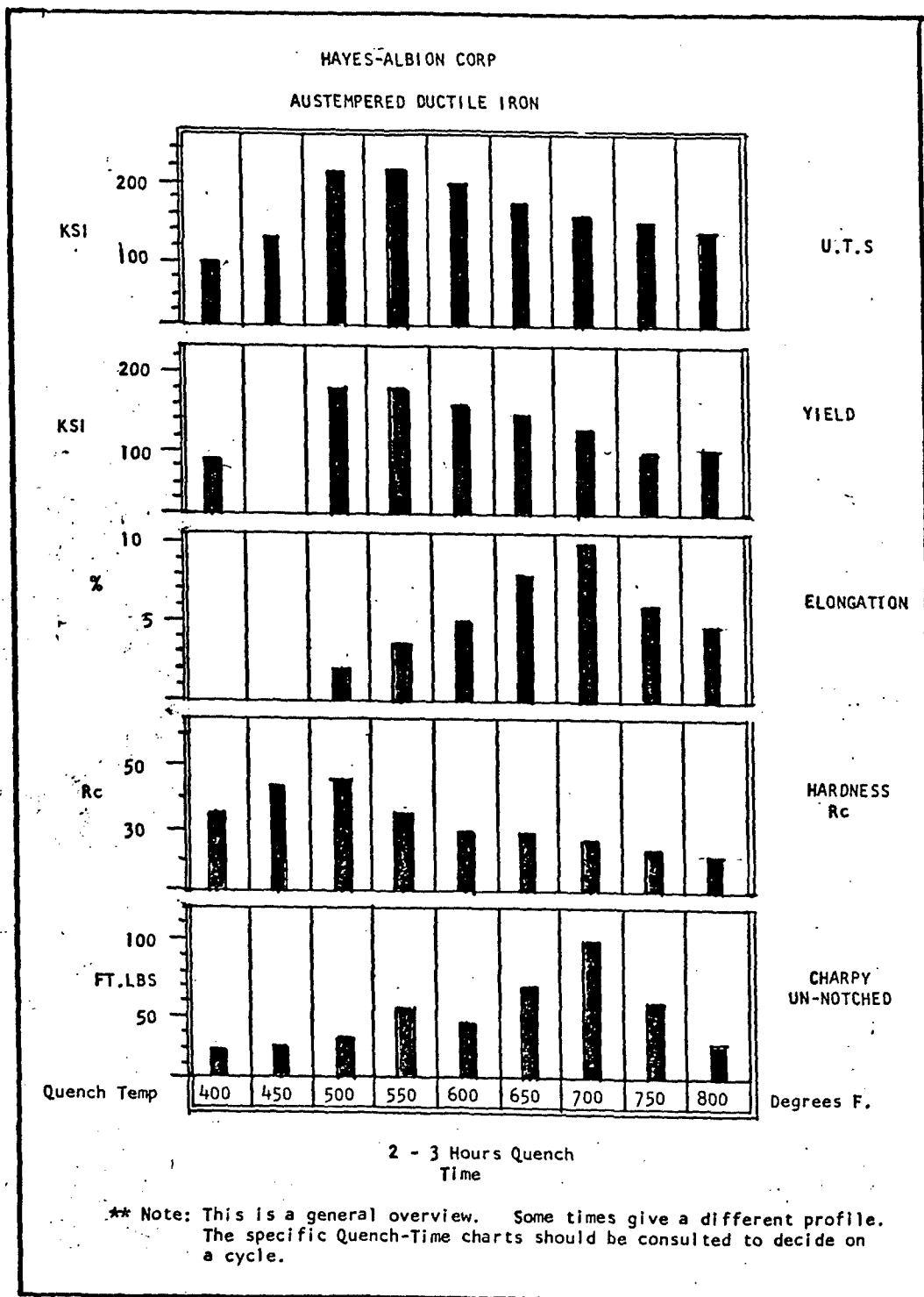


Fig. 5-4. Bar Chart Showing the Relationships between the Various Mechanical Qualities.

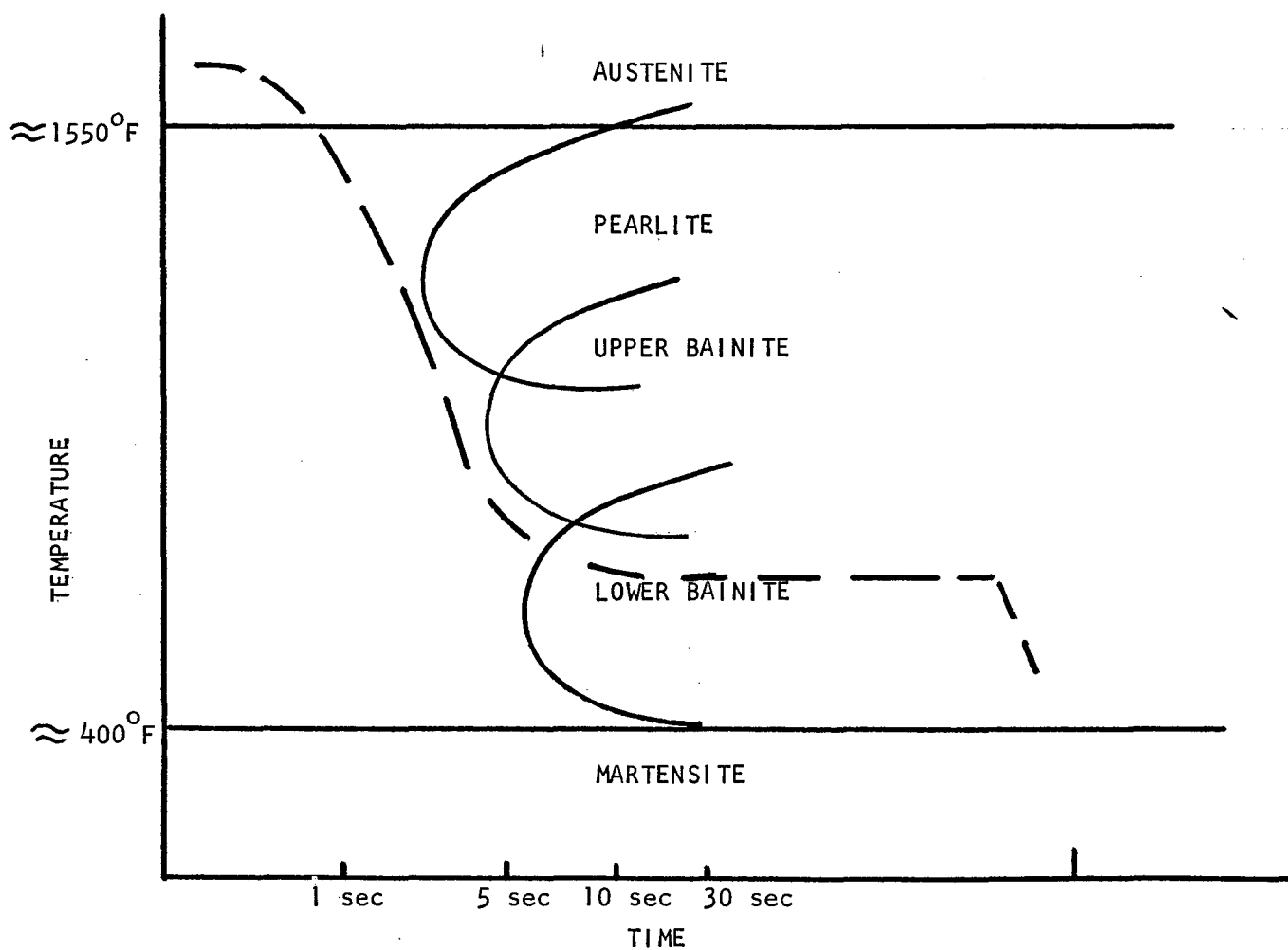


Fig. 5-5. Time-Temperature Diagram Showing the Precipitous Nature of the Quench needed to Avoid the Pearlite Field.

the arm would behave in the quench as if it were at the higher temperature. It was also decided, in deference to published research, that 0.25 percent molybdenum would be beneficial in allowing for a little more time for the transition to be effected. It was thought that the box section of the arm would require that most of the temperature drop occur from the outside and anything that pushed the "nose" of the pearlite curve towards the right of the transformation diagram would be helpful (see Fig 5-5).

5.5.1. First Sample Road Wheel Arm. A plastic pattern and two half cast-aluminum core boxes were constructed (see Fig 5-6 and 5-7). First castings were sectioned to check for uniform wall thickness. Afterwards a casting was made for static testing. This casting was X-rayed for integrity and metallurgically approved. It was machined complete then isothermally heat-treated and assembled.

5.5.2. First Static Test. For the first static test, the arm was mounted on a special shaft that was attached to a circular mounting plate. This plate was doweled and bolted to the test bed in such a way that a force of 20,000 pounds could be applied to the spindle. From a brittle lacquer survey, 15 strain gage locations were chosen (see Fig 5-8). Loads in 1000-pound increments were applied to the spindle and the strain recorded. As shown in Fig 5-9, these strains have a straight line relationship. The complete results are shown in APPENDIX F.

5.5.3. Discussion of the Static Test Results. It was obvious from the pattern of strain that besides a bending moment in the arm, a torque was also at work. The combination of these forces contributed to high stresses in certain areas, particularly at the knee of the offset. It was then decided to redesign the arm, attempting to reduce some apparent stresses of up to 38,000 p.s.i. at 20,000 pounds load. The redesign was a smoother transition of the arm into the hubs and an increase in the internal radii. At this time, an additional request for dynamic testing came from TACOM and plans were made to do this.

5.5.4. Second Static Test. Having made modifications to the arm design a second cast was made. Chemistry and test bar results from keel blocks cast in the same molds are shown in Tables 4-1c and 5-4.

5.5.5. Second Static Test Arrangement. More information about the application and duty of the component was now made available. A test rig was made in which the arm was held rigidly by a splined shaft extending six inches from both sides of the arm. The arm was inclined 17 degrees to the vertical and 14 degrees off the perpendicular in that plane. A load of 18,000 pounds was to be applied at 90 degrees to the spindle and 4,500 pounds normal to the spindle from the arm towards the wheel. This loading resulted in a load of 18,554 pounds being applied to the spindle at an angle of 14 degrees to the longitudinal centerline and away from the vehicle (see Fig 5-10). This figure shows the test setup with the load being applied as a pull towards the cylinder.

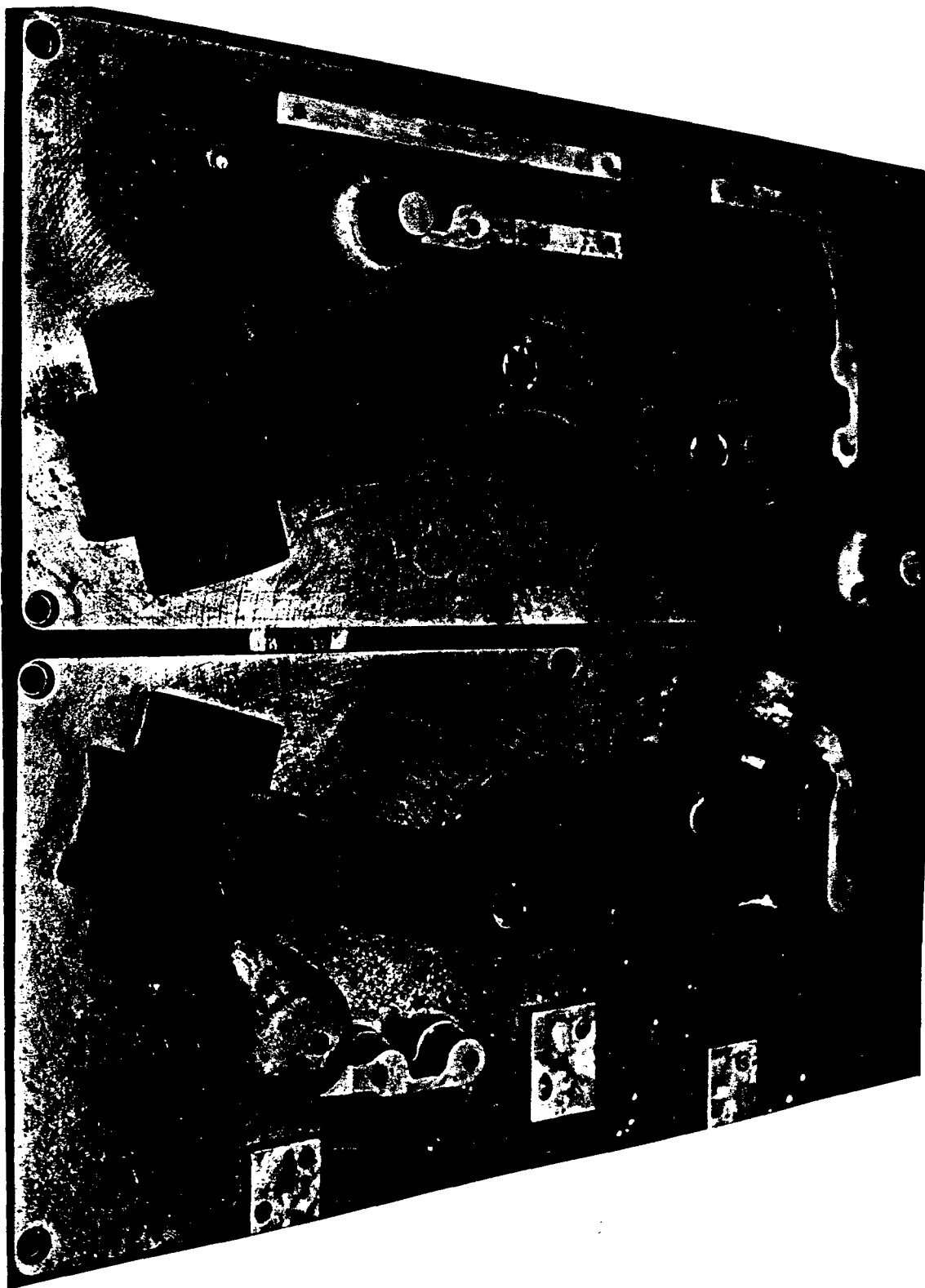


Fig. 5-6. Pattern Equipment used to produce the Road Wheel Arm.

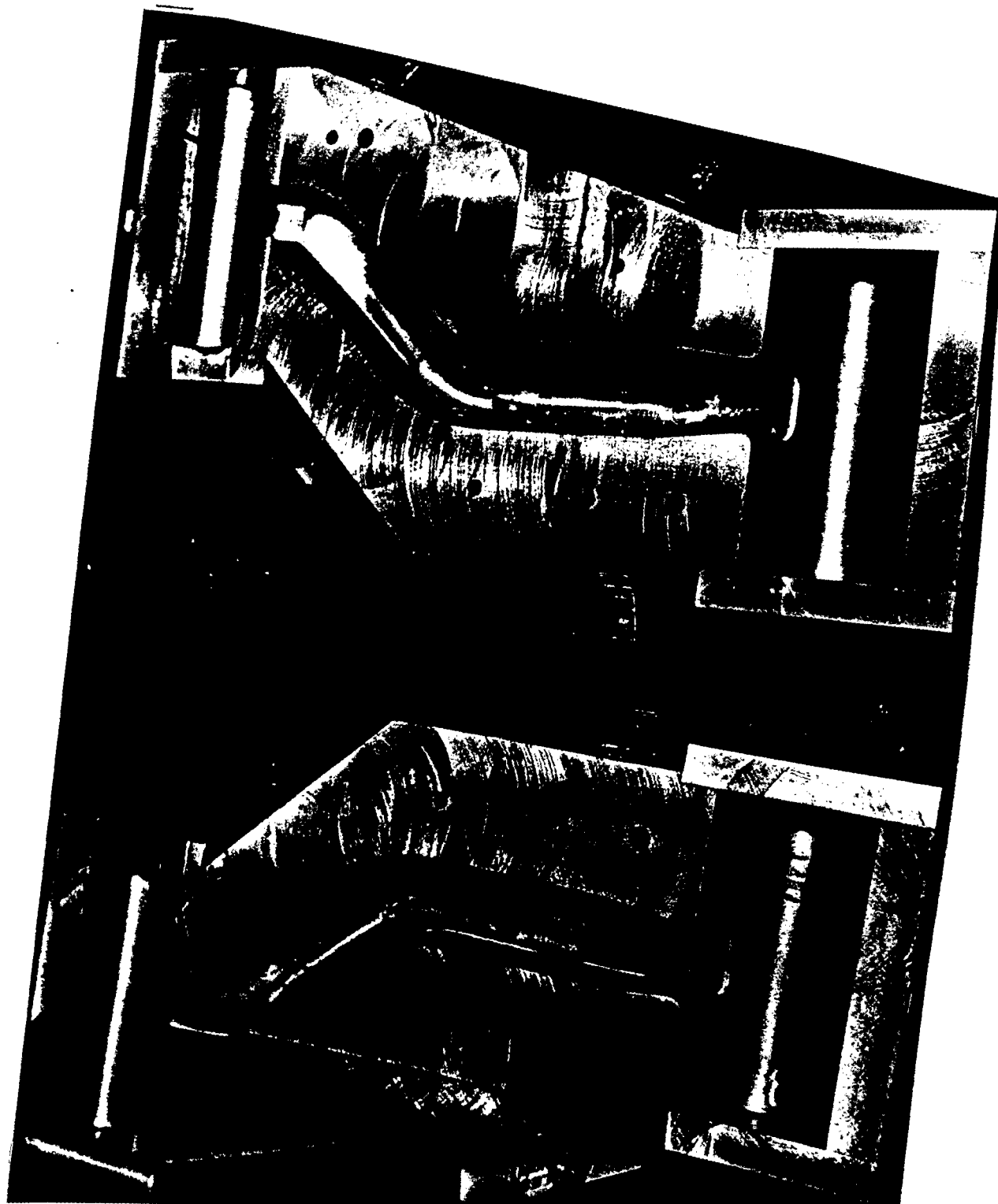


Fig. 5-7. Core Boxes used to Produce The Road Wheel Arm

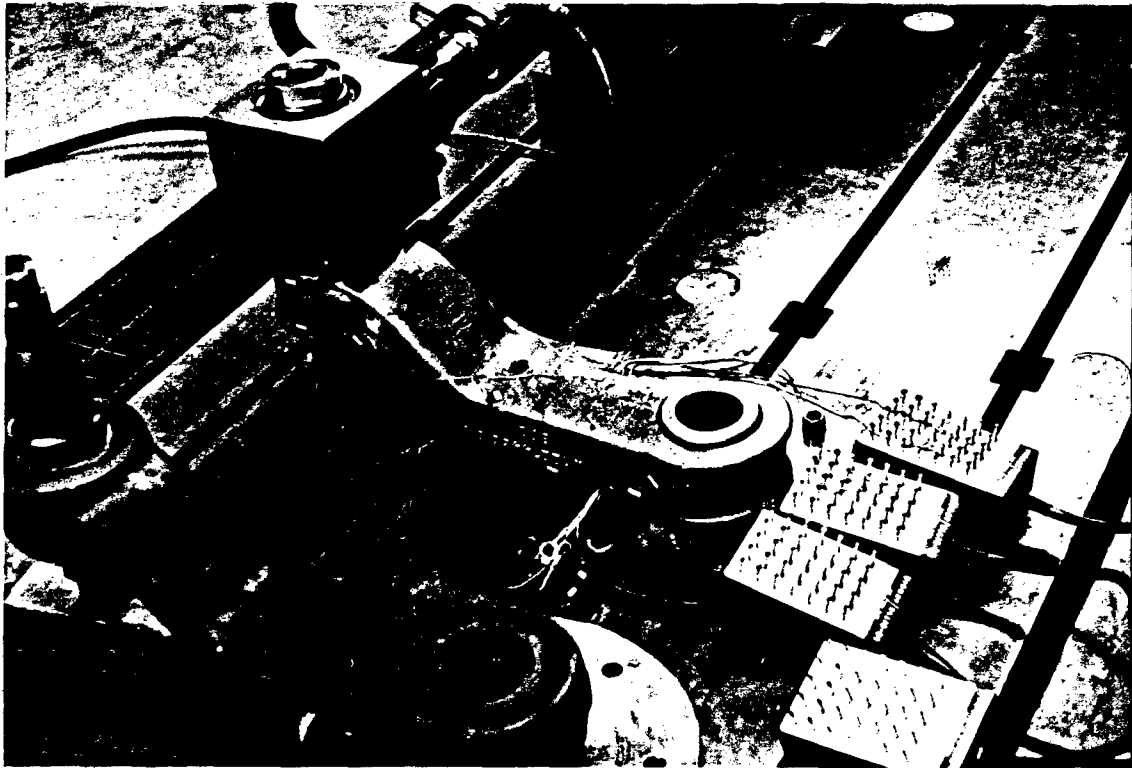


Fig.5-8 First Static Test Set-up. Comparison of the casting with the forging can be seen in this picture. Multiple strain gage attachment posts are shown in the lower right-hand corner.

