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Report No. 39
(Technical Report)

THE EFFECTS OF CARBON, PHOSPHOROUS,
AND ALLOY CONTENTS ON THE NOTCHED BAR IMPACT
PROPERTIES OF QUENCHED AND TEMPERED STEELS

by

H. Schwartzbart and J. P. Sheehan

Conducted as Project No. 90-468 B

by

ARMOUR RESEARCH FOUNDATION
of
Illinois Institute of Technology
Technology Center
Chicago 16, Illinois

for

OFFICE OF NAVAL RESEARCH
U. S. Navy

Contract N6 onr 274 T.O.I. Project NR 031-115

Copy No. 49

February 24, 1953

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IN REPLY
REFER TO:

April 16, 1953

Chief of Naval Research
Department of Navy
Washington 25, D. C.

ATTN: Dr. Oscar Marzke, Head
Materials Branch
Office of Naval Research

Dear Sir:

We are submitting, herewith, Technical Report No. 39 entitled, "The Effects of Carbon, Phosphorus, and Alloy Contents on the Notched Bar Impact Properties of Quenched and Tempered Steels", dated February 24, 1953, Contract N6 onr 274 T.O.I.

This work is a continuation of the study of the notched bar impact properties of a number of common AISI-SAE grades of steel in which carbon and phosphorus contents are varied.

Yours very truly,

John P. Sheehan
John P. Sheehan

Supervisor
Mechanical Metallurgy Section

JPS/jo

Encl.

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(Technical Report)

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THE EFFECTS OF CARBON, PHOSPHOROUS, AND ALLOY CONTENTS
ON THE NOTCHED BAR IMPACT PROPERTIES
OF QUENCHED AND TEMPERED STEELS

ABSTRACT

The V-notch Charpy impact properties of eight alloy grades of quenched and tempered steel have been investigated. In addition to presenting additional data on the effects of carbon, phosphorous, and alloy contents on the impact properties, the report includes data from past reports on these subjects.

Three types of brittleness, manifested by high transition temperatures, are observed:

1. "A" brittleness, or 500°F embrittlement. This phenomenon is universally exhibited by practically all steels at all carbon levels and is greatest for the highest carbon level, 0.80% C.

2. "B" brittleness, or the 1200°F reversal. This is exhibited by the 2300 series and consists of an elevation in transition temperature for specimens tempered at 1200°F.

3. Temper brittleness. This is observed principally in the 0.80% C heat of each grade with the exception of the 2300 series. Steels containing molybdenum exhibit less temper brittleness than those containing no molybdenum.

The transition temperature of a quenched and tempered steel is dependent, among other things, on carbon content, alloy content, and tempering temperature. Curves are presented relating these variables, which can be used to choose the optimum carbon level, alloy grade, and tempering temperature.

Phosphorous raises the transition temperatures of 4100 and 5100 steels at practically all carbon levels and hardnesses. The deleterious

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effect of this element is greater in the 5100 grade, which contains no molybdenum, than in the 4100 grade, which contains molybdenum.

THE EFFECTS OF CARBON, PHOSPHOROUS, AND ALLOY CONTENTS
ON THE NOTCHED BAR IMPACT PROPERTIES
OF QUENCHED AND TEMPERED STEELS

I. INTRODUCTION

This work is a continuation of the study of the notched bar impact properties of medium alloy grades of steel in the quenched and tempered condition. Report No. 22¹ dealt with the impact properties of eight 0.40% carbon grades. Report No. 28² extended the study to lower and higher carbon contents of some of these grades. The present report extends the study still further to include more of the grades with varying carbon content and in addition, at two different levels of phosphorous content.

II. MATERIALS AND PROCEDURES

Report No. 28² presented results of investigations of the properties of three grades of steel, 4300, 2300, and 8600, each with a range of carbon contents from 0.20 to 0.80%. The 4300 series was investigated throughout a tempering range of 400 to 1200°F, and the 2300 and 8600 series at tempering temperatures of 800, 1000, and 1200°F. Those results will be presented again in the present report for comparison purposes.

The present report will present data on several additional steel grades in the as-quenched condition and tempered over the range from 300°F to 1200°F. These grades are as follows: 1300, 3100, 4100, 4600, and 5100 series. At least three carbon levels, 0.20%, 0.40%, and 0.80% were investigated, and for the 2300, 4300, and 8600 series, carbon levels of 0.30% and 0.60% were also tested. The 4100 and 5100 series were investigated at two levels of phosphorous content. In addition, the 4300, 2300, and 8600 series data presented in Report No. 28² were extended to include the complete range of tempering temperatures from as-quenched to 1200°F. Chemical

compositions of the steels investigated are given in Table I.

Fine grain laboratory induction furnace heats were used. Furnace practice, ingot size, forging, normalizing, specimen preparation, heat treatment, and testing procedures were the same as those described in Report No. 22,¹ except that the normalizing and austenitizing temperatures were adjusted to the carbon contents of the various heats. Normalizing and austenitizing were carried out at the same temperature; these temperatures are listed in Table II, together with the austenitic grain sizes.

Those heats which were investigated at two levels of phosphorous content were prepared by making a phosphorous addition to the metal remaining in the furnace after three ingots had been cast. Three more ingots were then cast from this metal which was high in phosphorous content. These are denoted by having a letter "P" after the grade number.

III. EXPERIMENTAL DATA

Conventional impact energy-temperature curves are presented in Appendix I. In general, the impact energy reaches a maximum which remains constant as the testing temperature is increased. This permits the use of the temperature at 80% of the maximum energy as the measure of transition temperature. An exception to this rule is made in the case of the material tested in the as-quenched condition. In this case, the maximum energy has not yet been reached at a testing temperature of room temperature. Testing at a temperature higher than room temperature results in some tempering taking place during testing so that the impact energy curve in this region is not actually for an as-quenched specimen. Thus, in this case, no single value is taken as the transition temperature.

Table III contains the transition energies and temperatures taken from the impact energy curves in the Appendix, as well as hardness data.

These data are plotted in Figures 1-26, in which tempering temperature is used as the independent variable. Composite curves of transition temperature vs. tempering temperature with carbon content as the parameter are presented in Figures 27-30.

In order to take into account the different hardnesses obtained for steels of different carbon contents at a given tempering temperature, the data are also plotted with hardness as the independent variable. These plots are presented in Figures 31-41.

Figures 42-44 are three-variable summary plots which best illustrate the inter-relations among hardness, carbon content, and transition temperature for three series of steels, 2300, 4300, and 8600.

The effects of phosphorous contents on the transition temperatures of the 4100 and 5100 series are illustrated in Figure 45.

IV. DISCUSSION

In general, the results presented in previous reports of this study of the behavior of tempered martensite in the V-notch Charpy test are substantiated and extended by the present data.

It was reported previously that several types of embrittlement can occur in tempered martensite. These are (1) 500°F embrittlement, or "A" brittleness, (2) 1200°F reversal, or "B" brittleness, and (3) conventional temper brittleness. The variation of transition temperature with tempering temperature is determined by the occurrence of these types of embrittlement, either singly or in combination, which is, in turn, determined principally by composition and heat treatment.

A. 500°F Embrittlement

The curves of tempering temperature vs. hardness and the energy and temperature at 80% of maximum energy are presented in Figures 1-26.

Examine now the curves of Figures 27-30 which summarize Figures 1-26 and which include data for all the different grades of steel at various carbon levels studied on this program. Practically all the steels exhibit 500°F or "A" brittleness. The tempering temperature at which the maximum in this type of brittleness occurs is not necessarily 500°F, but may occur somewhere between 500 and 700°F. Exceptions to this general behavior are 4320 and 4340, which exhibit maxima in their transition temperatures at tempering temperatures of 800°F. It should be noted that the amount of "A" brittleness is greatest for the 0.80 C heat in each grade, with the exception of the 4300 series, in which 4360 exhibits as much "A" brittleness as 4380.

B. 1200°F Reversal

The 1200°F reversal is exhibited only by the 2300 series, (Figure 27), a straight nickel grade. Slight reversals are exhibited also by 4640 and 5140, but the 2300 series is the only one which shows this behavior as a grade and to such a large extent. It is believed that this type of brittleness is caused by the formation of austenite upon tempering at 1200°F, which then transforms to martensite upon quenching from the temper or at a later time upon testing. The formation of austenite on tempering 2340 at 1200°F has been observed and its occurrence described in Report No. 22¹.

C. Temper Brittleness

The particular type of brittleness known as temper brittleness is also observed in some of the curves of Figures 27-30. Temper brittleness is developed in alloy steels by tempering in the range from 950 to 1150°F for extended times, or by cooling slowly through this range. The specimens used in the present study were tempered for one hour and quenched. Ordinarily, this treatment would develop very little, if any, temper brittleness. However, with the exception of the 2300 and the 8600 grades, the 0.80 C heat of every grade of steel investigated exhibits a peak in

transition temperature at a tempering temperature of 1000°F. Even in the 8600 grade (Figure 30), whereas the transition temperatures for low carbon contents decrease as the tempering temperature rises from 700°, the transition temperature for 8660 does not decrease until the tempering temperature exceeds 1000°, and for 8680 the transition temperature does not decrease at all. This peak at a tempering temperature of 1000° is generally not as high as the peak caused by "A" brittleness at a tempering temperature of 500-700°F. Thus, it is shown that a high carbon content aggravates temper brittleness; grades of steel which develop no temper brittleness at low and intermediate carbon contents do develop temper brittleness in the 0.80 C heats.

D. Effect of Carbon and Alloy Content

The data are also plotted as a function of hardness rather than tempering temperature to allow us to determine to what extent hardness is a common denominator in relating transition temperature to carbon and alloy contents. These plots are presented in Figures 31-38 with carbon content as the parameter, and in Figures 39-41 with alloy grade as the parameter. Also plotted in these figures is the value for 80% of the maximum energy.

The curves of transition temperature vs. hardness have the same general shape as those of transition temperature vs. tempering temperature; however, they are displaced relative to one another because of the use of the different abscissa. Consider first the curves of Figures 31-38. With the exception of the temper brittleness exhibited at a hardness around Rc 40 in the 0.80 C heats, the curves of transition temperature vs. hardness are somewhat homologous within any one grade, the curves being displaced toward higher hardness as carbon content increases. This includes the 500°F embrittlement peak which moves toward higher hardness as the carbon content increases. The height of this peak is the greatest for the 0.80 C heat in each grade, and is the lowest for the 0.40 C heat in the 1300, 3100, 4600,

5100, and 8600 series. The height of the peak in the 0.20 C heat is the lowest for the remaining grades with the exception of the 4100 series in which the 0.20 C and the 0.40 C heats have peaks of equal height.

The carbon content with the lowest transition temperature for any given hardness depends upon the particular hardness chosen. It is difficult to state general truths in regard to this point because of the absence of valid generalizations that apply to all grades. The best overall compromise seems to be carbon contents of 0.40% and 0.30% which generally have the lowest transition temperatures at hardnesses under about 40 and above about 49. Exceptions are the low carbon heats of the 2300, 4100, and 4300 grades which have lower transition temperatures as-quenched or tempered only slightly than steels of higher carbon contents at the same hardness.

Examine now Figure 35, in which are presented the transition temperature data for the 4300 series. It can be seen that the transition temperature is a function of the hardness and the carbon content, but that the maximum energy (or 80% of the maximum energy) is dependent only on hardness, within a narrow band. Within this band, at a given hardness, the energy generally increases as the carbon content decreases. It will be noted that the width of the band is much greater for most of the other grades, especially for the 1300 and 5100 series. It is generally true, however, that for any grade the energies increase as the carbon contents decrease for any given hardness. The same sort of an analysis applied to Figures 39-41 indicates that steels of various alloy grades, but of the same carbon content, likewise do not exhibit a unique relationship between 80% of maximum energy and hardness, but that a band is obtained for this function. This is particularly true of the 0.20 C and 0.40 C heats. The 0.80 C heats exhibit considerably less scatter in their 80% of maximum energy vs. hardness curve. The disposition within the band is different for these figures than for

Figures 31-38 in that the relative positions of the various alloy grades differ at the different carbon levels, whereas in Figures 31-38 it is generally true that the lower the carbon the higher the energy for a given hardness.

The question of which alloy or combination of alloys best promote low transition temperatures is one of vital interest to all engineers who design structures for low temperature service. Stated in other words, the question is this: "For a given hardness and a given carbon content, which grade of steel possesses the lowest transition temperature?" Examination of Figures 39-41 indicates that the answer depends upon the particular carbon content and hardness under consideration. Some general remarks, however, can be made. (It should be emphasized at this time that the curves apply to the particular heat treatment used in this investigation and that for a different heat treatment the curves would have a different relationship to one another. In particular, a tempering treatment more conducive to temper brittleness would change the order of the curves at low hardnesses).

The three Ni-Cr-Mo grades investigated, 4300, 4600, and 8600 series, among them have the lowest transition temperatures at most of the carbon contents and over most of the hardness range. The 4300 series and the 4600 excel at the highest hardness levels for all carbon contents. In addition, 4340 has superior properties at the lowest hardnesses, and 4640 at intermediate hardnesses, and both these series at the 0.80 C level have superior properties at the lowest hardnesses. The 8600 series, which is a leaner alloy than the 4300 or 4600 series is superior at the lowest hardnesses at the 0.20 C level, but varies from intermediate to poorest at other hardnesses and carbon levels.

The Ni-Cr grade, 3100, is intermediate at the 0.20 C and 0.40 C levels and varies from poor to good at the 0.80 C level.

The Cr-Mo grade, 4100, varies from intermediate to good at all carbon levels.

The straight chromium grade, 5100, is poor at the 0.20 C level, and varies from poor to good at the 0.40 C and 0.80 C levels.

The straight manganese grade, 1300, and the straight nickel grade, 2300, are, in general, the poorest of the grades investigated. Exceptions to this general statement are 1380 which has a relatively low transition temperature around a hardness of Rc 46 and 2320 which has a relatively low transition temperature over most of the hardness range.

The important conclusion to be reached from this discussion is that no one alloy grade is the universal panacea, even within the limits of the present investigation. From curves such as Figures 39-41, an order of merit can be established for steels of various grades at a given carbon content and hardness and a choice made accordingly. There are particular values of carbon content and hardness where there is very little spread in transition temperature for all grades of steel, i.e., Rc 34 at the 0.20 C level, while at other carbon contents and hardnesses the spread may amount to hundreds of degrees.

An examination of the temper embrittlement maxima obtained by tempering the 0.80 C heats at 1000°F (Figure 41) indicates the beneficial effect of molybdenum in minimizing temper brittleness. Grades 2380, 4380, and 8680 exhibit no maxima at all. Of these, 2380 is a straight nickel grade, and the other two contain molybdenum. The remaining grades fall into the following order as regards amount of temper brittleness exhibited with 4100 showing the smallest peak and 5100 the largest: 4100, 4600, 1300, 3100, and 5100. The 4100 and 4600 grades contain molybdenum, and the 1300,

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3100, and 5100 do not. Thus, the three worst grades, insofar as temper brittleness is concerned, contain no molybdenum, while those grades which exhibit less or no temper brittleness do contain molybdenum; the straight nickel grade also exhibits no temper brittleness.

Three-variable plots summarizing the inter-relations among hardness, carbon content and transition temperature for the 2300, 4300, and 8600 series are presented in Figures 42-44. These curves have already been adequately discussed previously. The three-variable representation is a convenient, clear method of presenting these data and for studying the relationships obtained.

E. Effect of Phosphorous Content

The effect of phosphorous content on the impact properties of two grades of steel are presented in Figure 45. The two grades investigated were 4100, containing about 1% chromium and 0.20% molybdenum, and 5100, which is the same as 4100 except that it contains no molybdenum. The low phosphorous heats contain from 0.014% to 0.023% phosphorous, while the high phosphorous heats (signified by the letter "P") contain from 0.031% to 0.037% phosphorous.

It can be seen that the added phosphorous has a deleterious effect on the transition temperature in every case except for 4180. It can further be seen that the transition temperature is elevated more for the steel containing no molybdenum, 5100, than for the steel containing molybdenum, 4100. This is in accordance with the results presented previously in Report No. 30,³ in which it was shown that the addition of molybdenum offsets the deleterious effect of phosphorous. A Mo/P ratio of 5 was found to be necessary to offset the harmful effect of phosphorous in raising the transition temperature in the absence of temper brittleness. The low phosphorous 4140 used in the present investigation had a Mo/P ratio of about

11, and the high-phosphorous 411:0 a ratio of about 6. Such a high Mo/P ratio notwithstanding, phosphorous was still shown to be deleterious. It is questionable whether the harmful effects of phosphorous could ever be completely offset by molybdenum, no matter how high the Mo/P ratio.

Examination of Figures 12-14 and Figures 18-21 reveals that the phosphorous has practically no effect on the temperability of the steels; hardness after tempering is the same regardless of whether the material contains low or high phosphorous.

The data for one heat of 5135 with high phosphorous are included (Figure 20) as a matter of interest. This was intended to be a heat of 511:0 P, but the carbon came out too low, so another heat was made for comparison with the low phosphorous 511:0. A comparison of the two heats of high phosphorous material (Figures 19 and 20) indicates very little difference in properties.

V. SUMMARY

The Charpy impact properties of eight alloy grades of quenched and tempered steel have been investigated.

A. The following three different types of brittleness, manifested by high transition temperatures, have been observed:

1. "A" brittleness, or 500° embrittlement. This phenomenon is universally exhibited by practically all steels at all carbon levels. The 0.80 C heat in each grade exhibits the greatest amount of "A" brittleness.

2. "B" brittleness, or the 1200° reversal. This type of embrittlement is exhibited by the 2300 series, a straight nickel grade, and consists of an elevation in transition temperature in specimens tempered at 1200°F. The cause of this type of embrittlement is probably the formation of austenite upon tempering, which decomposes to martensite upon quenching or later upon testing.

3. Temper brittleness. This is observed principally in the 0.80 C heat of each grade with the exception of the 2300 series. The steels containing molybdenum exhibit less temper brittleness than those containing no molybdenum.

B. The transition temperature of a quenched and tempered steel is dependent, among other things, on carbon content, alloy content, and tempering temperature. Curves are presented relating these variables and can be used to choose the carbon level, alloy grade, and tempering temperature for the lowest transition temperature. Some of the general conclusions that can be drawn are as follows:

1. A carbon level of 0.30% or 0.40% offers the best overall compromise as regards minimum transition temperatures. These generally have the lowest transition temperatures at hardnesses under about 40 and above about 49.

2. The three Cr-Ni-Mo grades among them have the lowest transition temperatures at most of the carbon contents and over most of the hardness range. Generalizing broadly, it can be said that the straight manganese grade, 1300, and the straight nickel grade, 2300, are the poorest of the grades investigated.

C. High phosphorous contents raise the transition temperatures of 4100 and 5100 steels at practically all carbon levels and hardnesses. The deleterious effect of this element is greater in the 5100 grade, which contains no molybdenum, than in the 4100 grade, which contains molybdenum.

VI. CONTRIBUTING PERSONNEL

Contributing personnel: W. T. Chamberlain, T. Kisiel, A. Nelson, K. Coleman, J. P. Sheehan, and H. Schwartzbart.

VII. NOTEBOOKS

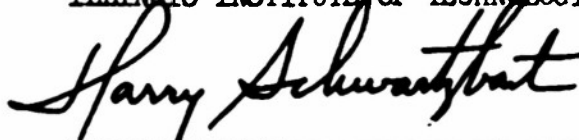
Data in this report are recorded in ARF Logbook Nos. C-1280, C-2507, and C-2338.

VIII. REFERENCES

1. M. Baeyertz, W. F. Craig, Jr., and J. P. Sheehan, "Effect of Alloying Elements on Impact Properties of Quenched and Tempered Steels", Report No. 22, ONR Contract N6 omr 274 T.O.I. Project NR 031-115, September 1, 1949.
2. M. Baeyertz, W. F. Craig, Jr., and J. P. Sheehan, "The Effect of Carbon Content on the Notched-Bar Impact Properties of Quenched and Tempered Steel", Report No. 28, ONR Contract N6 omr 274 T.O.I. Project NR 031-115, September 14, 1950.
3. M. Baeyertz, W. F. Craig, Jr., and J. P. Sheehan, "The Effect of Mo/P Ratio Upon the Notched-Bar Impact Properties of Tempered Martensite", Report No. 30, ONR Contract N6 omr 274 T.O.I. Project NR 031-115, March 13, 1951.

Respectfully submitted,

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TABLE I
CHEMICAL ANALYSES, FINE GRAIN LABORATORY HEATS

<u>Heat</u>	<u>Nominal Grade</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>SI</u>	<u>NI</u>	<u>Cr</u>	<u>Mo</u>
3740	1320	0.24	1.60	0.023	0.027	0.23	—	—	—
I	1340	.40	1.70	.018	.031	.21	0.04	None	Trace
3779	1380	.73	1.66	.023	.022	.17	—	—	—
2714	2320	.18	.91	.025	.027	.17	3.47	—	—
2722	2330	.33	.86	.025	.027	.16	3.50	—	—
O	2340	.43	.83	.020	.028	.22	3.38	—	—
2725	2360	.57	.91	.025	.026	.16	3.50	—	—
2727	2380	.75	1.00	.025	.025	.19	3.50	—	—
3745	3120	.23	.75	.022	.020	.30	1.26	.58	—
J	3140	.38	.77	.013	.031	.19	1.26	.64	—
3781	3180	.72	.92	.022	.028	.25	1.34	.63	—
3808-3	4120	.24	.89	.019	.020	.30	—	.95	.21
3808-6	4120P*	.24	.89	.031	.020	.30	—	.95	.21
K	4140	.40	.89	.016	.026	.26	—	.89	.20
3729	4140P	.41	.87	.037	.025	.22	—	.96	.21
3814-3	4180	.74	.95	.023	.029	.20	—	1.02	.20
3814-6	4180P	.74	.95	.034	.029	.20	—	1.03	.20
2921	4320	.21	.74	.020	.016	.23	1.53	1.09	.19
2716	4330	.30	.84	.024	.021	.31	1.69	1.10	.20
M	4340	.38	.77	.020	.035	.25	1.65	.93	.21
2718	4360	.57	.87	.025	.019	.23	1.62	1.08	.22
2720	4380	.76	.91	.024	.020	.23	1.67	1.11	.21

TABLE I (Contd)
CHEMICAL ANALYSES, FINE GRAIN LABORATORY HEATS

<u>Heat</u>	<u>Nominal Grade</u>	<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr</u>	<u>Mo</u>
3751	L620	0.20	0.67	0.015	0.011	0.25	1.85	0.30	0.18
L	L640	.43	.69	.009	.018	.30	1.78	.29	.20
3792	L680	.74	.77	.012	.011	.19	1.81	.30	.21
3798-3	5120	.23	.85	.023	.025	.28	--	1.00	--
3798-6	5120P	.23	.85	.036	.025	.28	--	1.00	--
P	5140	.38	.80	.014	.034	.19	--	.87	--
3816	5140P	.40	.81	.037	.024	.16	--	.89	--
3717	5135P	.35	.79	.037	.031	.21	--	.91	--
3813-3	5180	.72	.95	.023	.029	.23	--	1.00	--
3813-6	5180P	.72	.95	.035	.029	.23	--	1.00	--
2730	8620	.20	.89	.022	.018	.14	.60	.68	.20
2820	8630	.34	.77	.020	.020	.12	.66	.62	.22
N	8640	.45	.78	.020	.011	.16	.65	.61	.20
2928	8660	.56	.81	.018	.022	.34	.70	.56	.25
2817	8680	.76	.81	.020	.011	.11	.67	.60	.22

* The letter "P" indicates a high phosphorous heat.

TABLE II
NORMALIZING AND AUSTENITIZING TEMPERATURES,
AS-AUSTENITIZED GRAIN SIZE

<u>Heat</u>	<u>Nominal Grade</u>	<u>Norm. and Aust. Temp., °F</u>	<u>Aust. Grain Size ASTM No.</u>
3740	1320	1650	9
I	1340	1550	8
3779	1380	1450	8
2714	2320	1650	6 - 7
2722	2330	1575	7 - 8
O	2340	1550	8 - 9
2725	2360	1475	7 - 8
2727	2380	1450	7 - 8
3745	3120	1650	
J	3140	1550	8 - 9
3781	3180	1450	9
3808-3	4120	1650	8 - 9
3808-6	4120P	1650	8 - 9
K	4140	1550	8 - 9
3729	4140P	1550	8 - 9
3814-3	4180	1450	8 - 9
3814-6	4180P	1450	8 - 9
2921	4320	1650	8 - 9
2716	4330	1575	8 - 9
M	4340	1550	8 - 9
2718	4360	1475	7 - 9
2720	4380	1450	8 - 9
3751	4620	1650	8 - 9
L	4640	1550	7 - 8
3792	4680	1450	8
3798-3	5120	1650	7 - 9
3798-6	5120P	1650	8
P	5140	1550	7 - 8
3816	5140P	1550	8
3717	5135P	1550	7 - 9
3813-3	5180	1450	8 - 9
3813-6	5180P	1450	8
2730	8620	1650	8 - 9
2820	8630	1575	7 - 9
N	8640	1550	8 - 9
2928	8660	1475	8 - 9
2817	8680	1450	8 - 9

TABLE III
TRANSITION ENERGIES AND TEMPERATURES,
FINE GRAIN LABORATORY HEATS

Heat	Nominal Grade	Temper °F	Rockwell C	Transition Energy and Temp. 80% of Maximum Energy	
				Ft.-lb.	F
3740	1320 (0.24%C)	As-Quenched	43	20*	
		300	44	21.5	75
		400	44	21.5	10
		500	43	21.5	260
		600	42	24	255
		700	39	32	155
		800	33	48	- 45
		1000	23	68	- 25
		1200	15	96	- 75
I	1340 (0.40%C)	A.Q.	55	8.5*	
		300	53.5	13	- 10
3779	1380 (0.73%C)	500	56	3	345
		600	54	5.5	350
		700	51	10	315
		800	46	11	- 50
		1000	38	20	150
		1200	26	37	40
2714	2320 (0.18%C)	A.Q.	43	32*	
		300	43.5	24	-200
		400	42.5	22	-200
		500	42	21.5	10
		600	39.5	23	- 10
		700	36	32	35
2722	2330 (0.33%C)	A.Q.	52	18*	
		300	50.5	19	- 75
		400	48	16	- 95
		500	46	17	60
		600	43	18.5	100
		700	39	24	50
2725	2360 (0.57%C)	400	54.5	9.5	55
		500	51.5	11	225
		600	49	11	160
		700	44	15	90
2727	2380 (0.75% C)	500	54.5	5.5	350
		600	51	9	450
		700	47	11	240

TABLE III (Contd)
TRANSITION ENERGIES AND TEMPERATURES.
FINE GRAIN LABORATORY HEATS

Heat	Nominal Grade	Temper °F	Rockwell C	Transition Energy and Temp. 80% of Maximum Energy	
				Ft-lb.	°F
3745	3120 (0.23%C)	A.Q.	44	29*	
		300	43	23	- 85
		400	44	25.5	- 45
		500	43	21.5	25
		600	43	25	100
		700	40	28	45
		800	35	39	- 15
		1000	26	62.5	- 40
		1200	19	76	-135
J	3140 (0.38%C)	A.Q.	53	18*	
		300	52.5	16	-125
3781	3180 (0.72%C)	500	56	4	275
		600	54	7	285
		700	51	9	165
		800	47	10.5	-120
		1000	40	22	120
		1200	31	37.5	- 5
3808-3	4120 (0.24%C)	A.Q.	44	33*	
		300	44	26.5	- 50
		400	45	26.5	- 20
		500	44	24	65
		600	43	23	90
		700	41	25	105
		800	39	33.5	25
		1000	31	53	- 65
		1200	23	81.5	-150
3808-6	4120P [†] (0.24%C)	A.Q.	44	31*	
		300	45	26.5	10
		400	45	23	- 40
		500	45	24	150
		600		21	110
		700	42	23	160
		800	40	35	65
		1000	31	55	- 25
		1200	22	86.5	-125
K	4140 (0.40%C)	A.Q.	53.5	15*	
		300	53	15	-100

† The letter "P" after a grade number indicates a high phosphorous heat.

TABLE III (Contd)
TRANSITION ENERGIES AND TEMPERATURES,
FINE GRAIN LABORATORY HEATS

Heat	Nominal Grade	Temper °F	Rockwell C	Transition Energy and Temp. 80% of Maximum Energy	
				Ft.-lb.	°F
3729	4140P (0.41%C)	A.Q.	56	8*	
		300	54	13.5	75
		400	52	15	95
		500	50	11	115
		600	48	12	110
		700	46	14.5	130
		800	44	19	90
		1000	37	29.5	- 20
		1200	29	57	- 35
		3814-3	4130 (0.74%C)	500	58
600	56			6.5	240
700	54			8.5	130
800	51			10.5	- 50
1000	42			20	75
1200	34			41	25
3814-6	4180P (0.74%C)			500	55
		600	55	6.5	330
		700	52	8	30
		800	45	9.5	- 20
		1000	41	18.5	60
		1200	38	43	40
2921	4320 (0.21%C)	A.Q.	43.5	30*	
		300	43.5	24	-175
		1000	33	37	- 20
M	4340 (0.38%C)	A.Q.	55	15*	
		300	54	14.5	-225
3751	4620 (0.20%C)	A.Q.	42	35*	
		300	42	28	-100
		400	41	27.5	- 90
		500	42	25.5	0
		600	42	28	20
		700	38	35	15
		800	34	44	- 55
		1000	29	63	- 80
		1200	19	92	-115

TABLE III (Contd)
TRANSITION ENERGIES AND TEMPERATURES,
FINE GRAIN LABORATORY HEATS

<u>Heat</u>	<u>Nominal Grade</u>	<u>Temper °F</u>	<u>Rockwell C</u>	<u>Transition Energy and Temp. 80% of Maximum Energy</u>	
				<u>Ft.-lb.</u>	<u>°F</u>
L	4640 (0.43%C)	A.Q. 300	55.5 54.5	15* 14	- 150
3792	4680 (0.74%C)	500	56	6.5	90
		600	52	9	155
		700	50	9.5	45
		800	46	12	- 85
		1000	41	21	90
		1200	31	35.5	- 10
3798-3	5120 (0.23%C)	A.Q.	45.5	26*	
		300	45	23	- 20
		400	45	23	- 35
		500	46	22	120
		600	44	24	175
		700	41	25	135
		800	38.5	37	10
		1000	28	68	- 20
		1200	22	96	- 50
3798-6	5120P (0.23%C)	A.Q.	44	23*	
		300	44	22.5	65
		400	45	22.5	25
		500	44	21.5	135
		600	43	22.5	260
		700	41	25	250
		800	38	40	85
		1000	26	69	50
		1200	18	89.5	- 65
3816	5140P (0.40%C)	A.Q.	55	6*	
		300	55	12	160
		400	52	13	175
		500	50	11	330
		600	48	11	240
		700	46	15	220
		800	42	22.5	40
		1000	33	44	40
		1200	26	68	0

TABLE III (Contd)
TRANSITION ENERGIES AND TEMPERATURES,
FINE GRAIN LABORATORY HEATS

Heat	Nominal Grade	Temper °F	Rockwell C	Transition Energy and Temp.	
				80% of Maximum Energy Ft-lb.	°F
3717	5135P (0.35%C)	A.Q.	55	5*	
		300	54.5	10.5	15
		400	52	12	70
		500	49	12	290
		600	49	11.5	320
		700	47	14.5	285
		800	43	22.5	100
		1000	34	41.5	35
		1200	27.5	57.5	- 35
		3813-3	5180 (0.72%C)	500	56
600	55			6	280
700	51.5			6.5	- 55
800	47			10.5	-105
1000	39			24	135
1200	28.5			47	75
3813-6	5180P	500	57	3.5	385
		600	55	4	400
		700	51	7	295
		800	48	9	100
		1000	38	26	245
		1200	29	37.5	60
2730	8620 (0.20%C)	A.Q.	42.5	35*	
		300	43	28	- 60
		400	43	25.5	- 85
		500	42.5	24	- 20
		600	41.5	25.5	65
		700	39.5	29	55
2820	8630 (0.34%C)	A.Q.	53	17*	
		300	52	16.5	-100
		400	50	17.5	-100
		500	48	16	15
		600	46.5	16	- 10
		700	44.5	19	70
N	8640 (0.45%C)	A.Q.	59	6*	
		300	56	13	- 25

TABLE III (Contd)

TRANSITION ENERGIES AND TEMPERATURES,
FINE GRAIN LABORATORY HEATS

<u>Heat</u>	<u>Nominal Grade</u>	<u>Temper °F</u>	<u>Rockwell C</u>	<u>Transition Energy and Temp.</u>	
				<u>80% of Maximum Energy</u>	<u>°F</u>
				<u>Ft.-lb.</u>	<u>°F</u>
2928	8660 (0.56%C)	400	57	10	125
		500	55.5	9	200
		600	52.5	10.5	175
		700	50	12	40
2817	8680 (0.76%C)	500	56	8	385
		600	54	6.5	70
		700	52	9	125

* These values are the energies absorbed at room temperature and not 80% of the maximum energy, as is the case for the specimens tempered at 300°F and above. Although the energy-testing temperature curves for as-quenched specimens were determined above room temperature, they are invalid in this region, because some tempering was obtained during testing. The curve generally did not become horizontal until a testing temperature above room temperature was used.