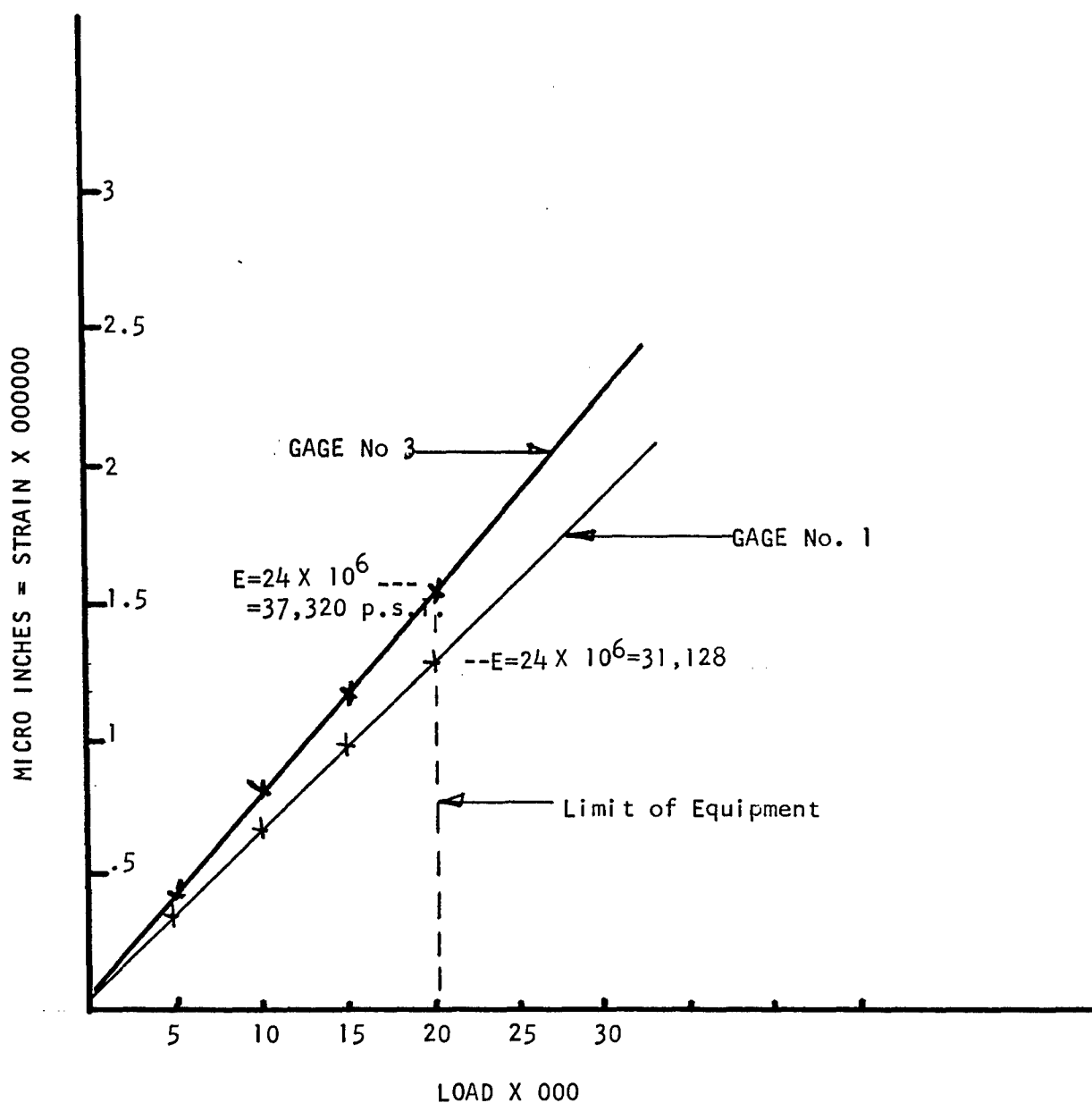


Fig. 5-9. Graph of Readings from Highest Value Strain Gages
 E = Young's Modulus of Elasticity. The value 24×10^6
 was found experimentally during this project.

Table 5-4. Test Bar Results from BDI with the Chemistry Shown in Table 4-1c. This is questionable material.

Tensile p.s.i.	Yield p.s.i.	Elongation percent
165,000	135,000	2.5



Fig. 5-10. Second Static Test Set-up. This Set -up is also that Used for the Dynamic Testing. Notice that the power cylinder is at a lateral as well as a longitudinal angle to the center line of the fixture

Table 5-5. Second Static Test Strain Gage Results

LOAD	Strain Gage Numbers					
	11	3	2	15	12	11
	Microinches					
1000	-36	-46	-48	14	50	94
2000	-75	-111	-92	19	95	190
3000	-116	-117	-133	24	139	282
4000	-150	-235	-173	29	179	367
5000	-187	-296	-214	34	222	456
6000	-225	-360	-257	39	267	551
7000	-261	-419	-298	44	308	640
8000	-300	-483	-343	49	354	737
9000	-337	-544	-384	54	398	831
10000	-370	-599	-424	59	436	914
11000	-407	-659	-467	64	480	1007
12000	-446	-720	-512	69	525	1103
13000	-482	-778	-554	74	567	1194
14000	-518	-834	-596	79	609	1283
15000	-552	-889	-636	84	649	1369
16000	-590	-950	-682	90	695	1467
17000	-624	-1004	-722	95	736	1554
18000	-660	-1061	-765	100	778	1645
19000	-697	-1120	-810	105	823	1740
20000	-721	-1158	-839	109	852	1804

5.5.6. Second Static Test Results. From a brittle lacquer survey, six strain gage sites were selected. These were approximately in the same positions as the first strain gage survey and were numbered accordingly. Table 5-5 shows the results.

5.5.7. First Dynamic Test Procedure. Initially a 20,000 pound capacity load cell was calibrated using a Satec Universal Test System and a Hewlett-Packard X,Y Plotter to record the calibrated curve. The load cell was then placed into a test apparatus which consisted of an MTS Testline 820 Structural Test System, a bolted down frame, and a tank arm assembly. With an upper limit of 19,600 pounds and a lower limit of 2,000 pounds, the arm was cycled at 2.5 hertz. Each day the load cell was shunt calibrated to correct any electronic drift that might have occurred. The load cell's shunt calibration limits and the attenuator's displacement were recorded with a Gould brush recorder and documented. Failure of the arm occurred at 596,720 cycles against a 650,000 target.

5.5.8. Analysis of Failure. Fig. 5-11 illustrates the location of the fracture. It was determined that the fracture originated in the tapped hole, propagating across the area of high stress caused by the bending and torque moments. The substandard material compounded the failure.

5.5.9. Third Static Test. In anticipation of this failure, a second cast was made with an analysis shown in Table 4-1c. This is a base nodular iron with an addition of molybdenum. (note that the Mo addition is almost half the amount in the first dynamic test). Test bars from this heat gave the results shown in Table 5-6. This is excellent material, but in particular the elongation is twice that of the previous dynamic test specimens. This would indicate that Mo additions must be made with caution. Current thinking is that Mo should not exceed 0.25 percent. No holes were drilled in the arm. Two strain gage rosettes were attached in areas of high stress. The readings from these rosettes are shown in Table 5-7, with positions shown in Fig. 5-12. The highest strain of 1,550 microinches translates to 37,200 p.s.i.

5.5.10. Second Dynamic Test. Dynamic testing began under the same conditions as explained in 5.5.7. At 1,037,620 cycles, the test was terminated. The tank arm was then removed from the apparatus and given a Magnaflux test to check for cracks. None was found.

5.5.11. Analysis of Second Dynamic Test. It is obvious from the foregoing results that the arm design and material are adequate for the application. Data now obtained would allow fine tuning of the design and add even further to the safety factor and life.

5.5.12. Manufacture of the 14 Contract Arms. The required completion

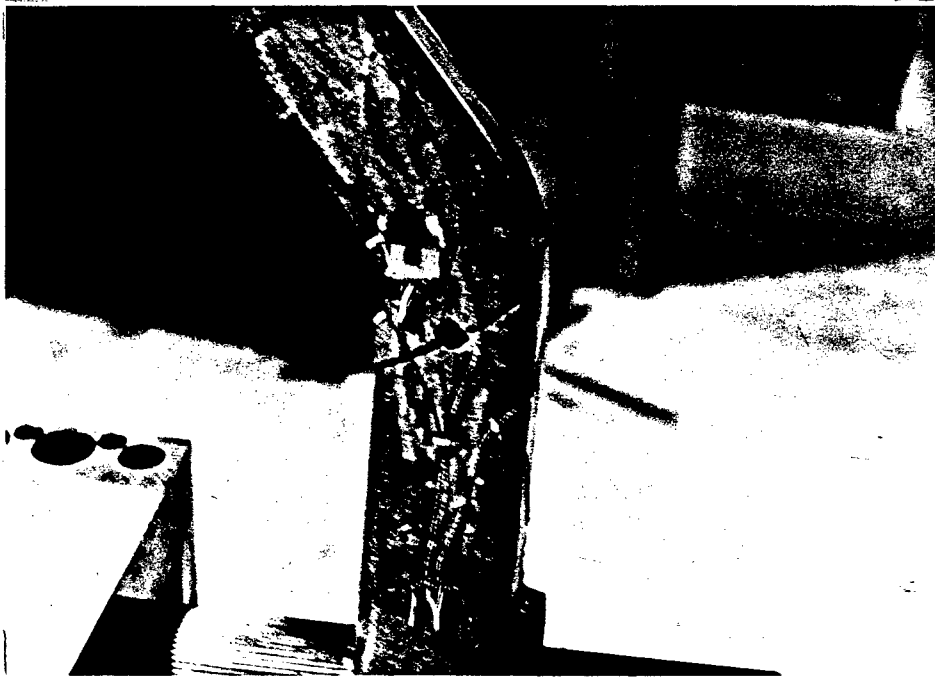


Fig. 5-11. Fracture of First Dynamic Test Arm. The Tapped hole was originally installed in order to allow a filler to be installed into the interior of the arm.

Table 5-6. Test Bar Results of BDI in Second Dynamic Test Specimen. This is excellent material.

Bar No.	Tensile p.s.i.	Yield p.s.i.	Elongation percent
1	195,400	165,000	5
2	196,600	163,400	6
3	193,900	163,300	4
4	196,400	166,800	5
5	194,800	167,500	5

Table 5-7. Readings from Rosett Strain Gages, Second Dynamic Test

ROAD WHEEL ARM STRAIN READINGS
TEST #2

GAGES

Load	Upper Rosett			Lower Rosett		
	Ø	1	2	3	4	5
Ø	Ø	Ø	Ø	Ø	Ø	Ø
1K	83	40	5	66	33	-32
2K	160	79	10	106	67	-40
3K	240	122	14	146	101	-54
4K	318	162	20	186	136	-63
5K	394	203	25	224	172	-73
6K	471	246	31	261	205	-84
7K	548	288	38	300	238	-93
8K	626	331	45	337	272	-101
9K	702	374	51	375	308	-110
10K	780	417	58	412	342	-117
11K	859	460	64	451	375	-126
12K	934	501	71	488	412	-131
13K	1013	544	77	527	448	-139
14K	1090	586	83	567	483	-144
15K	1166	631	90	605	521	-153
16K	1244	670	97	646	560	-157
17K	1322	713	106	687	598	-166
18K	1398	755	110	728	634	-173
19K	1474	799	117	770	673	-180
20K	1550	838	123	812	709	-187

Principal strains and their corresponding stresses were calculated based on a 20,000 pound load:

Upper Rosette: $\epsilon_{\text{Max}} = 1,903 \mu\text{in. per in.}$ $\sigma_{\text{Max}} = 43,267 \text{ p.s.i.}$
 $\epsilon_{\text{Min}} = 229 \mu$ " $\sigma_{\text{Min}} = 11,999 \text{ p.s.i.}$
 $\tau_{\text{Max}} = 2,132 \mu$ " $\tau_{\text{Max}} = 23,451 \text{ p.s.i.}$
 $\phi_{\text{Max}} = 45^\circ$

Lower Rosette $\epsilon_{\text{Max}} = 1,079 \mu\text{in. per in.}$ $\sigma_{\text{Max}} = 22,023 \text{ p.s.i.}$
 $\epsilon_{\text{Min}} = -109 \mu$ " $\sigma_{\text{Min}} = 7,338 \text{ p.s.i.}$
 $\tau_{\text{Max}} = 1,270 \mu$ " $\tau_{\text{Max}} = 18,060 \text{ p.s.i.}$
 $\phi_{\text{Max}} = 32.5^\circ$

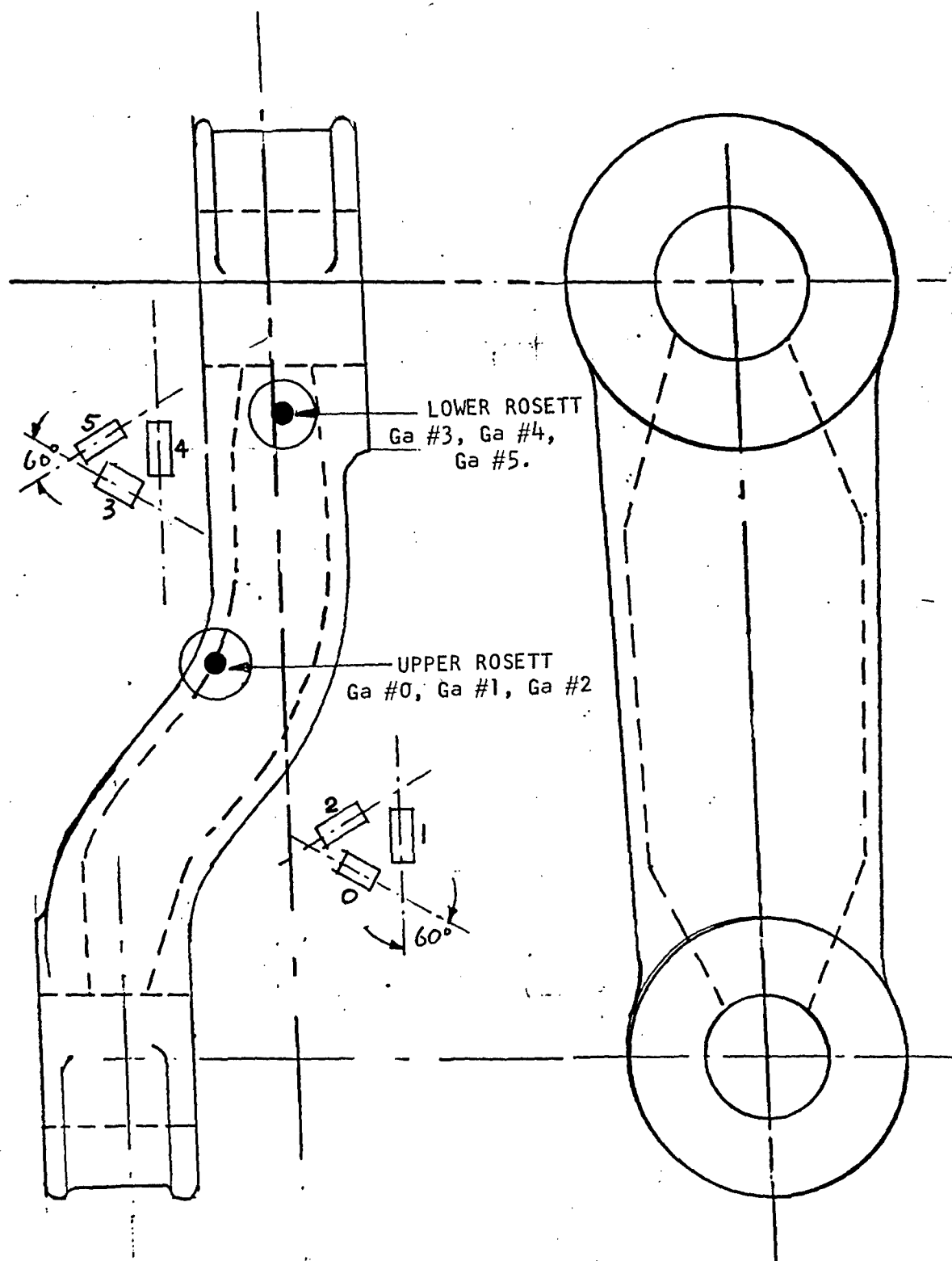


Fig. 5-12. Position of Rosett Strain Gages. These gages are positioned so that one is normal and the other two are at an angle of 45° to No 1 and 90° to each other.

of the 14 arms was then completed without incident. The fact that the heat-treatment was done after machining required that an allowance be made for growth of 0.002 ins. per inch. Heating the arm in order to shrink the spindles in place was done by induction and held to a maximum of 400°F, the spindles being frozen to -100°F. An application of Loctite 620 was made to the inboard side of the splined spindle where it mates with the arm to seal off the spline from oil seepage. The weld called for on the outboard end of the splined spindle was done by heliarcing a silver solder into a "V". No metallurgical damage occurred as this was only a seal and not a structural weld.

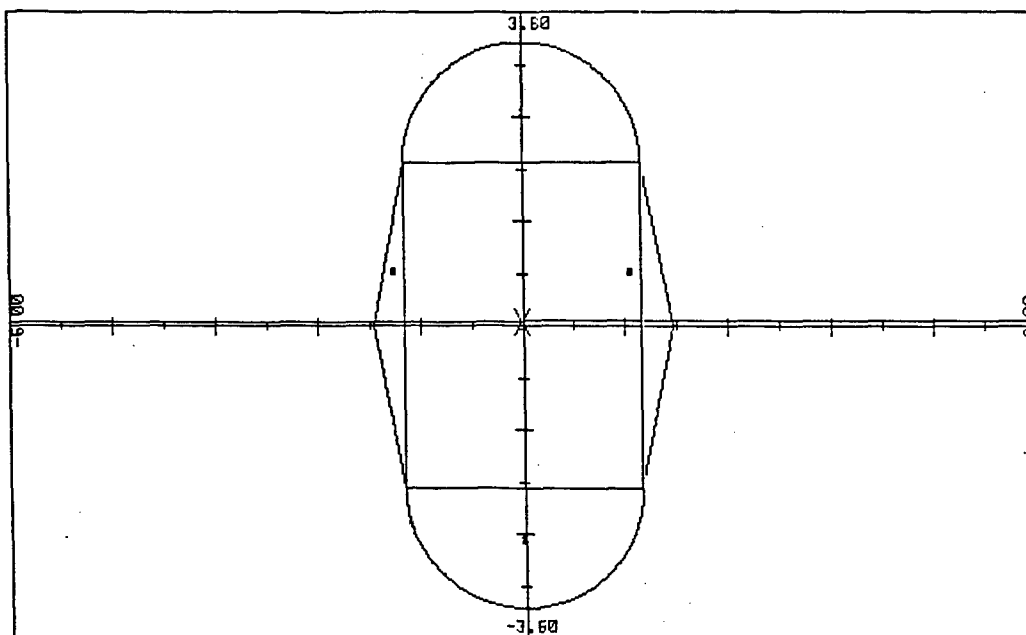
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APPENDIX A
COMPARATIVE CALCULATIONS
ON
THREE DIFFERENT CROSS-SECTIONS

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 SECTION ANALYSIS



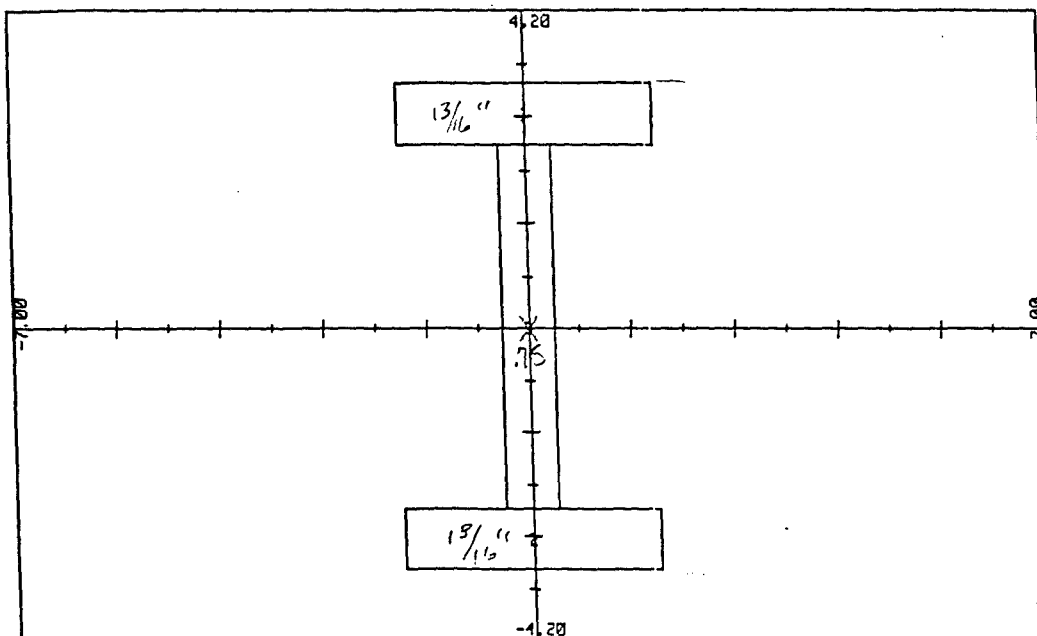
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HAYES-ALBION CORPORATION
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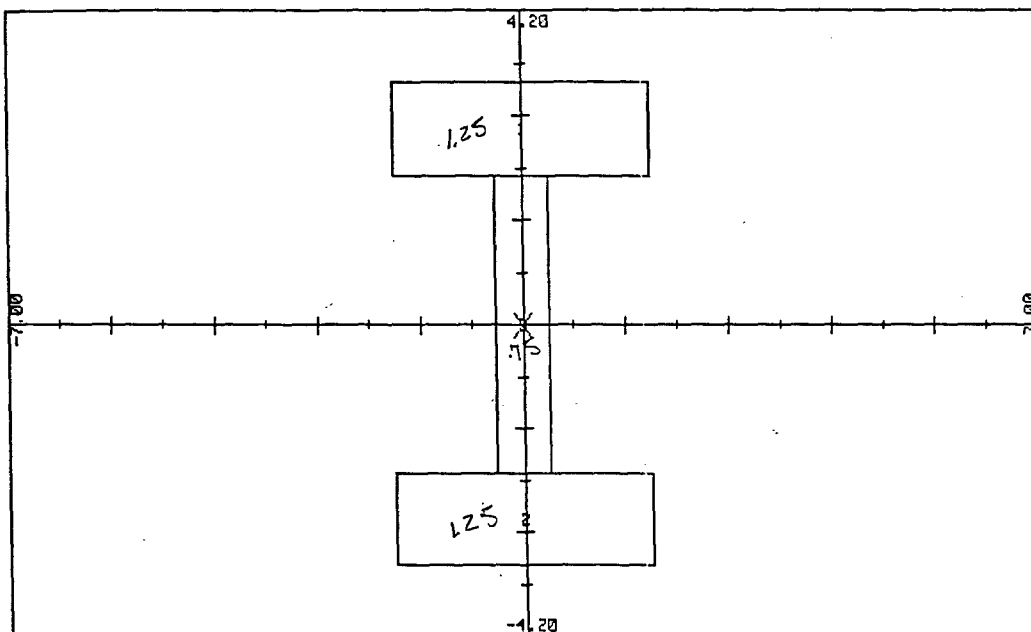
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P2-2