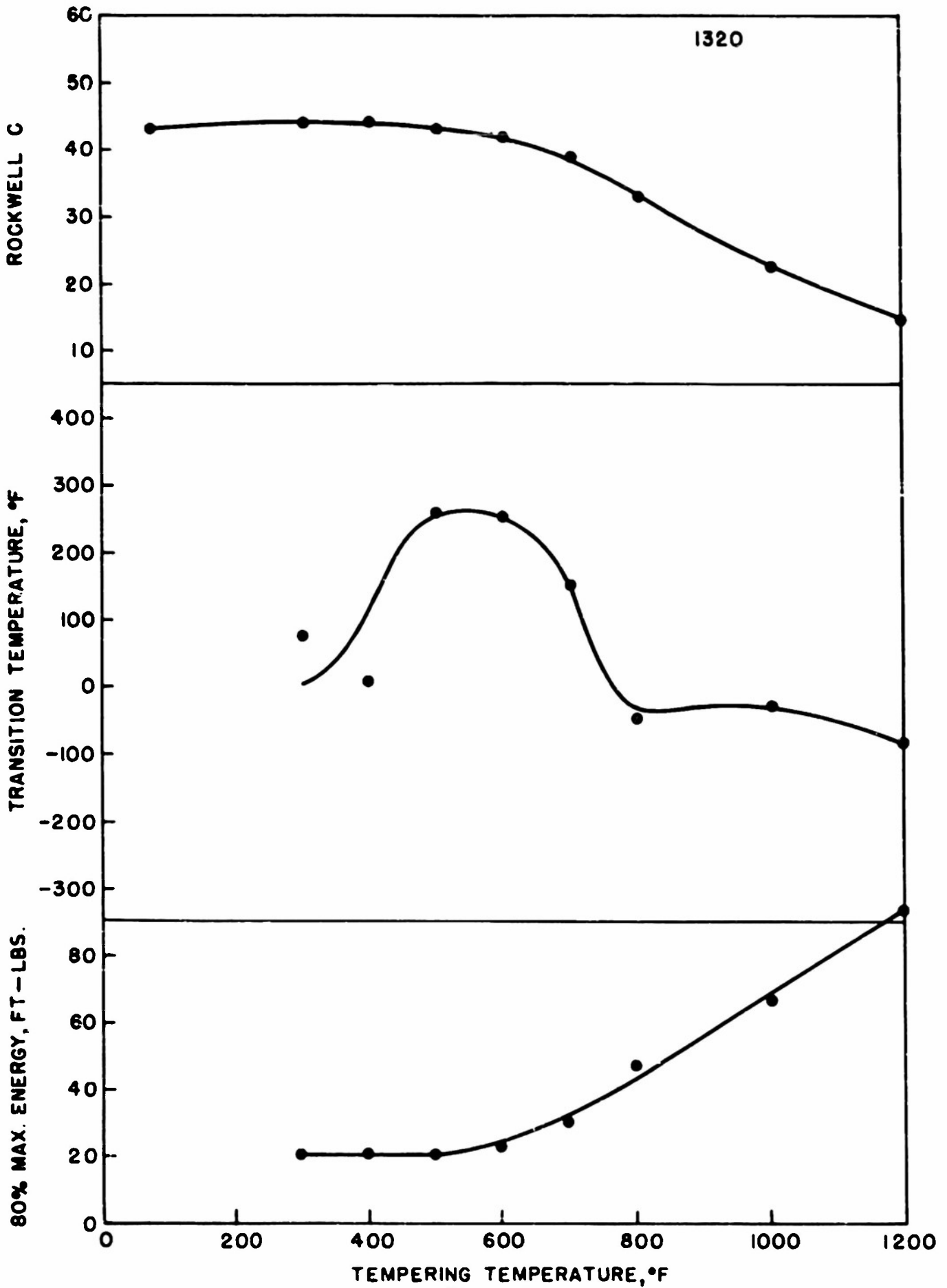


Figure 1

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 1320.

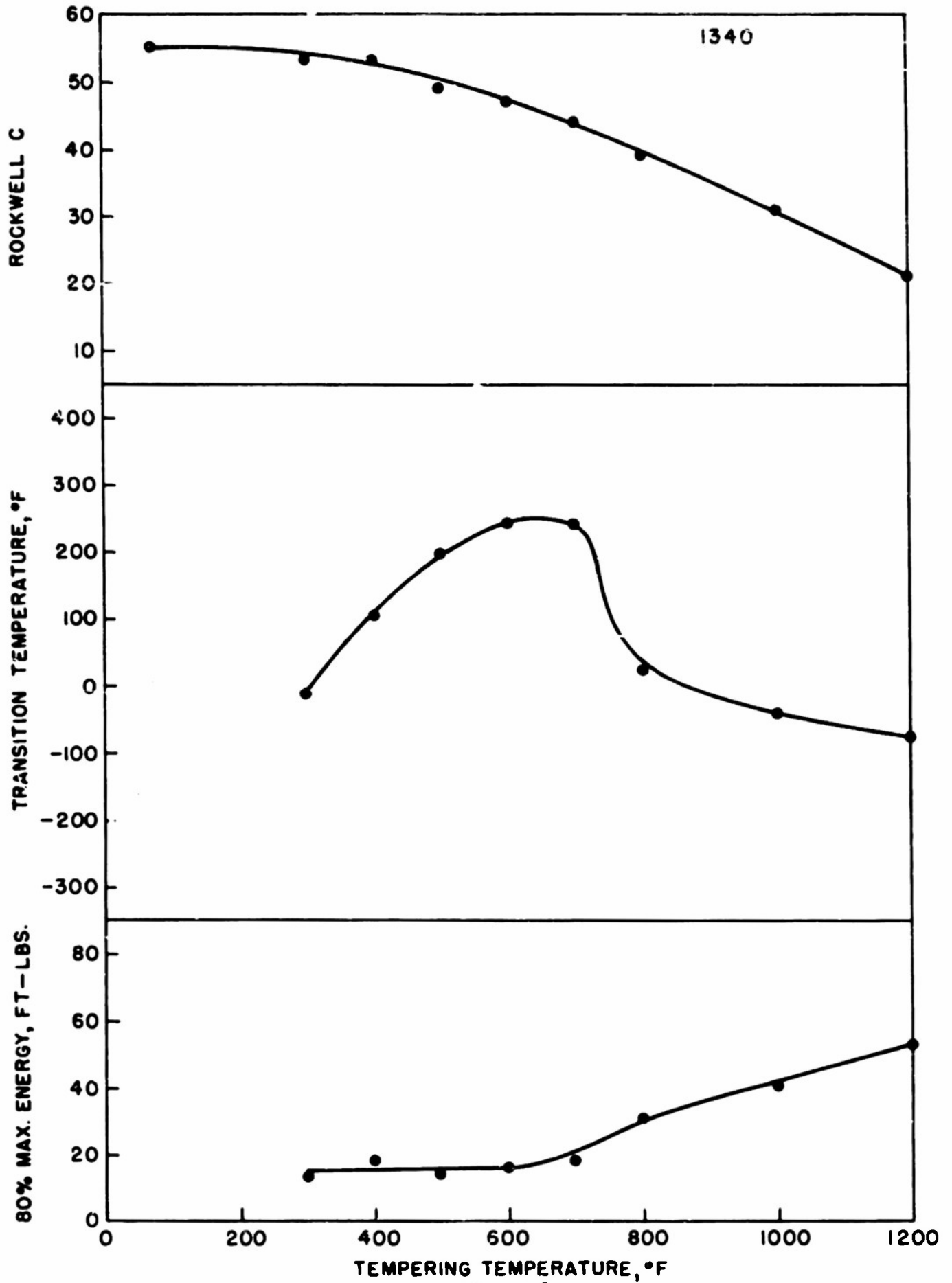


Figure 2

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 1340.

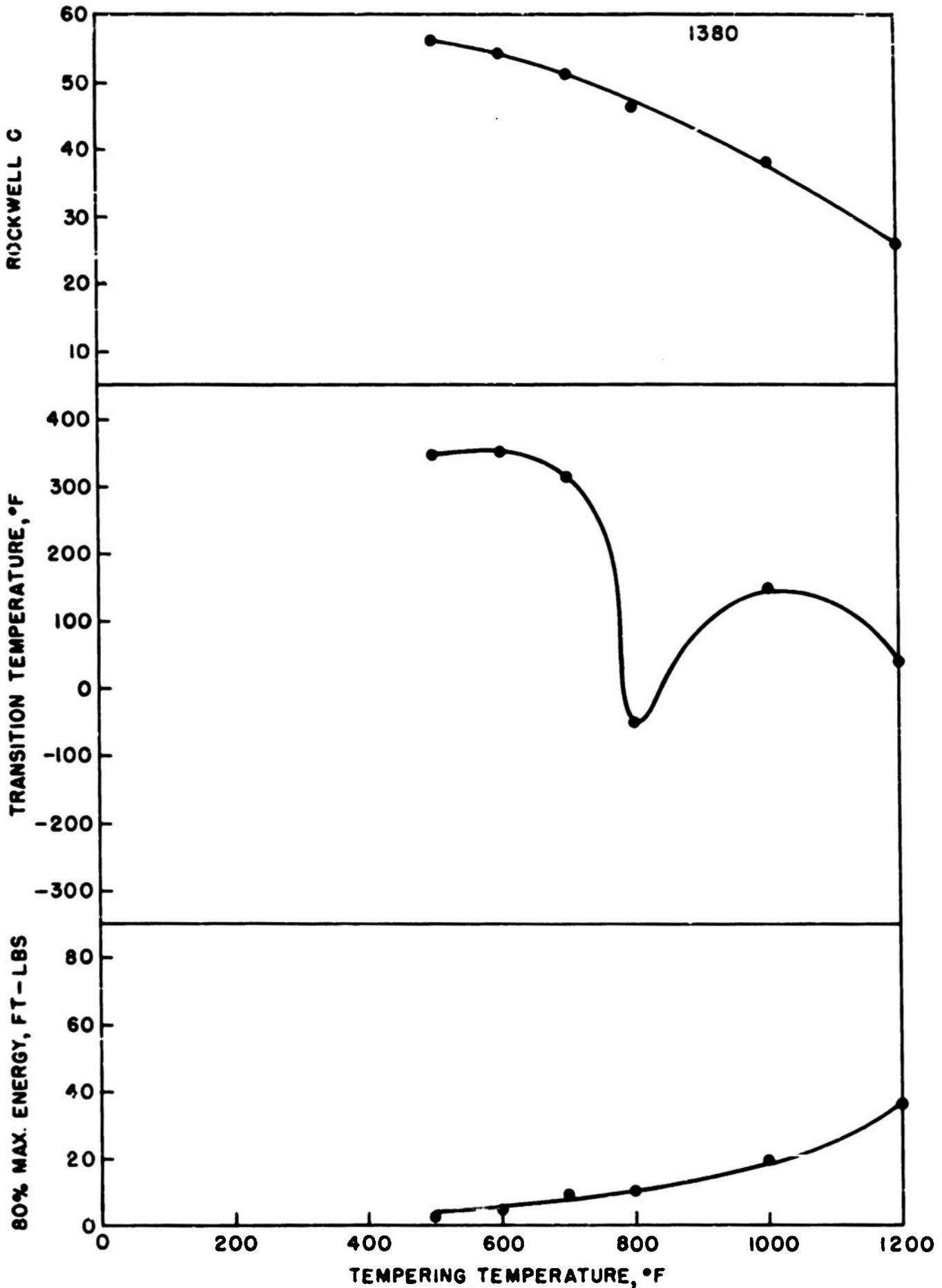


Figure 3

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 1380.

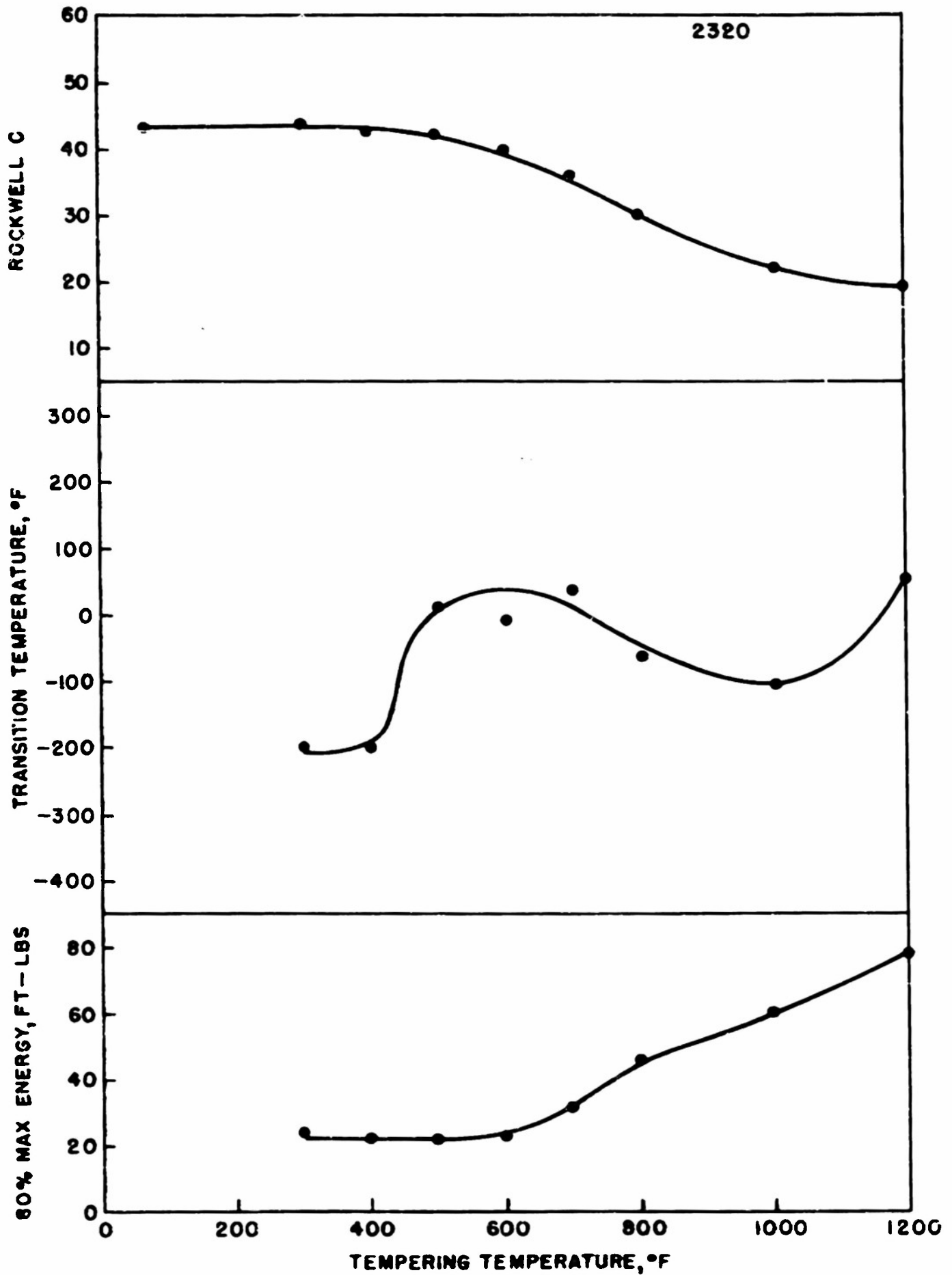


Figure 4

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 2320.

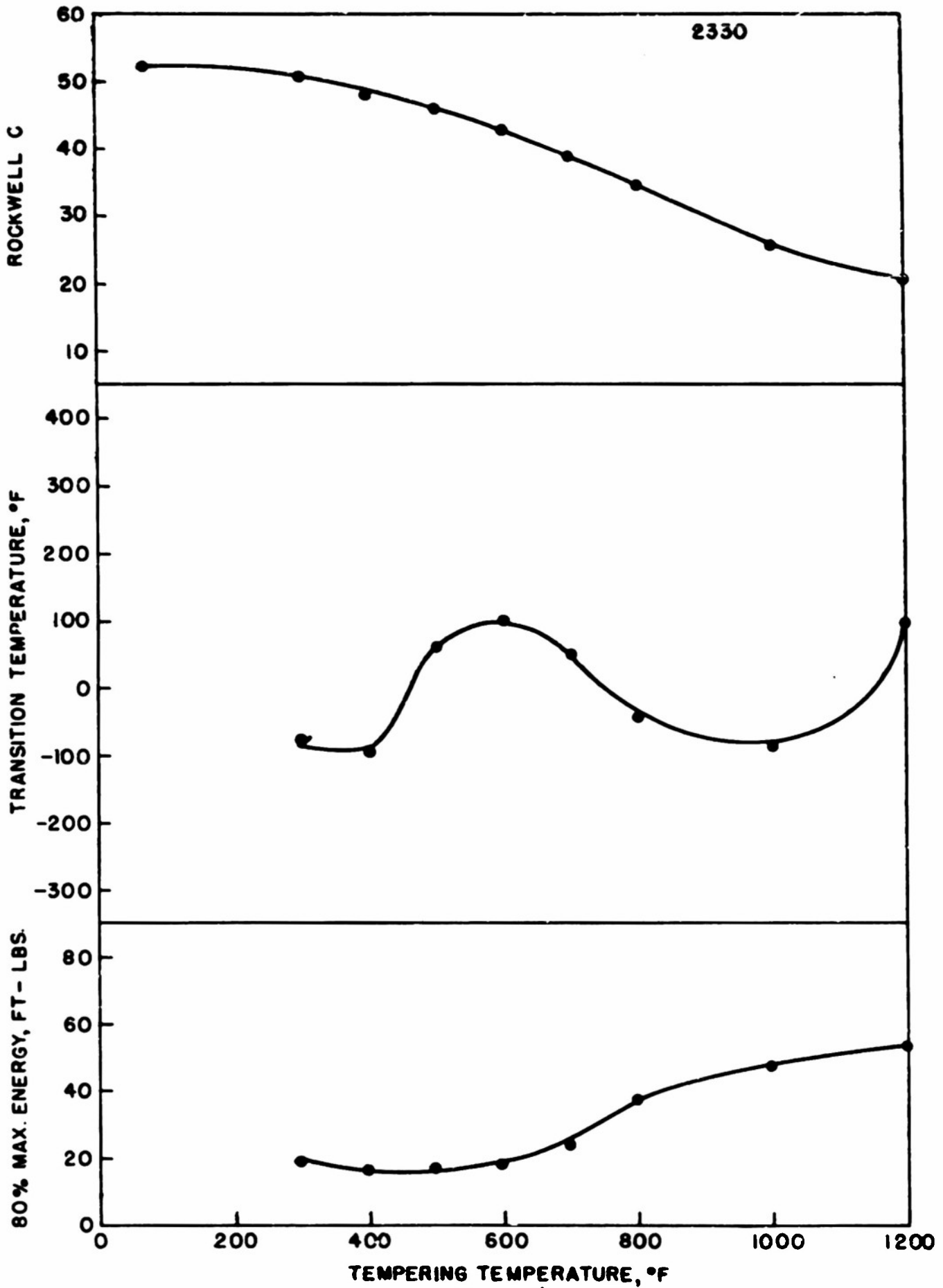


Figure 5

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 2330.

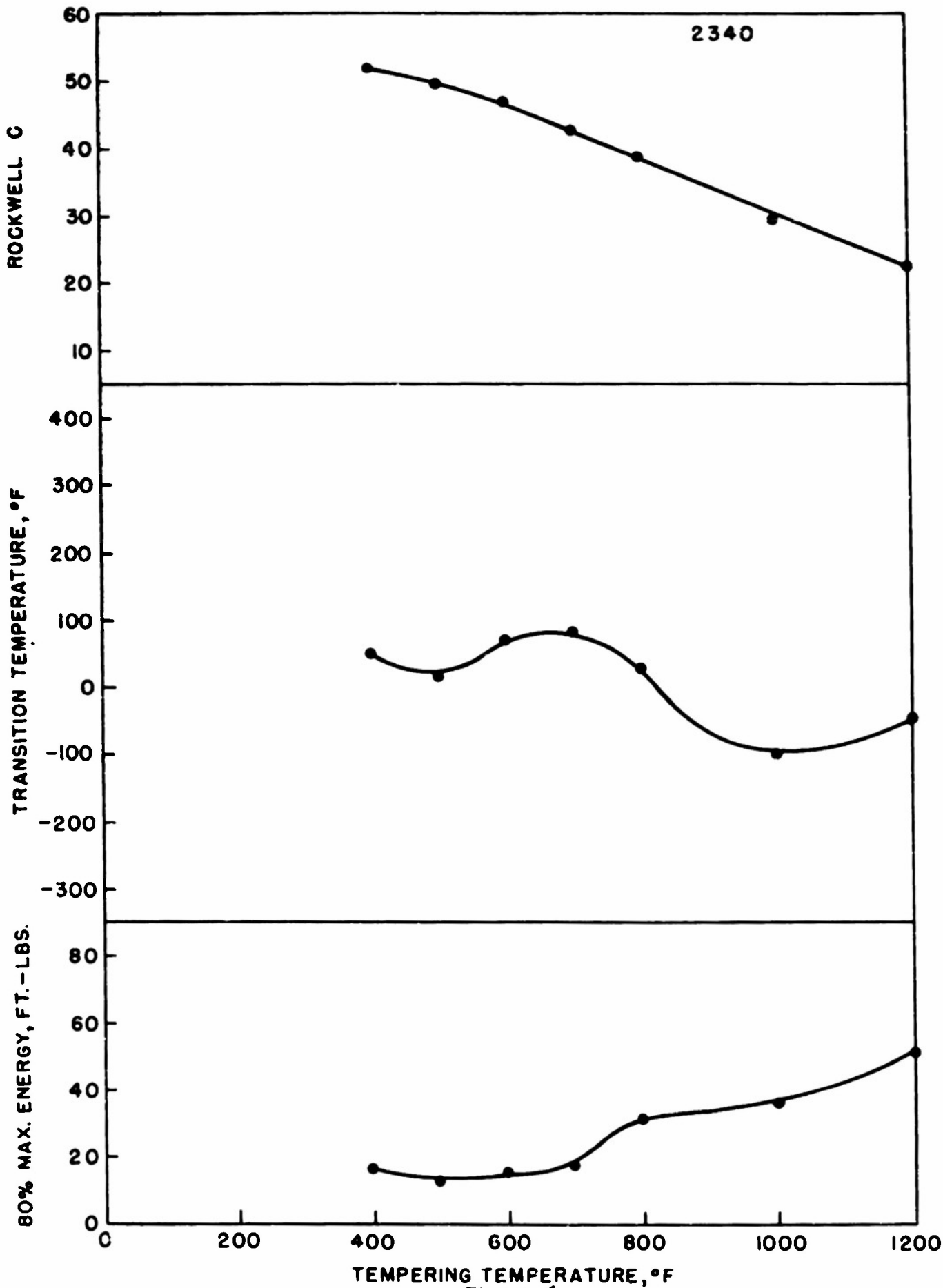


Figure 6

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 2340.

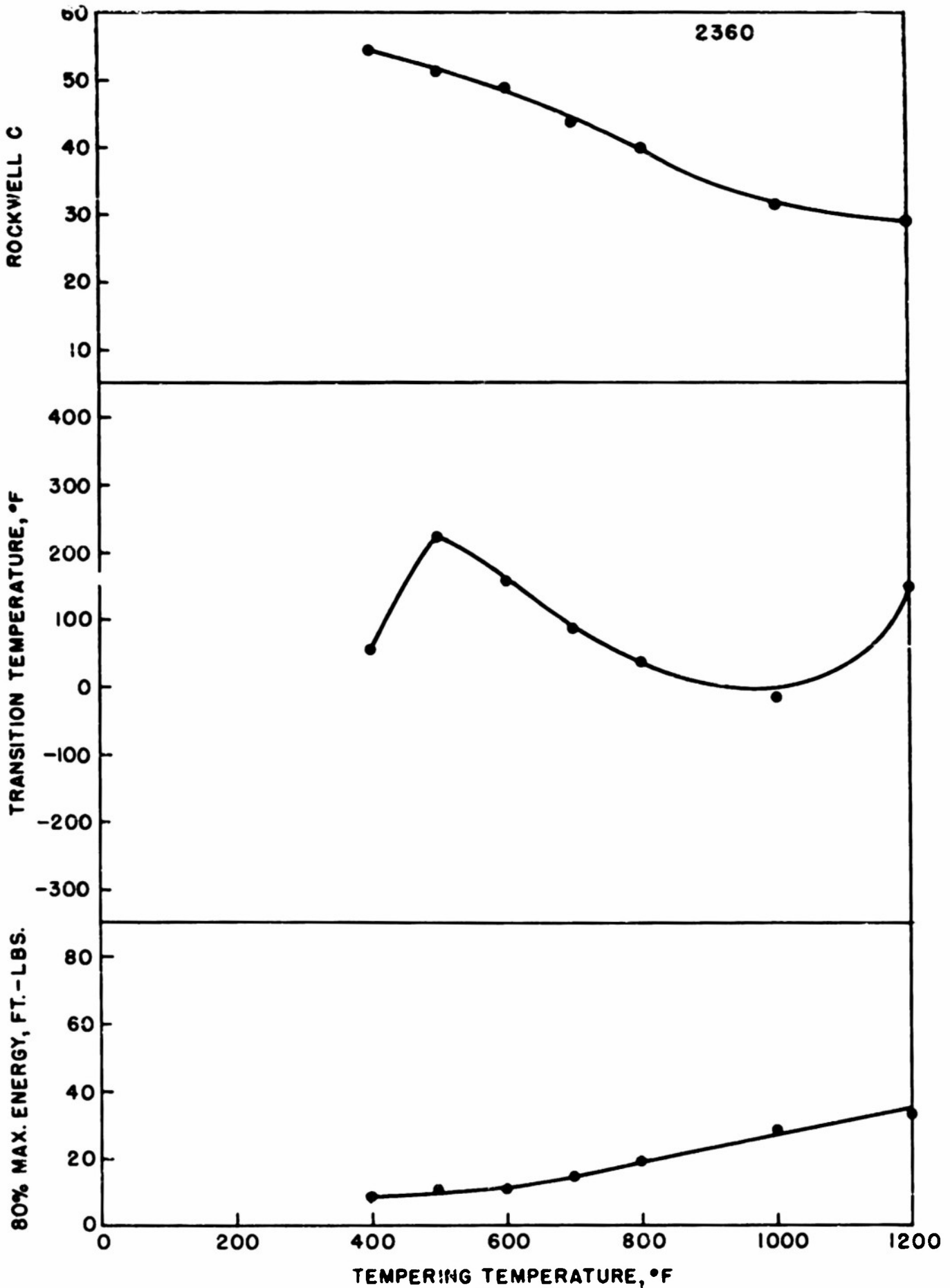


Figure 7

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 2360.

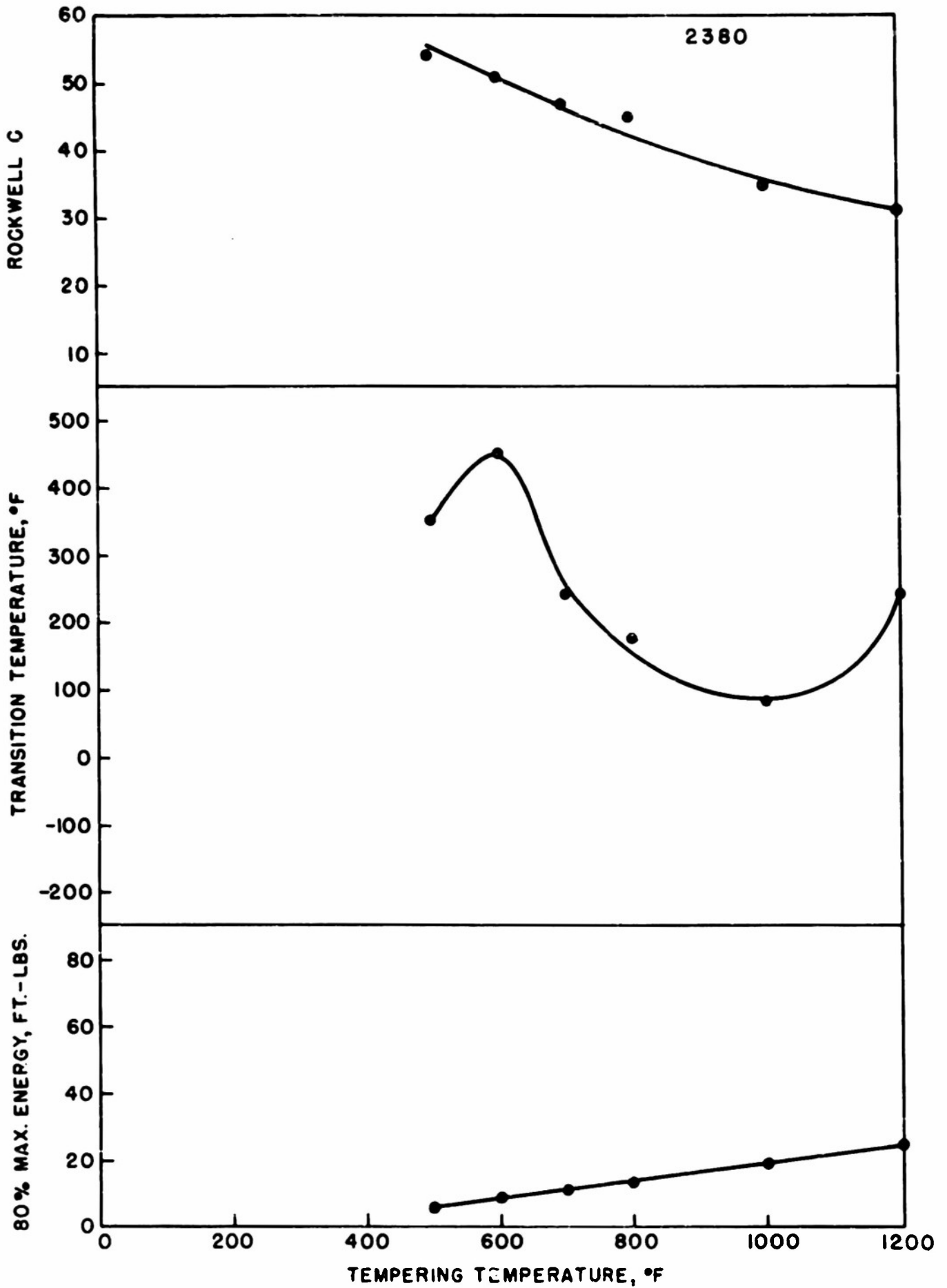


Figure 8

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 2380.

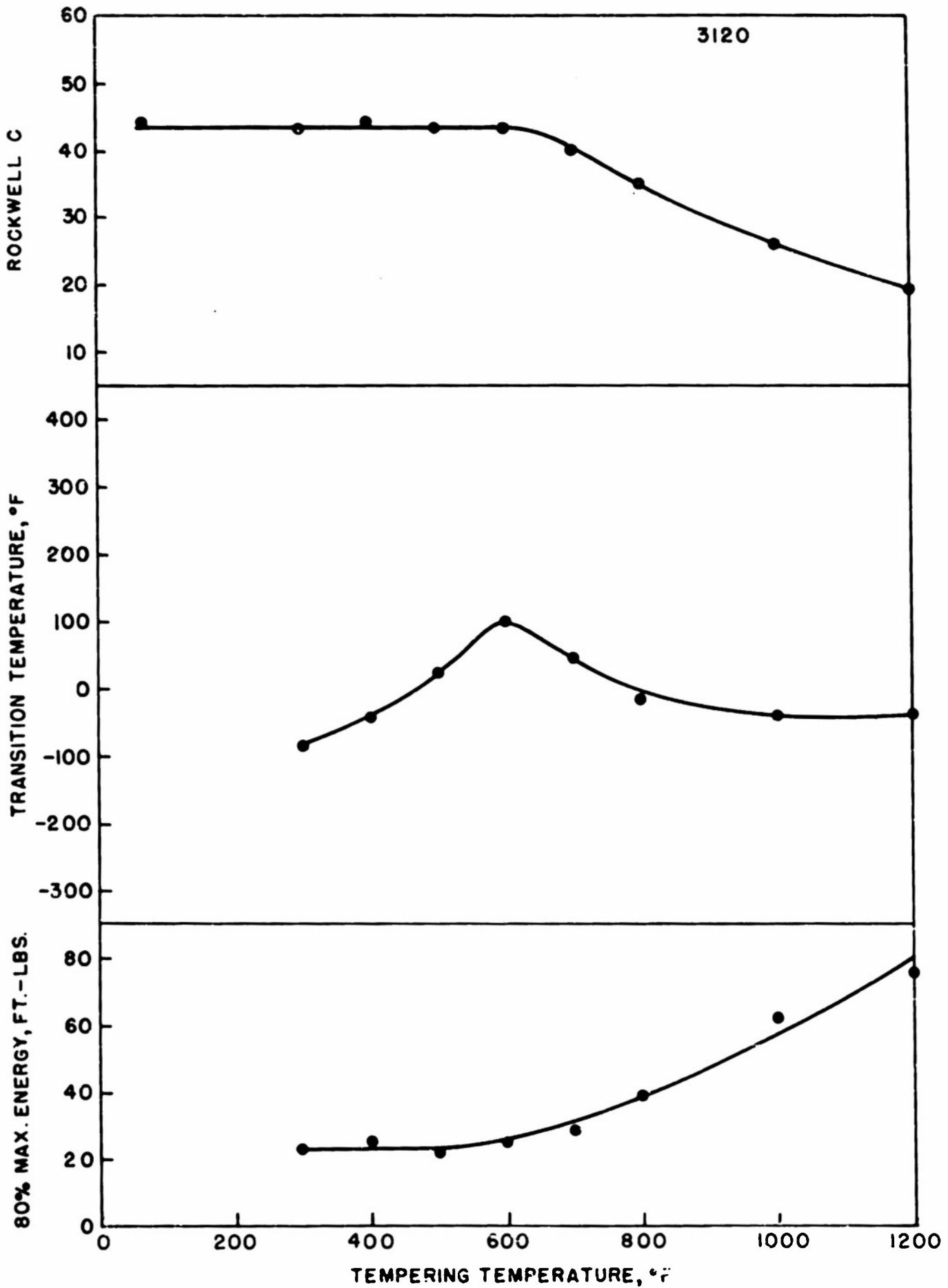


Figure 9

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 3120.

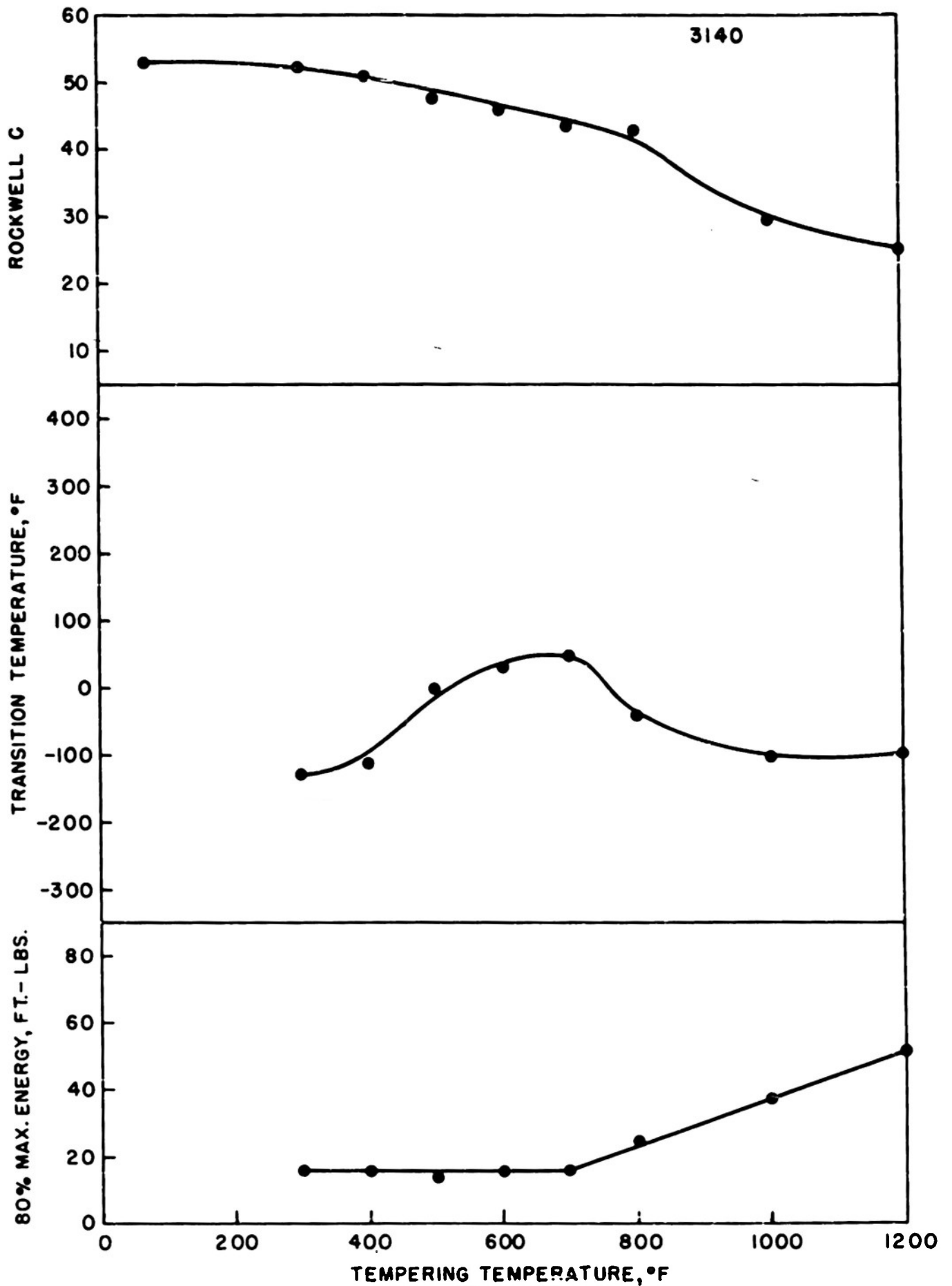


Figure 10

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 3140.

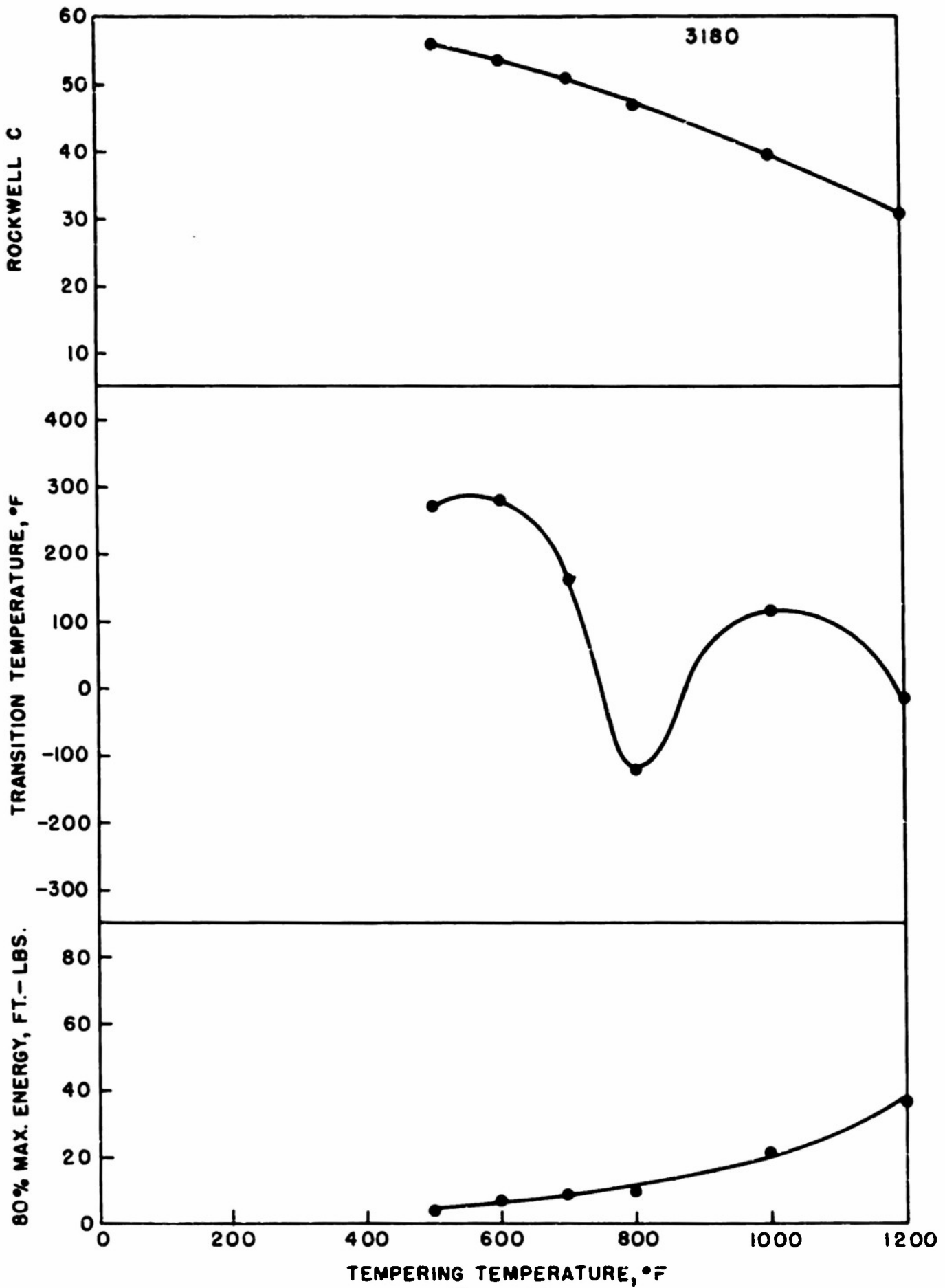


Figure 11

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 3180.

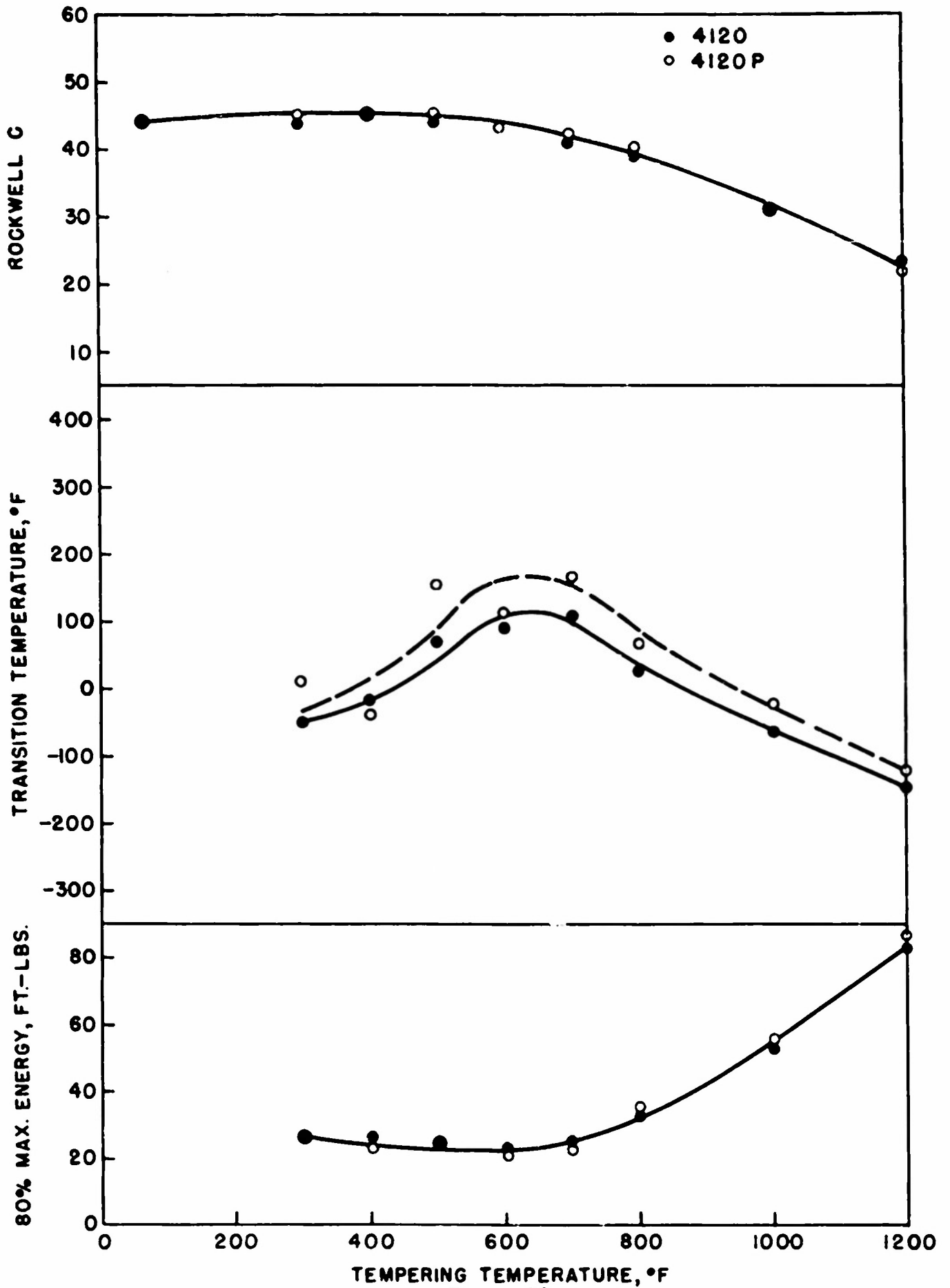


Figure 12

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 4120 with two different phosphorous contents.

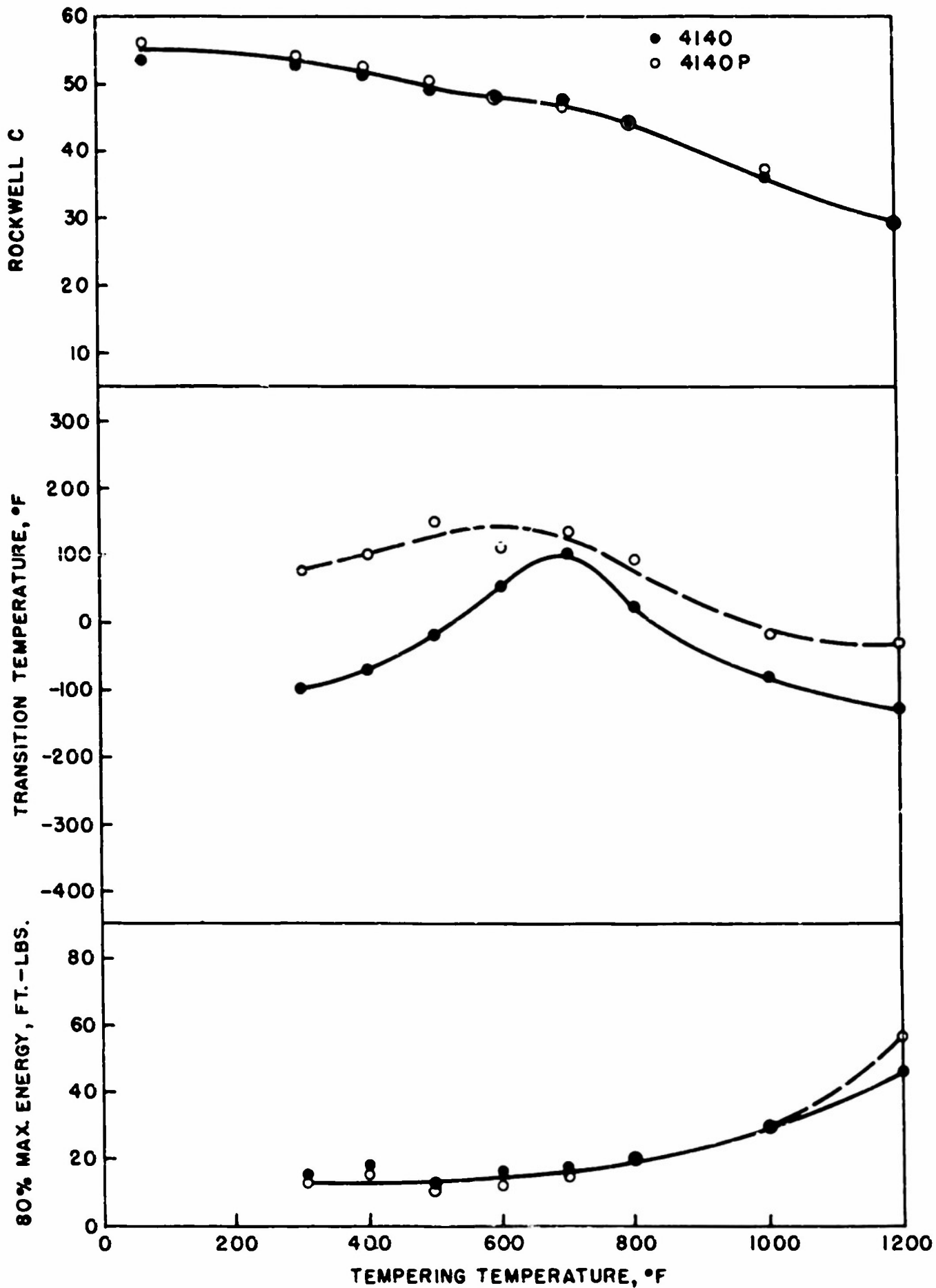


Figure 13

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 4140 with two different phosphorous contents.

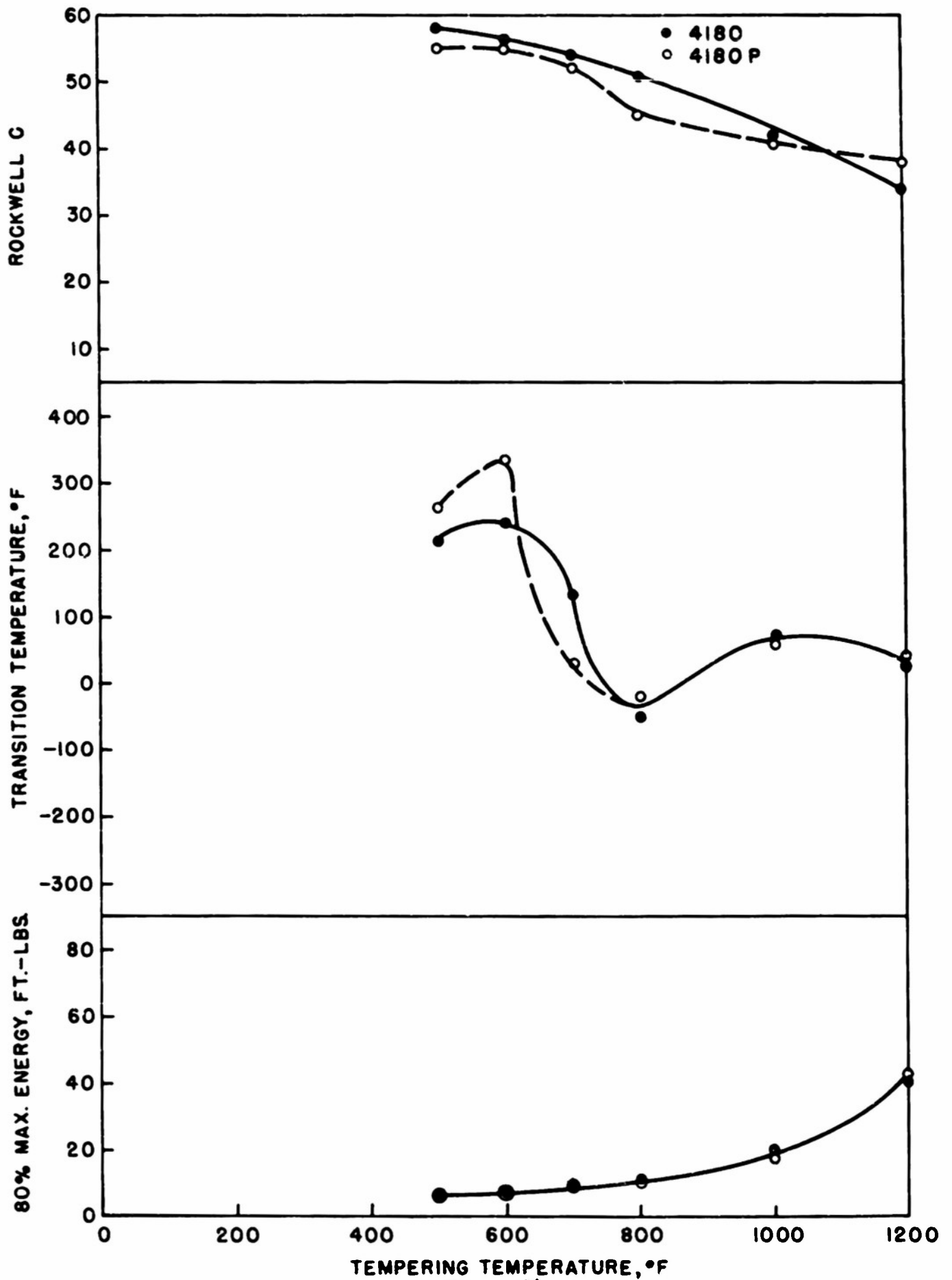


Figure 11

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 4180 with two different phosphorous contents.

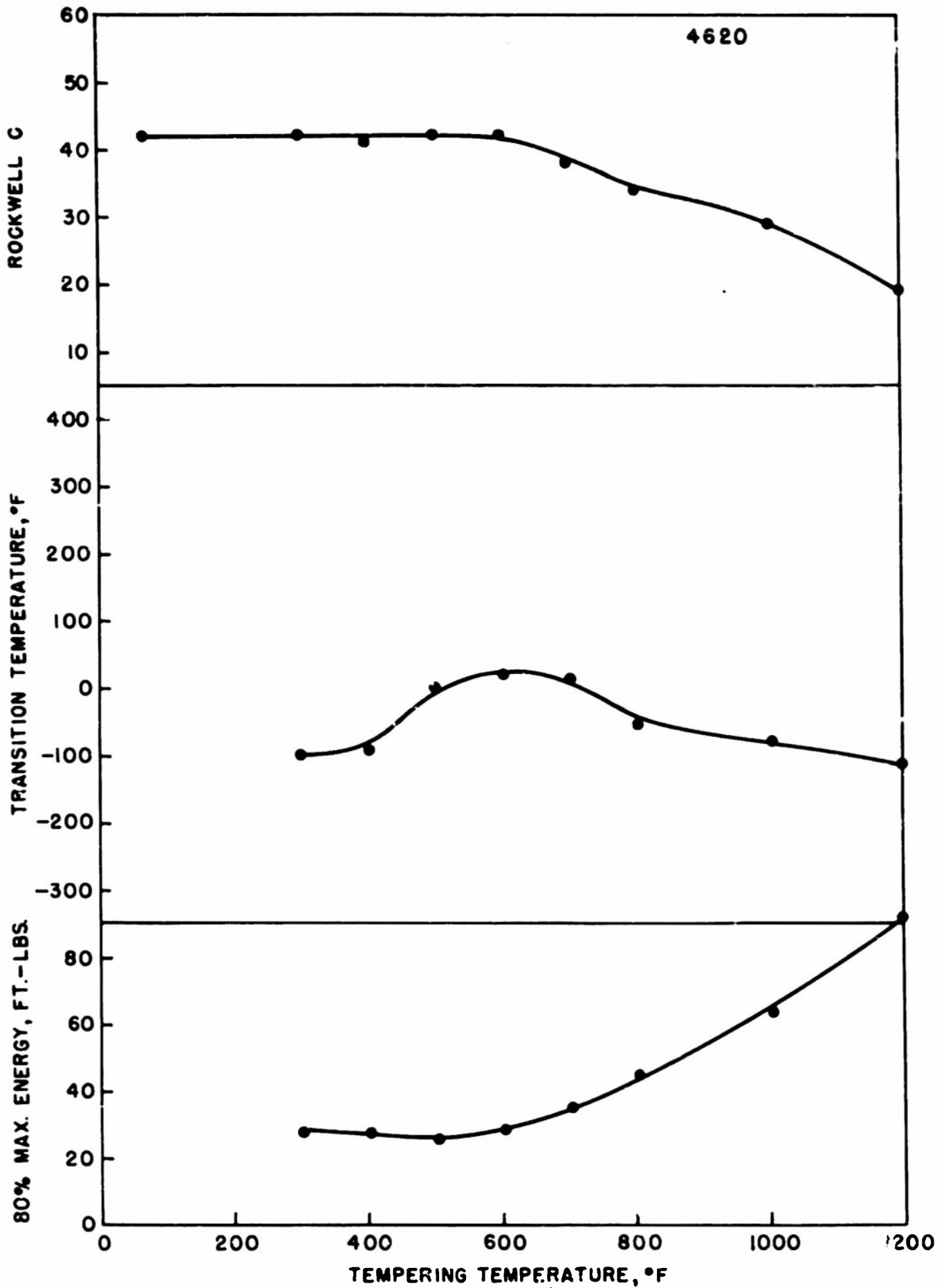


Figure 15

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 4620.

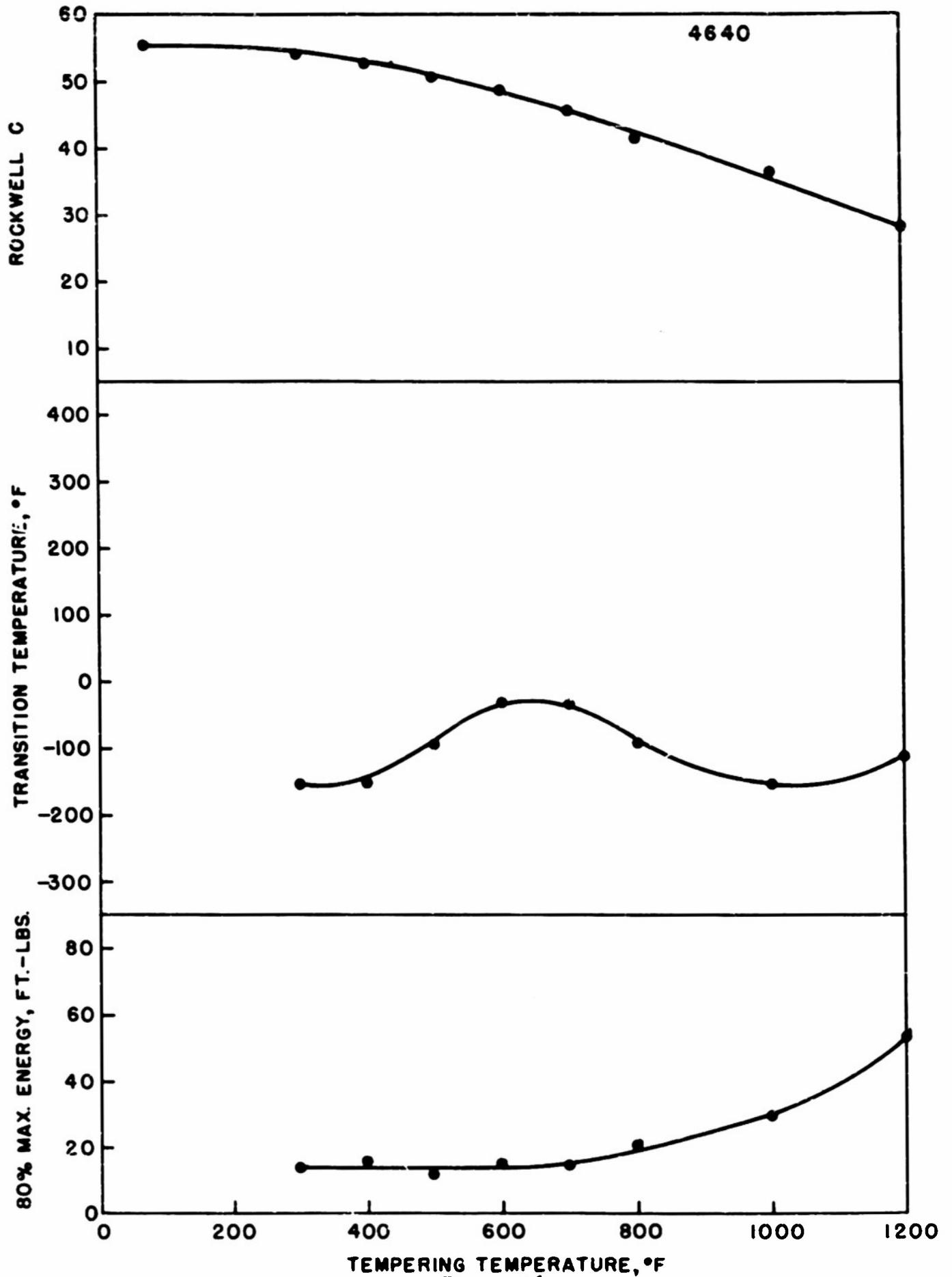


Figure 16

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 4640.