HAYES-ALBION CORPORATION
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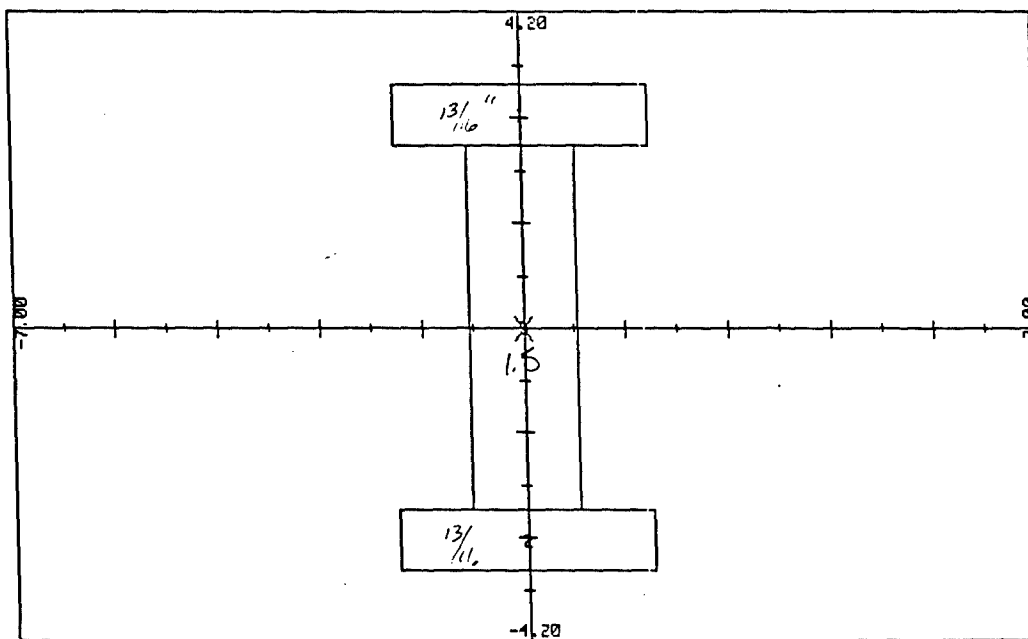
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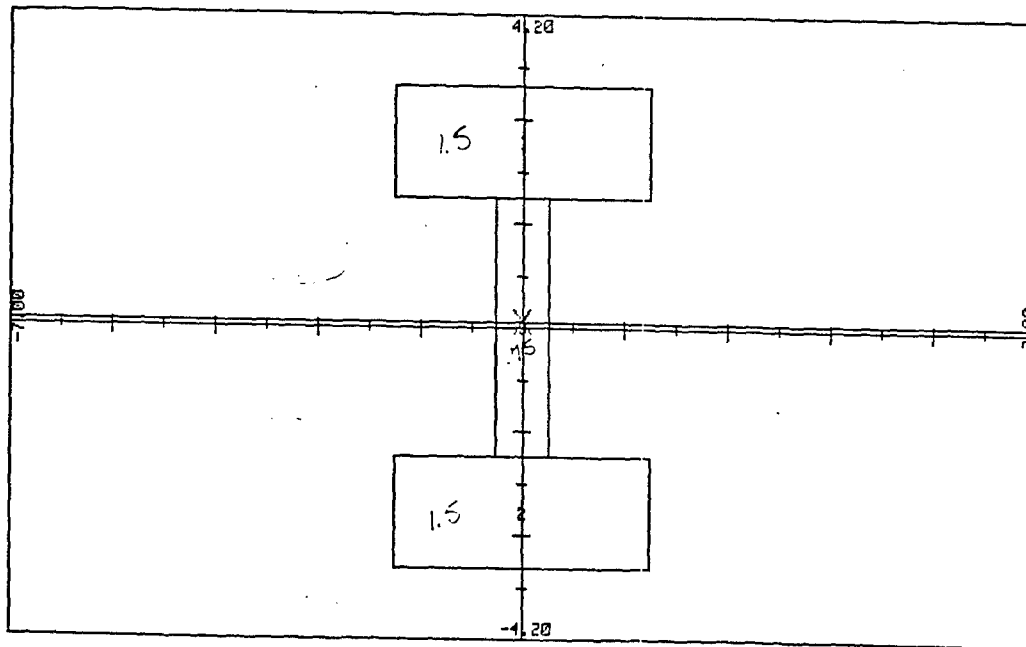
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HAYES-ALBION CORPORATION
SECTION ANALYSIS



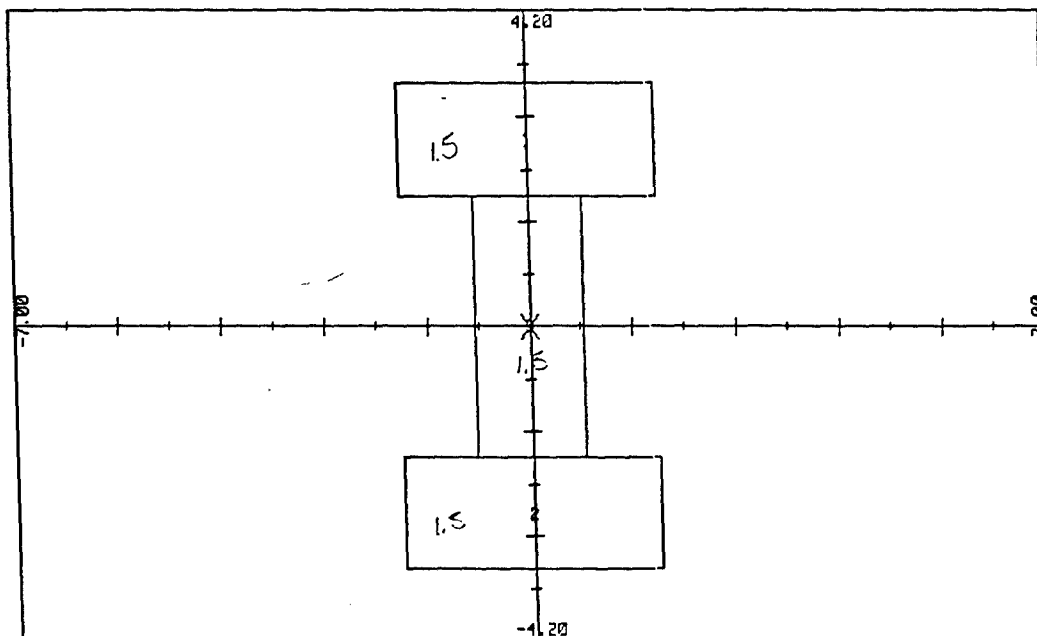
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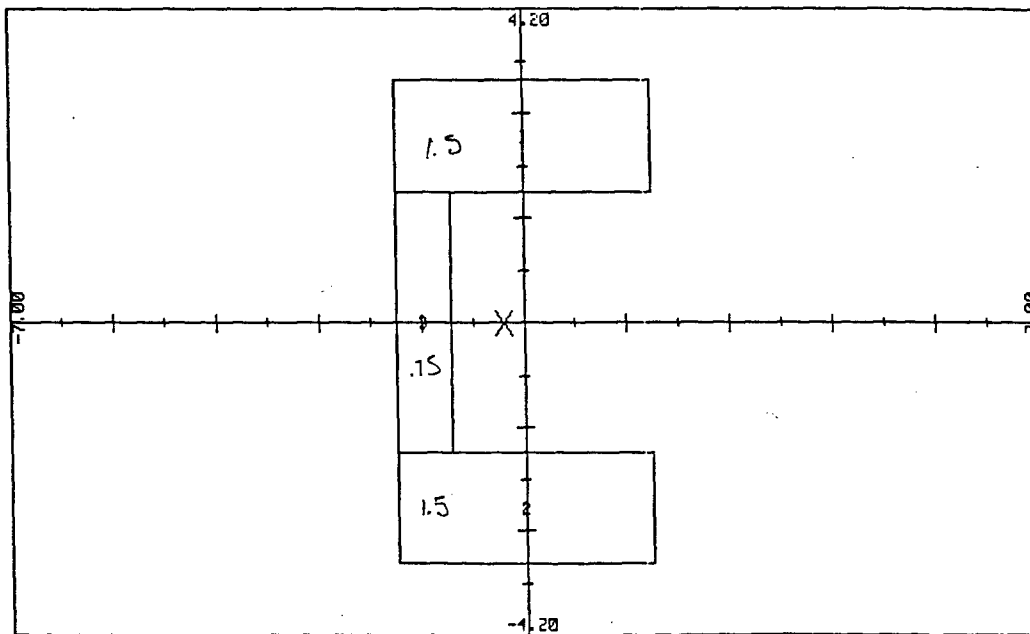
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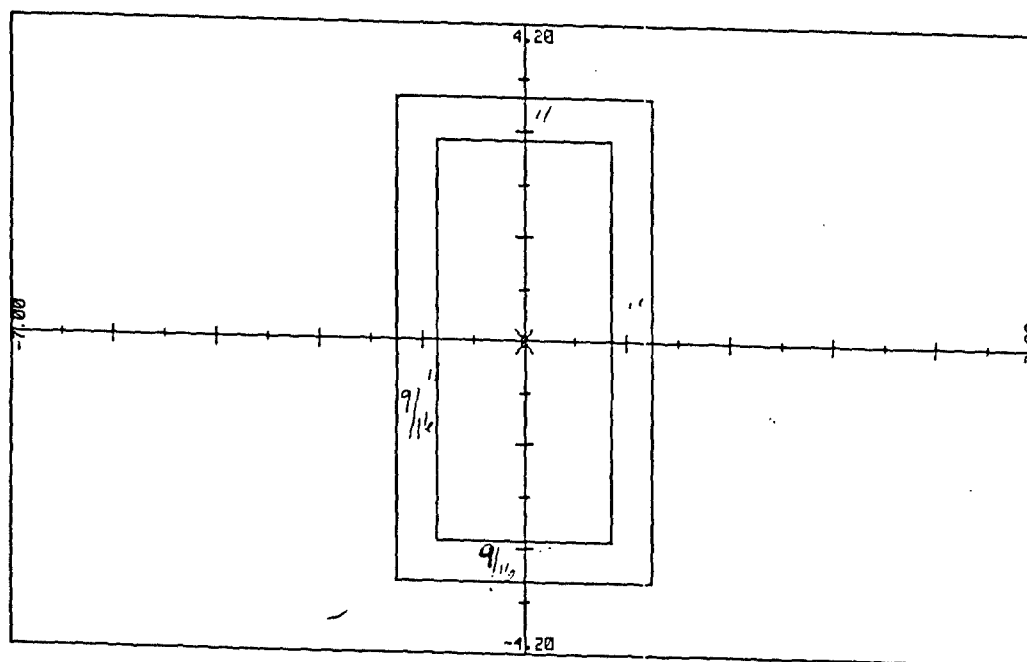
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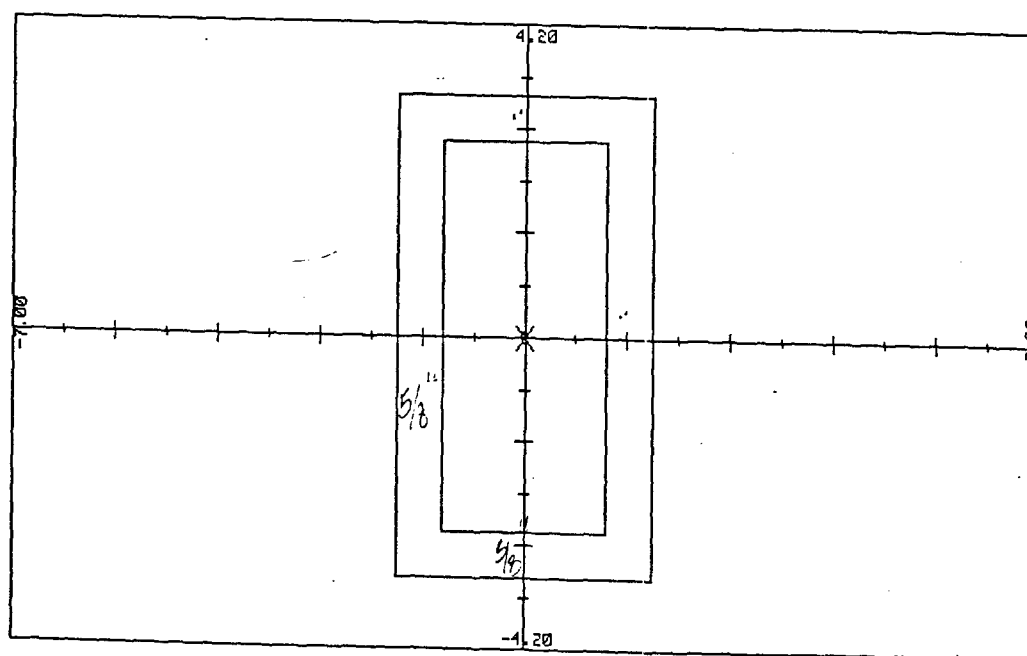
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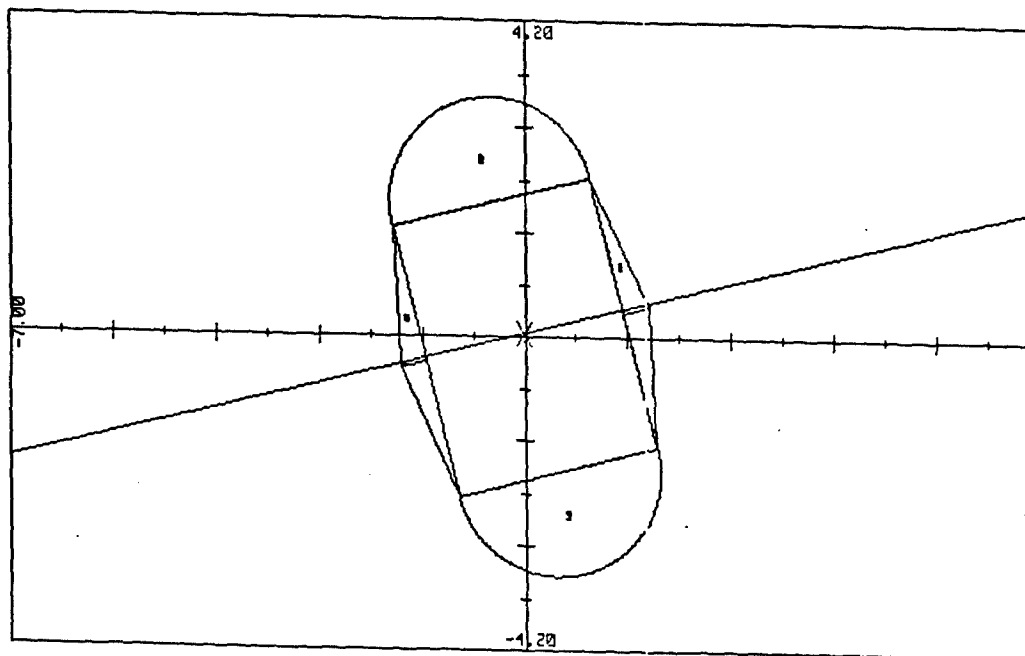


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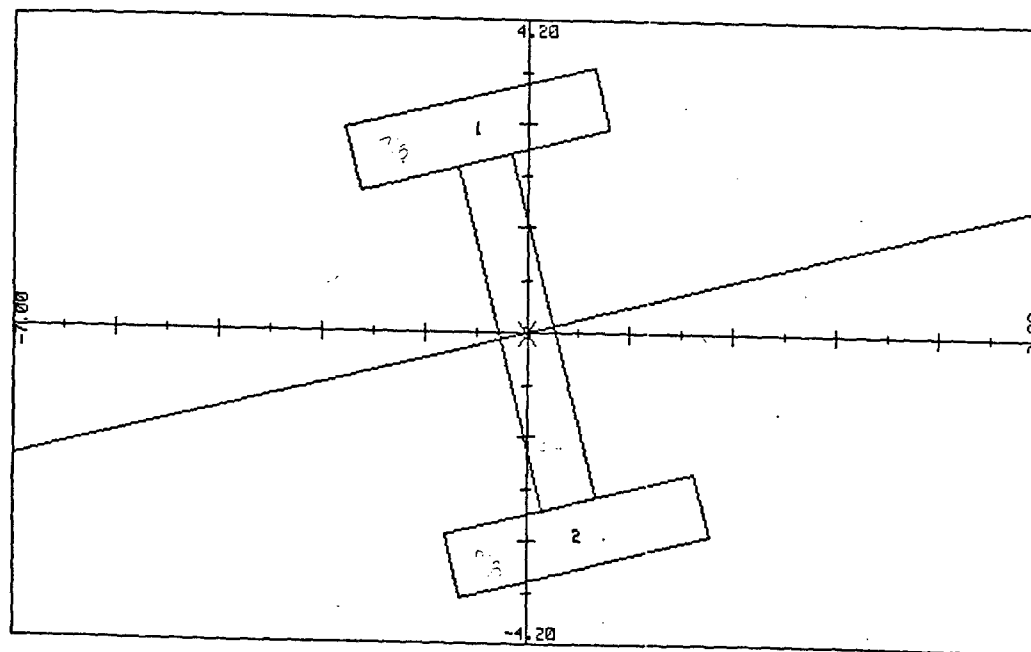
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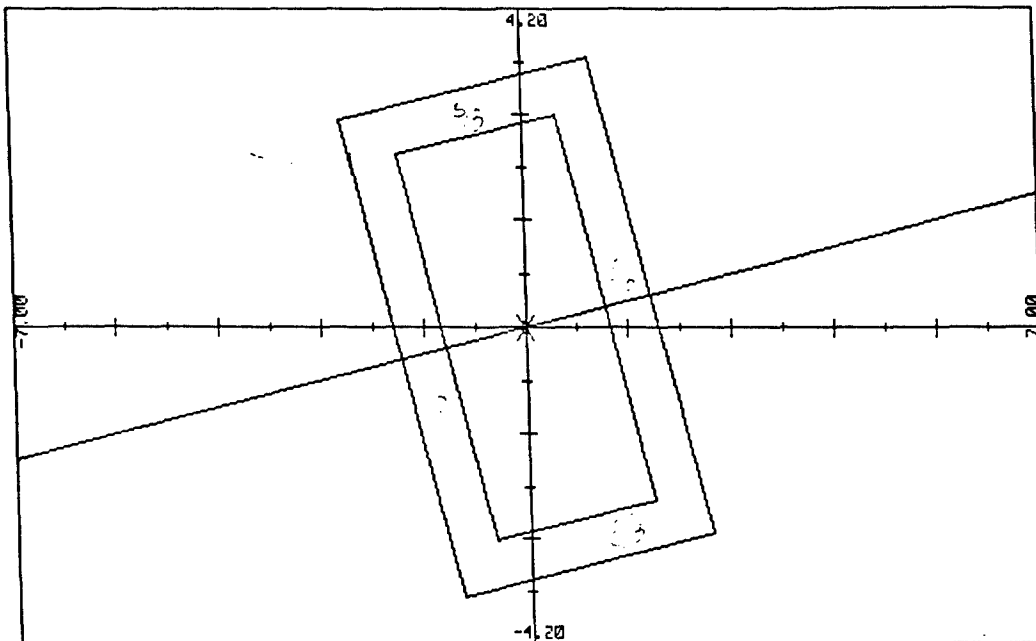
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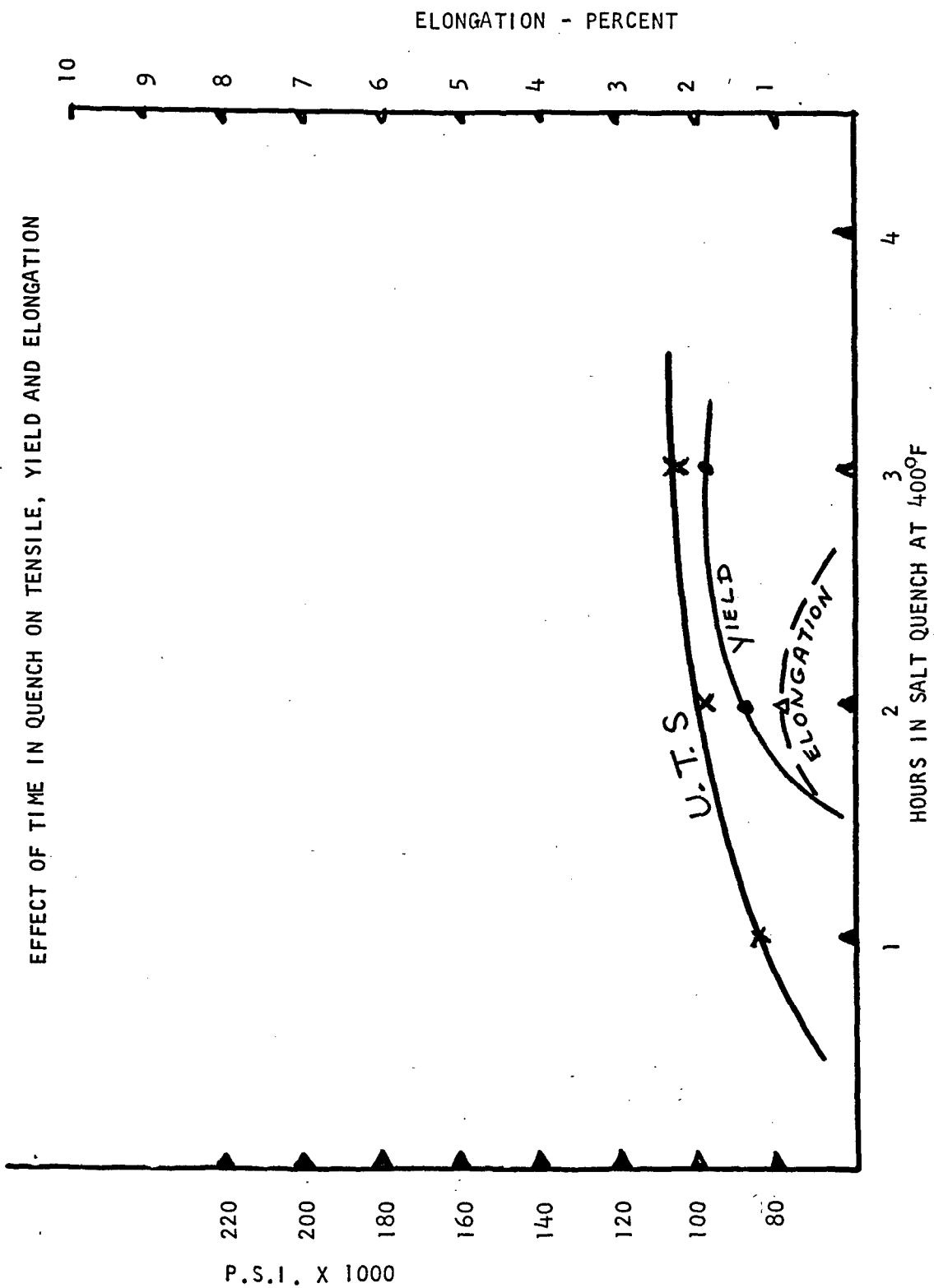
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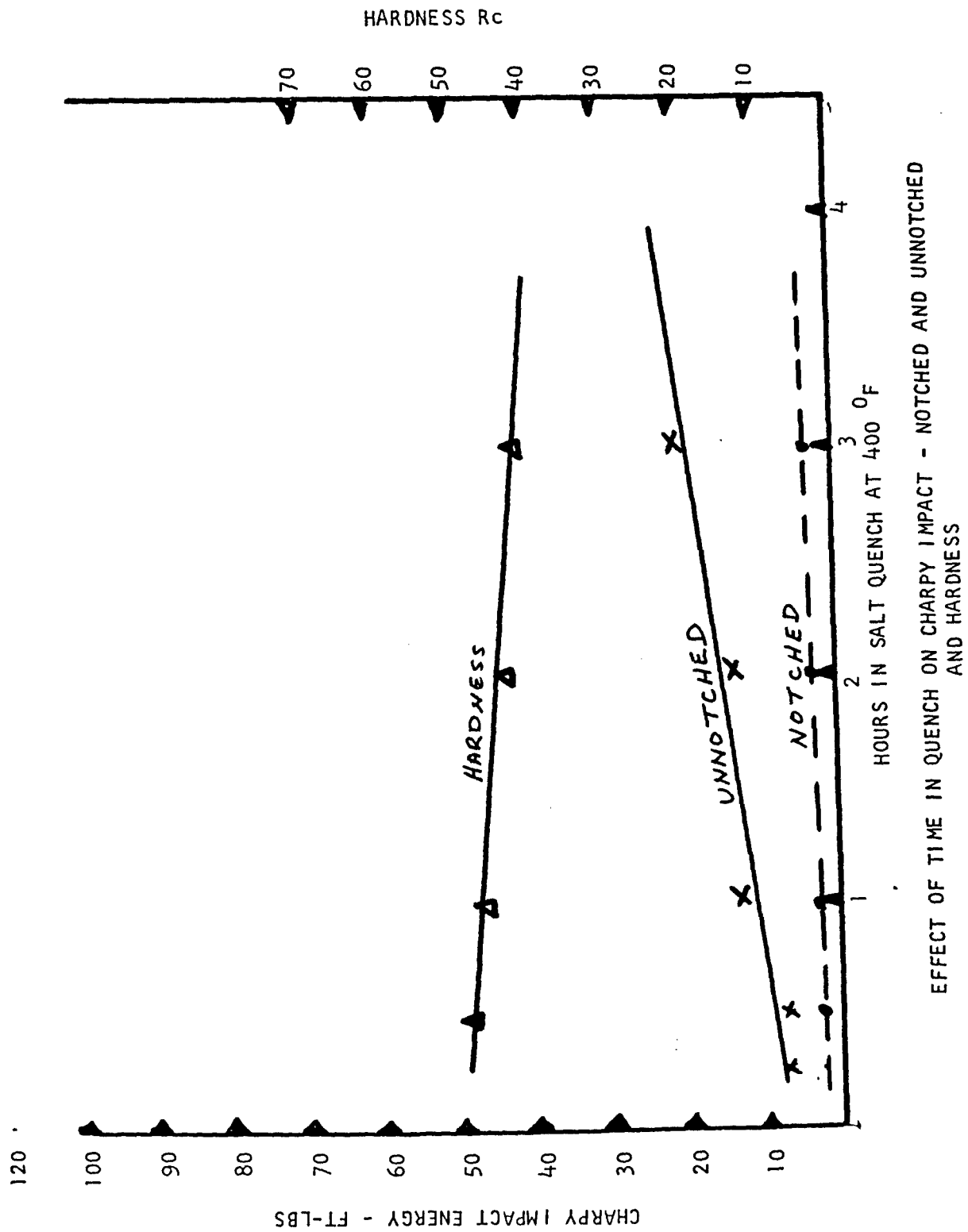
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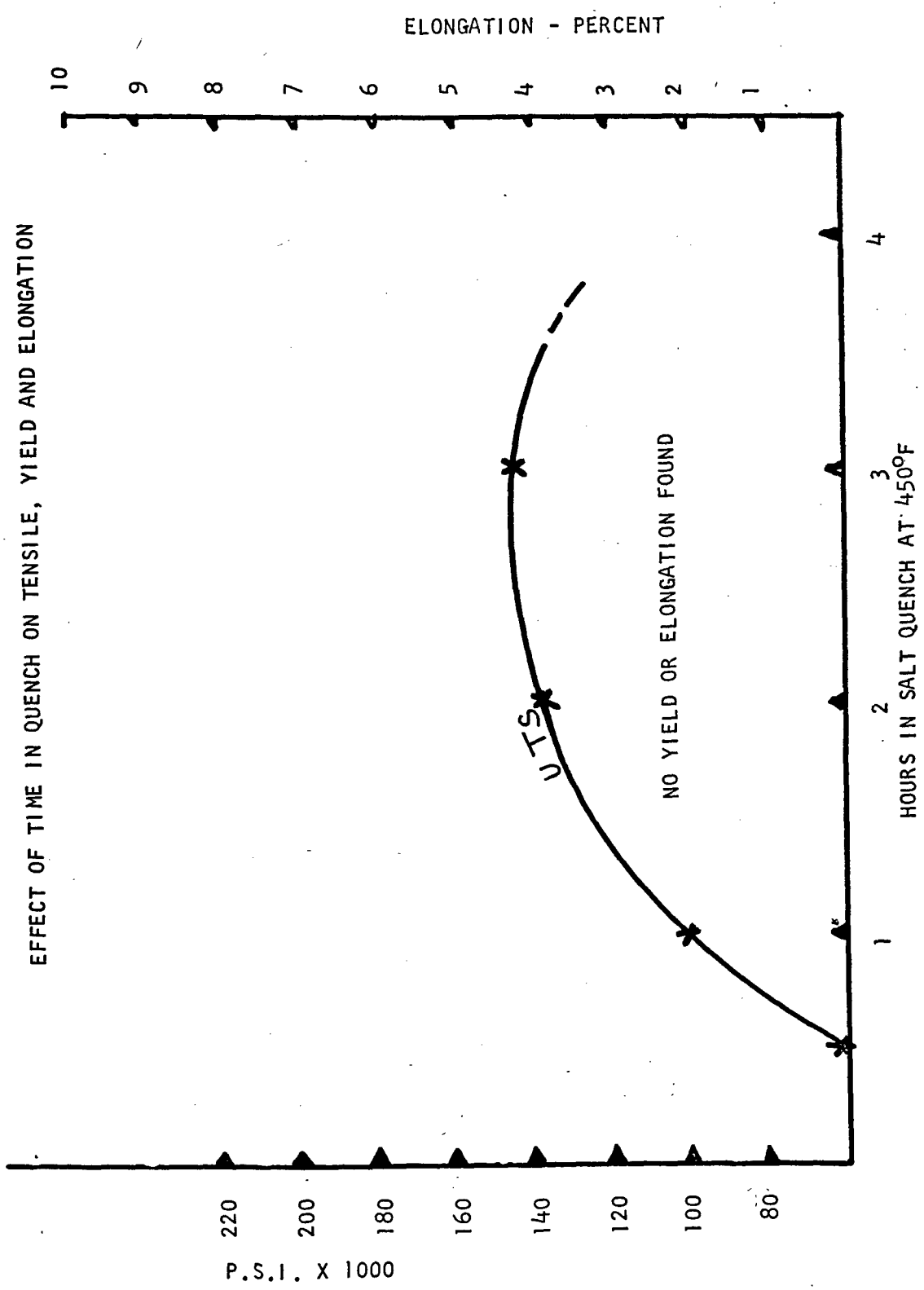
APPENDIX B
EFFECT OF VARYING QUENCH TEMPERATURE
AND TIME
ON
MECHANICAL PROPERTIES