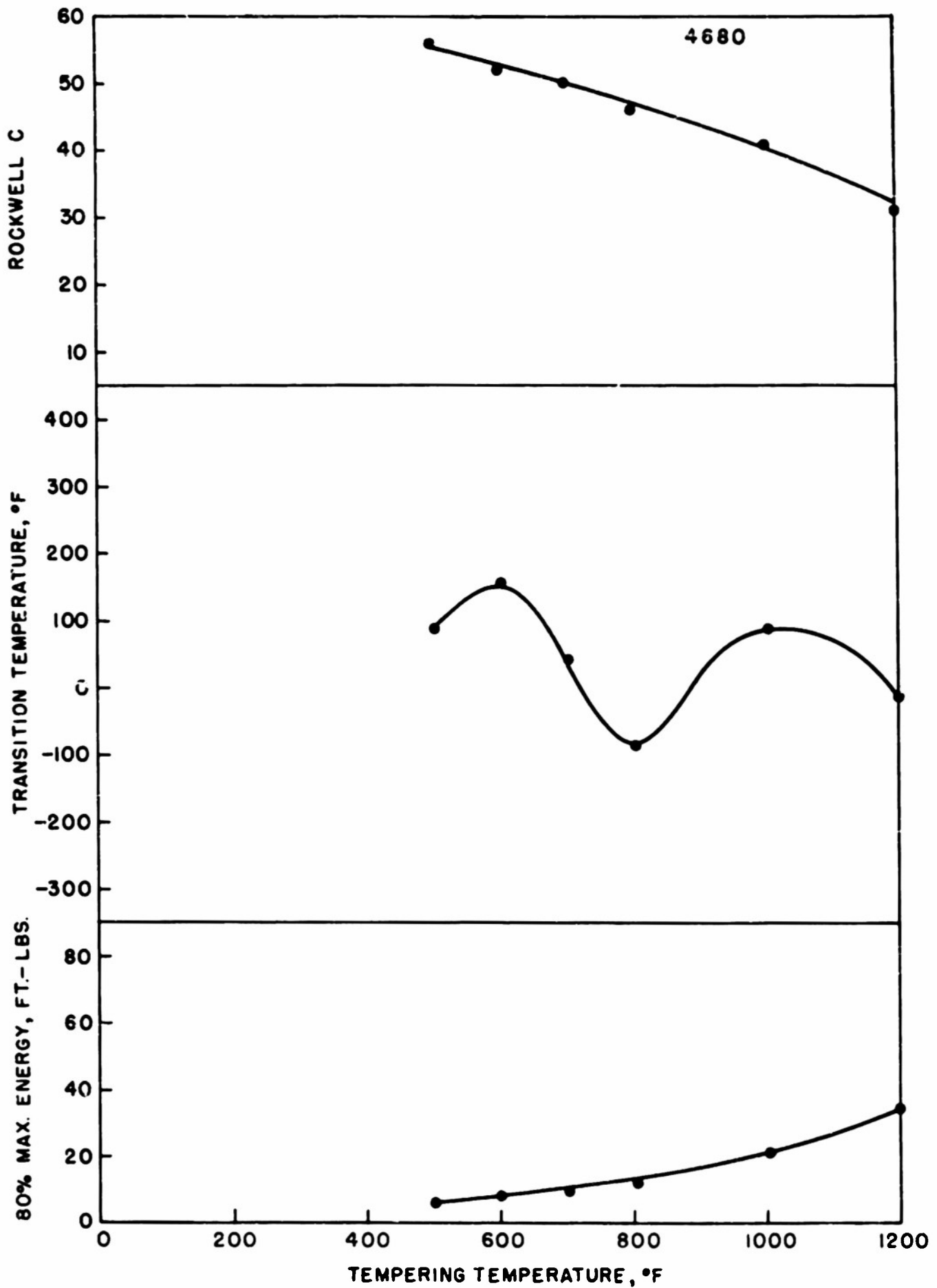


Figure 17

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 4680.

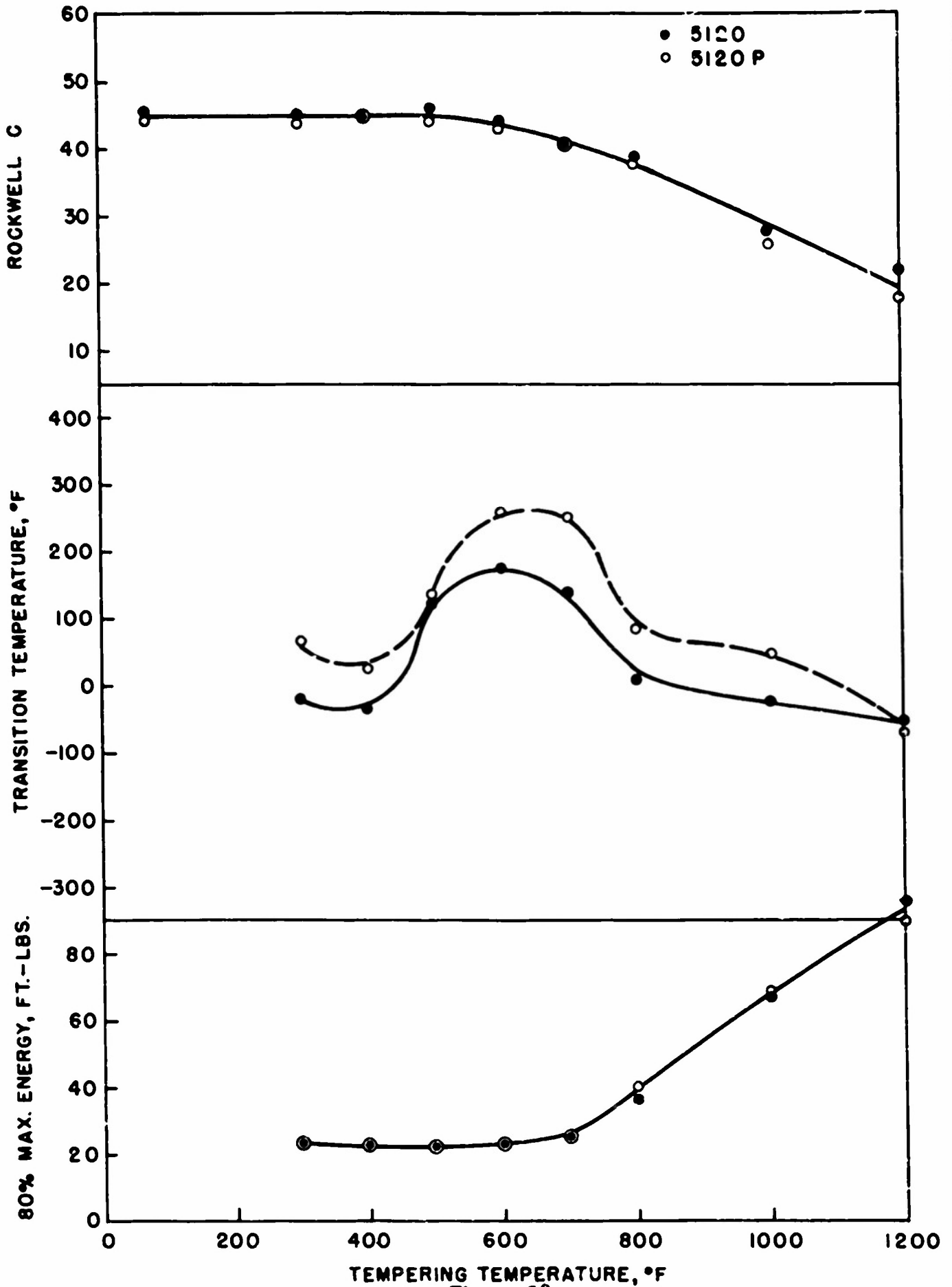


Figure 18

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 5120 with two different phosphorous contents.

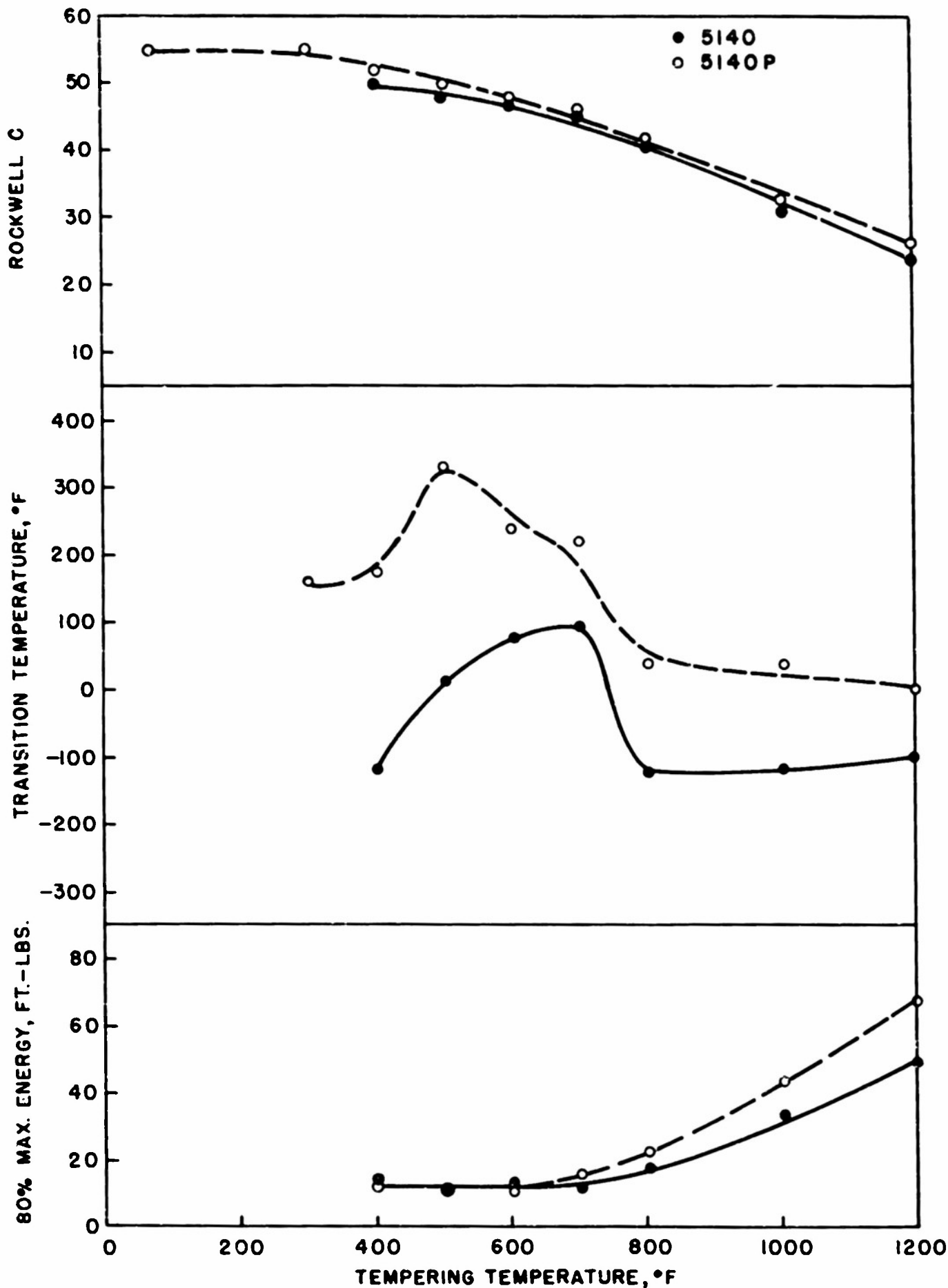


Figure 19

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 5140 with two different phosphorous contents.

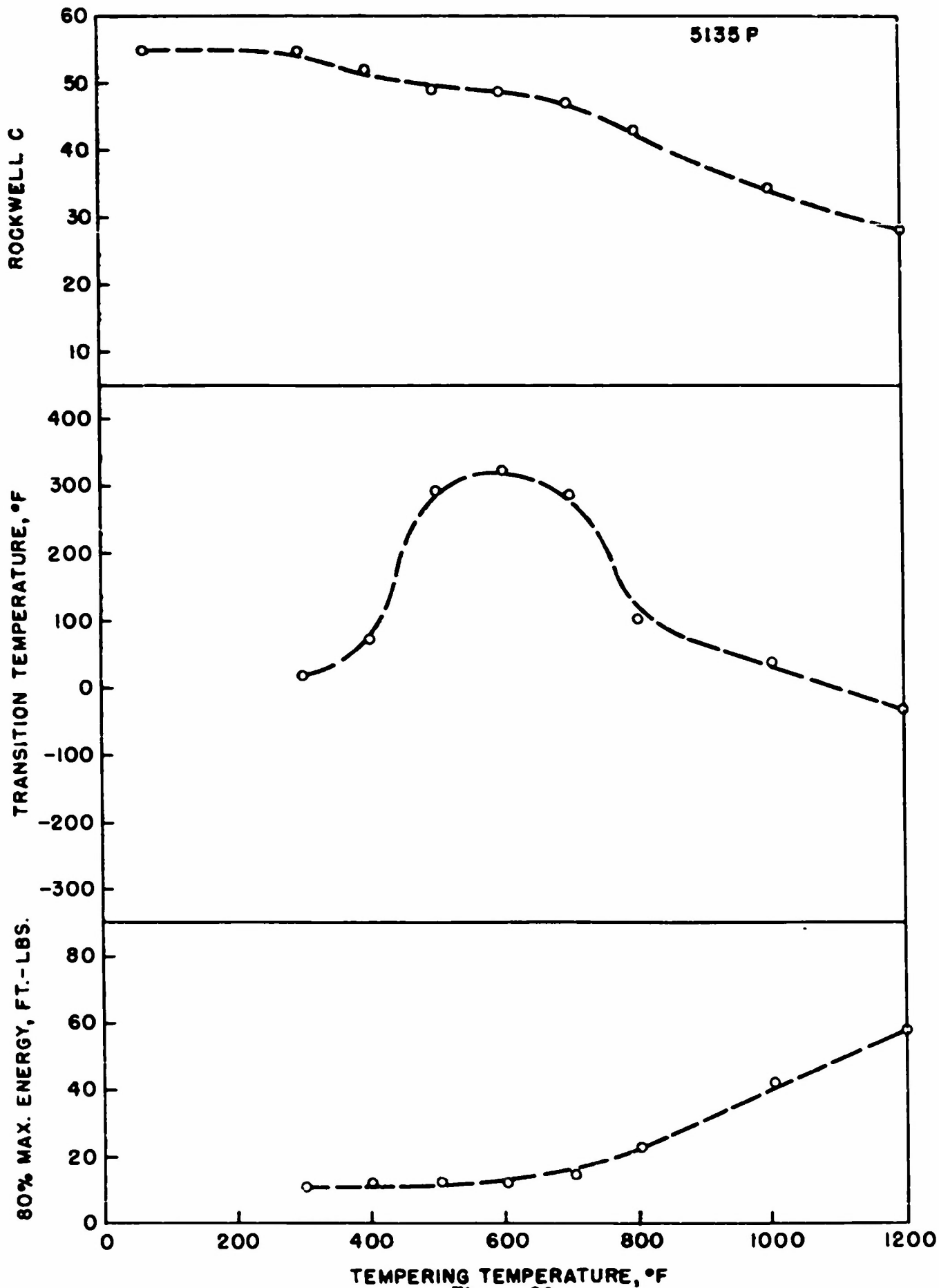


Figure 20

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 5135P.

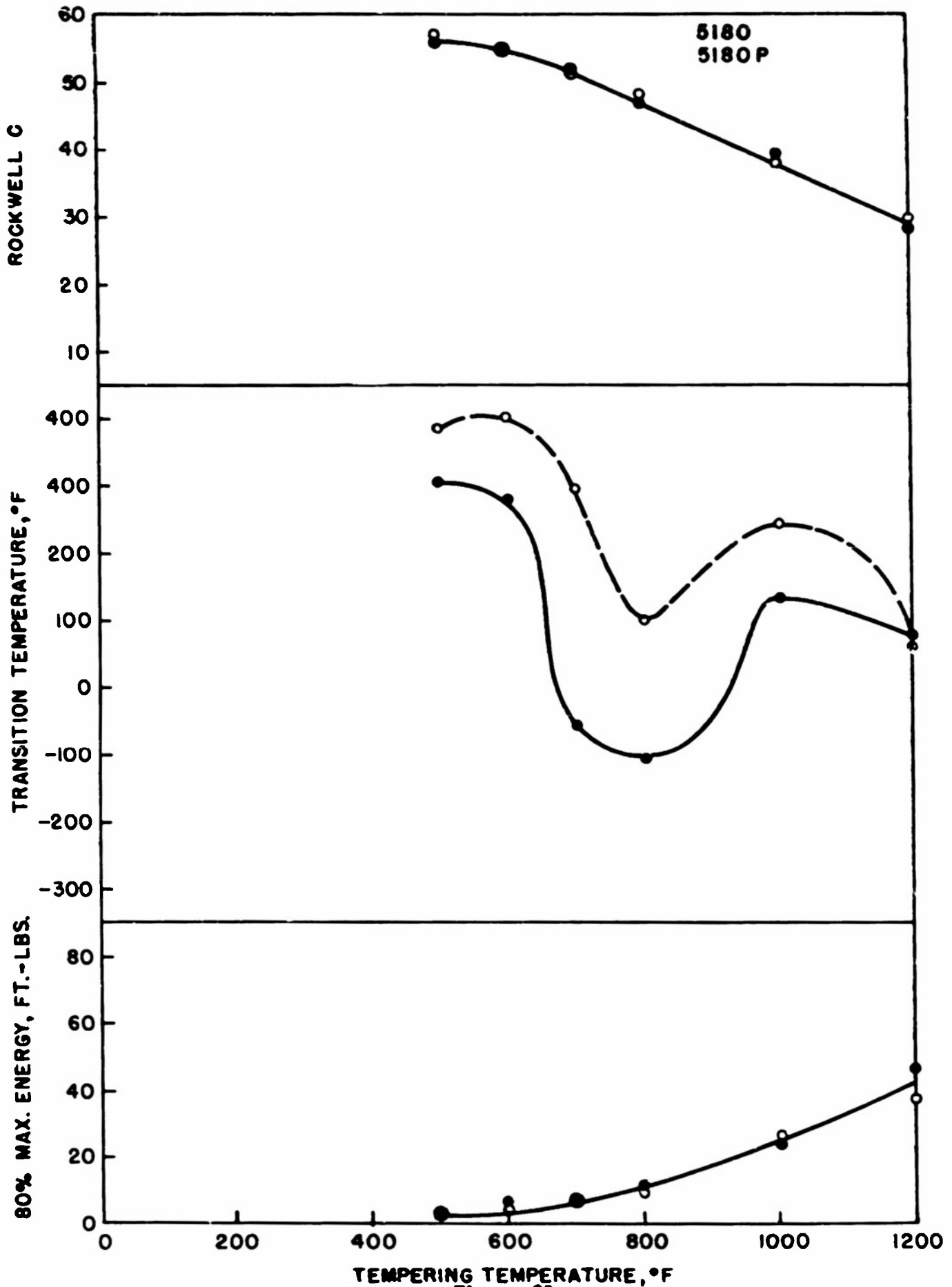


Figure 21

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 5180 with two different phosphorous contents.

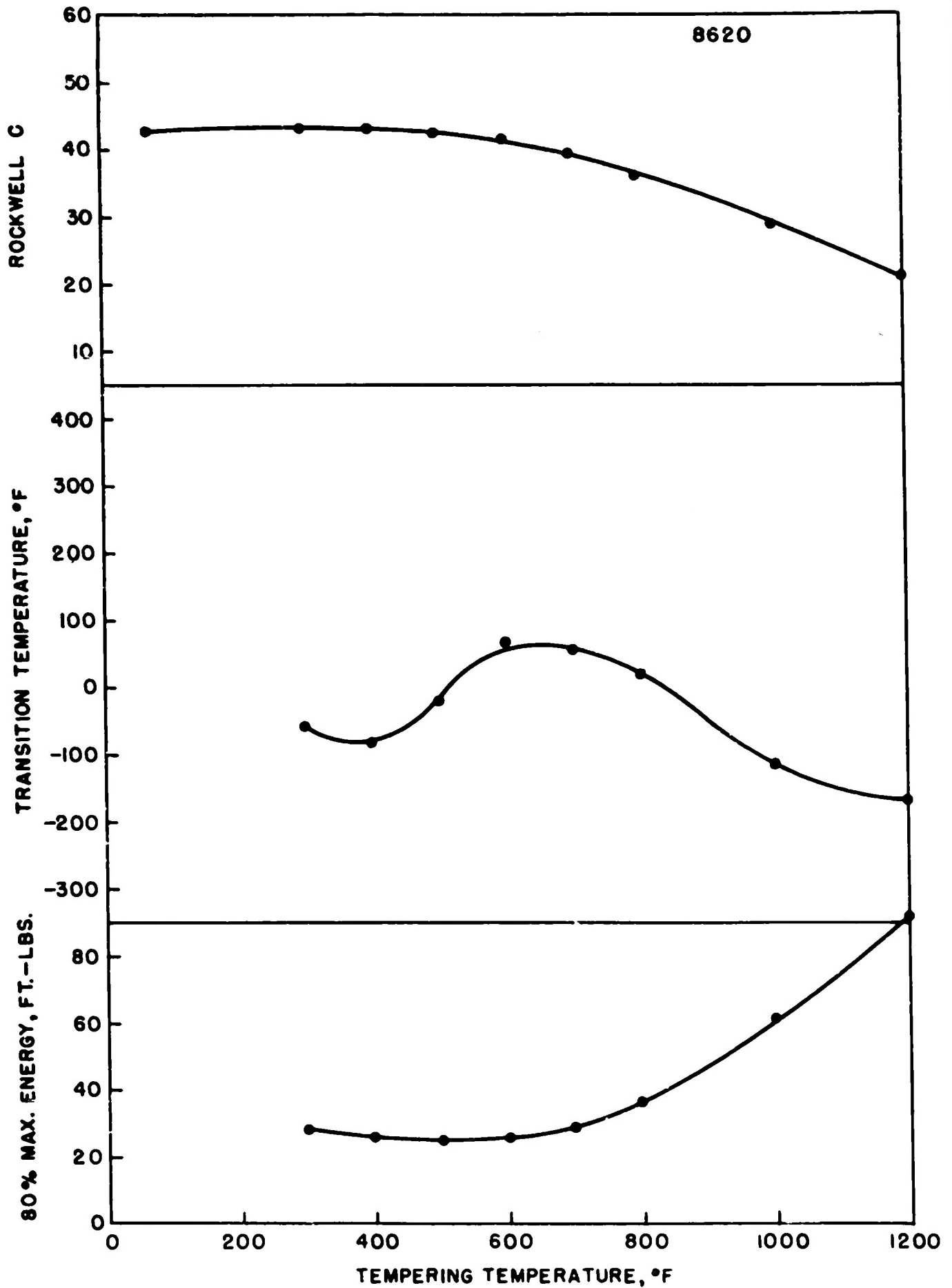


Figure 22

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 8620.

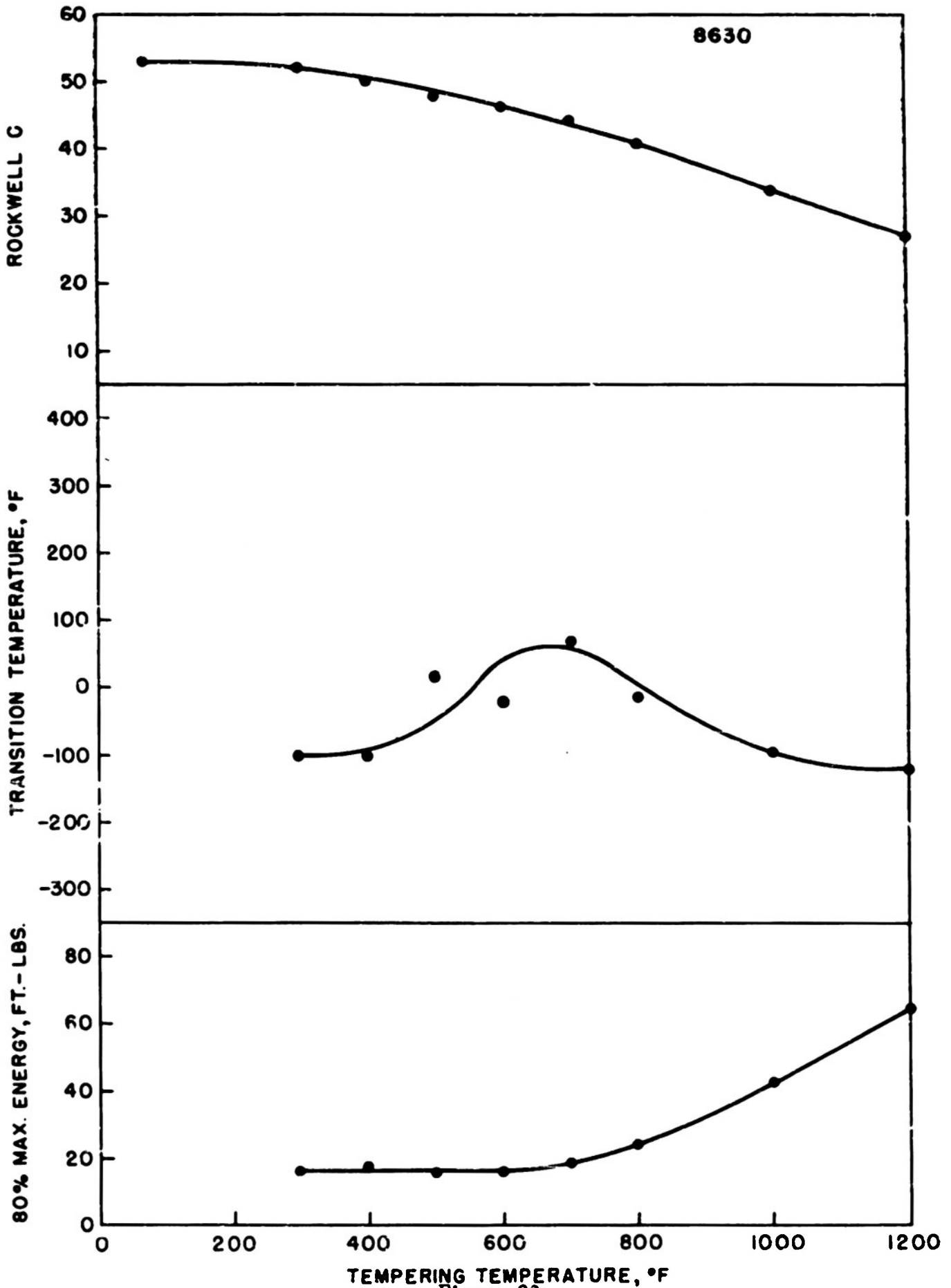


Figure 23

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 8630.

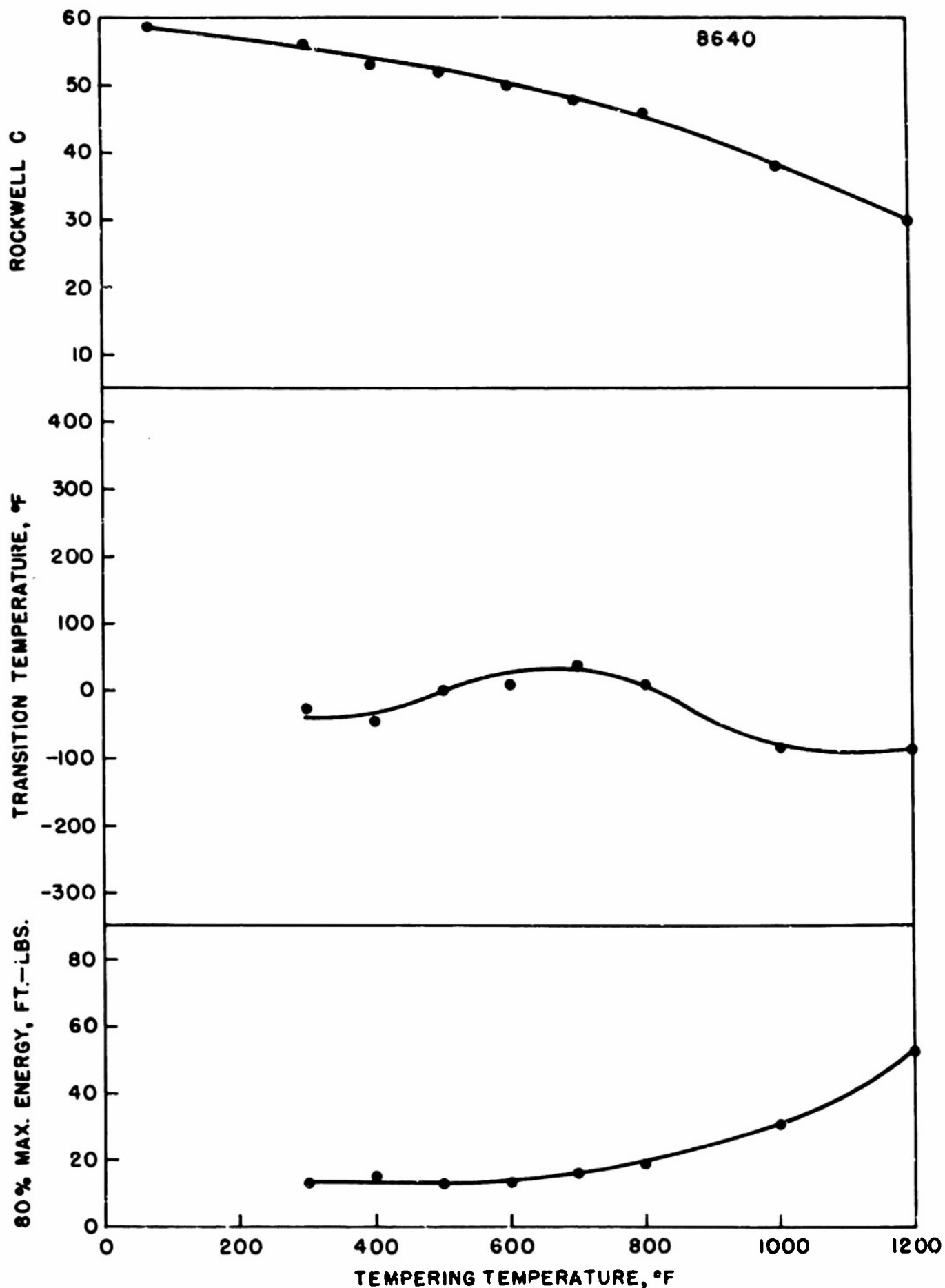


Figure 24

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 8640.

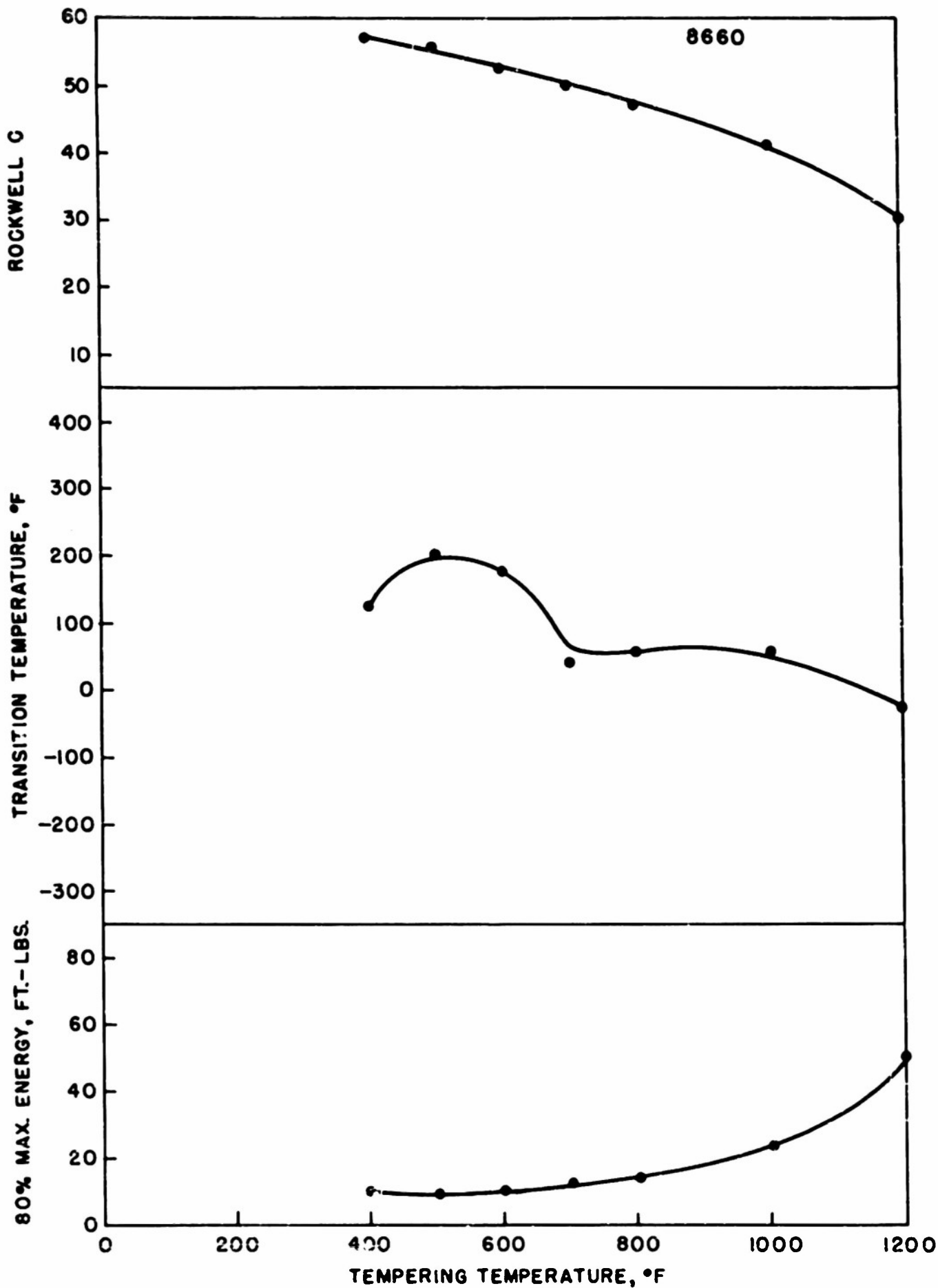


Figure 25

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 8660.

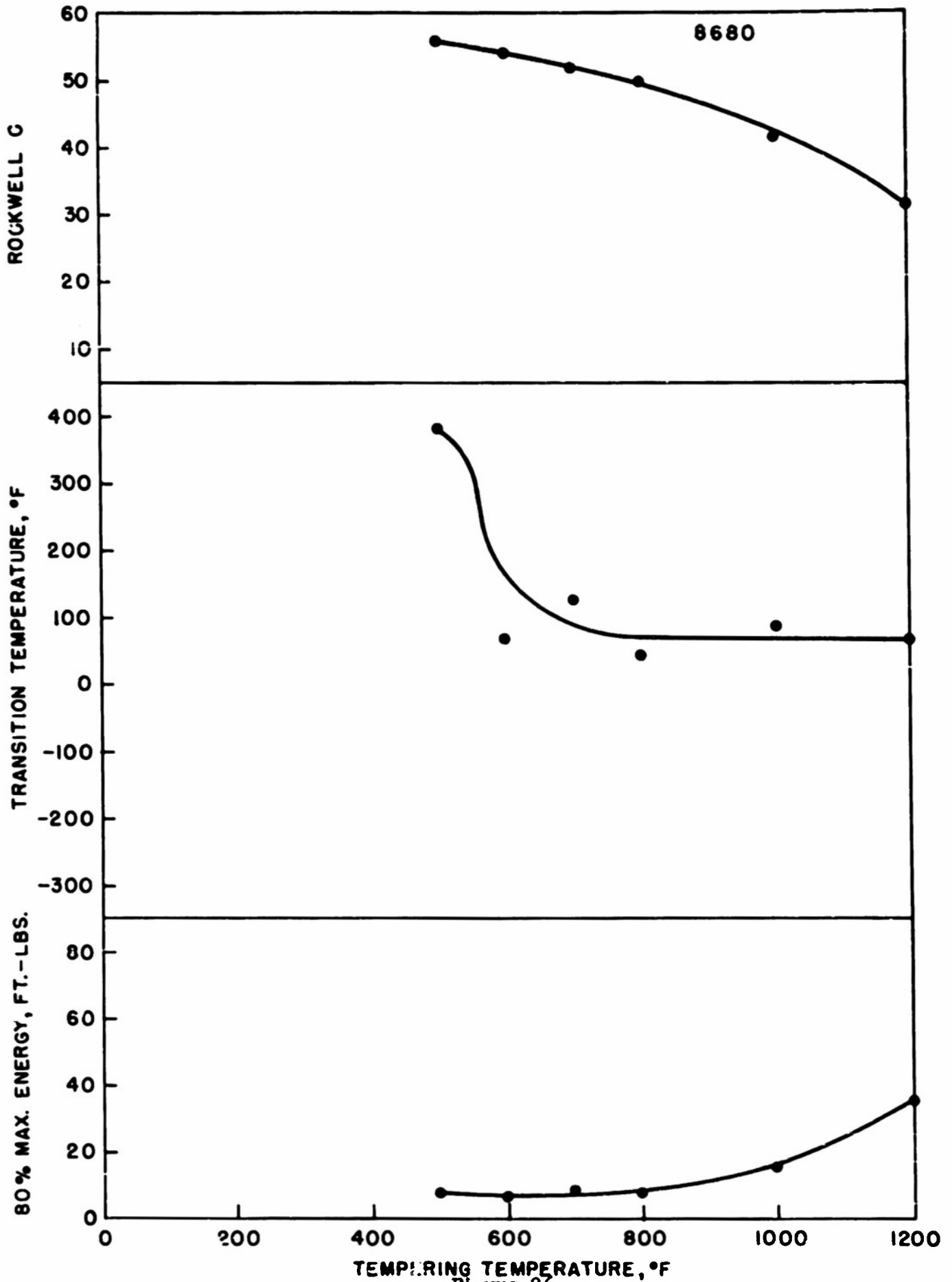


Figure 26

Variation of transition temperature, 80% of maximum energy and hardness with tempering temperature for 8680.

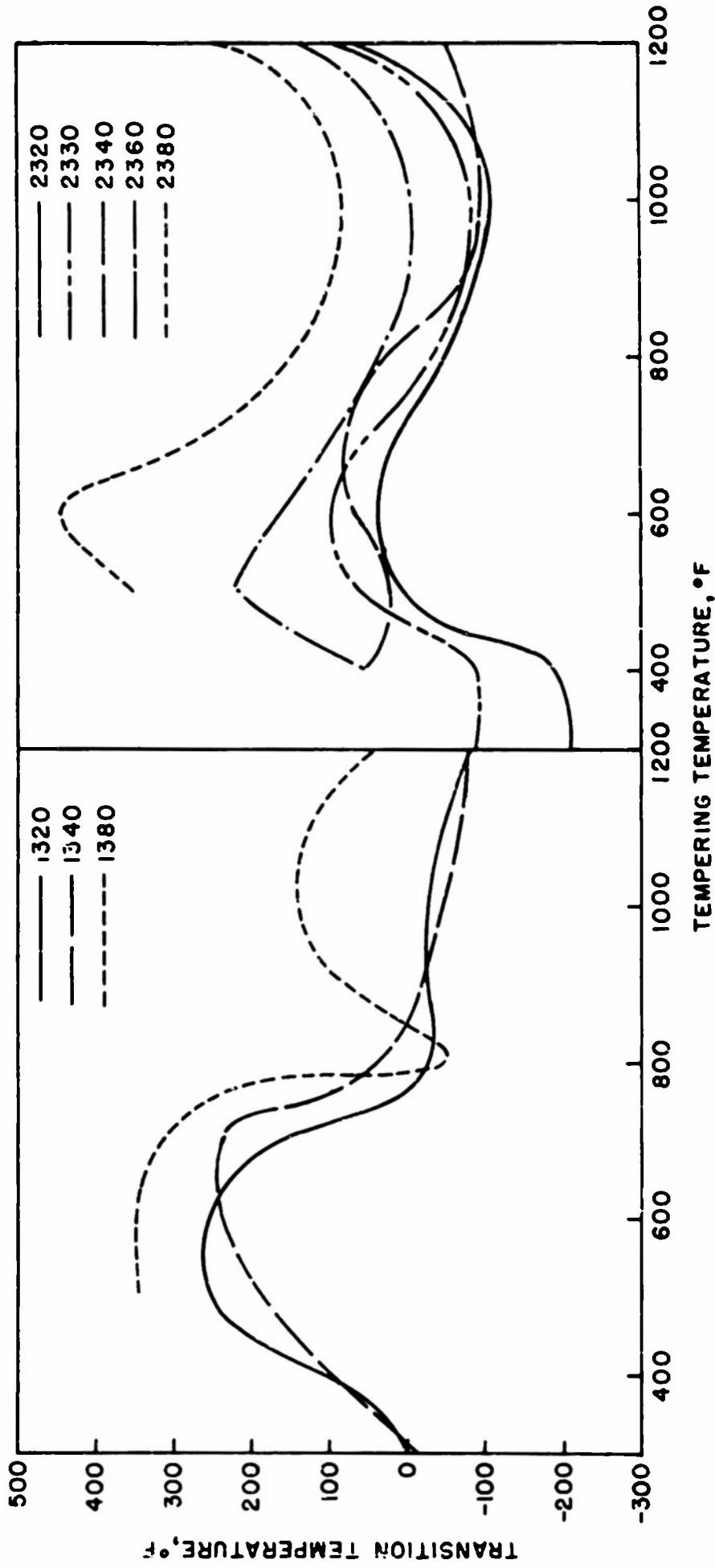
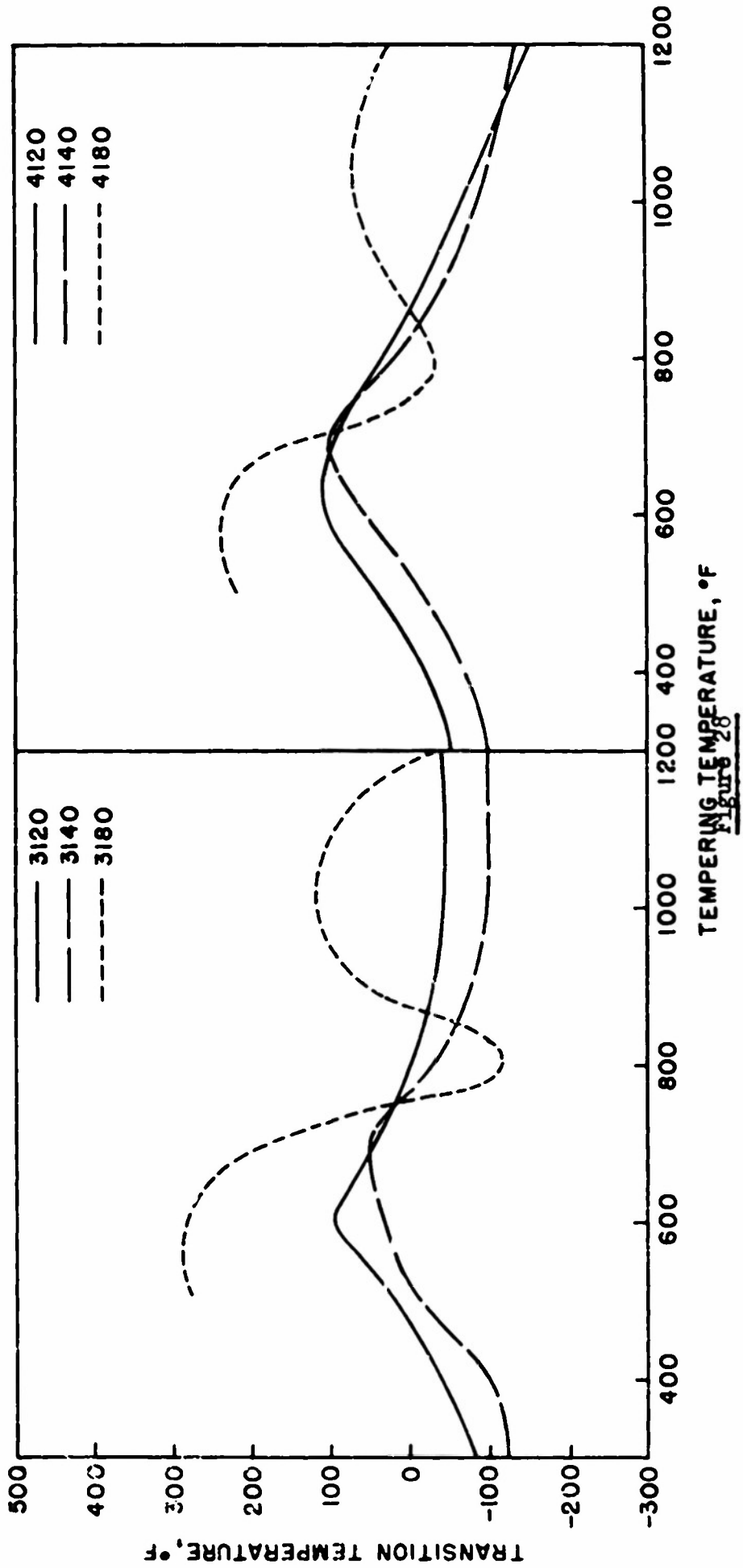


Figure 27

Transition temperature as a function of tempering temperature and carbon content for the 1300 and 2300 series.



Transition temperature as a function of tempering temperature and carbon content for the 3100 and 4100 series.

TEMPERING TEMPERATURE, °F
Figure 28

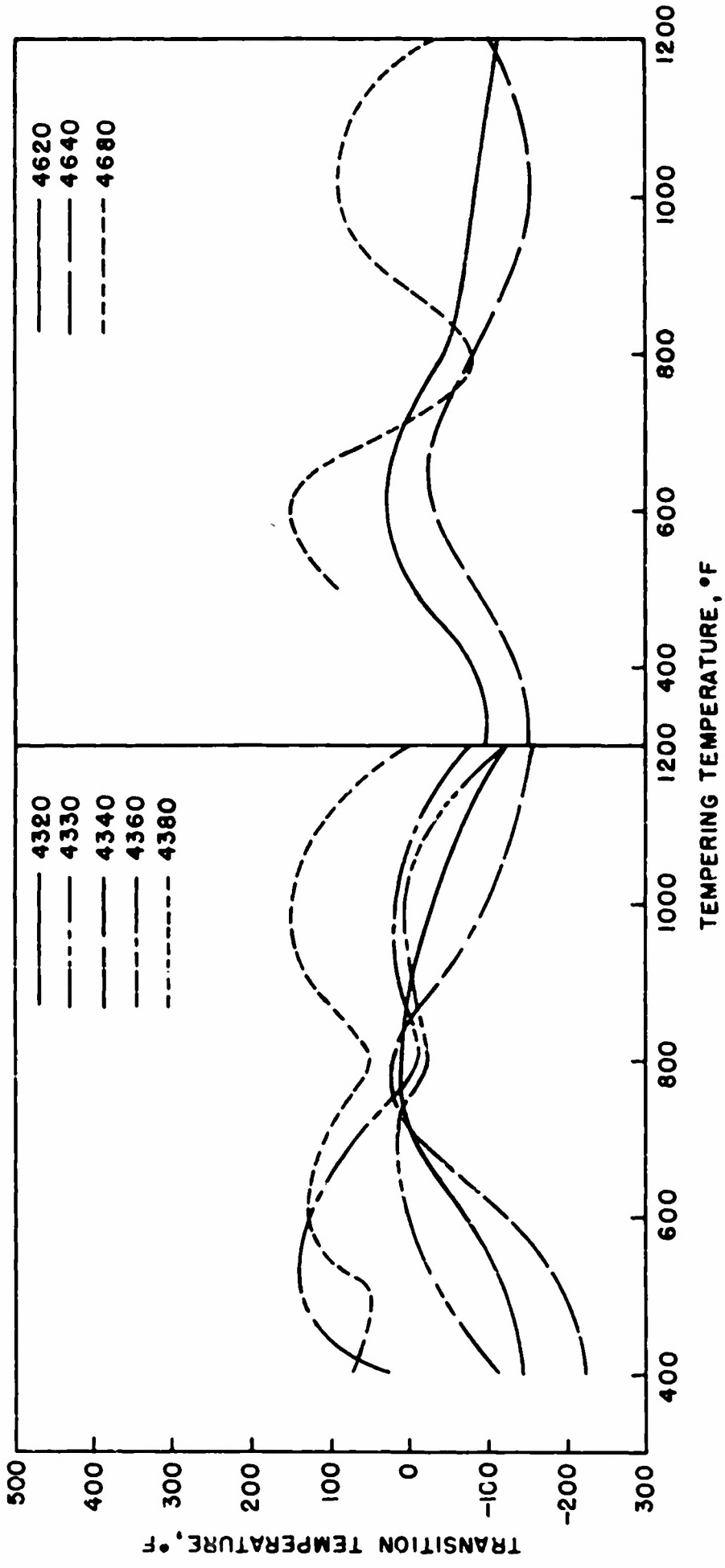


Figure 29

Transition temperature as a function of tempering temperature and carbon content for the 4300 and 4600 series.

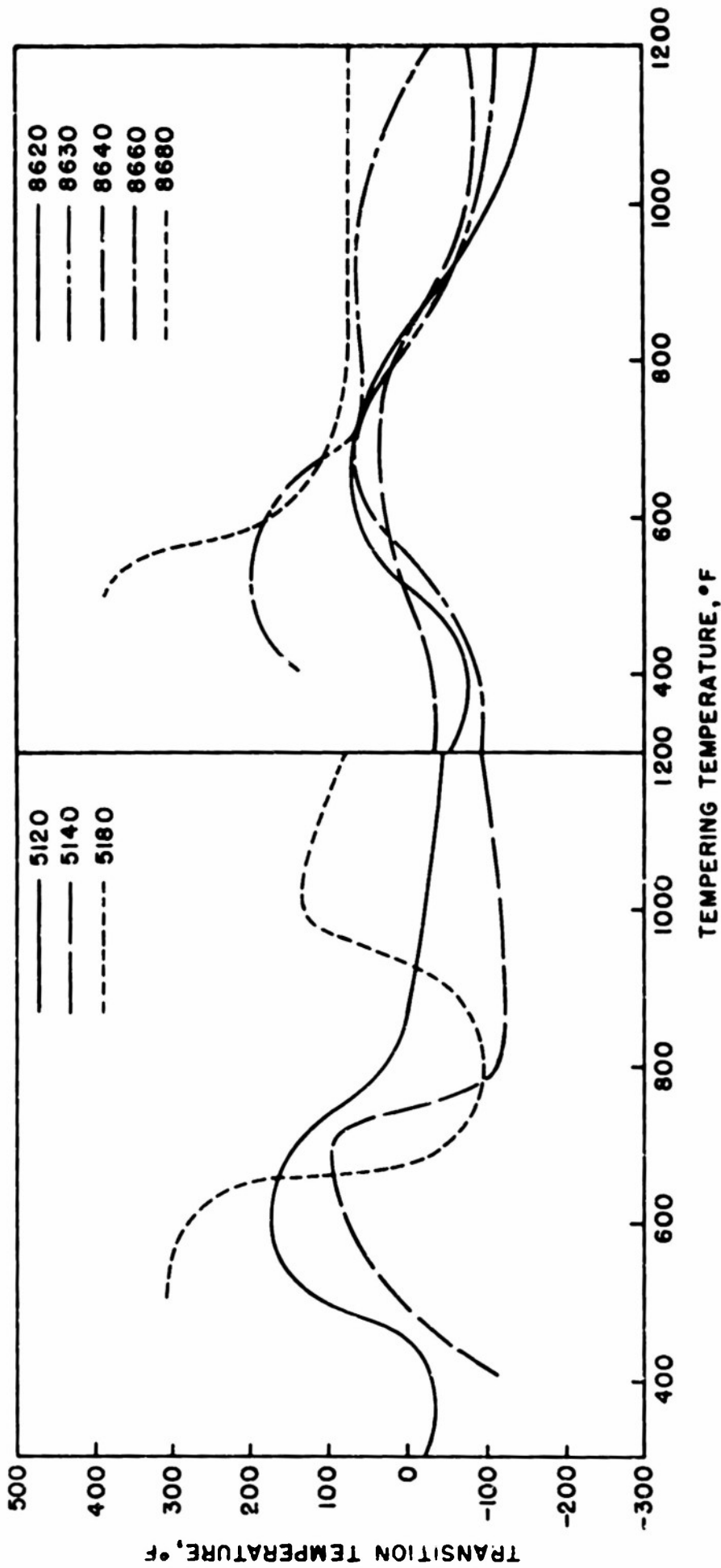


Figure 30

Transition temperature as a function of tempering temperature and carbon content for the 5100 and 8600 series.

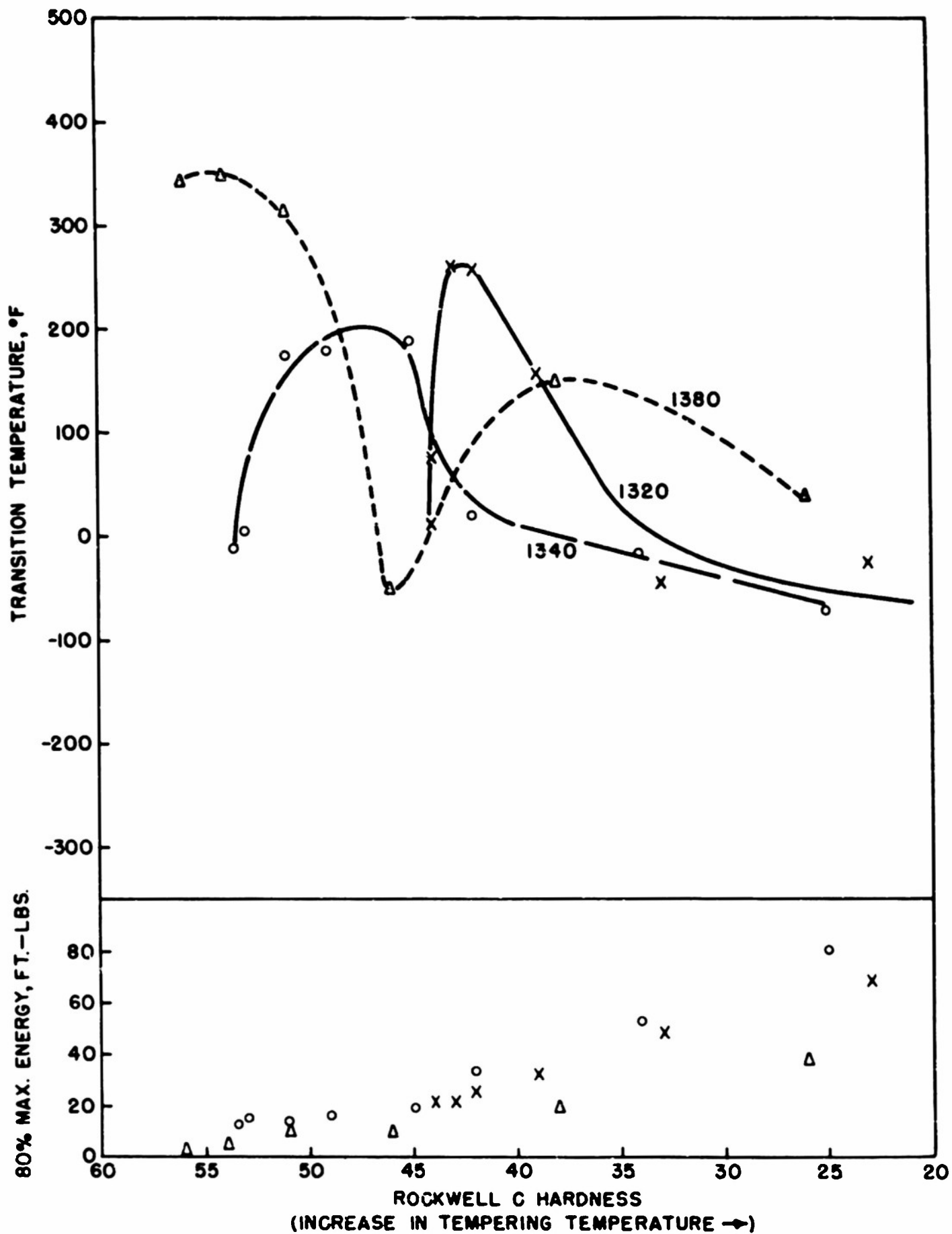


Figure 31

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 1300 series.

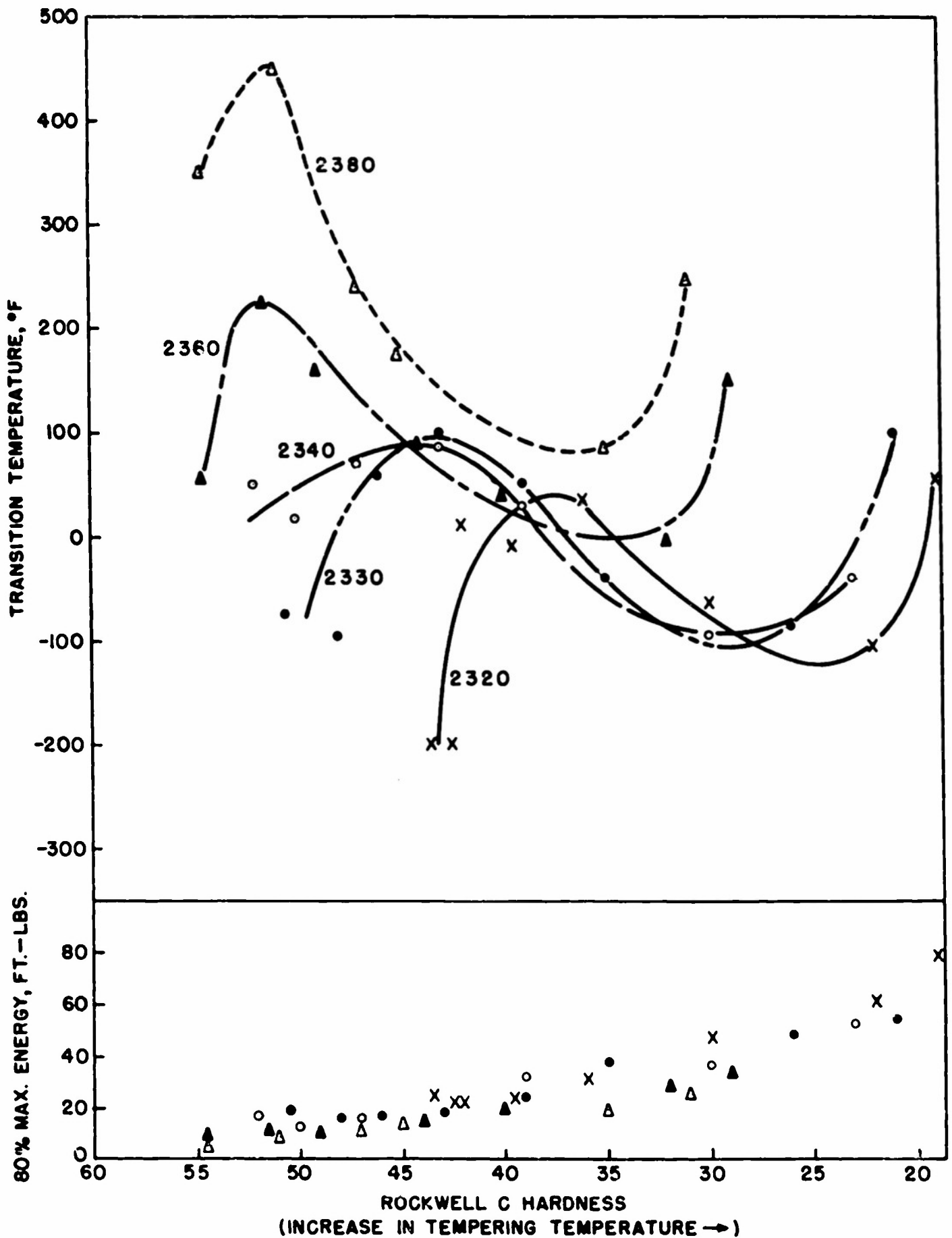


Figure 32

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 2300 series.