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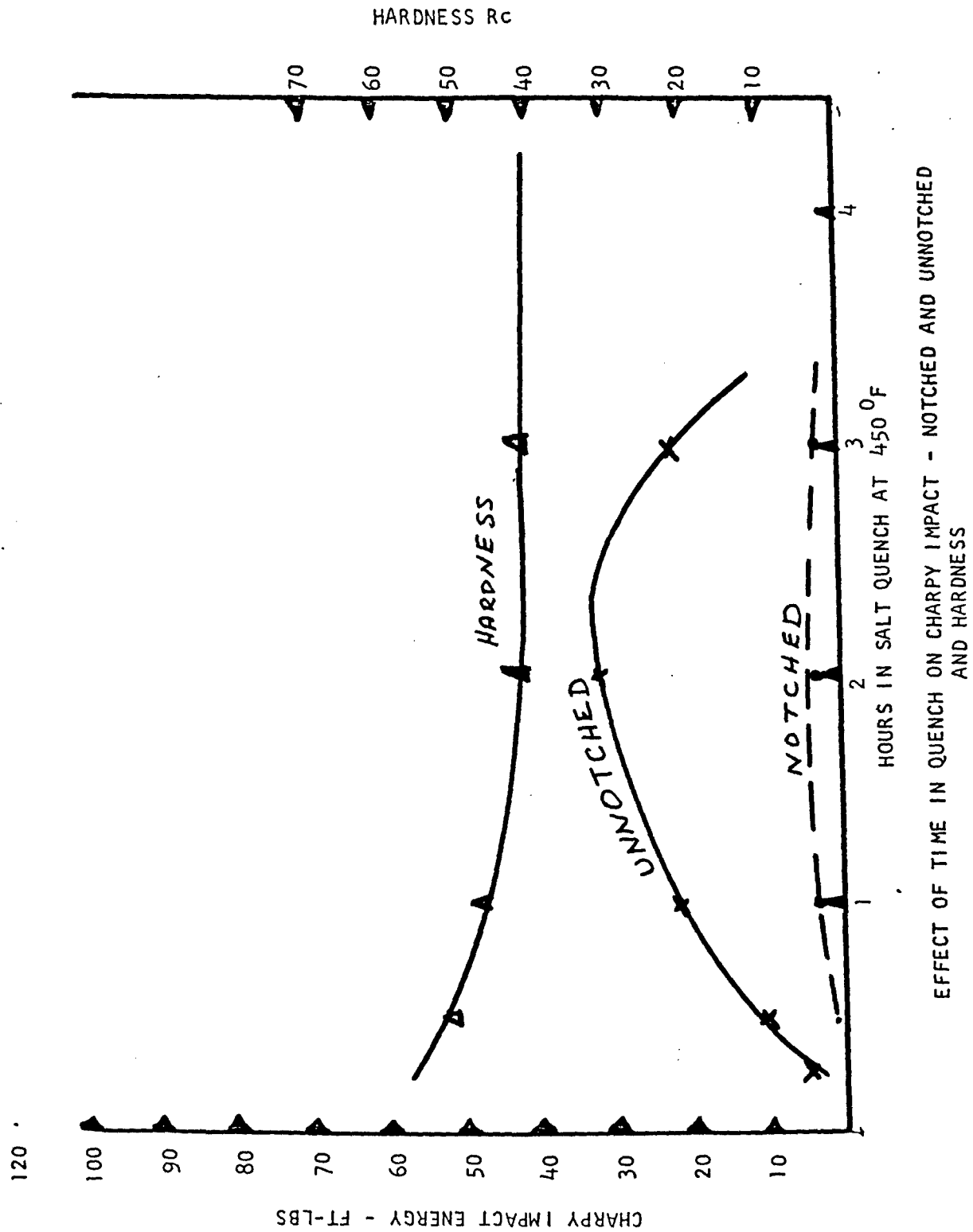


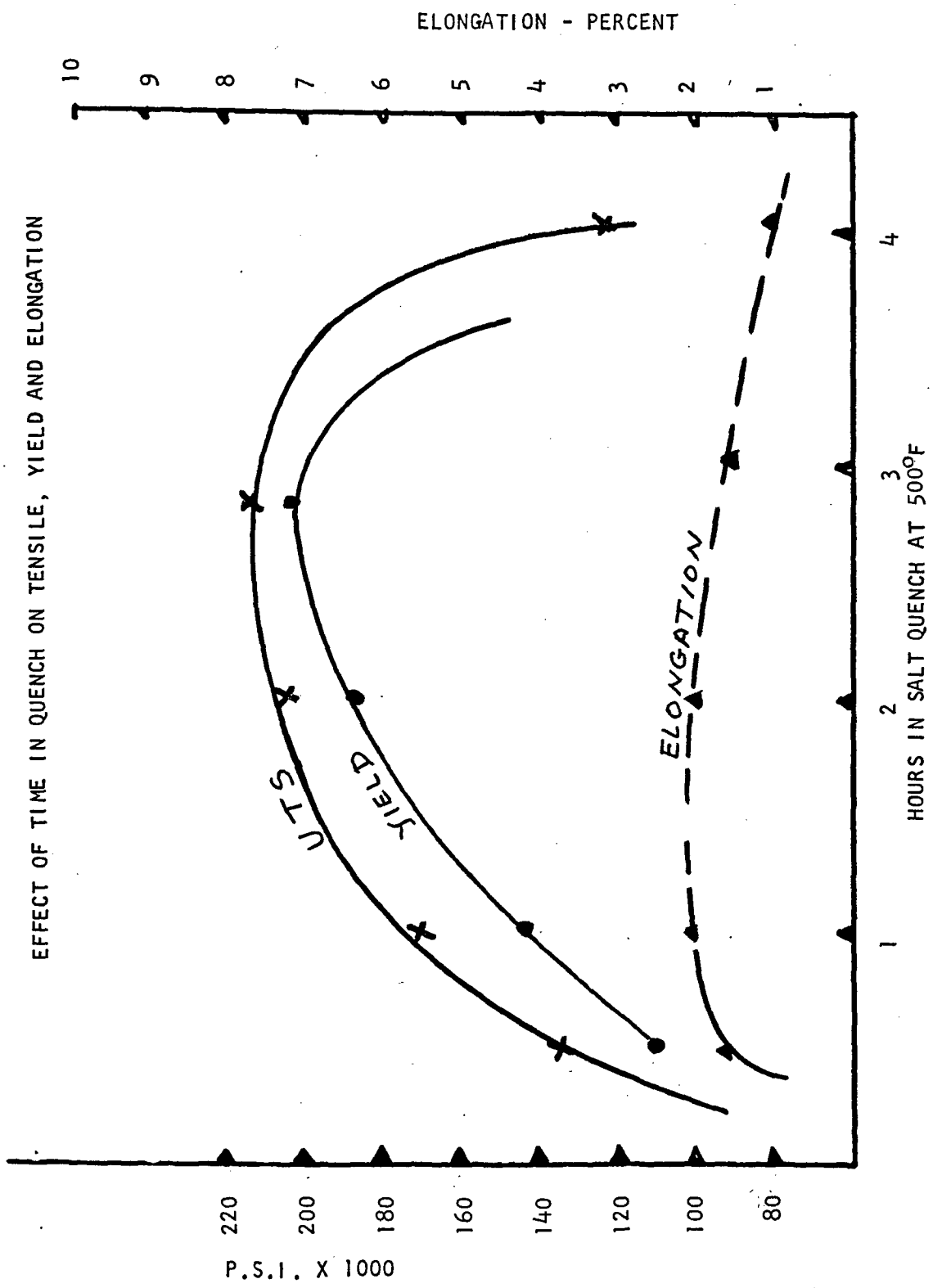
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Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.