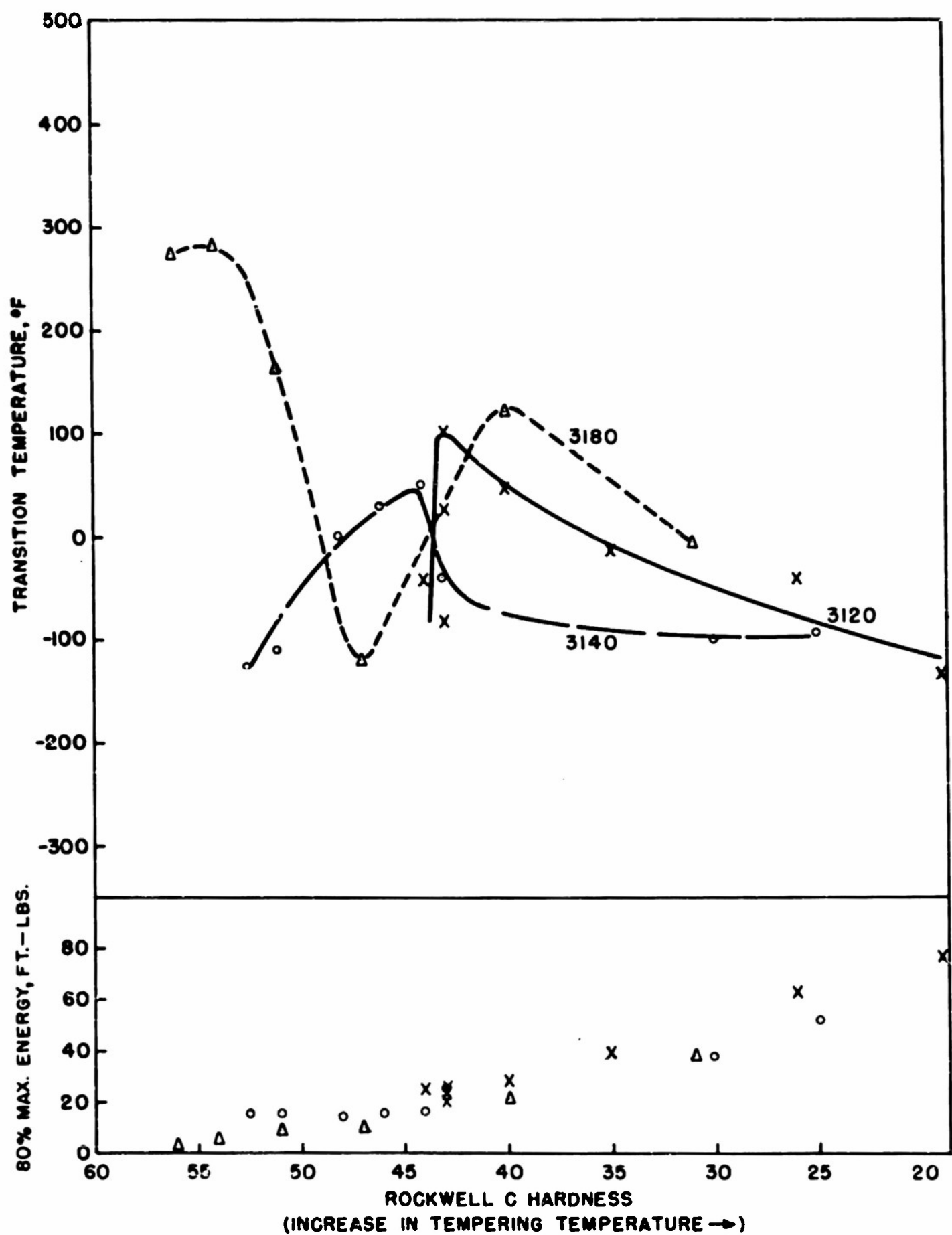


Figure 33

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 3100 series.

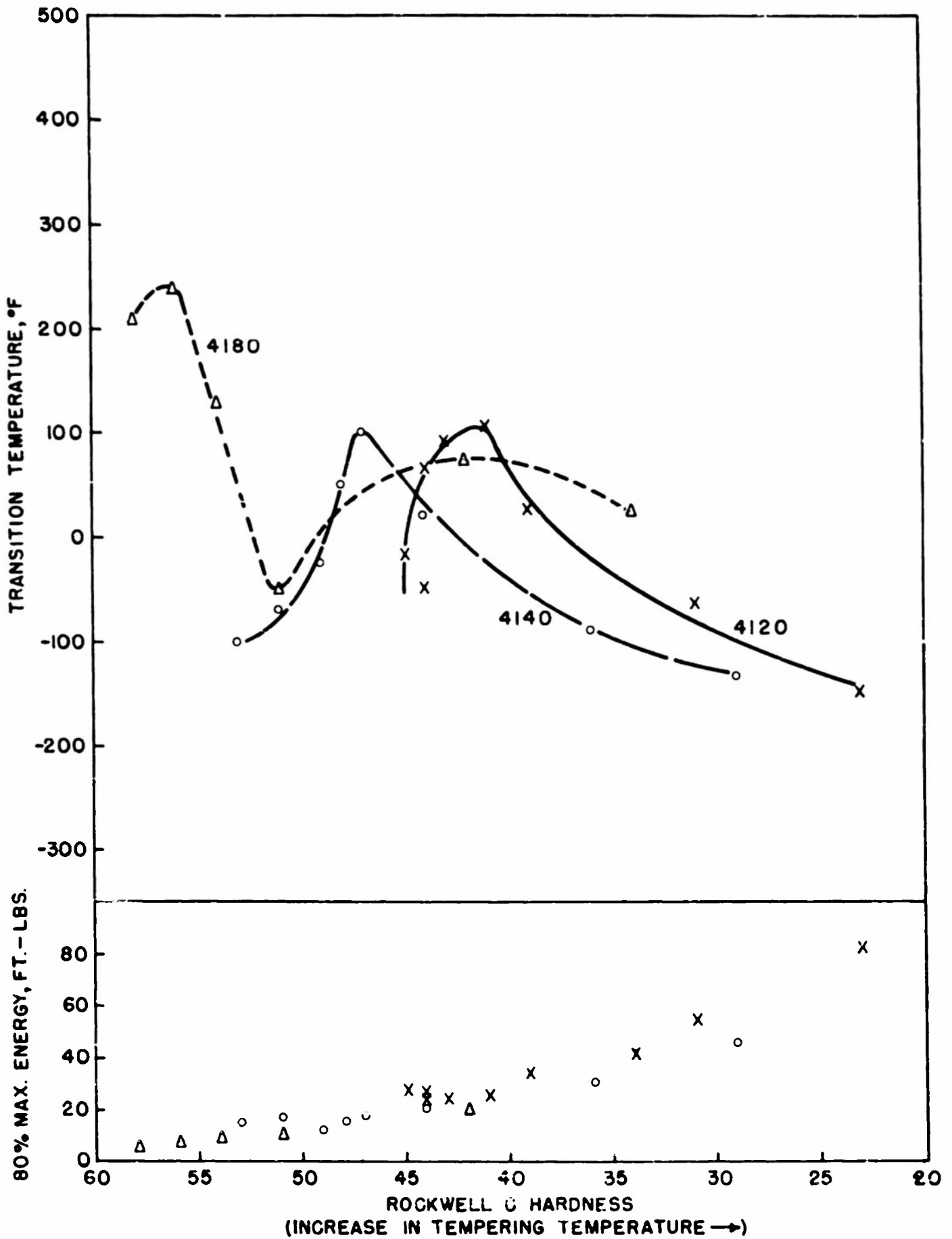


Figure 34

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 4100 series.

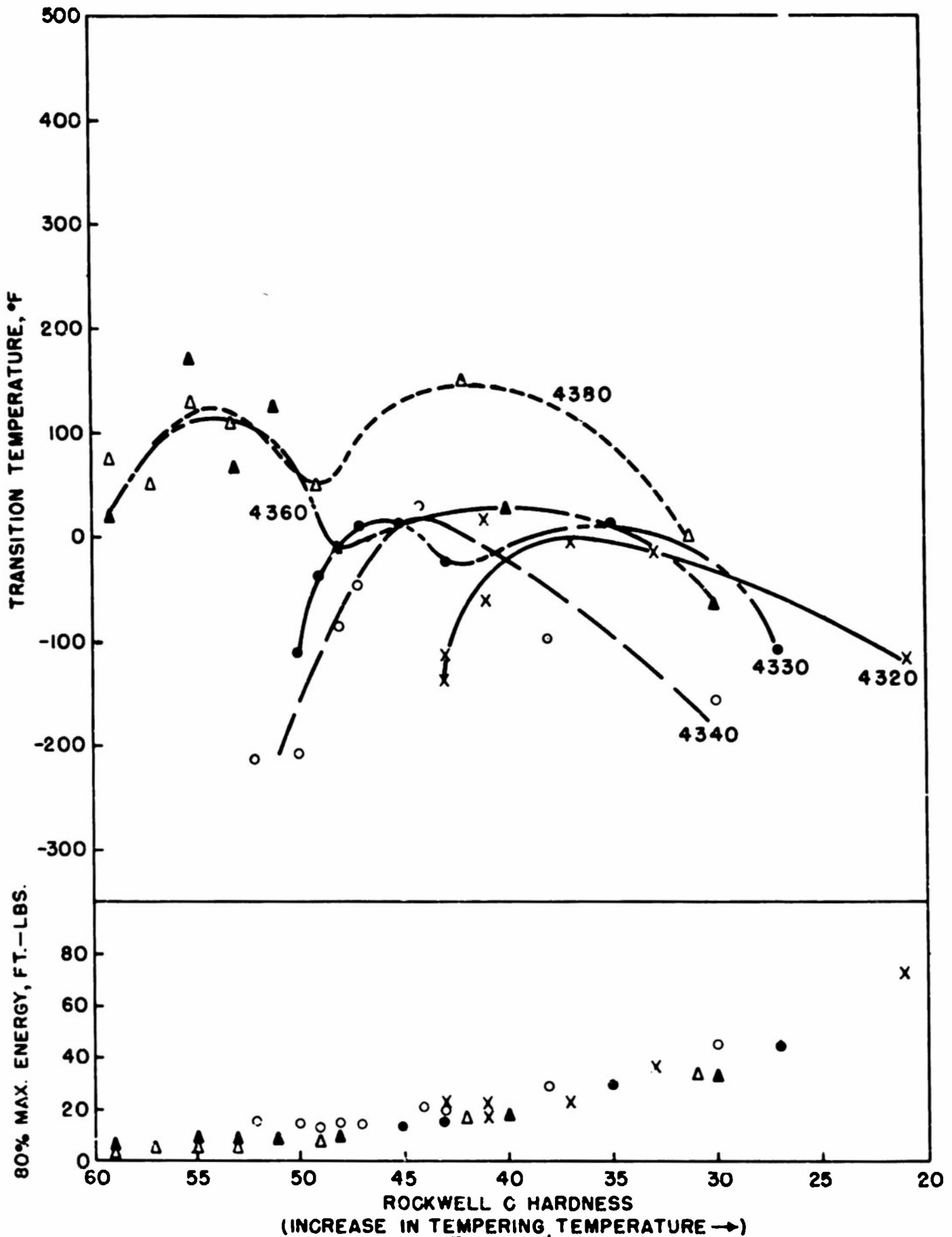


Figure 35

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 4300 series.

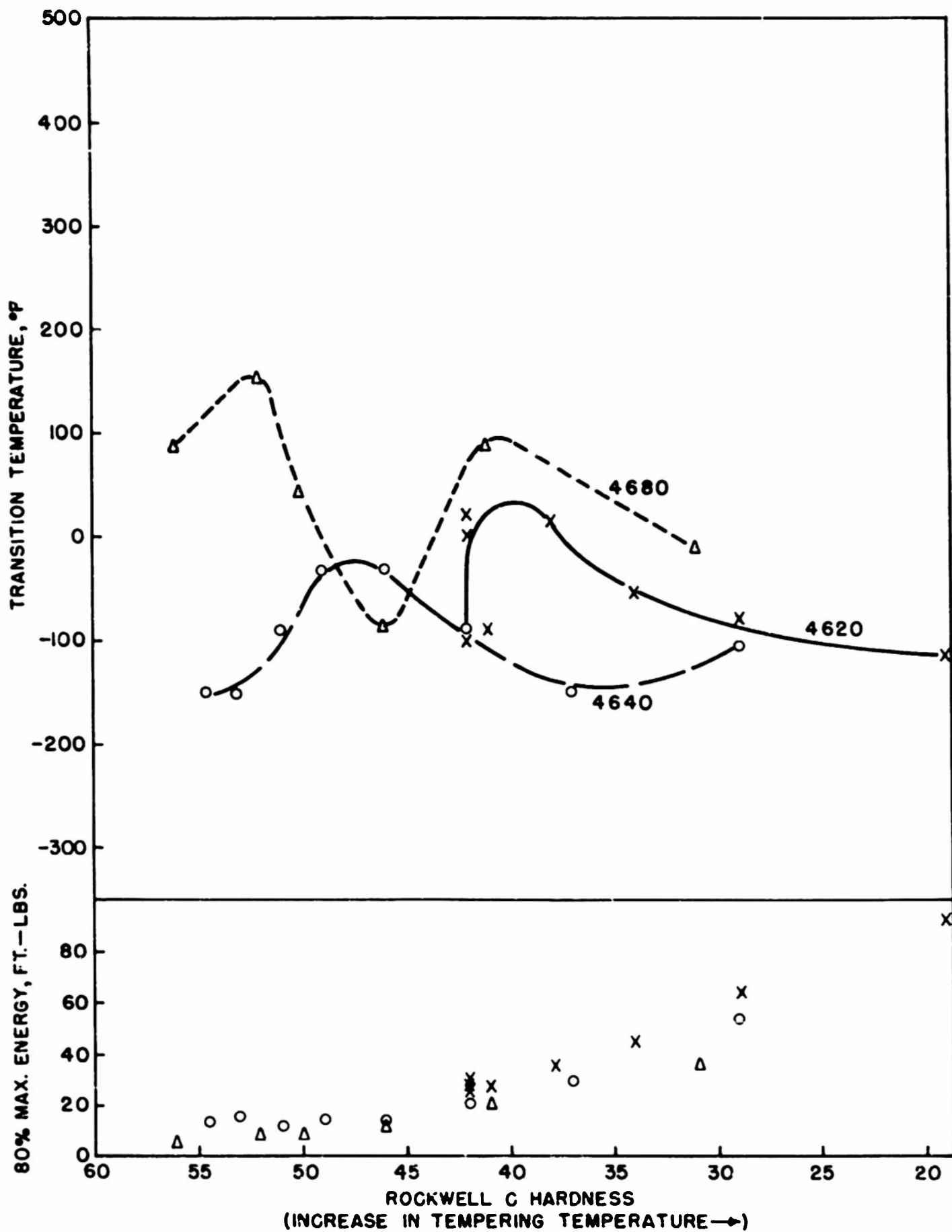


Figure 36

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 4600 series.

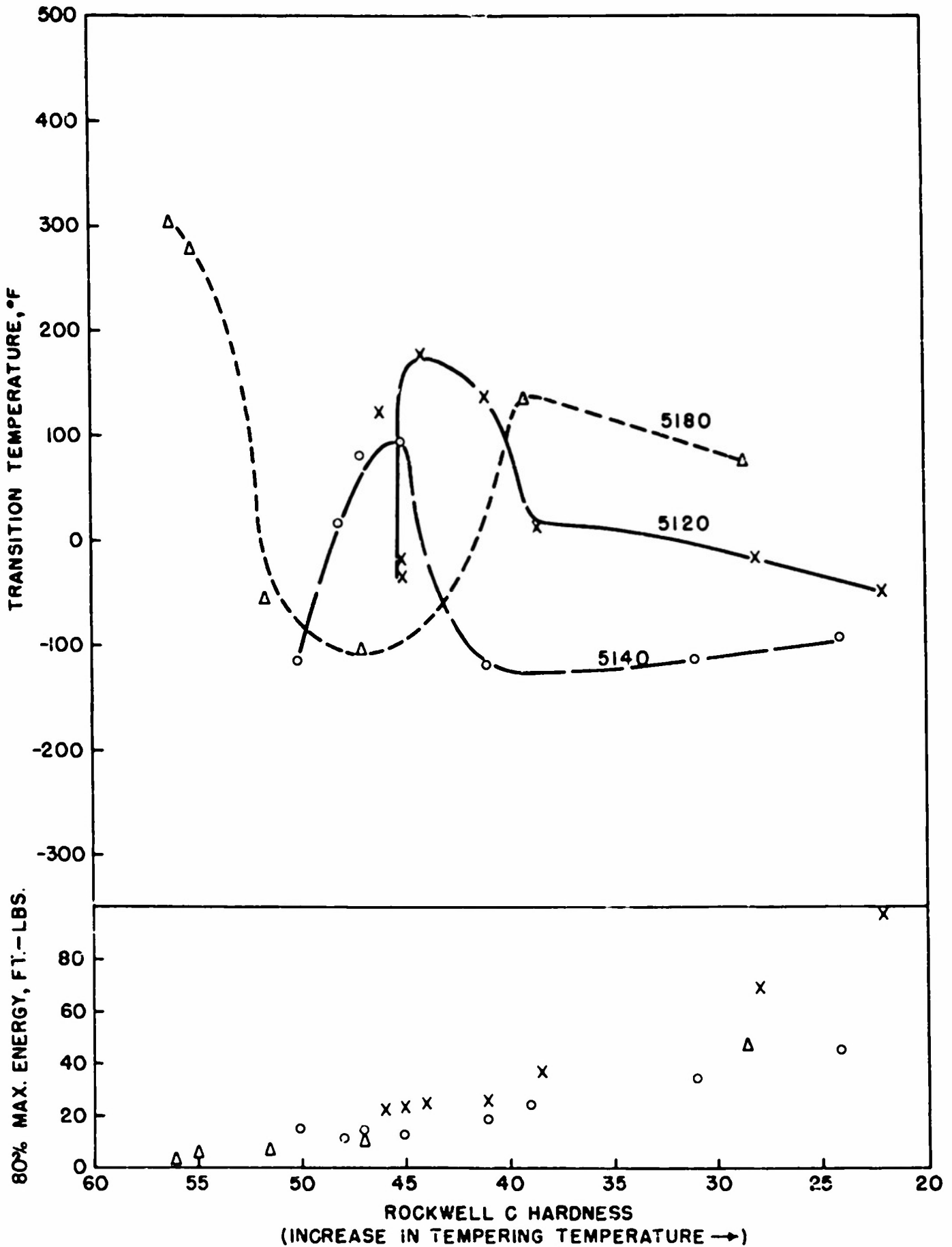


Figure 37

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 5100 series.

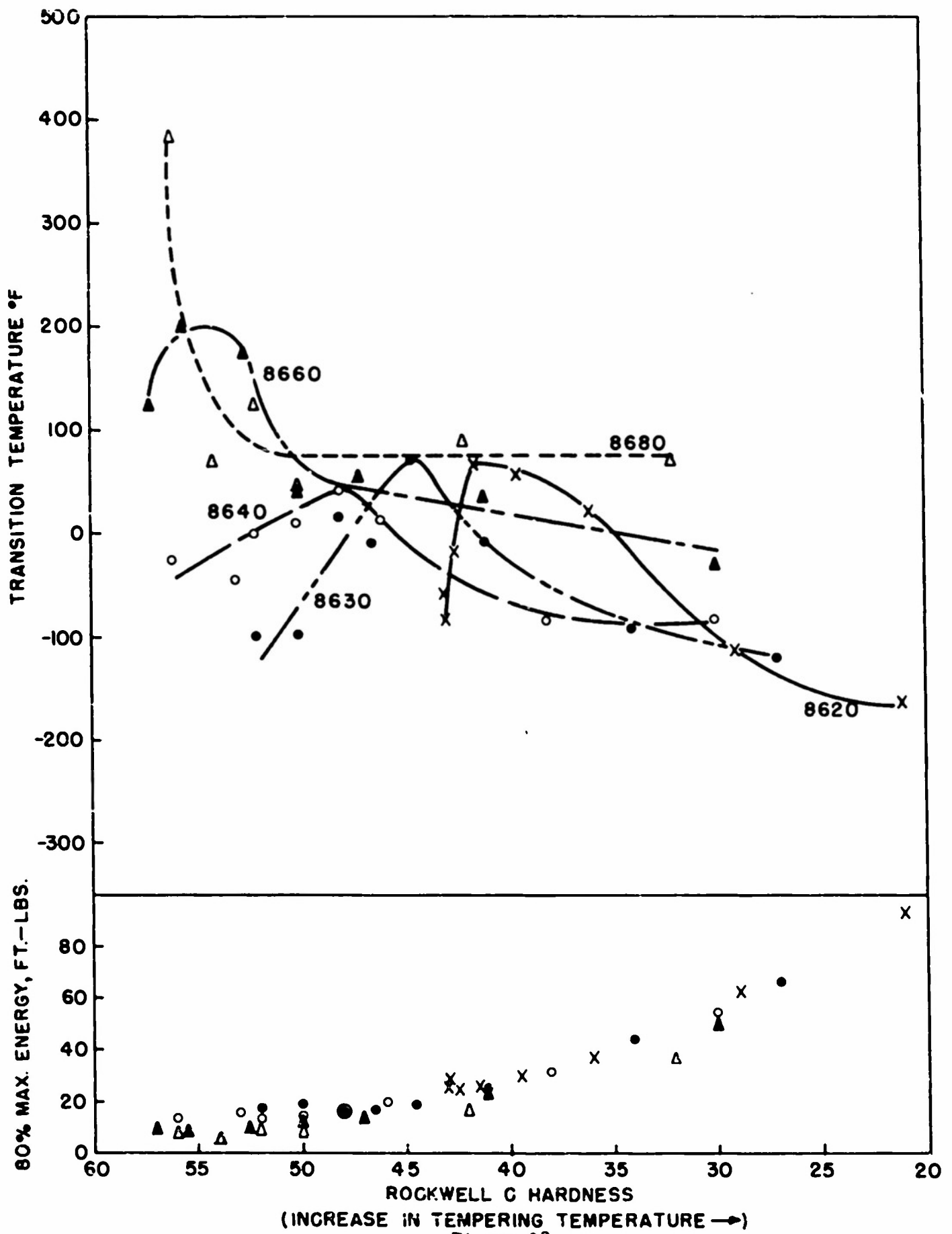


Figure 38

Transition temperature and 80% of maximum energy as a function of hardness and carbon content for the 8600 series.

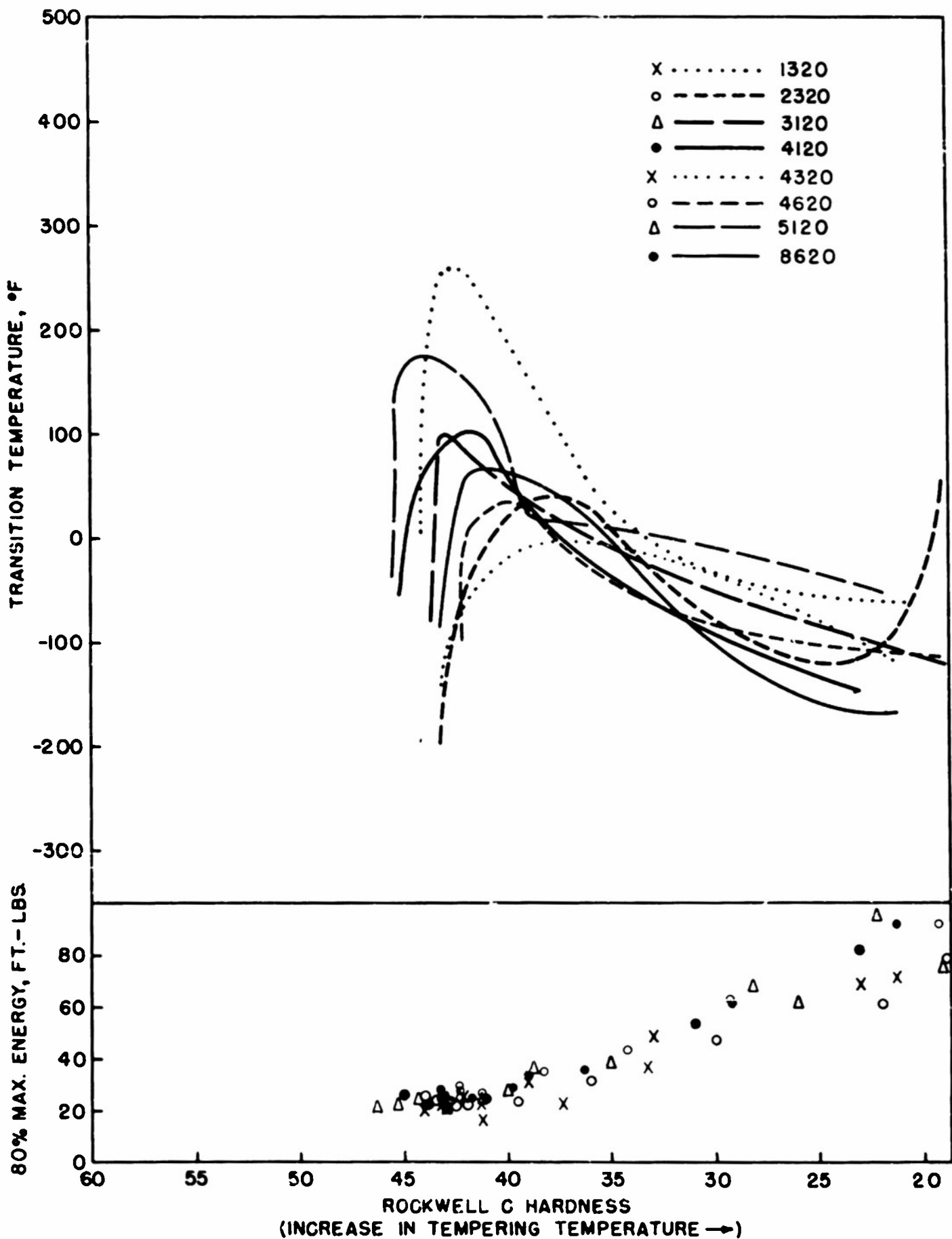


Figure 39

Variation of transition temperature and 80% of maximum energy with hardness for various grades of steel at the 0.2% carbon level.

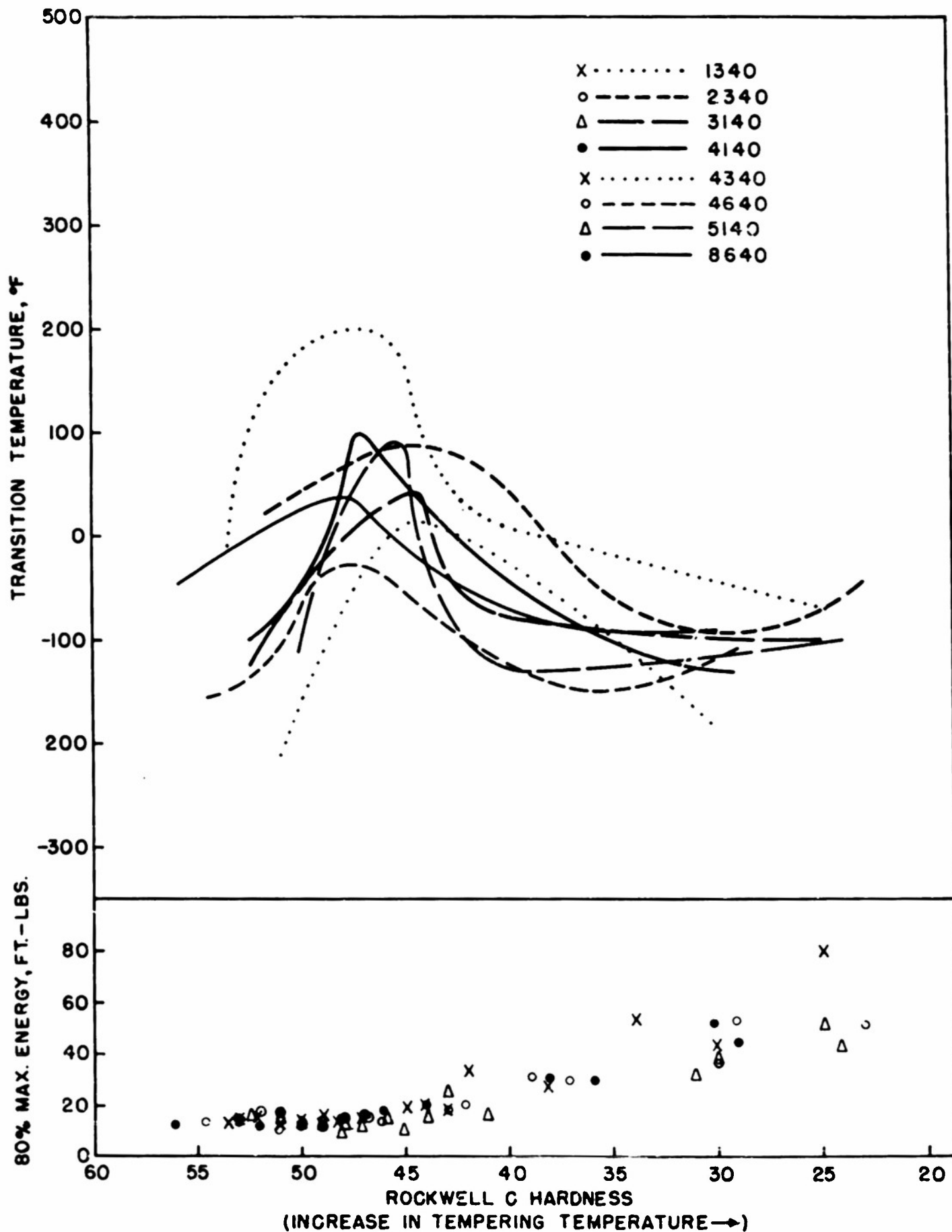


Figure 40

Variation of transition temperature and 80% of maximum energy with hardness for various grades of steel at the 0.40% carbon level.

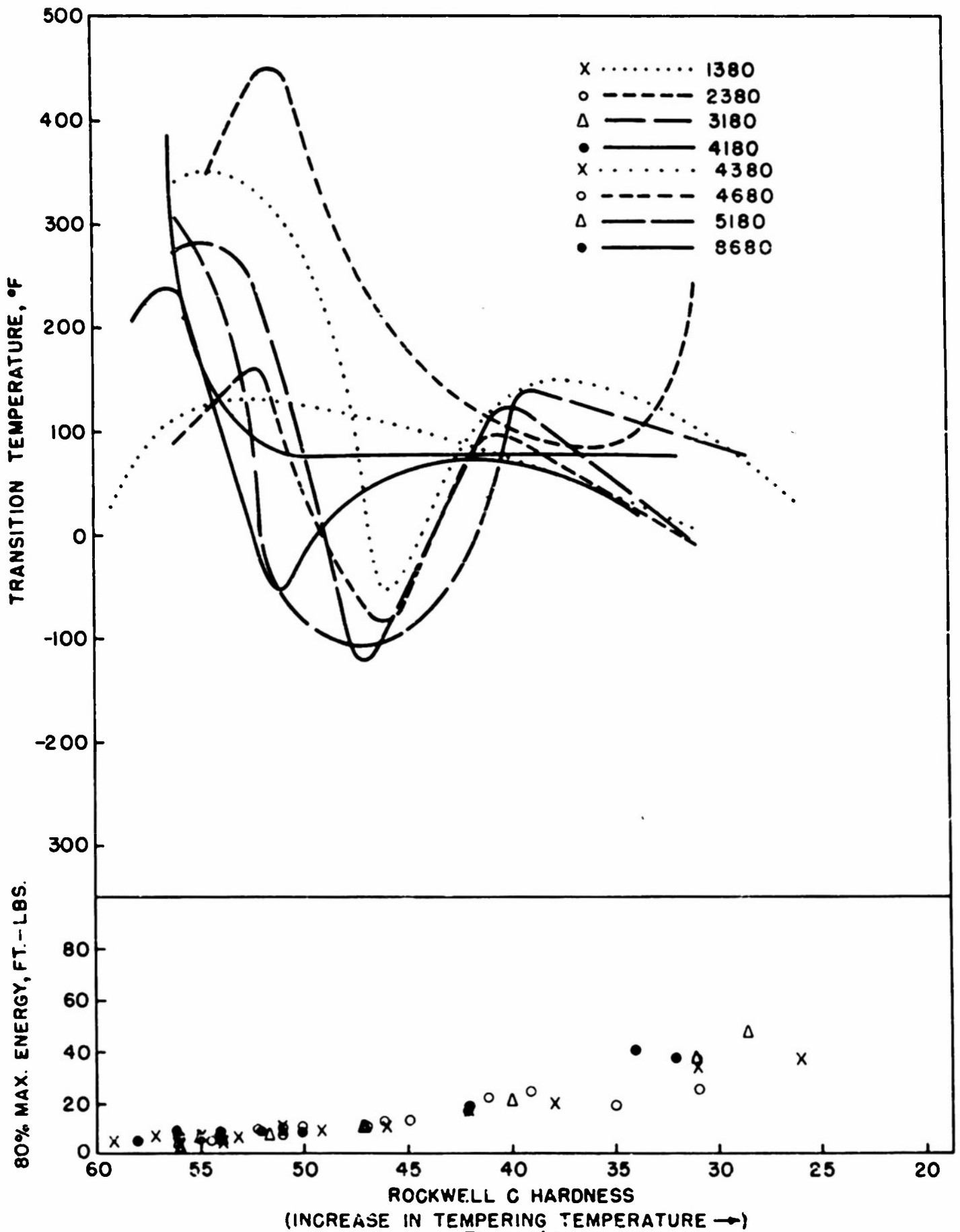


Figure 41

Variation of transition temperature and 80% of maximum energy with hardness for various grades of steel at the 0.80% carbon level.

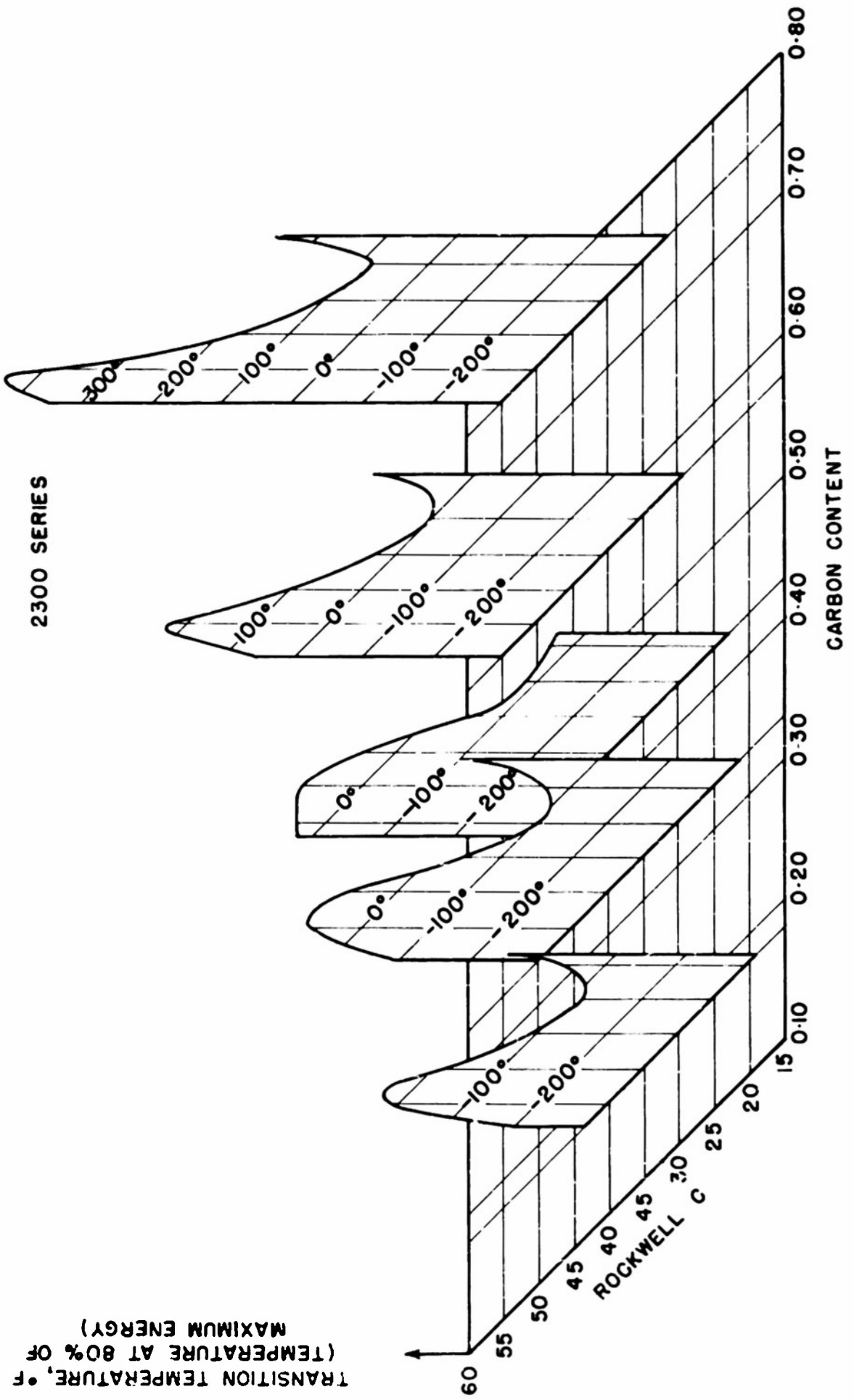


Figure 42

Inter-relations among carbon content, hardness and transition temperature for the 2300 series.

4300 SERIES

TRANSITION TEMPERATURE, °F
(TEMPERATURE AT 80% OF
MAXIMUM ENERGY)

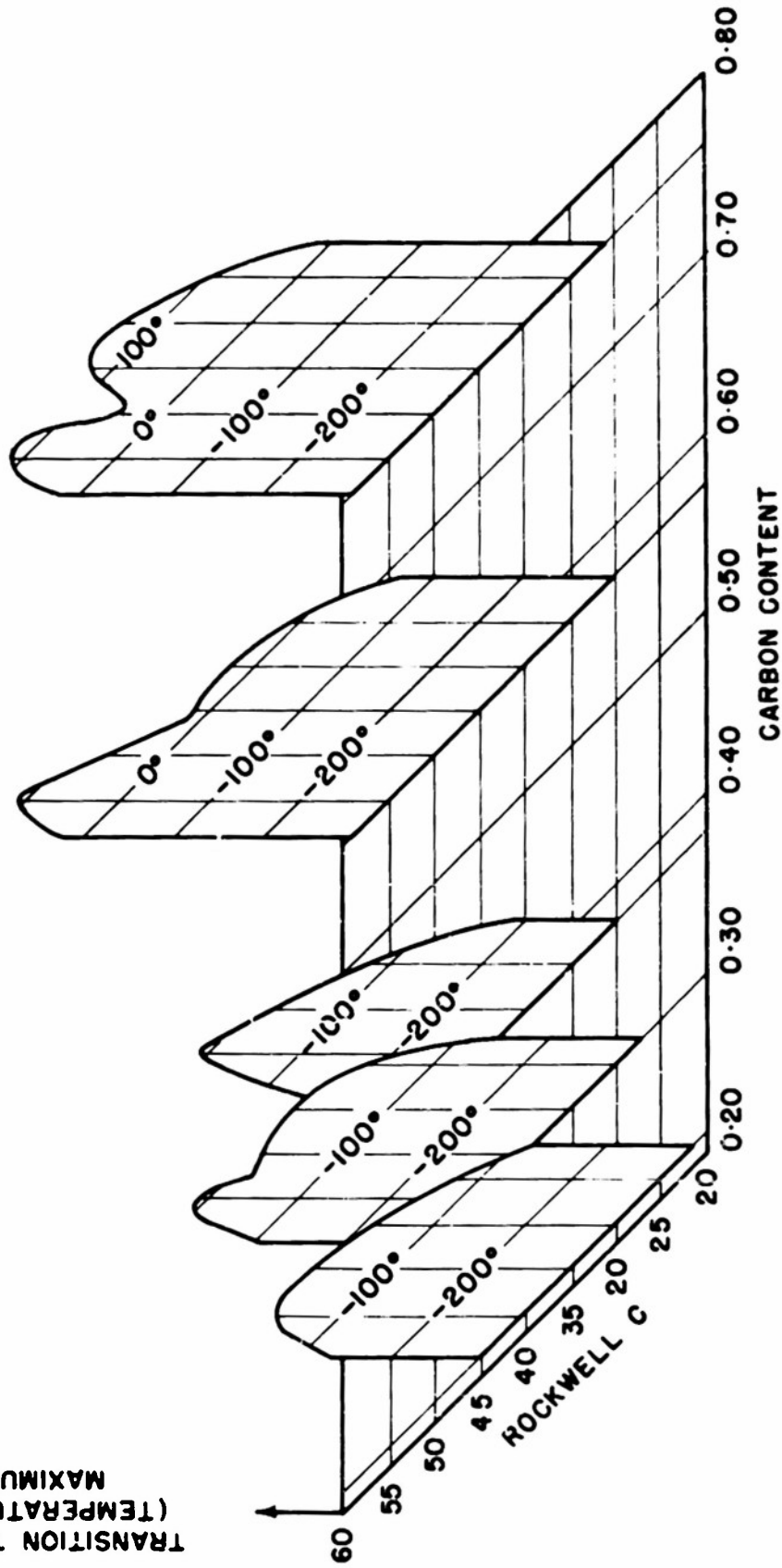


Figure 43

Inter-relations among carbon content, hardness and transition temperature for the 4300 series.

8600 SERIES

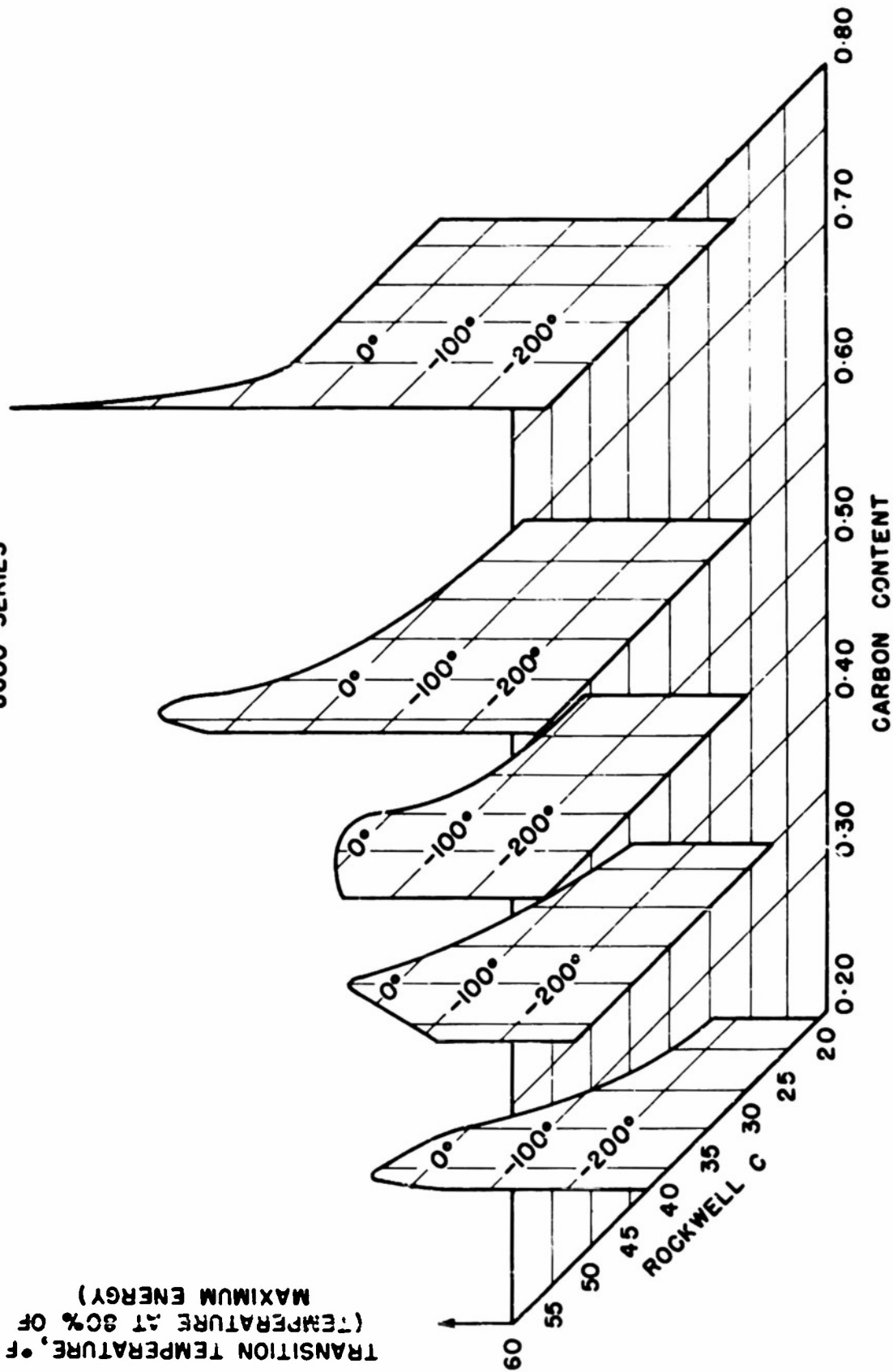


Figure 44

Inter-relationships among carbon content, hardness and transition temperature for the 8600 series.

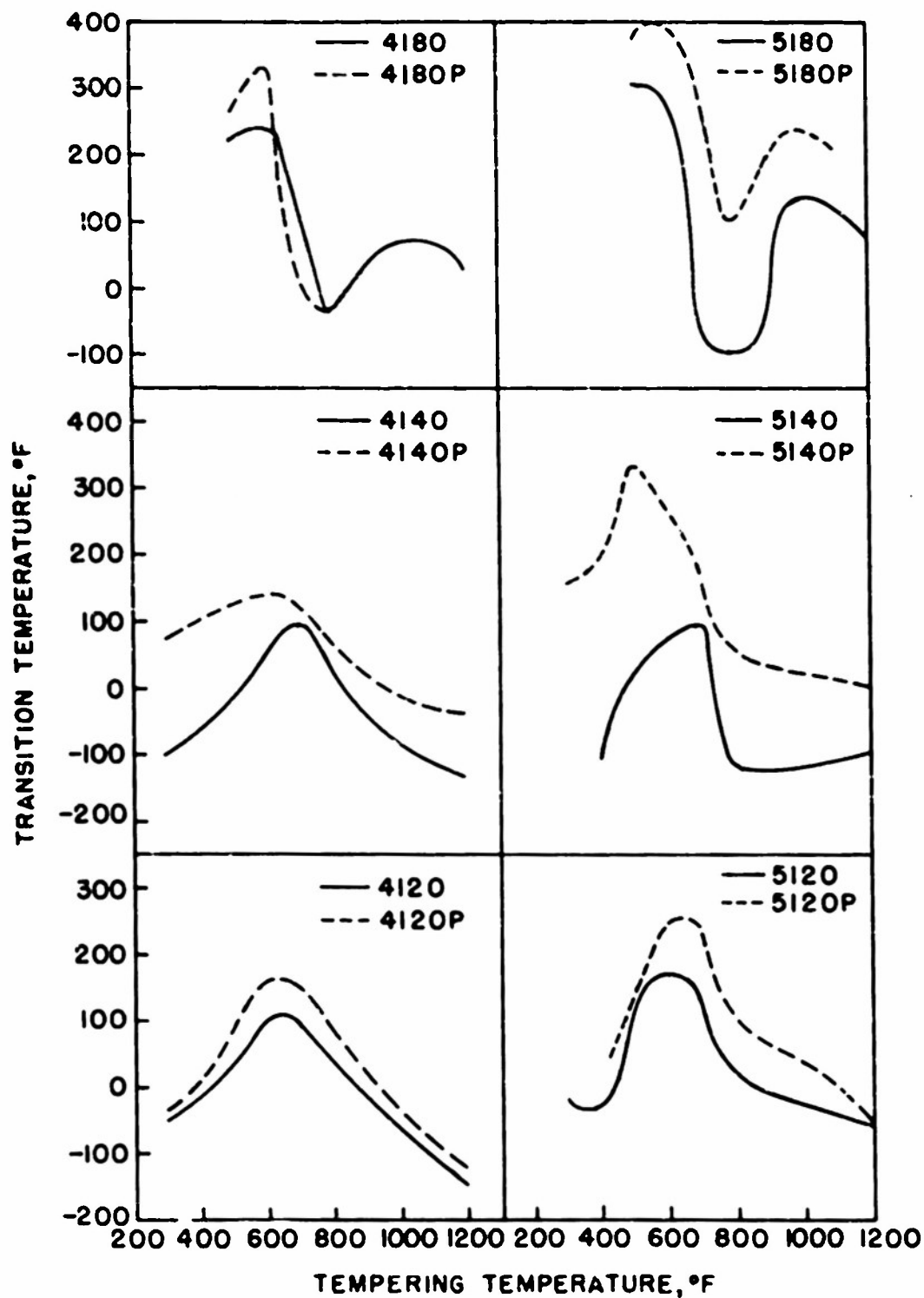


Figure 45

Effect of phosphorous on transition temperatures for the 4100 series which contains molybdenum and the 5100 series which has the same analysis as the 4100 series except that it contains no molybdenum.

APPENDIX

EXPERIMENTAL IMPACT DATA

The energy data obtained from the impact tests have been assembled in the figures in this Appendix. All experimental points represent individual observations, not averages.

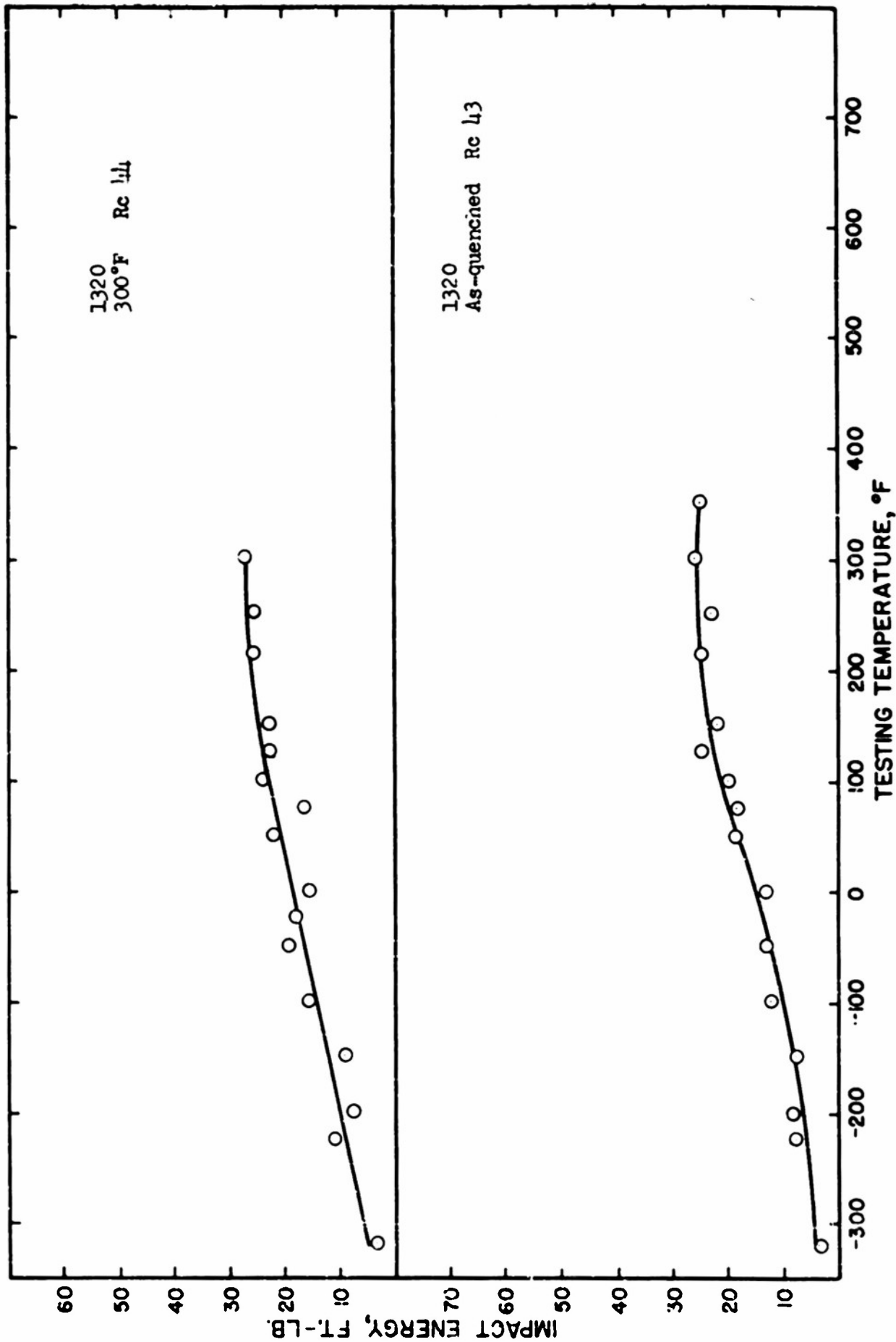


Fig. 1 - App. I

Heat 3740, laboratory fine grain 1320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

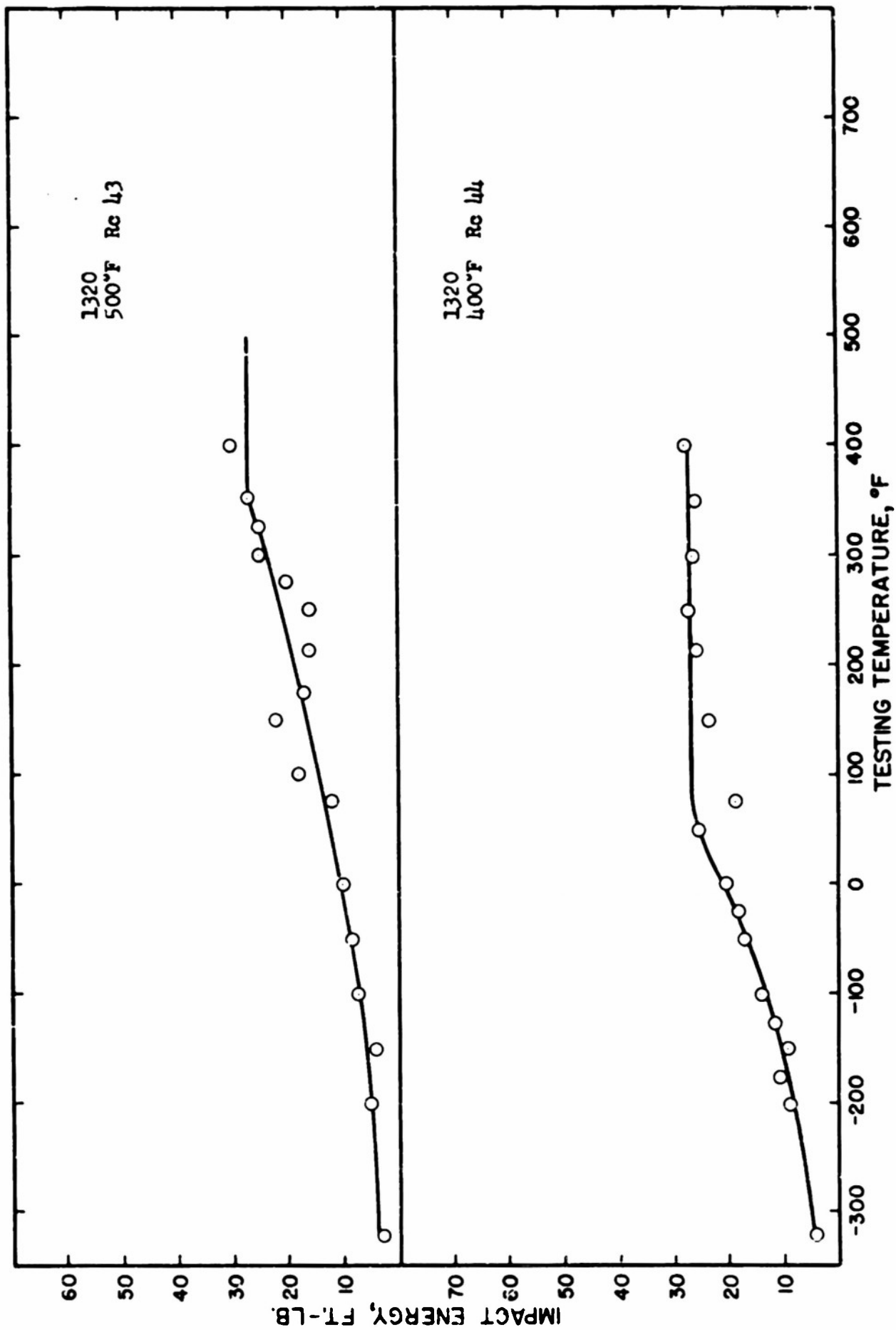


Fig. 2 - App. I

Heat 3740, laboratory fine grain 1320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

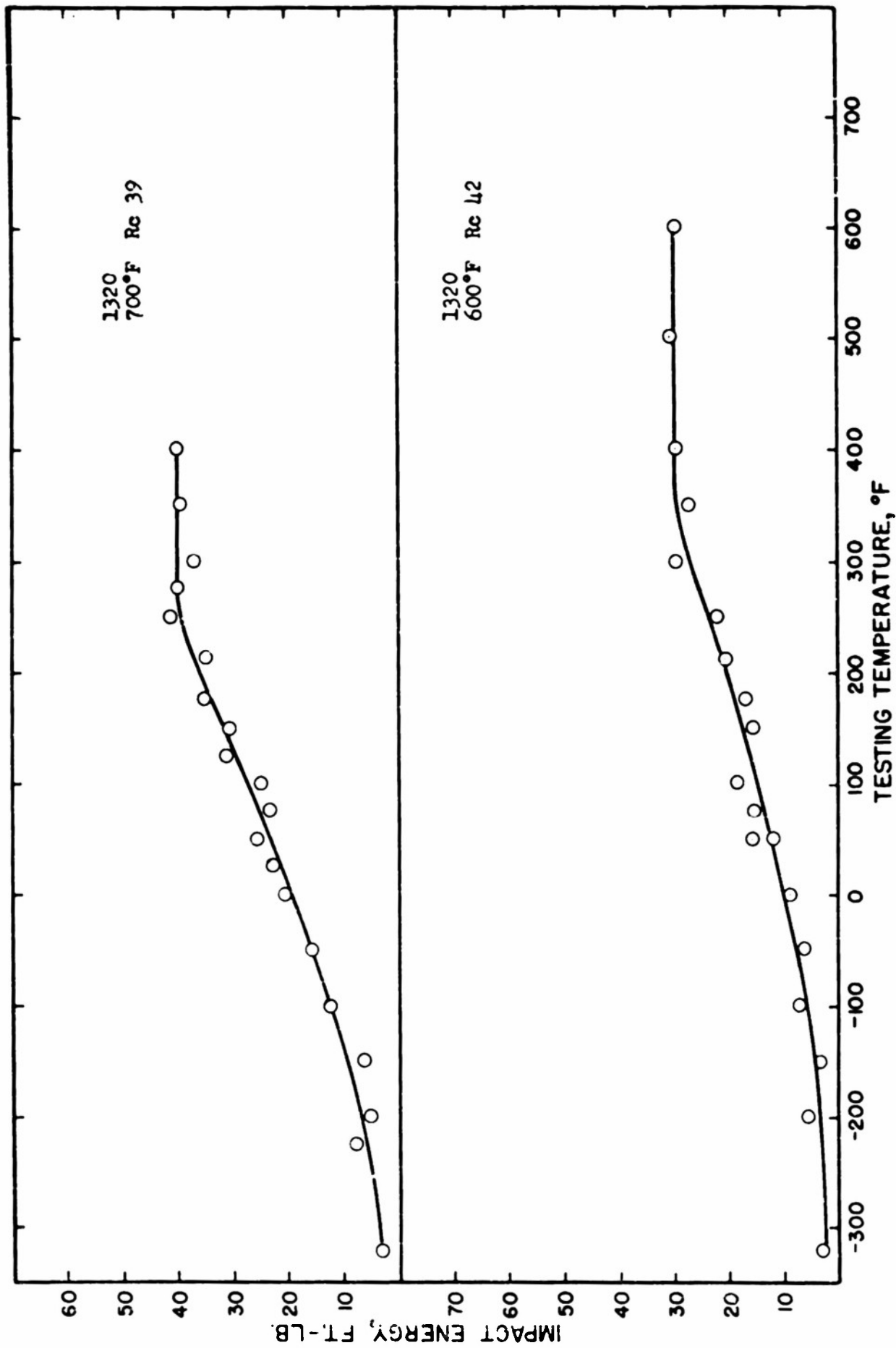


Fig. 3 - App. I

Heat 3740, Laboratory fine grain 1320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

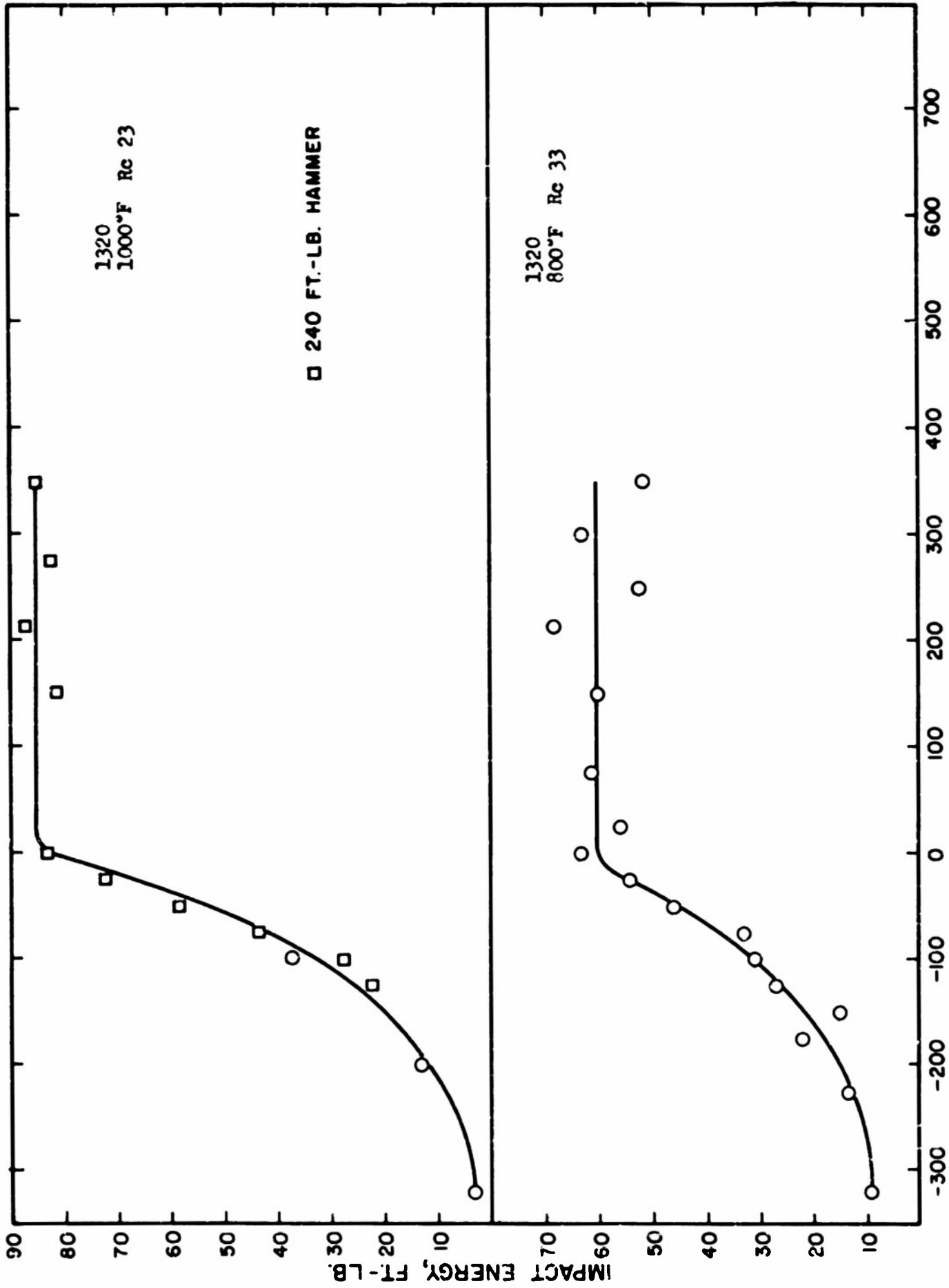


Fig. 4 - App. I,

Heat 3740, laboratory fine grain 1320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