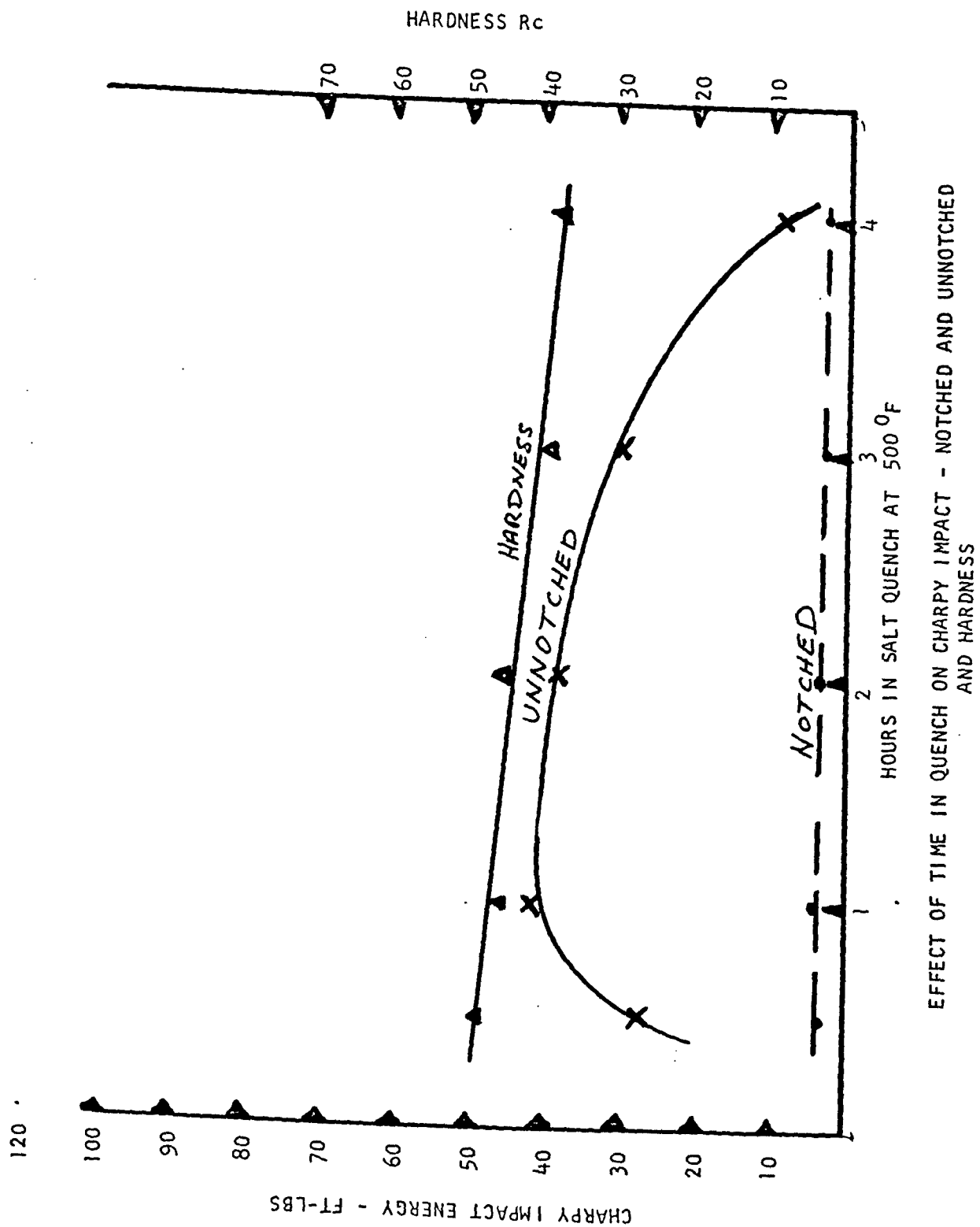


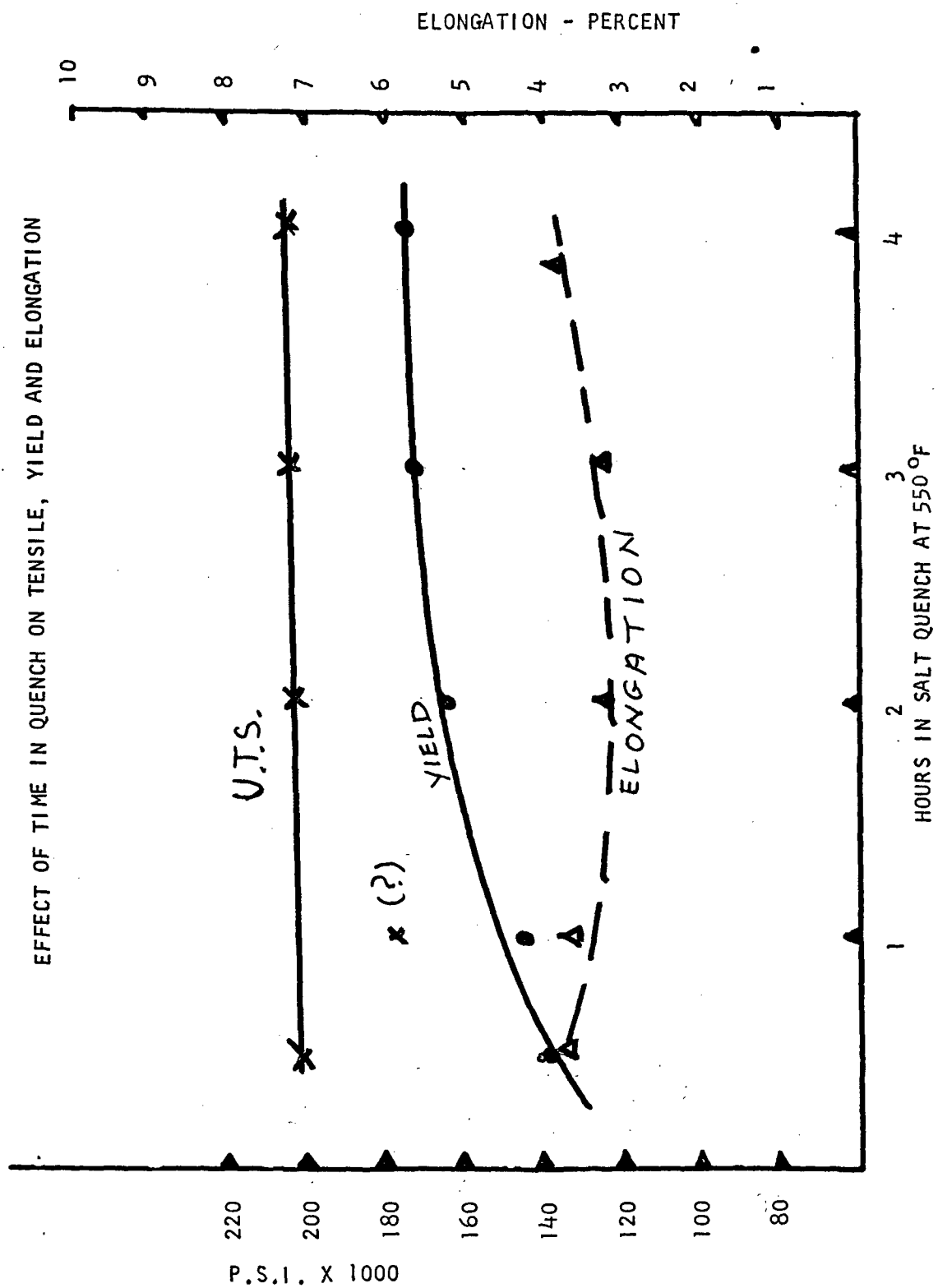
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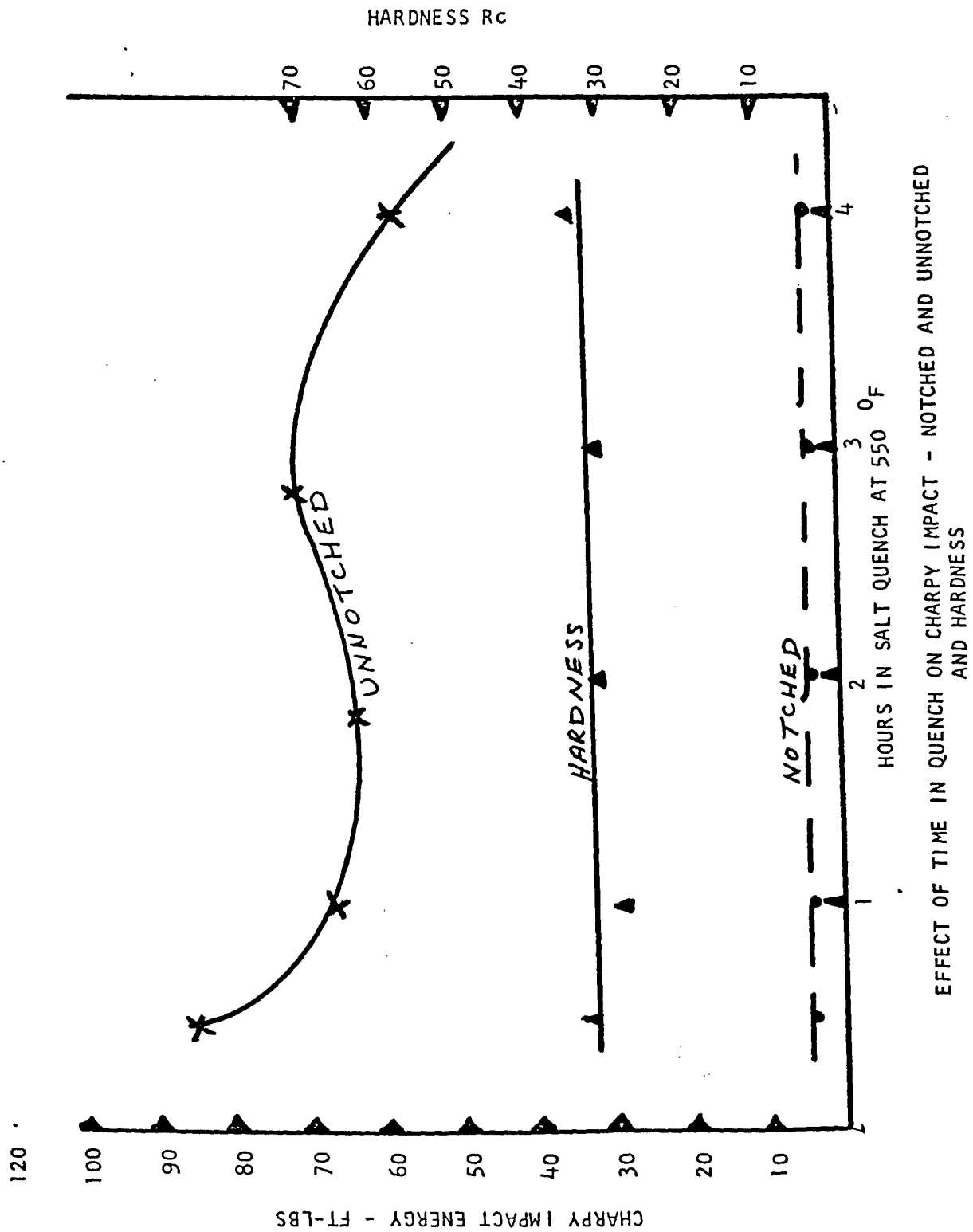


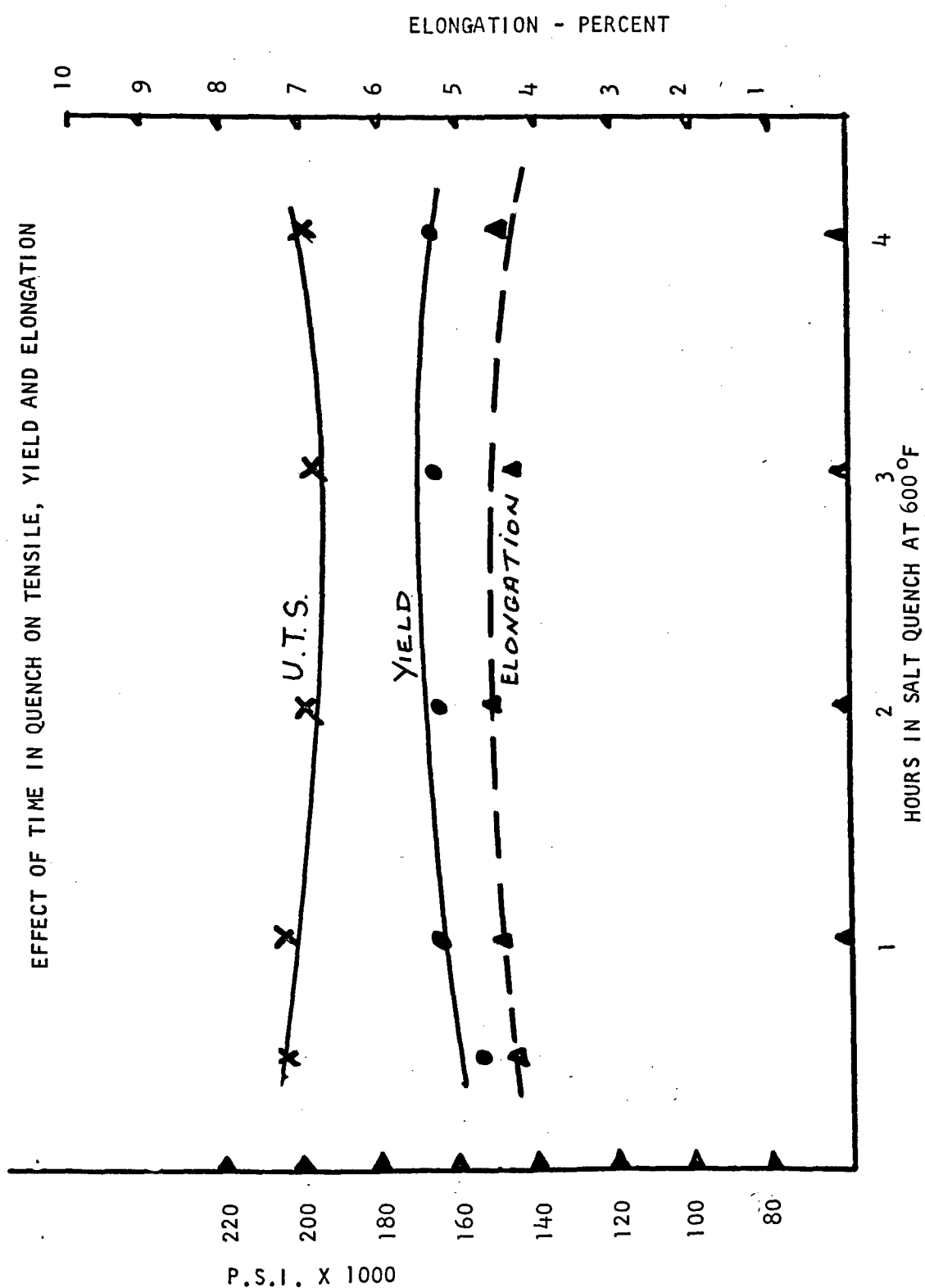
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tester will measure 5 to 7 points harder.



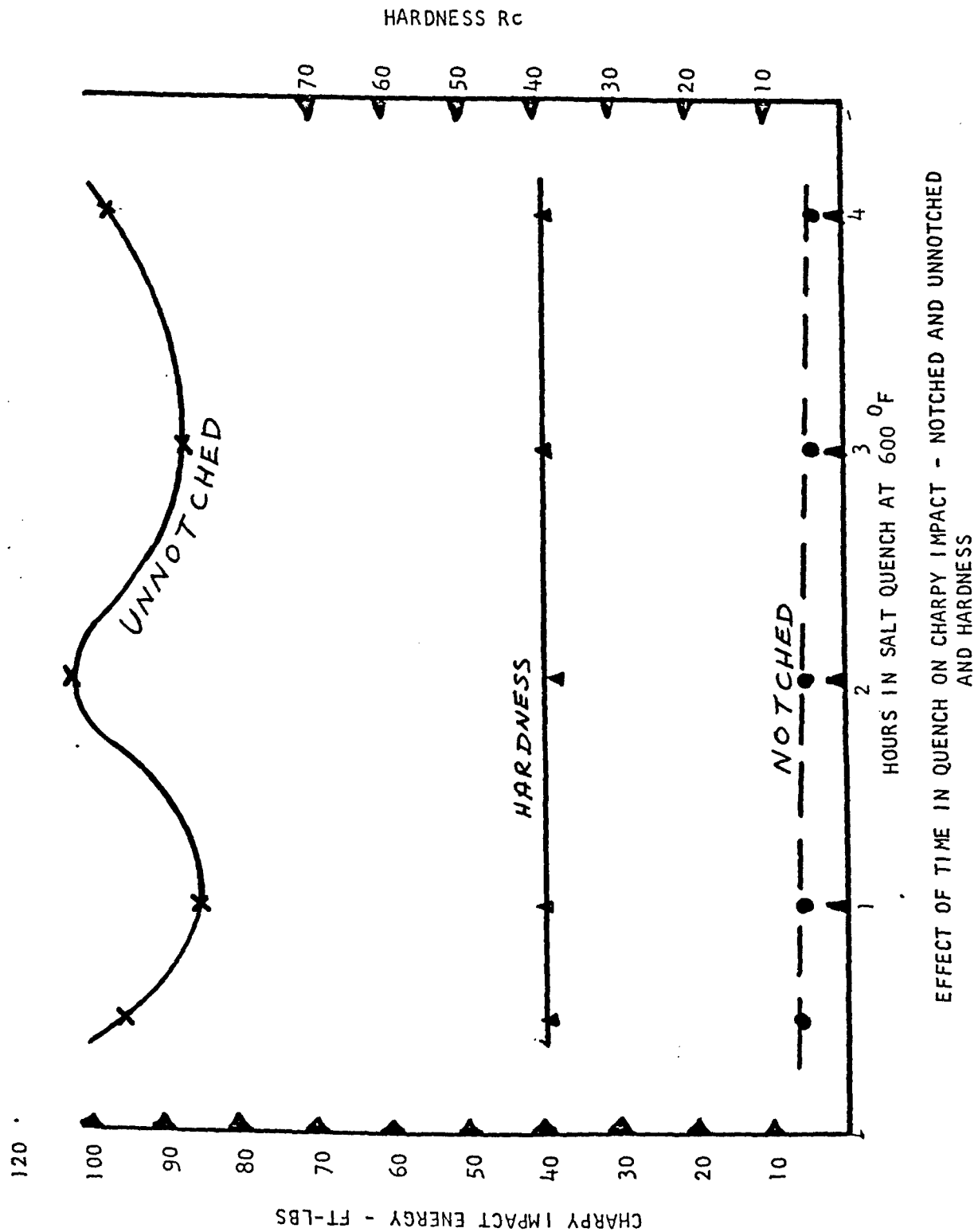


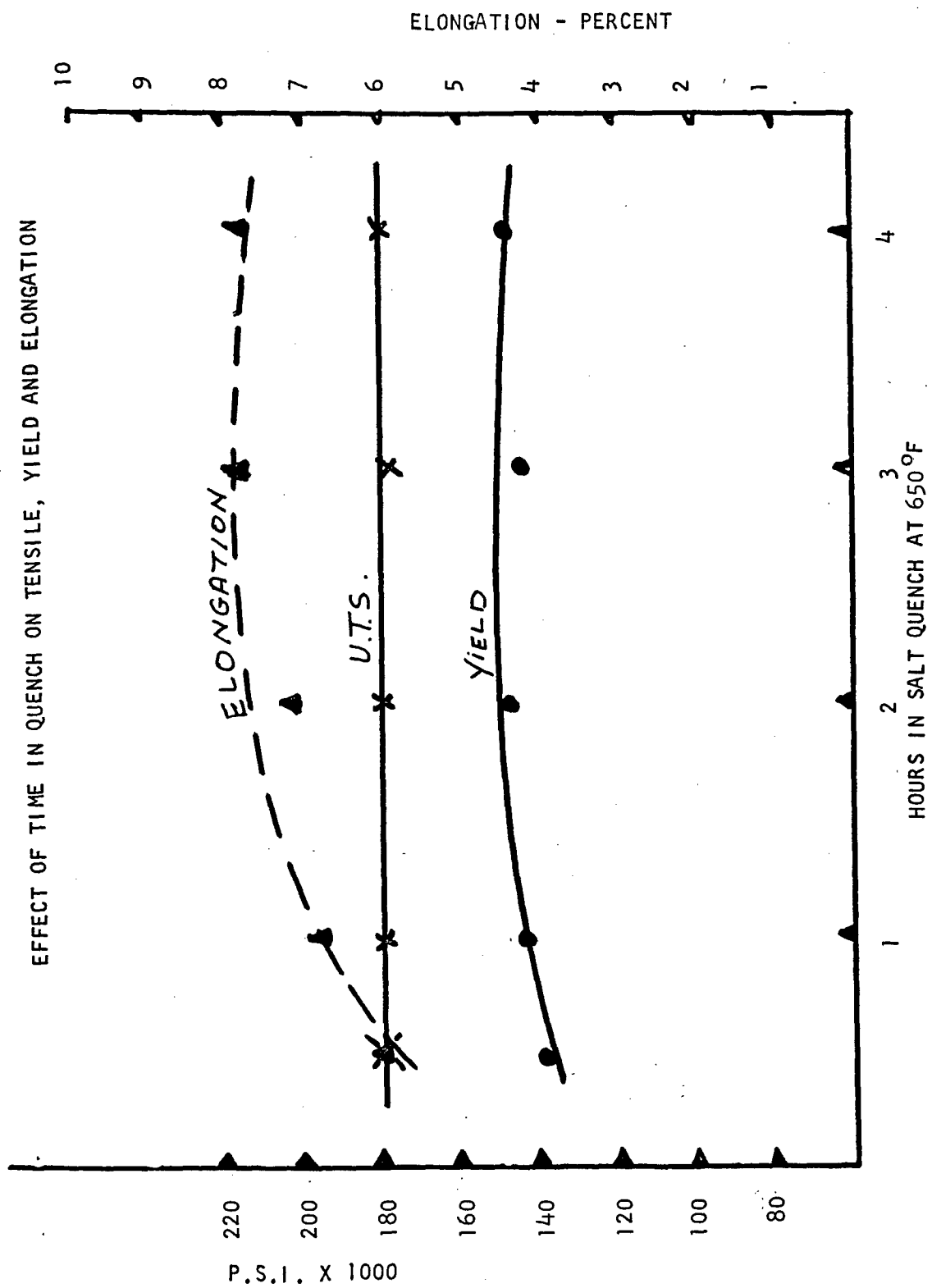
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Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.



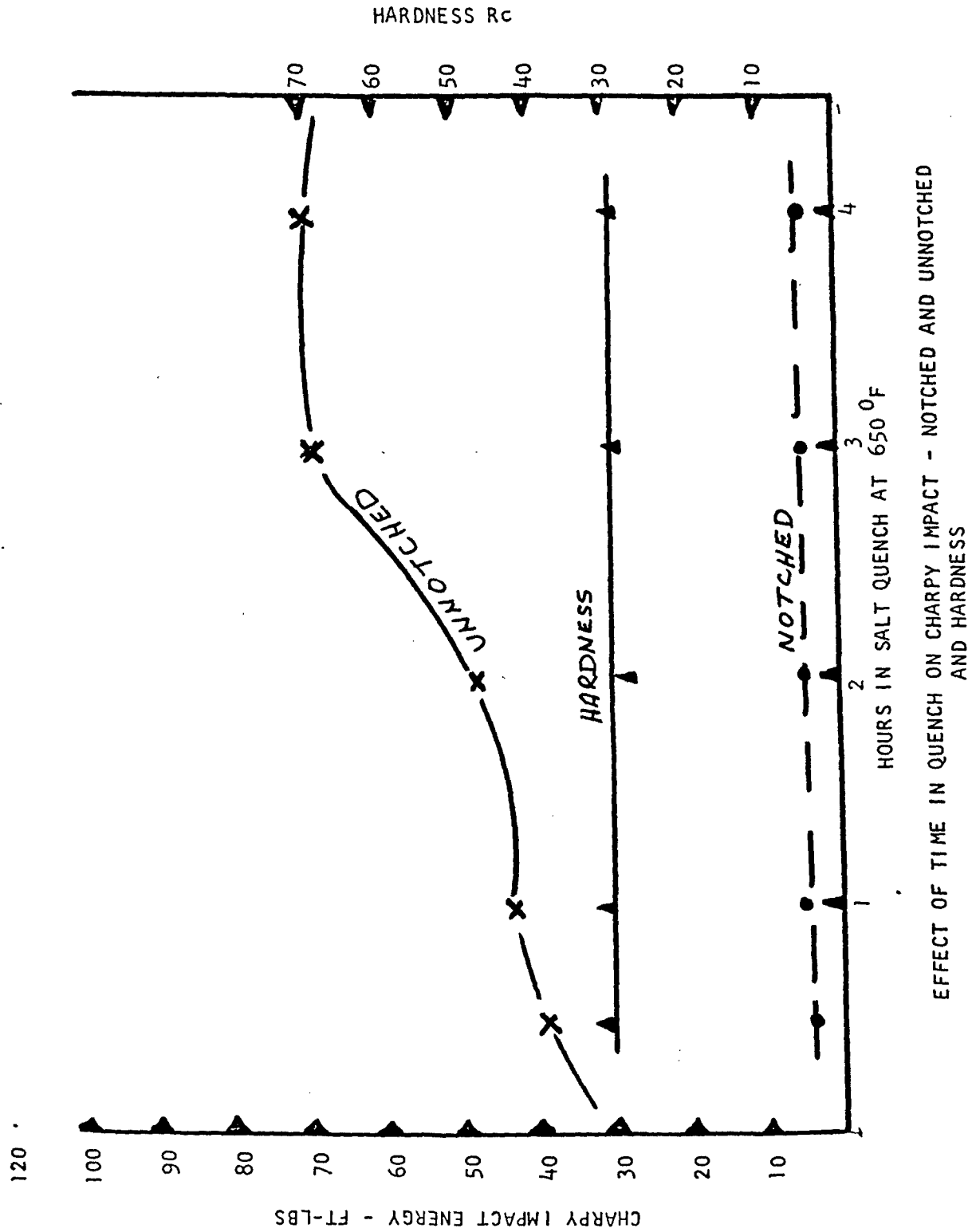


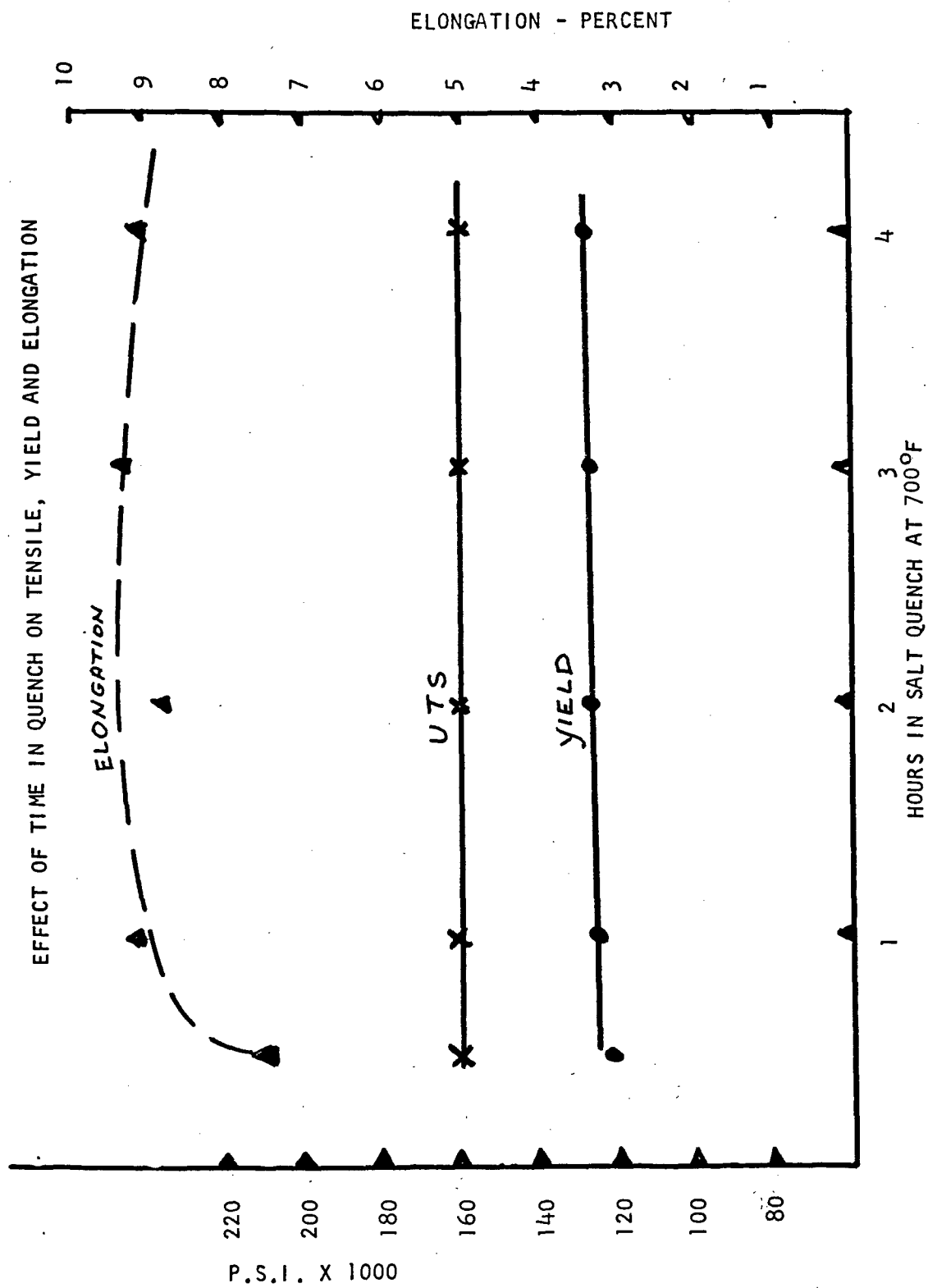
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Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.



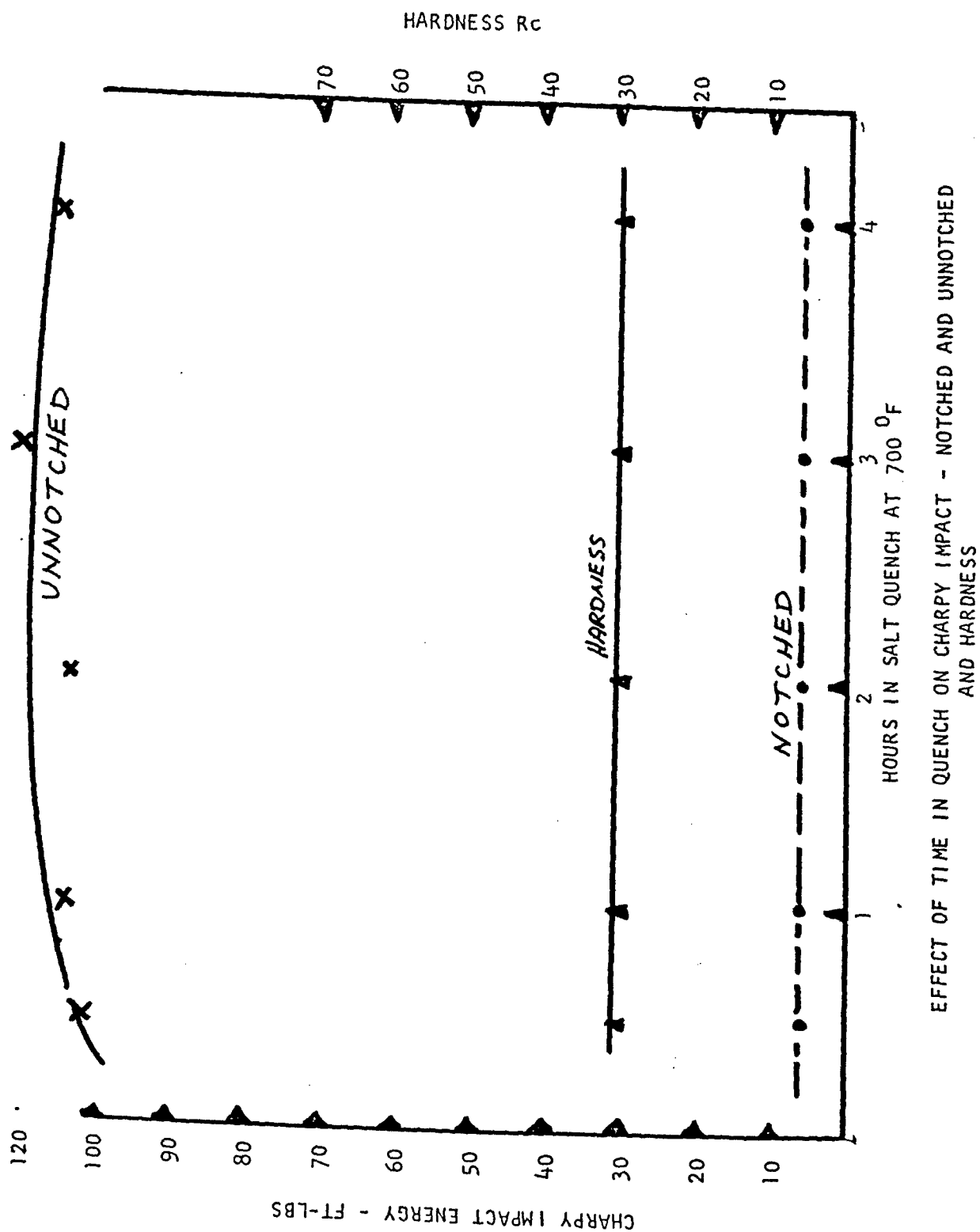


NOTE: Hardness shown is apparent or macro hardness.
Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.

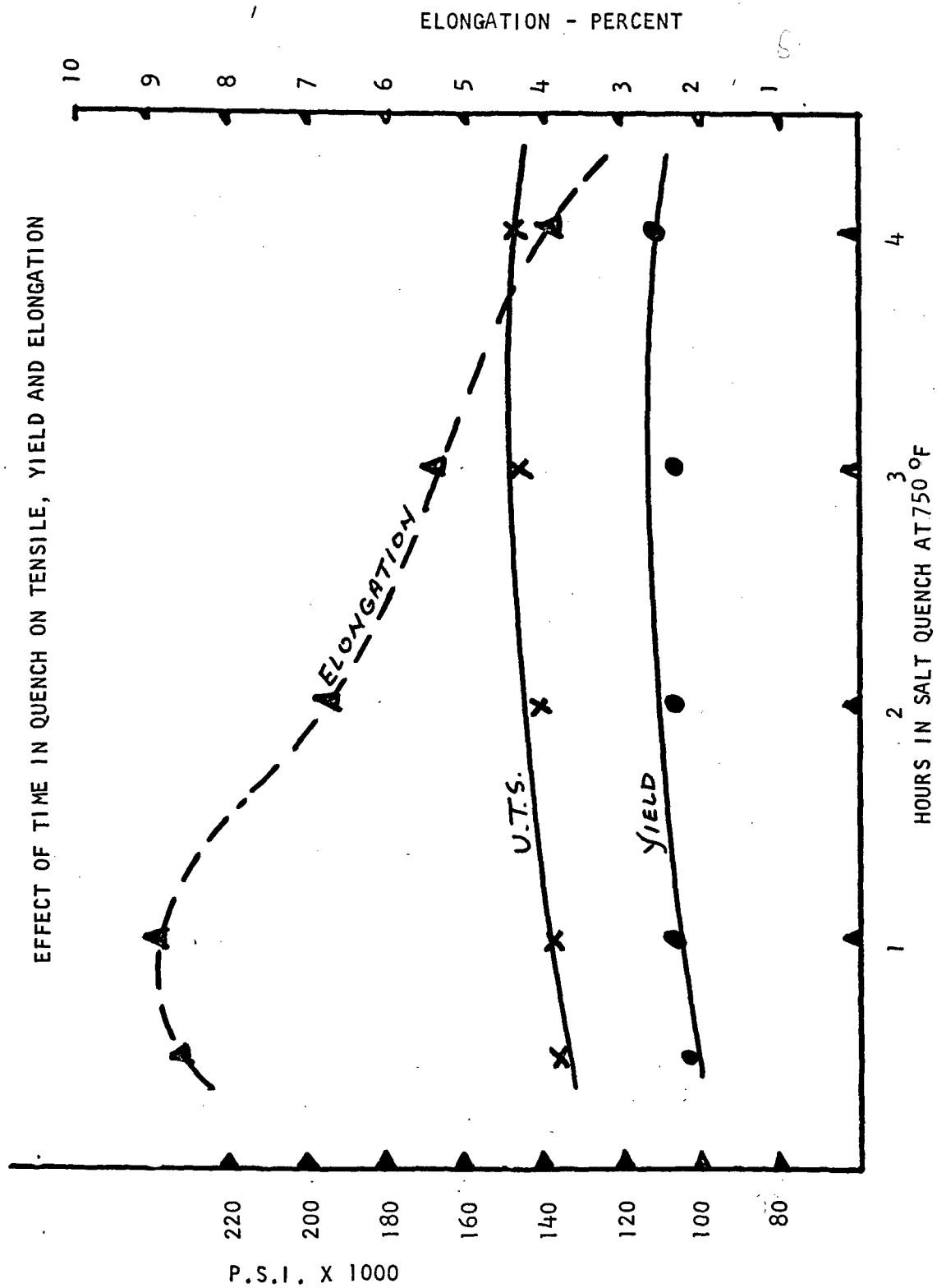




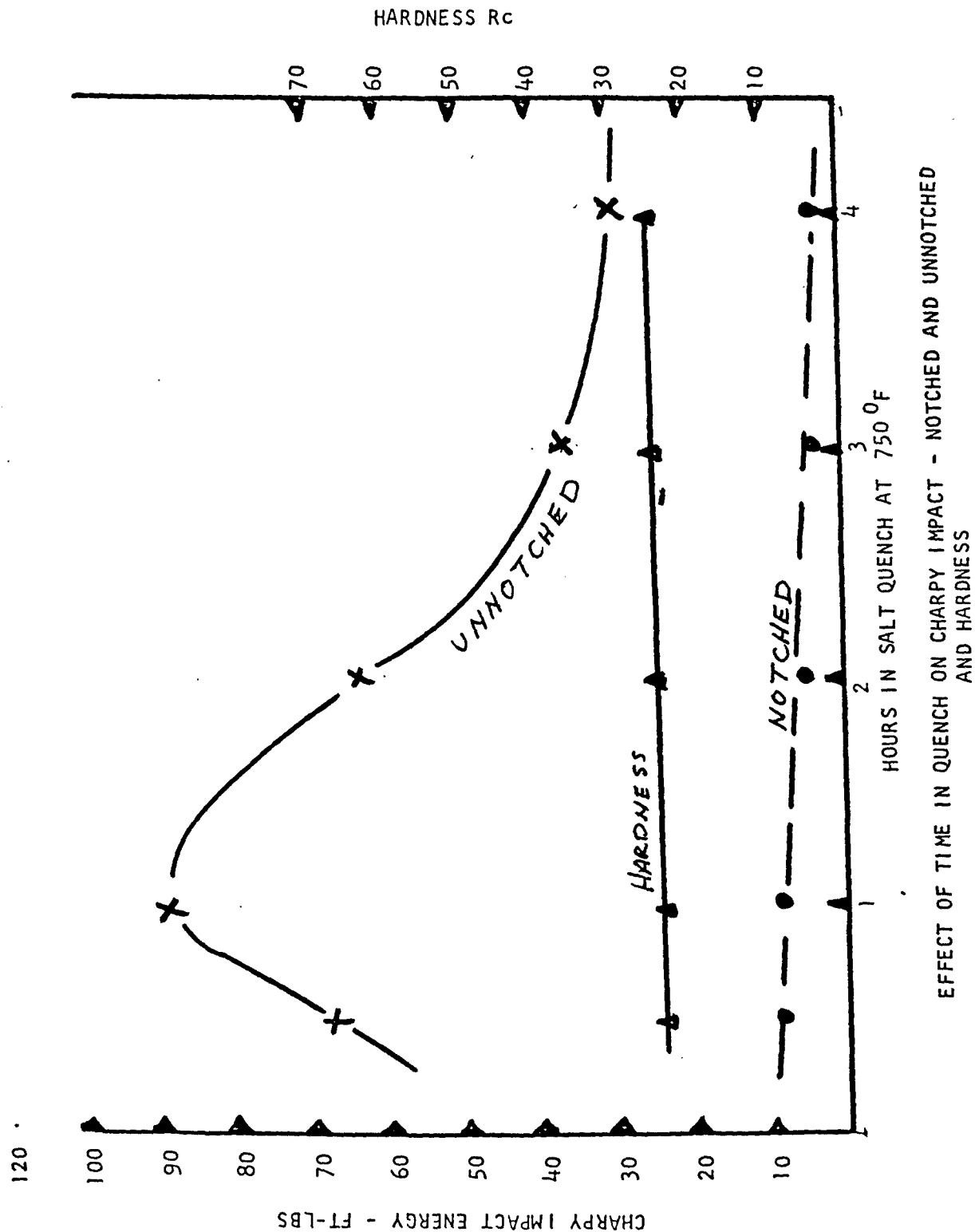
NOTE: Hardness shown is apparent or macro hardness.
Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.

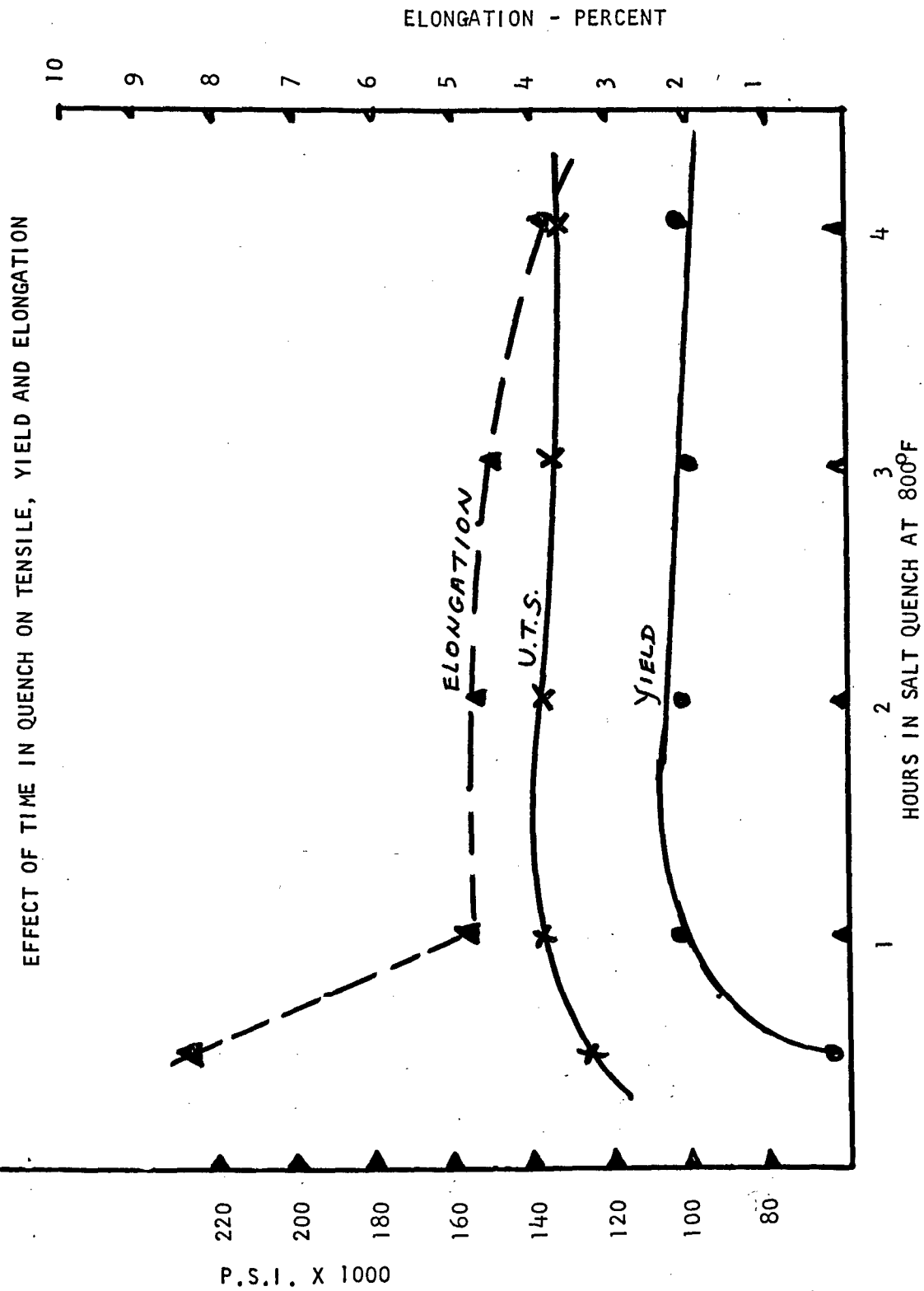


EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED
AND HARDNESS

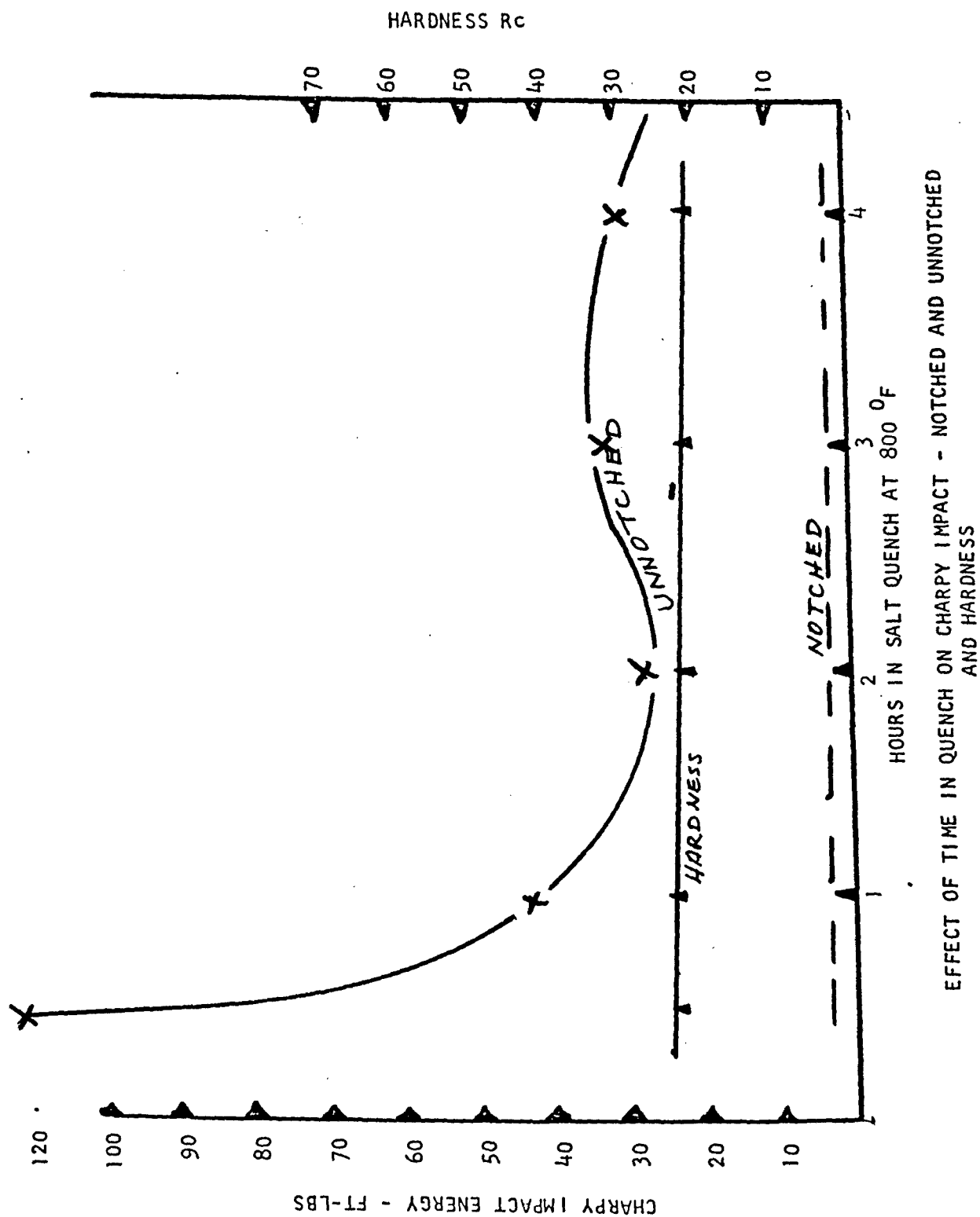


NOTE: Hardness shown is apparent or macro hardness.
Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.





NOTE: Hardness shown is apparent or macro hardness.
Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.



BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	N-UN CHARPY Ft Lb	LENGTH INCHES	COMMENT
400°	1	15min				51			4 1/2 - 7		BAR CRACKED LENGTHW
	2					48			2 1/2 - 9		" " "
	3					49		2.5	2 1/4 - 5 1/4	6.9	" " "
	4					48			2 - 7		" " "
	5					49			2 - 6 1/2		BAR BROKE IN THREADS
400°	1	30min		51		48			2 - 9		
	2					51			1 1/2 - 5 1/2		BROKE IN THREADS
	3			46		48		1.7	1 3/4 - 6 1/4	6.9	
	4					51			1 1/4 - 6 1/4		BROKE IN THREADS
	5			51		49			2 - 7 1/2		
400°	1	1 HRS		84		45			- - 14		
	2			77		50			2 - 1 1/4		
	3			79		48			1 3/4 - 12 1/2	4.2	
	4			89		48		2	2 1/4 - 12 1/4		
	5			88		46			2 - 35 1/2	14	CHARPY BAR DODGED IN Wk
400°	1	2 HRS		83		45			2 1/2 - 14		
	2		93	96	1.0	46		2.5	2 3/4 - 14 7/8	14.25	
	3		93	105	1.0	44		4.6	2 1/4 - 12 1/2		
	4		84	112	.5	44			2 1/4 - 12		
	5		82	91		44			2 - 30 1/2		
400°	1	3 HRS	88	102		43			2 1/2 - 9		DEFECT CHARPY
	2		92	92		40		3.2	3 1/4 - 14		
	3		101	115		44			4 - 26 3/4		
	4		101	105		39		4.4	3 1/4 - 8 1/2	21.16	DEFECT CHARPY
	5		104	111		41			3 - 22 3/4		

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	W-UNN CHARPY Ft Lb	LENGTH INCHES	COMMENT
450°	1	15min.	—	33	33.2	51	50	75	3/4 - 4 1/4	5.06	THIS ENTIRE LOT HAD EXCESSIVE SCALE. DEFECTIVE CHART
	2			35		18			3/4 - 3 3/4		
	3			—		52			1 - 6 1/4		
	4			35		48			3/4 - 6		
	5			—		51			1/2 - —		
450°	1	30min.	—	76	70.25	53	52.6	163	1 - 10 1/2	10.2	DEFECTIVE CHART
	2			67		53			2 - 10 1/4		
	3			65		51			2 1/2 - 9 3/4		
	4			73		53			1 1/2 - 10 1/4		
	5			—		53			1 1/4 - 2 1/4		
450°	1	1HR.	—	104	99.6	47	47.8	3.6	3 3/4 - 22 1/2	22.31	CHARTY BAR JAMMED IN MACHINE. DEFECTIVE CHART
	2			101		47			4 1/2 - 22 1/4		
	3			104		50			— 15 7/8		
	4			94		49			2 1/2 - 22 1/2		
	5			95		46			3 1/2 - 22		
450°	1	2HRS	—	141	137.6	45	44	3.2	3 1/2 - 18 1/2	32.6	DEFECTIVE CHART
	2			139		41			4 1/4 - 38 1/4		
	3			144		44			4 1/4 - 31 1/4		
	4			124		44			2 1/4 - 38 1/4		
	5			140		46			3 1/4 - 10 1/4		
450°	1	3HRS	—	154	142.2	41	44.4	3.16	3 3/4 - 28 1/4	22.25	DEFECTIVE CHART CHARTY BAR JAMMED IN MACHINE. 11 " 4
	2			126		44			— 21		
	3			149		44			— 22 1/2		
	4			140		47			2 3/4 - 22 1/2		
	5			142		46			3 - 23		

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	1 - UNN CHARPY Ft Lb	LENGTH INCHES	COMMENT
500°	1	30min	110	126	1.5	45			3 - 33 1/2	27.56	DEFECTIVE CHARPY
	2		110	122	1.0	48			3 3/4 - 17 1/2		
	3		112	124	1.5	49			3 3/4 - 33 1/4		
	4		111	158	2.0	49			3 1/4 - 23		
	5		109	152	2.0	50			2 1/2 - 30 1/2		
			110.4	136.4	1.6	48.1					
500°	1	1HR	155	164	2.0	47			3 - 43	41.875	DOUBLE HIT CHARPY
	2		—	148	2.5	47			3 1/4 - 46 3/4		
	3		163	183	2.0	45			3 - 37		DEFECTIVE CHARPY
	4		152	169	2.0	46			3 - 11 1/2		DEFECTIVE CHARPY
	5		149	186	2.0	46			2 3/4 - 14 1/2		
			144.75	170.4		45.6					
500°	1	2HRS	188	202	2.5	47			3 - 32 1/4	38	CHARPY JAMMED IN MOUTH
	2		186	203	2.0	44			— 38 1/2		
	3		194	202	1.0	46			2 3/4 - 42 1/4		DID NOT BREAK 1st TIME
	4		185	208	2.0	46			2 3/4 - 39 3/4		
	5		184	203	2.0	45			3 3/4 - 39		
			187	203.6		45.6					
500°	1	3HRS	199	222	2.0	42			3 1/4 - 30	30	
	2		—	202	1.5	43			3 - 14		
	3		205	215	1.5	41			2 3/4 - 38 3/4		
	4		200	202	1.5	36			2 1/2 - 39 3/4		
	5		203	221	1.5	36			2 3/4 - 28		
			201.75	212.4		39.6					
500°	1	4HRS	—	108	1.0	38			2 1/4 - 8 1/4	9.05	DEFECTIVE CHARPY
	2		—	—	—	41			2 1/4 - 9 1/8		TENSILE BROKE IN THROAT
	3		—	137	1.0	35			2 - 12 1/4		
	4		—	129	1.0	43			1 3/4 - 8 1/4		DEFECTIVE CHARPY
	5		—	121	1.0	41			1 3/4 - 8 1/2		DEFECTIVE CHARPY
				123.76		39.6					

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	N- UJAN CHARPY Ft Lb	LENGTH INCHES	COMMENT
550°	1	30 MIN.	135	203	4.0	36			5-76		
H ₂ O IN SALT	2		139	204	4.0	36			4 1/4-85 1/2		
	3		140	197	4.0	32			3 1/2-95 1/2		
	4		148	210	4.0	36			5-83		DEFECT CHIPPY
	5		134	200	3.5	30			4 1/2-85 1/2	45.5"	
			139.6	202.9	3.9	34					
550°	1	1 HR.	165	192	3.0	33			3 3/4-56		
H ₂ O IN SALT	2		158	193	4.0	38			3 1/2-71		
	3		135	173	4.0	25			5 1/2-60		DEFECT CHIPPY
	4		114	152	3.5	25			4 1/2-81 1/2		
	5		151	188	3.5	20	24		(55)	1 1/2	DEFECT CHIPPY
			145	179.6	3.6						
550°	1	2 HRS	168	202	2.5	30			4 1/4-63		
H ₂ O IN SALT	2		168	206	3.0	30			4-65		
	3		170	205	3.5	36			4 3/4-63 1/2		DEFECT CHIPPY
	4		154	186	3.5	31			3 3/4-62 1/2		DEFECT CHIPPY
	5		168	209	3.5	34	32.0		4-66	1 1/4	
			165.6	201.	3.2						
550°	1	3 HRS	176	211	4.0	32			4 1/2-86		
H ₂ O IN SALT	2		174	187	1.5	34			4-86		DEFECT TEUSICE
	3		171	197	2.0	31			4 1/4-65		
	4		169	206	4.5	33			4 3/4-70 1/2		
	5		168	204	4.5	35	32		4 1/2-53 1/2	72.2"	
			171.6	201	3.3						
550°	1	4 HRS	177	208	4.0	37			5 1/4-53		
H ₂ O IN SALT	2		180	209	4.0	34			4 1/2-52		
	3		165	195	4.0	34			5-83		
	4		178	207	3.0	37			4 1/4-91	57.2"	
	5		170	199	4.5	36			4 1/2-54 1/2		DEFECT CHIPPY
			174	202.	3.9	34					

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	11-000 CHARPY Ft Lb	LENGTH INCHES	COMMENT
600° RECO CONFIRM	1	30min	153	205	4.0	41			5 1/4 - 110		
	2		161	206	4.0	41			5 1/2 - 79		
	3		150	199	4.5	37			5 1/2 - 96.5		
	4		157	204	4.0	40			5.5 - 95		
	5		157	204	5.0	40					
			155	204	4.3	39.8					
600° RECO CONFIRM	1	1HR.	164	204	4.0	40			5 3/4 - 105		
	2		170	209	5.0	39			5 3/4 - 39		
	3		165	204	4.5	40			4 3/4 - 17 1/2		
	4		166	202	5.0	40			5 1/4 - 86		
	5		162	202	4.5	38					
			165	203		38.4					
600° RECO CONFIRM	1	2HRS	168	204	5.0	39			5 - 89		
	2		163	196	4.0	35			5 1/2 - 102		
	3		169	203	4.0	38			5 1/4 - 115 1/4		
	4		165	198	4.5	39			5 1/4 - 102		
	5		168	203	5.0	40					
			166.6	200	4.6	38.2					
600° RECO CONFIRM	1	3HRS	166	194	3.5	36			4 1/2 - 98		
	2		166	195	4.5	39			4 3/4 - 74		
	3		170	203	4.0	39			4 1/2 - 90		
	4		173	203	4.5	38			4.6 - 87		
	5		165	197	4.5	38					
			168	198	4.2	38					
600° RECO CONFIRM	1	4HRS	165	199	4.0	39			4 - 115 1/2		
	2		173	203	4.0	39			4 3/4 - 79		
	3		169	203	5.0	39			4 - 84		
	4		168	201	5.0	39			4.5 - 92		
	5		165	198	4.5	38					
			168	200	4.7	37					

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	N-UN-A CHARPY Ft Lb	LENGTH INCHES	COMMENT
650 ^c	1	30 MIN	142	183	6.0	33			5-34 1/2		
	2		140	178	5.0	32			4 1/2-44 1/2		
	3		137	181	5.5	34	32		3 1/2-36 1/2	40.3	
	4		133	179	7.0	27			4 1/2-54 1/2		
	5		138	181	6.0	34			5-31 1/2		
650 ^a	1	1 HR	146	180	6.0	32			5-50 1/2		
	2		143	178	7.0	32			3 1/2-32		
	3		145	180	7.0	29	31		5 1/2-38 1/2	44.63	
	4		142	179	7.0	31			5 1/2-35		
	5		—	180	7.0	31			5 1/2-66 1/2		
650 ^c	1	2 HRS.	158	181	7.0	31			5 1/2-38		DEFECT CHARPY
	2		146	178	7.0	24			6'-26 1/2	48.21	
	3		145	179	7.0	27	28.6		5 1/2-32		
	4		148	180	7.0	28			6'-53 1/2		
	5		144	179	7.5	31			5-81		
650 ^c	1	3 HRS.	146	178	8.0	31			6'-56		DEFECT CHARPY
	2		147	179	7.0	31			5 1/2-34 1/2	69.21	DEFECT TENSILE
	3		146	177	8.0	31	30		5 1/2-34		DEFECT CHARPY
	4		145	176	7.5	28			5 1/2-38 1/2	69.21	DEFECT CHARPY
	5		145	178	8.0	39			6'-82 1/2		
650 ^c	1	1 HRS	149	180	8.0	32			5 1/2-65		
	2		147	179	7.5	31			4 1/2-32	70.22	DEFECT CHARPY
	3		150	181	7.5	32	25.6		5 1/2-72		
	4		149	181	6.5	31			5 1/2-28		DEFECT CHARPY
	5		145	179	9.0	27			4 1/2-74		

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	N-UNN CHARPY Ft Lb	LENGTH INCHES	COMMENT
700°	1	30min	122	160	8.0	28			6-79		
	2		120	158	6.0	29			5 3/4-68 1/2		
	3		121	159	8.5	23	7.4		5 1/4-81		
	4		119	159	7.5	28			6 1/4-33 1/2		
	5		122	161	7.5	29			6 1/4-78 1/2		
700°	1	1hr.	124	162	11.5	29			- 62		
	2		124	159	8.0	27			6 1/2-35		DEFECT CHARPY
	3		125	162	9.5	27			6 1/4-61 1/2		
	4		125	160	7.5	28			5-40 1/2		DEFECT CHARPY
	5		123	162	9.5	29			6 1/4-93		
700°	1	2hrs	130	162	9.5	29			6 1/2-39 1/2		DEFECT CHARPY
	2		129	160	9.5	31			5 1/2-31		
	3		127	154	7.0	27			5 1/2-41 1/2		DEFECT CHARPY
	4		128	162	9.5	27			6 1/2-30 1/2		DEFECT CHARPY
	5		126	156	8.0	28			6 1/2-51 1/2		
700°	1	3hrs	123	158	8.5	26			6 3/4-109		
	2		128	161	9.5	28			6-17		DEFECT CHARPY
	3		128	160	9.0	26			6 1/2-95		
	4		127	161	9.5	30			6 1/4-32		
	5		125	163	10.5	28			6 1/2-97		
700°	1	4hrs	130	162	9.0	29			6 1/4-103		
	2		130	161	9.0	28			6-71 1/2		
	3		129	161	10.0	30			6-78 1/2		
	4		128	159	9.0	26			6-78 1/2		
	5		128	159	8.5	28			6-111		

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	K-UNK CHARPY Ft Lb	LENGTH INCHES	COMMENT
750°	1	30min	104	137	7.0	25			8-59		
	2		104	137	7.0	25			7 1/2-68 1/2		
	3		102	138	8.5	25			7 1/2-54 1/2		
	4		102	140	10.0	26			7 1/2-68		DEFECT CHARPY
	5		106	142	9.0	25			7 1/2-67 1/2		
750°	1	1hr.	107	138	7.0	25			7-41 1/2		DEFECT CHARPY
	2		105	138	8.0	24			6 1/2-70 1/2		
	3		107	141	9.5	26			6 3/4-79		
	4		106	140	9.5	24			7 1/2-86		
	5		103	139	8.5	26			6 3/4-103		
750°	1	2 hrs.	105	143	8.0	25			5 1/4-64		DEFECT CHARPY
	2		108	144	7.0	25			4 1/2-67		
	3		108	144	7.0	25			4 3/4-84		DEFECT CHARPY
	4		108	143	6.0	26			5-81 1/2		
	5		115	138	5.0	26			4 1/4-60 1/2		
750°	1	3 hrs.	109	146	5.5	26			3 1/4-36		DEFECT CHARPY
	2		109	145	5.5	25			3-36		DEFECT CHARPY
	3		111	148	5.0	26			2 3/4-36		DEFECT CHARPY
	4		109	143	5.0	24			2 3/4-36		DEFECT CHARPY
	5		111	151	6.0	24			4-36		
750°	1	4 hrs.	112	146	4.0	25			2-30		DEFECT CHARPY
	2		113	151	4.5	24			2 1/4-30		DEFECT CHARPY
	3		114	148	3.0	24			3-28		
	4		114	144	3.5	24			2 1/4-30		DEFECT CHARPY
	5		113	150	4.5	25			2 1/4-32		
SUSPECT 750°						JAL					

BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	N- ON CHARPY Ft Lb	LENGTH INCHES	COMMENT
800°	1	30 MIN	76	125	8.0	22			6- —		
	2		77	125	7.5	22			5-204		
	3		77	128	10.0	25	24		5 1/4 113	120 +	
	4		76	125	7.5	26			5 1/4 77		
	5		76	126	9.0	25			4 3/4 120+		
800°	1	1 HR.	102	137	5.0	24			2 1/2 11		DEFECT. CHARTY
	2		102	140	5.0	25	24.0		2- 1 1/2		DEFECT. CHARTY
	3		105	140	4.5	24			2 1/4 39		
	4		100	135	4.5	25			2 1/4 45	42	
	5		101	136	5.0	25			2- 26		
800°	1	2 HRS.	101	137	4.0	23			2- 20		DEFECT. CHARTY
	2		101	141	5.0	25	23.6		1 3/4 38		
	3		101	136	4.5	22			1 3/4 32	28.9	
	4		104	139	5.0	24			1 3/4 20		
	5		105	135	4.5	24			1 3/4 31 1/2		
800°	1	3 HRS.	100	135	4.5	23			1 1/2 33 1/2		DEFECT. CHARTY
	2		100	135	5.0	23			2- 29		
	3		100	135	4.5	22	22.8		2- 34 1/2	33.8	
	4		105	140	4.5	23			2- 37		
	5		102	133	4.0	23			2- 35		
800°	1	4 HRS.	101	131	3.5	22			2- 4		DEFECT. CHARTY
	2		104	140	5.0	23			2 1/4 26 1/2		
	3		104	135	4.0	23	22.4		2- 36	30.25	
	4		100	135	3.0	21			2- 28		
	5		103	133	3.5	23			2- 30 1/2		

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APPENDIX C
PHOTOMICROGRAPHS OF STRUCTURES
RESULTING FROM VARIOUS HEAT-
TREATMENTS

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BDI Quenched at 400°F. The sharp needle-like structure indicates a high proportion of martensite accounting for the high hardness and low UTS. X 800



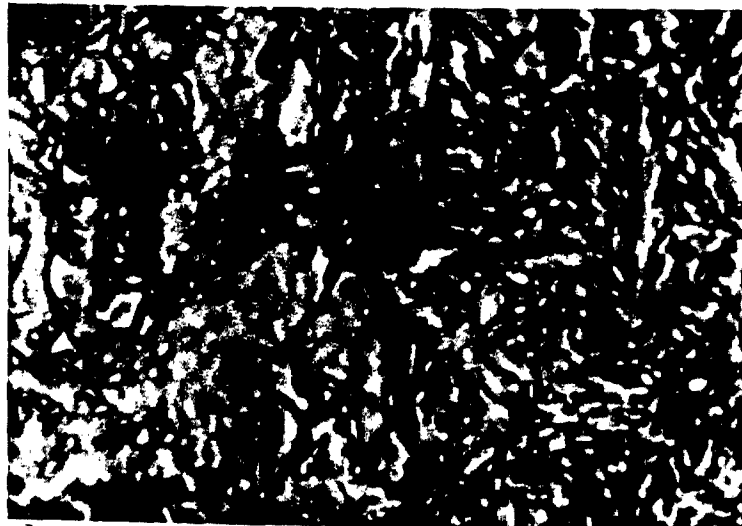
BDI Quenched at 500°F. Here the sharpness of the needles is replaced with the feathery structure of bainite. The UTS increases and the hardness decreases. X 800



BDI Quenched at 600°F. The feathery structure of bainite has increased to where it almost entirely fills the matrix. This is characteristic of good quality BDI. X 800



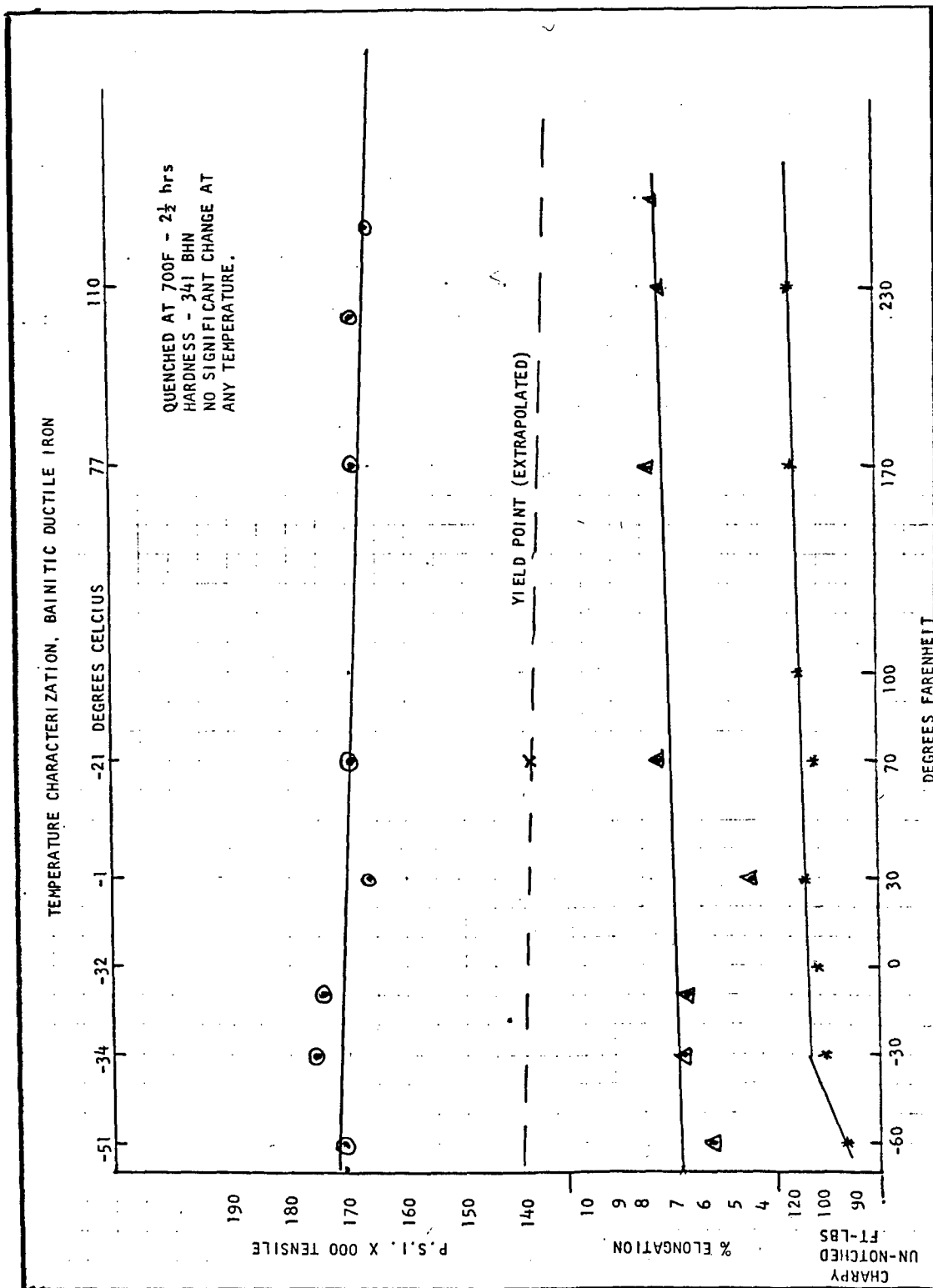
BDI Quenched at 700°F. The light areas are retained austenite which contributes to the lower hardness and greater toughness of this structure. X 800.



BDI Quenched at 800°F. The retained austenite has become more pronounced also some areas of pearlite. The structure is, in fact, getting back to a pearlitic nodular iron of very fine structure and has the physical properties to go with it. X 800

APPENDIX D
TEMPERATURE CHARACTERIZATION
OF BDI
FROM -60° to 230°F

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TEMPERATURE CHARACTERIZATION
BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	HRS QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	CHARPY Ft Lb	LENGTH INCHES	COMMENT
1	1	2.5	137.5	164.7	4.5				117.5		PULLED w/o JACKET
	2	1		172.2	7.0				94		
-60°F	3			171.7	5.0	15.9			87	93.7	
	4			169.3	5.5				84		
	5			174.2	7.5				86		
			AVE	170.4							
2	1			180.8	10.0				25		
	2			173.7	7.5				47		
-31°F	3			177.0	7.5				120+		UN BROKEN
	4			179.3	4.5				84.5		
	5			166.7	5.0				53		
			AVE	175.5	6.9				76		
3	1			172.6	5.5				66		
	2			177.2	7.0				34		
	3			171.4	5.5				120+		UN BROKEN
-10°F	4			177.0	9.0				120+		"
	5			174.2	5.5				62.5		
			AVE	174.5	6.5				92		
4	1			157.6	5.5				120		
	2			160.2	3.5				80		
	3			167.8	5.5				120+		UN BROKEN
35°F	4			165.0	5.0				46		
	5			164.0	4.0				120		
			AVE	162.9	4.7				110		
5	1		139.3	170.6	7.5				23		
	2		140.0	168.8	7.0				120+		UN BROKEN
	3		136.8	169.4	7.0				65		
72°F	4		141.8	172.1	9.0				60		
	5		138.2	164.6	6.0				54		
			AVE	139.2	169.1	7.5			74.75		
6	1										
	2										
	3										
	4										
	5										

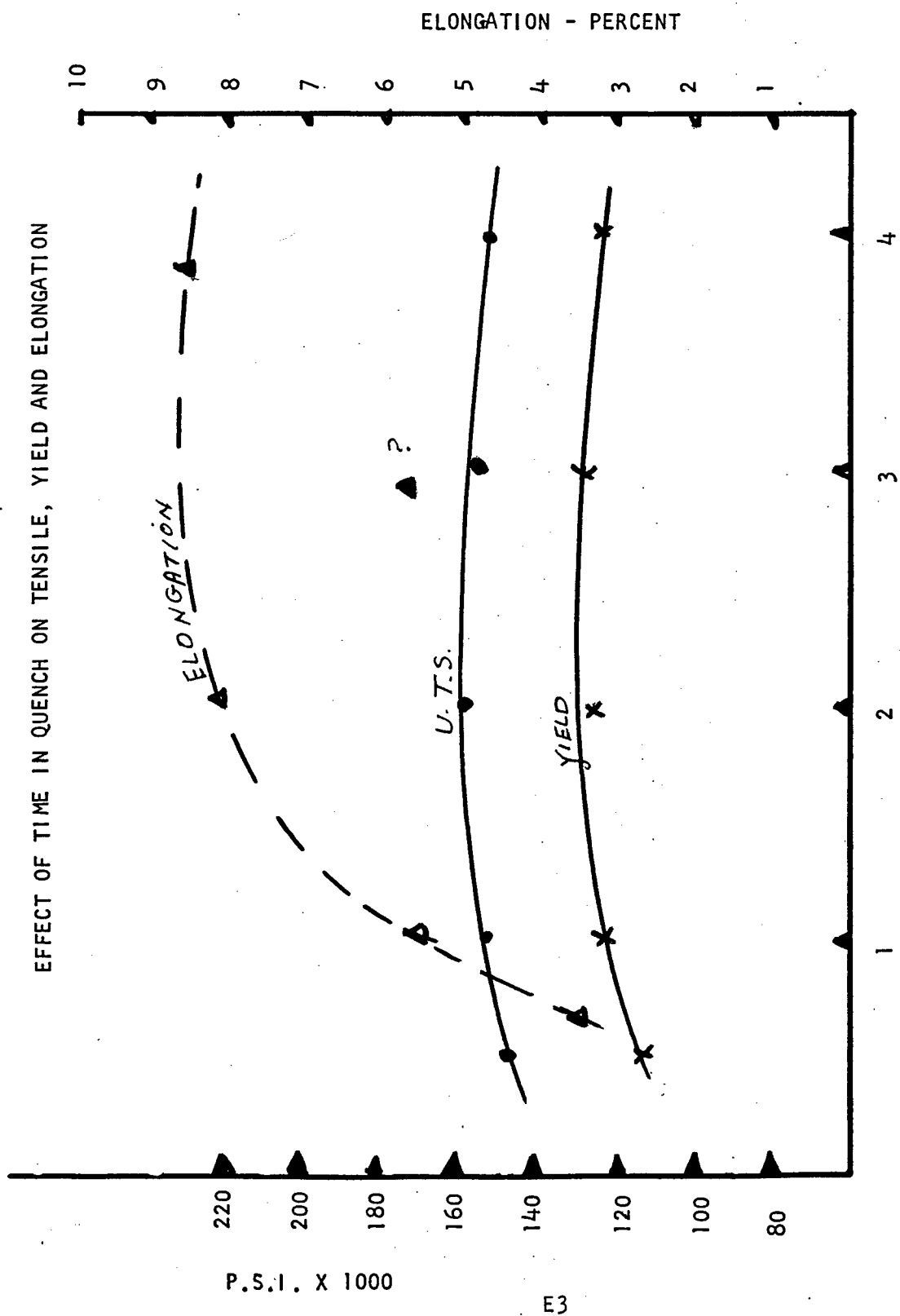
BAINITIC DUCTILE IRON PROJECT

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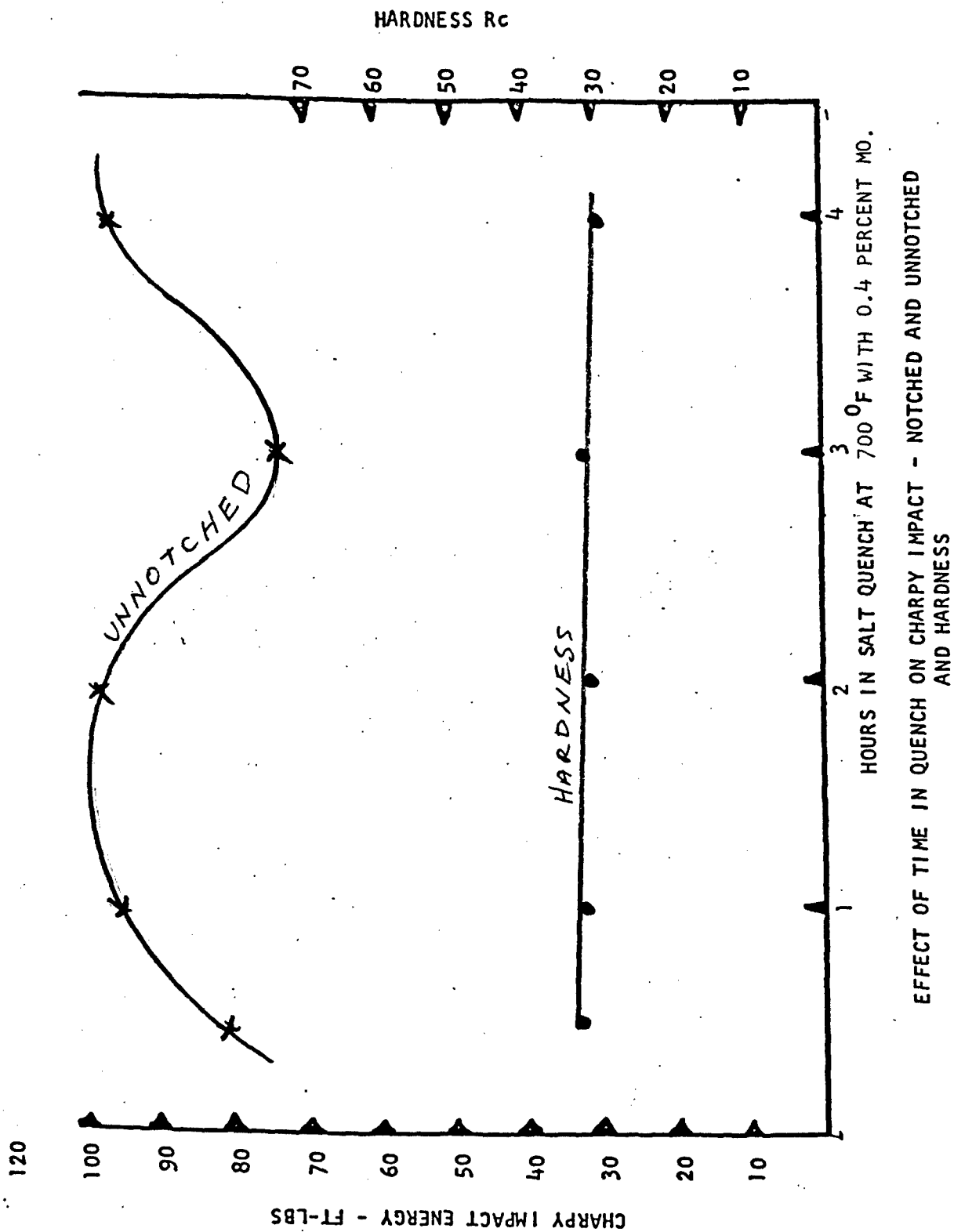
APPENDIX E
EFFECT OF HIGH MOLYBDENUM
&
RE-HEAT-TREATMENT ON MECHANICAL PROPERTIES

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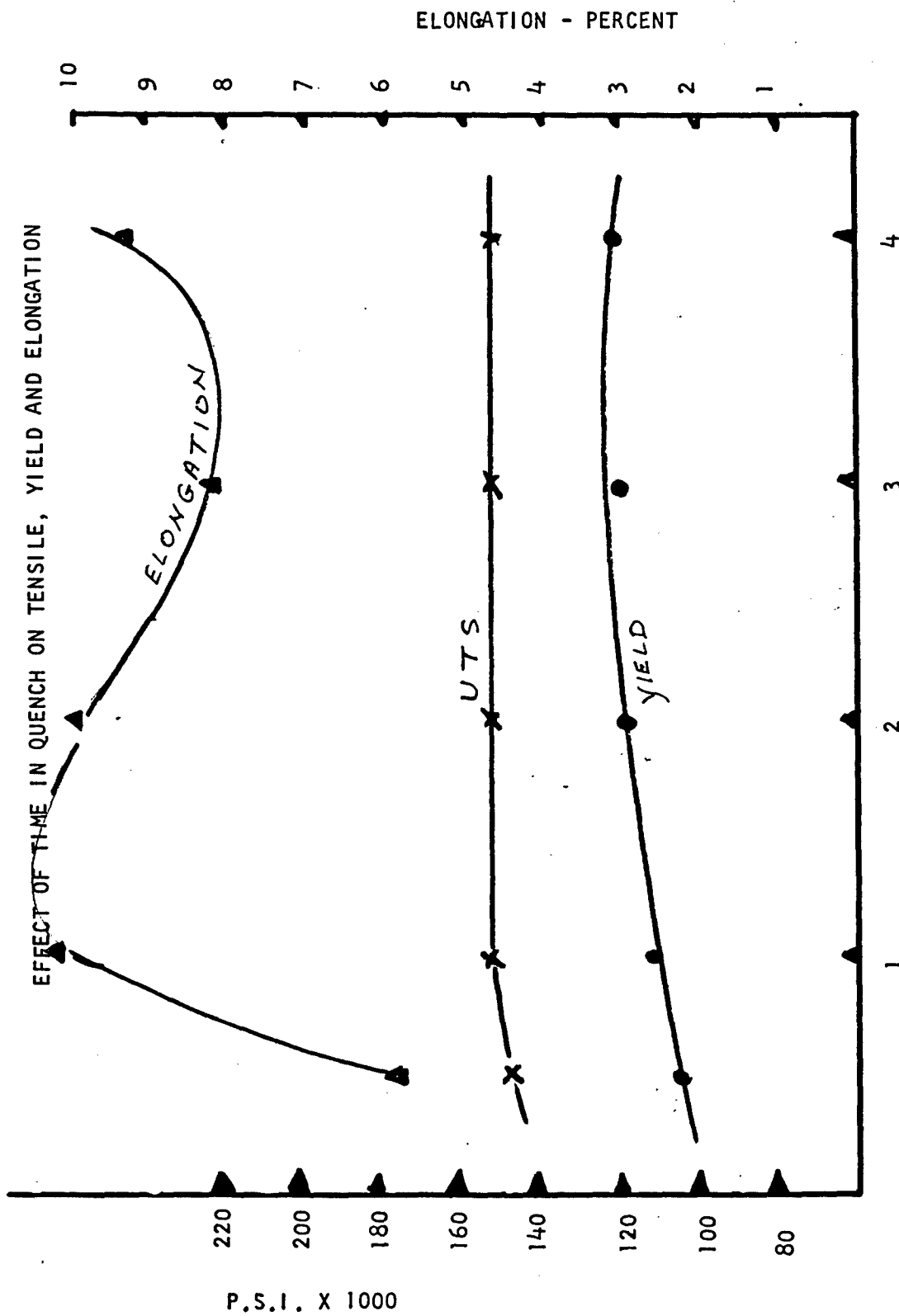
HOURS IN SALT QUENCH AT 700° F. WITH 0.40 PERCENT MOLYBDENUM.

NOTE: Hardness shown is apparent or macro hardness.
Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.



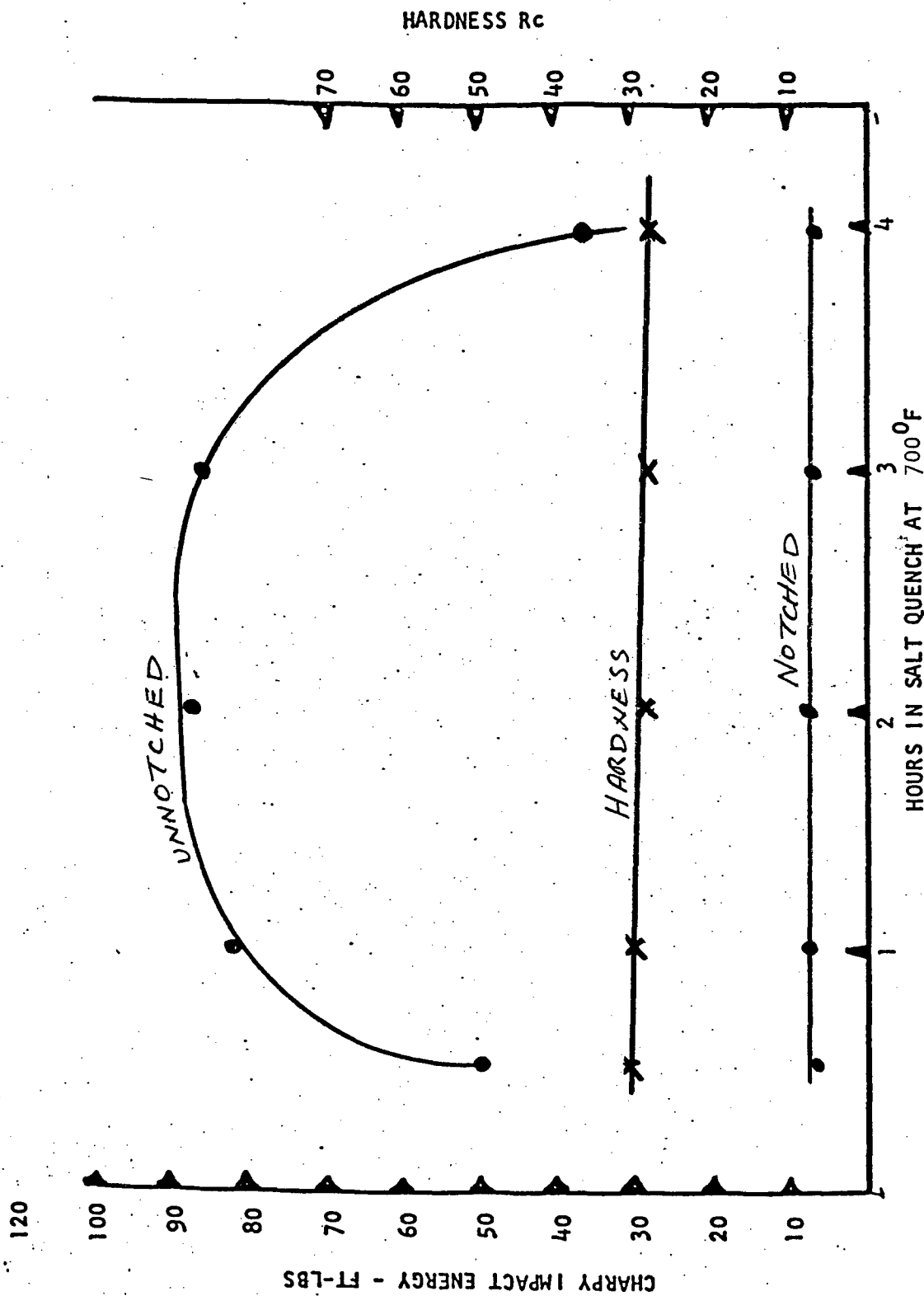
BAINITIC DUCTILE IRON PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	CHARPY FT Lb	LENGTH INCHES	COMMENT
700° 4% FeMo	1-2	30 MIN	117	149	3.5	34			62-78		
	3-4								77-81		DEFECT CHARPY
	5-6								76-84		DEFECT CHARPY
	7-8								80-89		DEFECT CHARPY
	9-10								95-107		
700° 4% FeMo	1-2	1 HR.	124	154	5.5	33			120-108		
	3-4								80-66		DEFECT CHARPY
	5-6								80-94		DEFECT CHARPY
	7-8								83-71		DEFECT CHARPY
	9-10								113-96	95	
700° 4% FeMo	1-2	2 HRS.	126	158	8.0	32			88-103		DEFECT CHARPY
	3-4								61-101		
	5-6								80-83		DEFECT CHARPY
	7-8								80-89		DEFECT CHARPY
	9-10								120-99	97	
700° 4% FeMo	1-2	3 HRS.	128	154	5.5	33			89-80		DEFECT CHARPY
	3-4								69-65		
	5-6								92-58		
	7-8								84-81		DEFECT CHARPY
	9-10								68-75	74	
700° 4% FeMo	1-2	4 HRS.	123	152	8.5	31			88-83		DEFECT CHARPY
	3-4								73-110		
	5-6								98-85		
	7-8								98-84		DEFECT CHARPY
	9-10								120-87	96	



HOURS IN SALT QUENCH AT 700° F.
REHEAT-TREATED, AUSTENITIZED AT 1700°F

NOTE: Hardness shown is apparent or macro hardness.
Actual hardness as measured by Brinnell hardness
tester will measure 5 to 7 points harder.



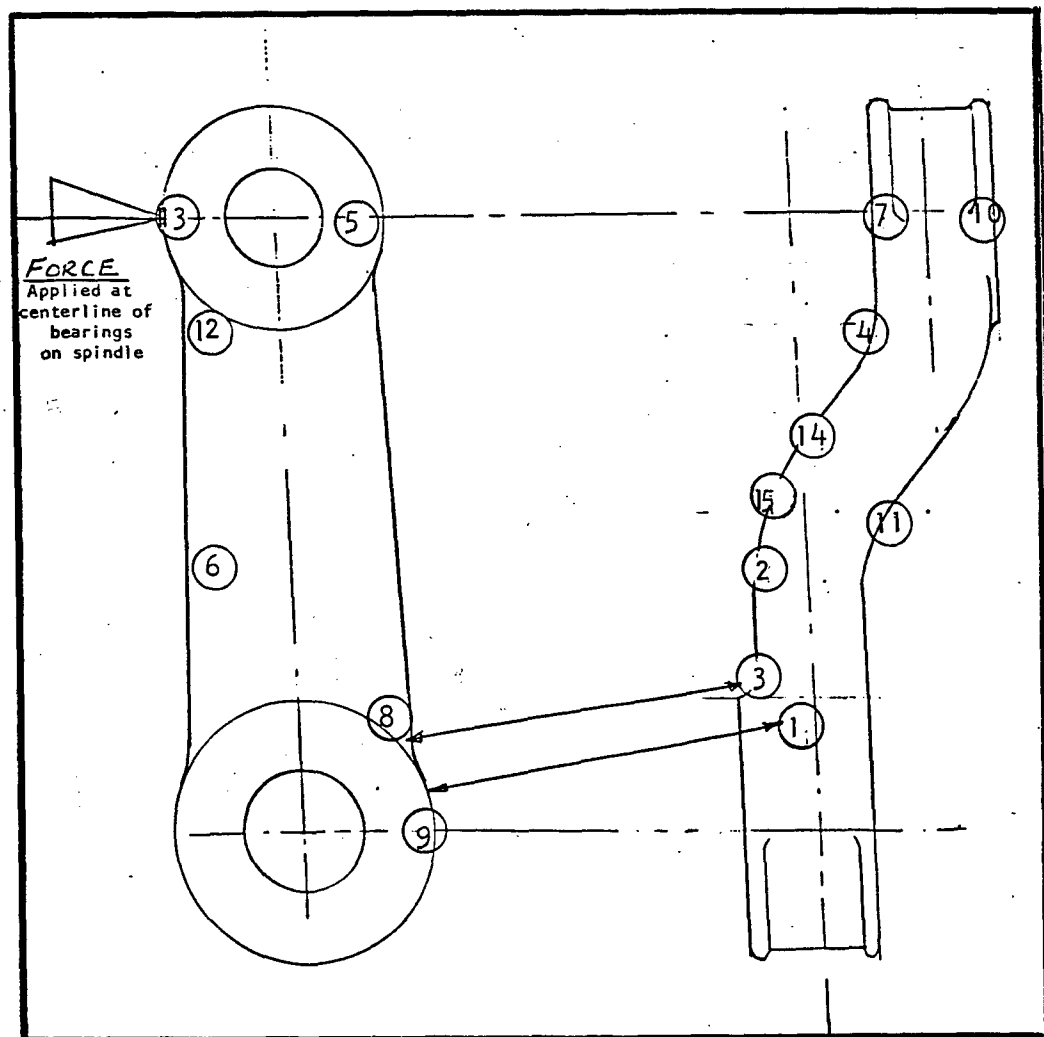
EFFECT OF TIME IN QUENCH ON CHARPY IMPACT - NOTCHED AND UNNOTCHED
AND HARDNESS
REHEAT-TREATED, AUSTENITIZED AT 1700°F

BAINITIC DUCTILE I PROJECT

LOT No.	BAR No.	QCH TIME	YIELD ,000	TENS. ,000	ELONG. %	Rc Macro	Rc Micro	BHN	N-VA CHARPY Ft Lb	LENGTH INCHES	COMMENT
1700°	1	30min	108	153	5.5	29			6 1/2 - 58 1/2		
700°	2		112	153	7.5	30			6 1/4 - 37		
REDO	3		106	147	5.5	30			6 1/2 - 41		
	4		—	146	6.0	29			6 - 57		
	5		112	147	5.0	31			6 1/2 (20)		DEFECT CHART
			109	144.2	5.9	29.8			6.33 (20.3)		
700°	1	1HR.	114	155	10.0	29			7 - (50)		DEFECT CHART
REDO	2		115	150	10.0	28			6 3/4 - 83		
	3		113	153	9.5	29			6 3/4 - 95		
	4		110	151	9.5	30			7 1/4 (33)		DEFECT CHART
	5		110	156	10.5	29			6 3/4 - 67		
			112	153	9.9	29			6.8 (31.6)		
700°	1	2HRS	121	152	8.5	29			6 1/2 (146)		DEFECT CHART
REDO	2		117	153	10.5	29			7 - 92		
	3		122	153	10.0	29			7 3/4 - 73 1/2		
	4		118	153	9.0	28			6 1/2 - 94		
	5		121	157	9.5	30			7 1/2 - 87 1/2		
			120	153.6	9.5	30			7.05 (86.75)		
700°	1	3HRS	122	152	7.5	30			7 - (16)		DEFECT CHART
REDO	2		125	155	7.5	28			6 1/2 (93)		DEFECT CHART
	3		121	156	8.0	27			6 3/4 (95)		DEFECT CHART
	4		118	153	9.5	29			6 1/4 - 99		DEFECT CHART
	5		121	151	8.5	29			6 3/4 - 73		
			121	153	8.2	29			6.65 (86)		
700°	1	4HRS	122	153	10.5	28			6 3/4 - 38 1/2		
REDO	2		123	153	9.0	28			5 1/2 -		
	3		124	155	9.0	29			7 - 102 1/2		
	4		120	155	9.0	29			7 (34)		DEFECT CHART
	5		122	157	9.5	27			7 - 41		
			122	154	9.4	27			6.55 (37.8)		

APPENDIX F
FIRST STATIC EXPERIMENTAL
STRESS ANALYSIS
STRAIN GAGE POSITIONS AND DATA

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STRAIN μ IN/IN															
Load	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5000	384	176	389	259	-3	226	21	-174	18	20	-435	-214	0	-113	-80
10,000	701	361	790	521	-9	445	66	-333	82	46	-874	-445	-9	-224	-157
15,000	1000	544	1184	779	-10	667	108	-483	158	123	-1311	-680	-8	-333	-232
20,000	1297	716	1555	1039	-10	892	153	-602	227	218	-1750	-912	-3	-439	-304

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