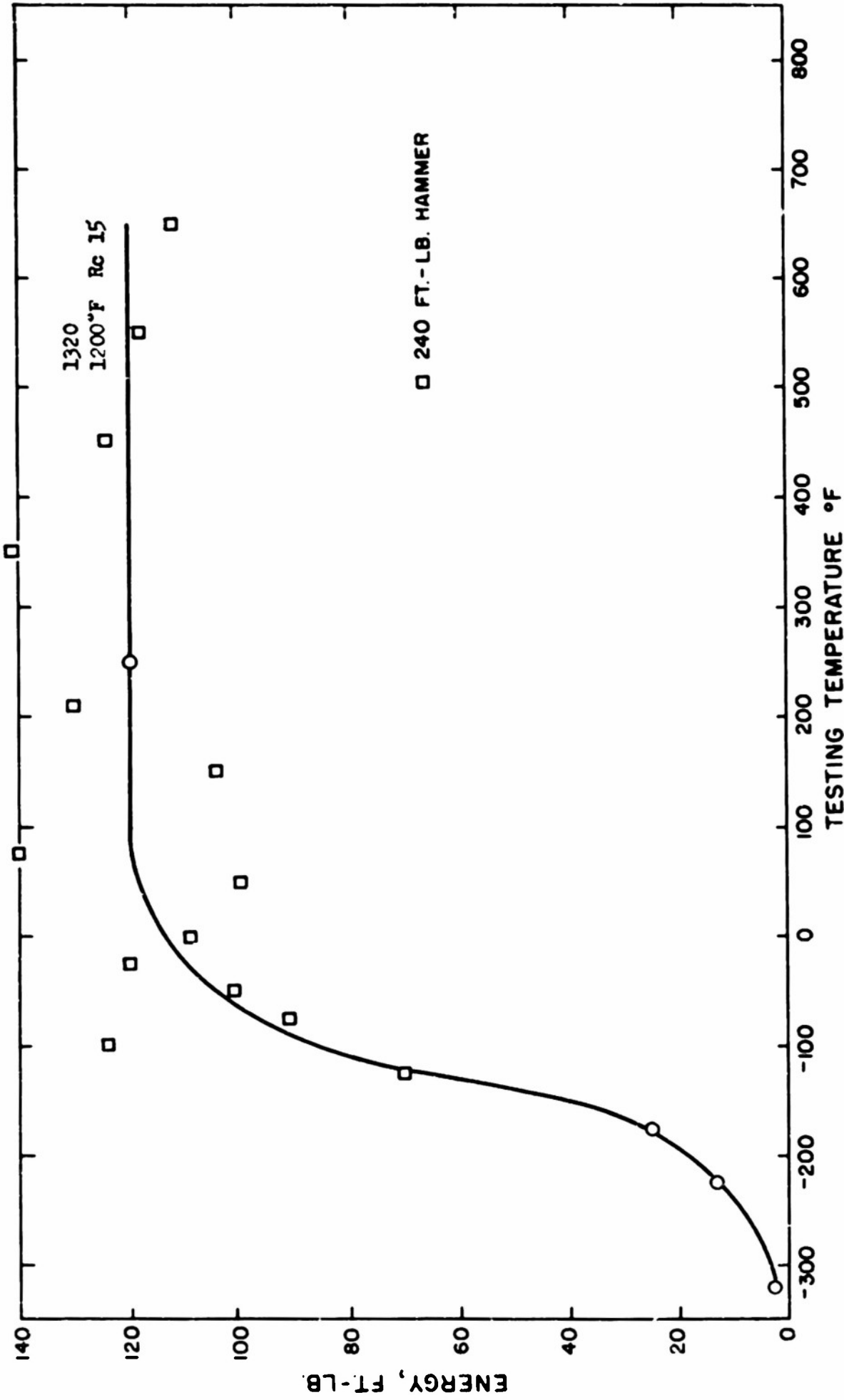


Fig. 5 - App. I

Heat 3740, laboratory fine grain 1320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

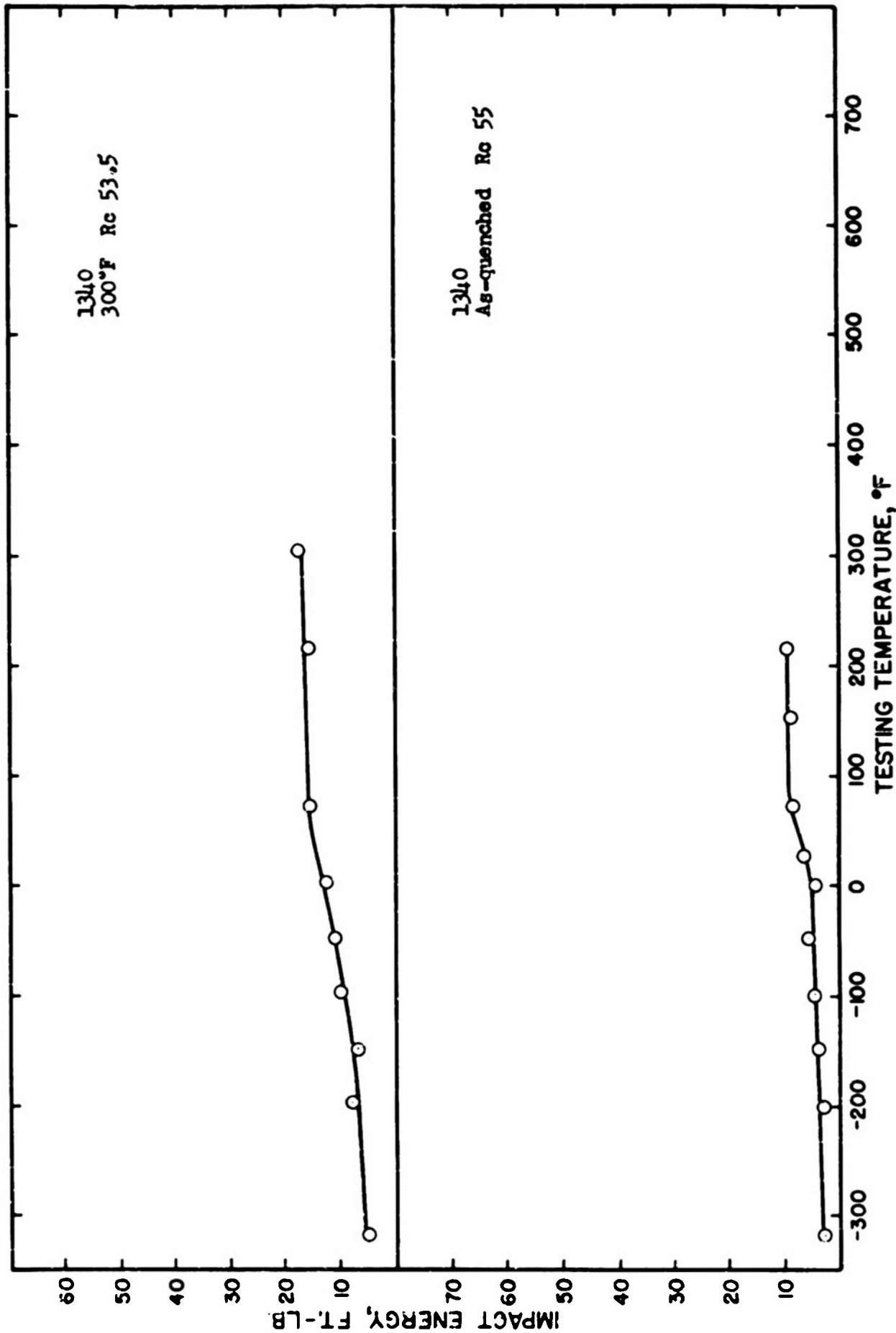


Fig. 6 - App. I

Heat I, laboratory fine grain 1340; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

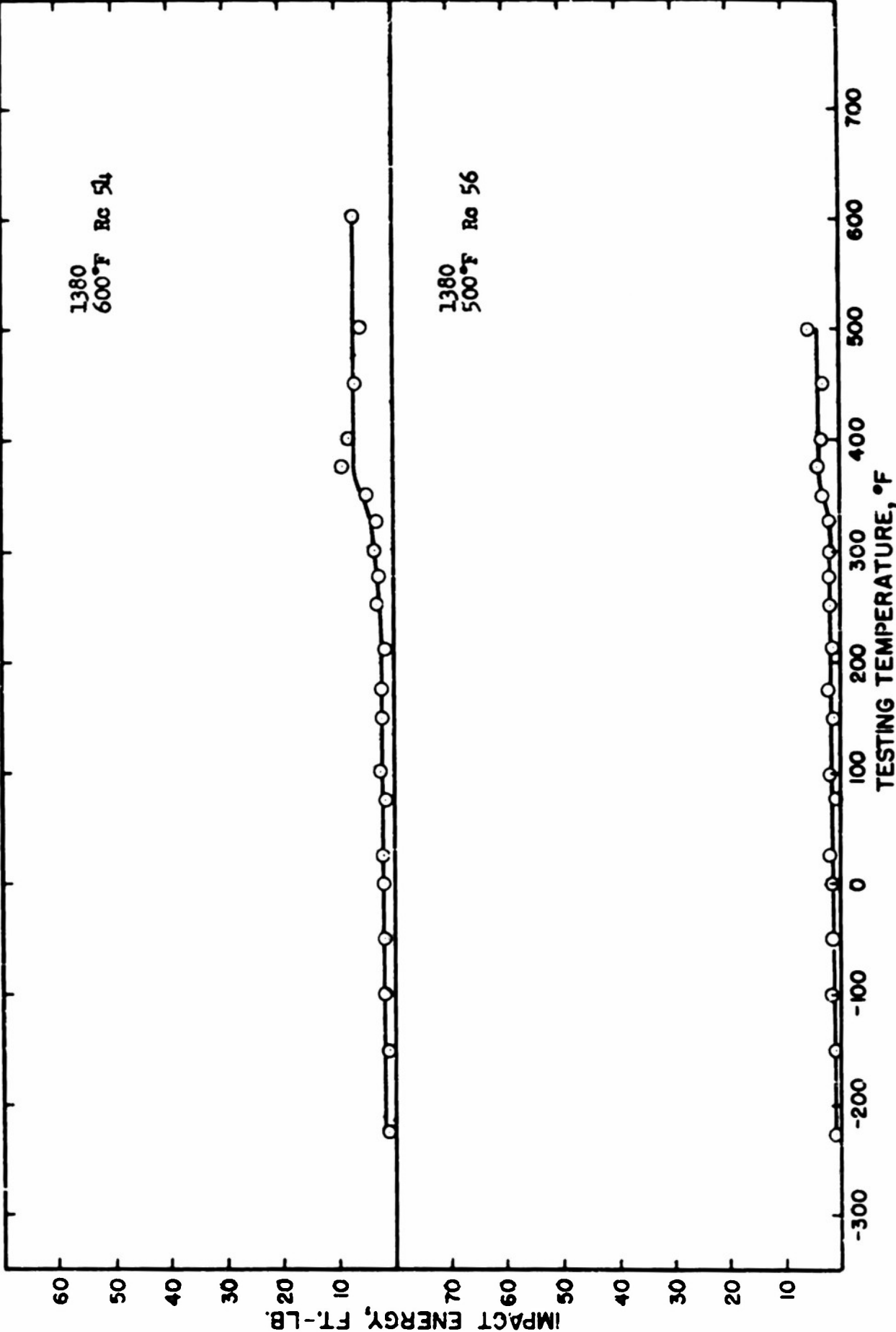


Fig. 7 - App. I

Heat 3779, laboratory fine grain 1380; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

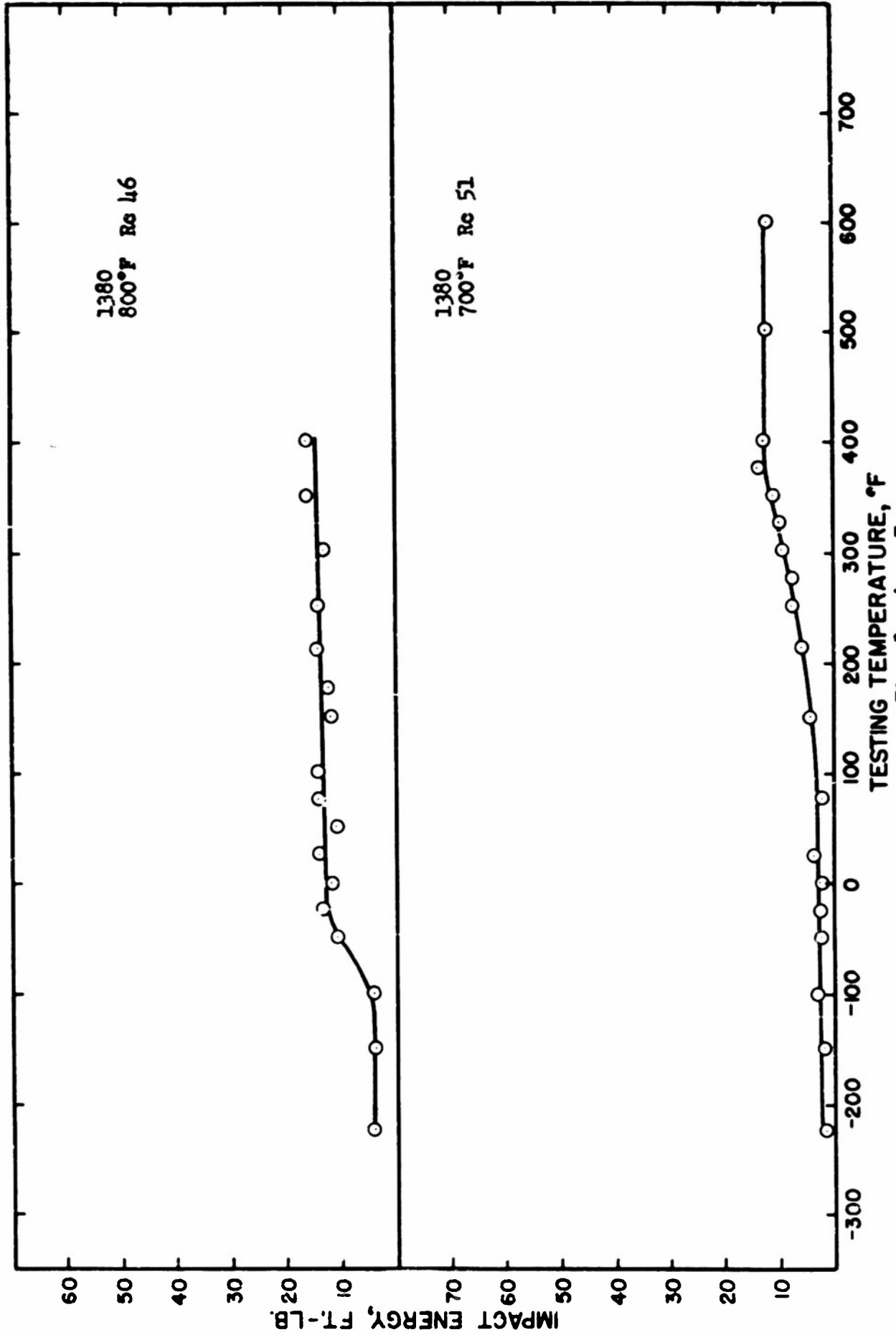


Fig. 8 - App. I

Heat 3779, laboratory fine grain 1380; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

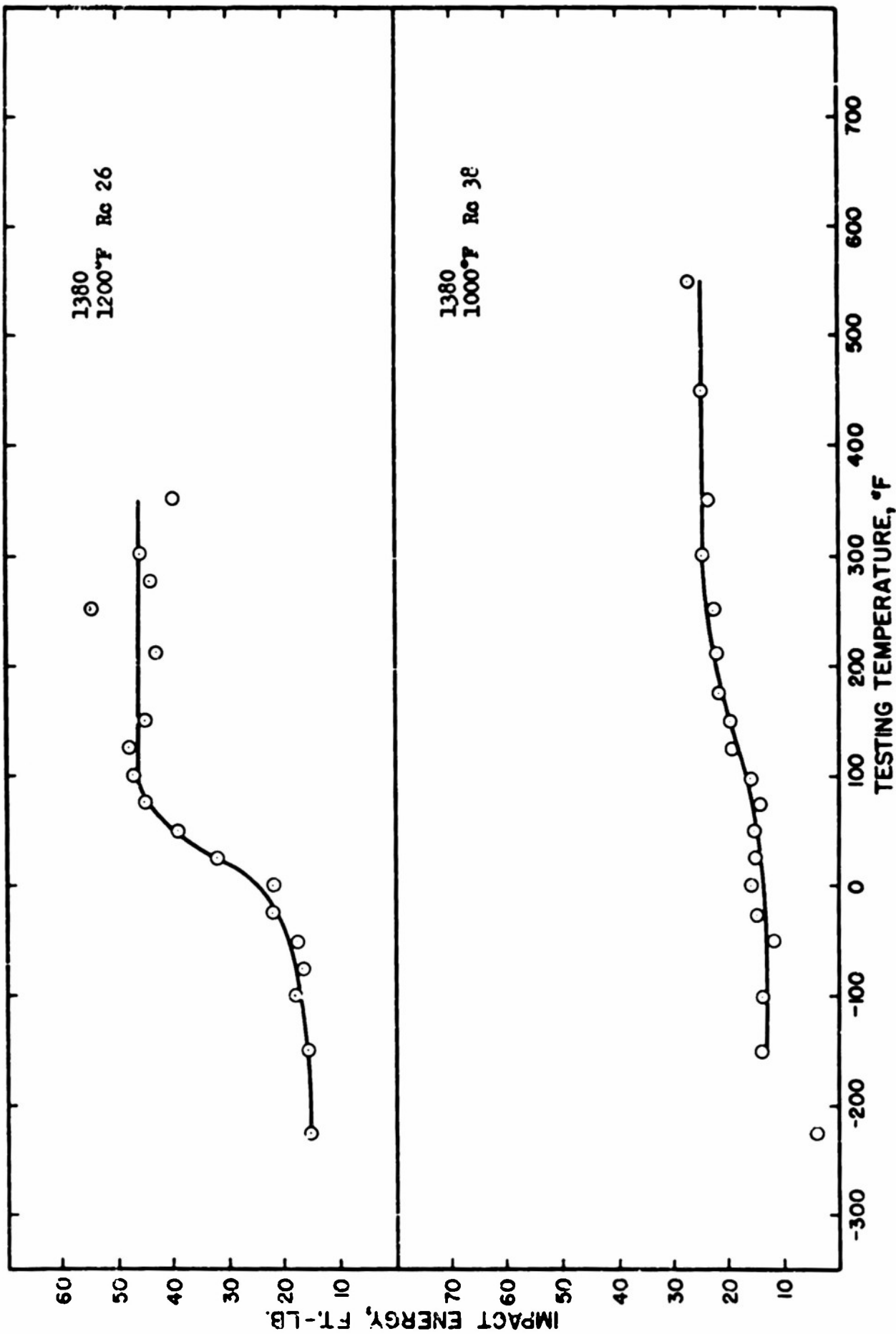


Fig. 9 - App. I

Heat 3779, laboratory fine grain 1380; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

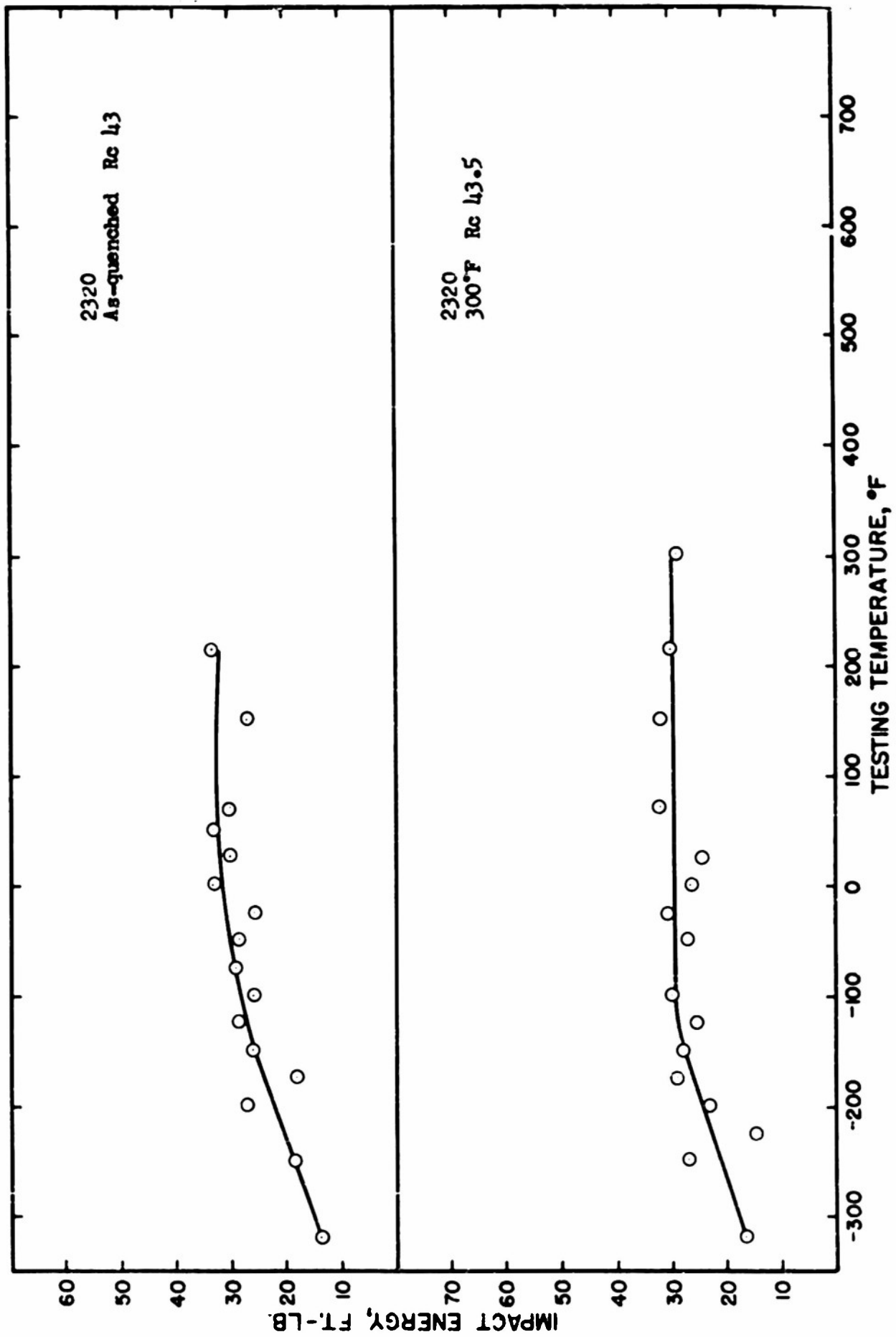


Fig. 10 - App. I

Heat 2714, Laboratory fine grain 2320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

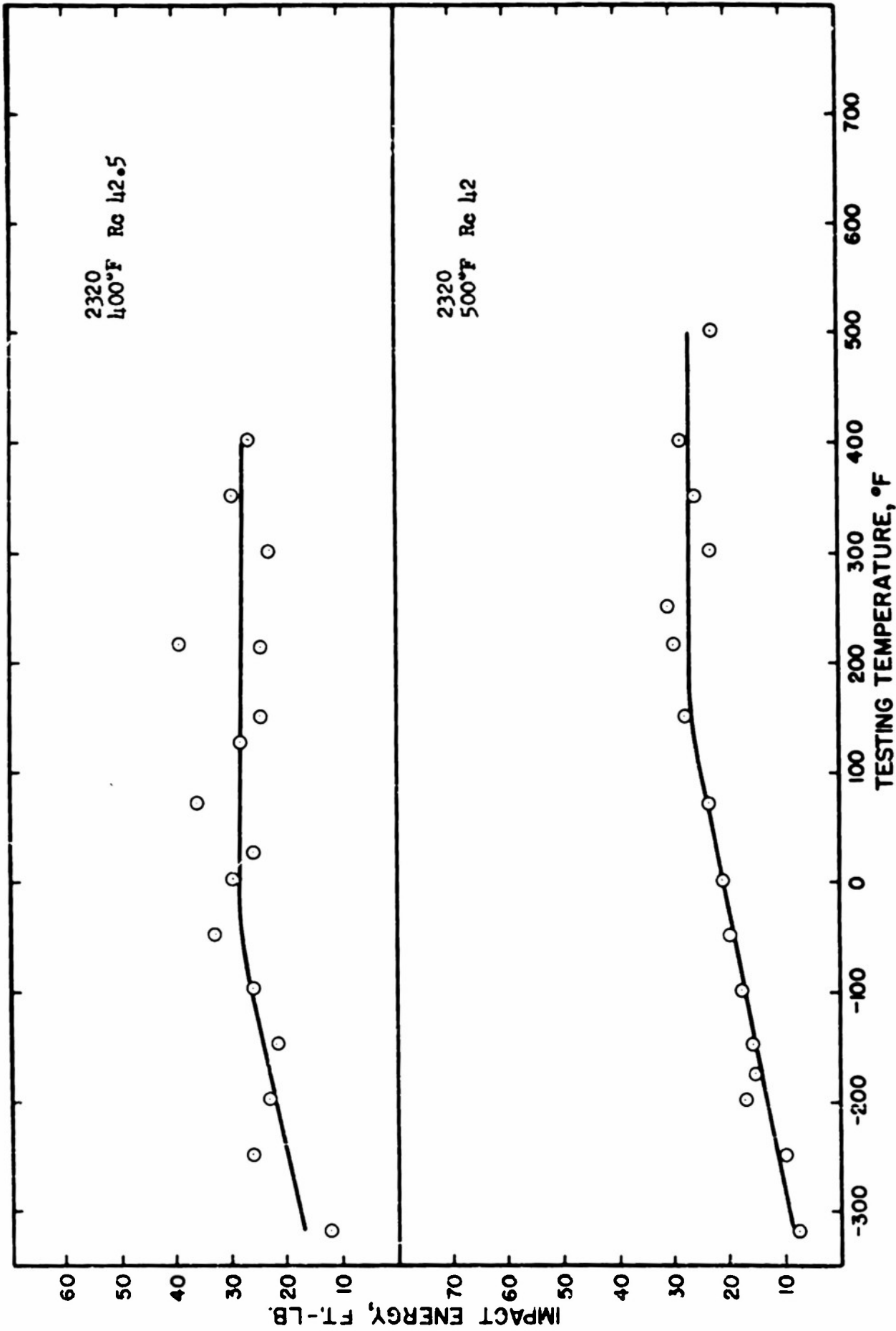


Fig. 11 - App. I

Heat 2714, laboratory fine grain 2320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

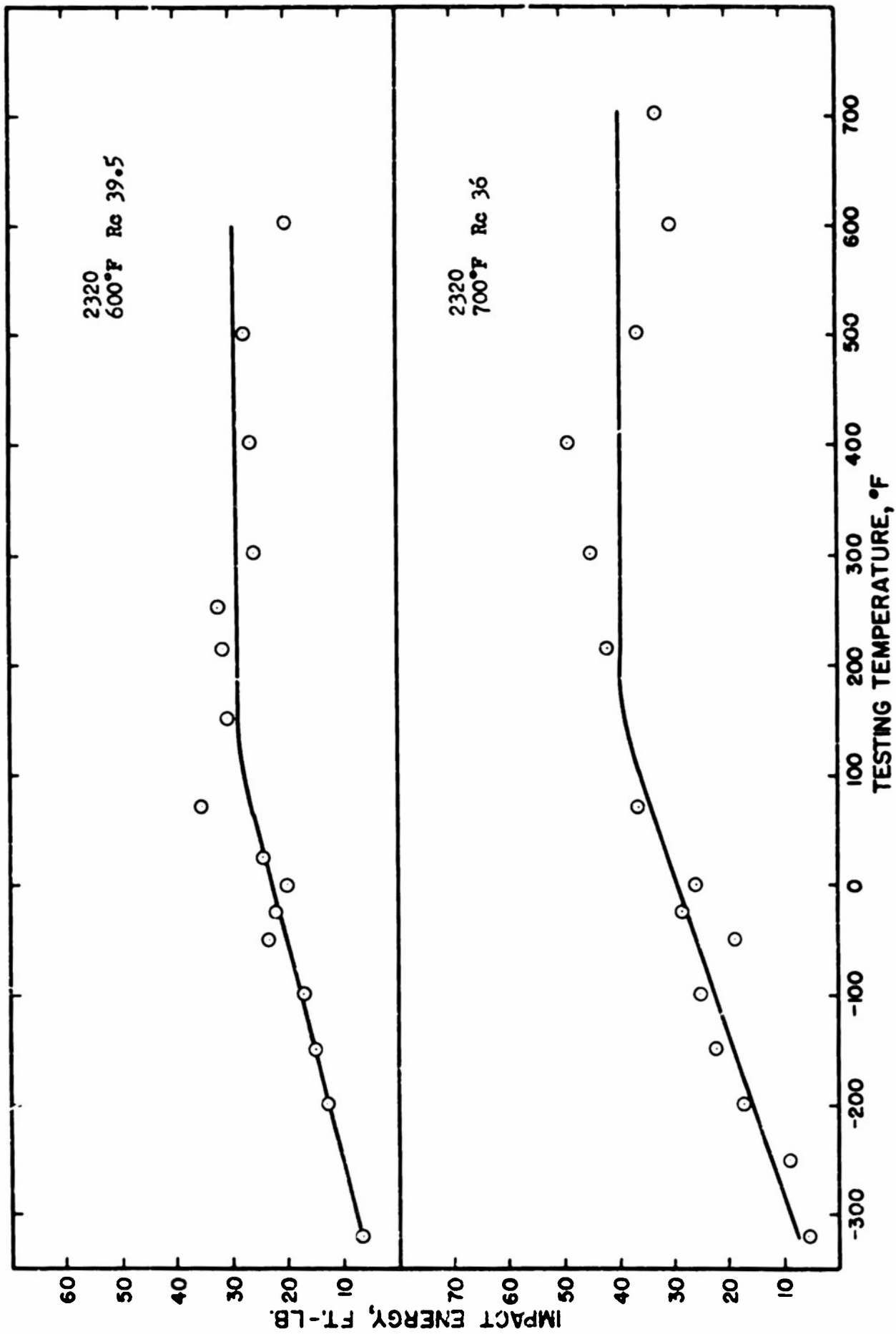


Fig. 12 - App. I

Heat 2714, laboratory fine grain 2320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

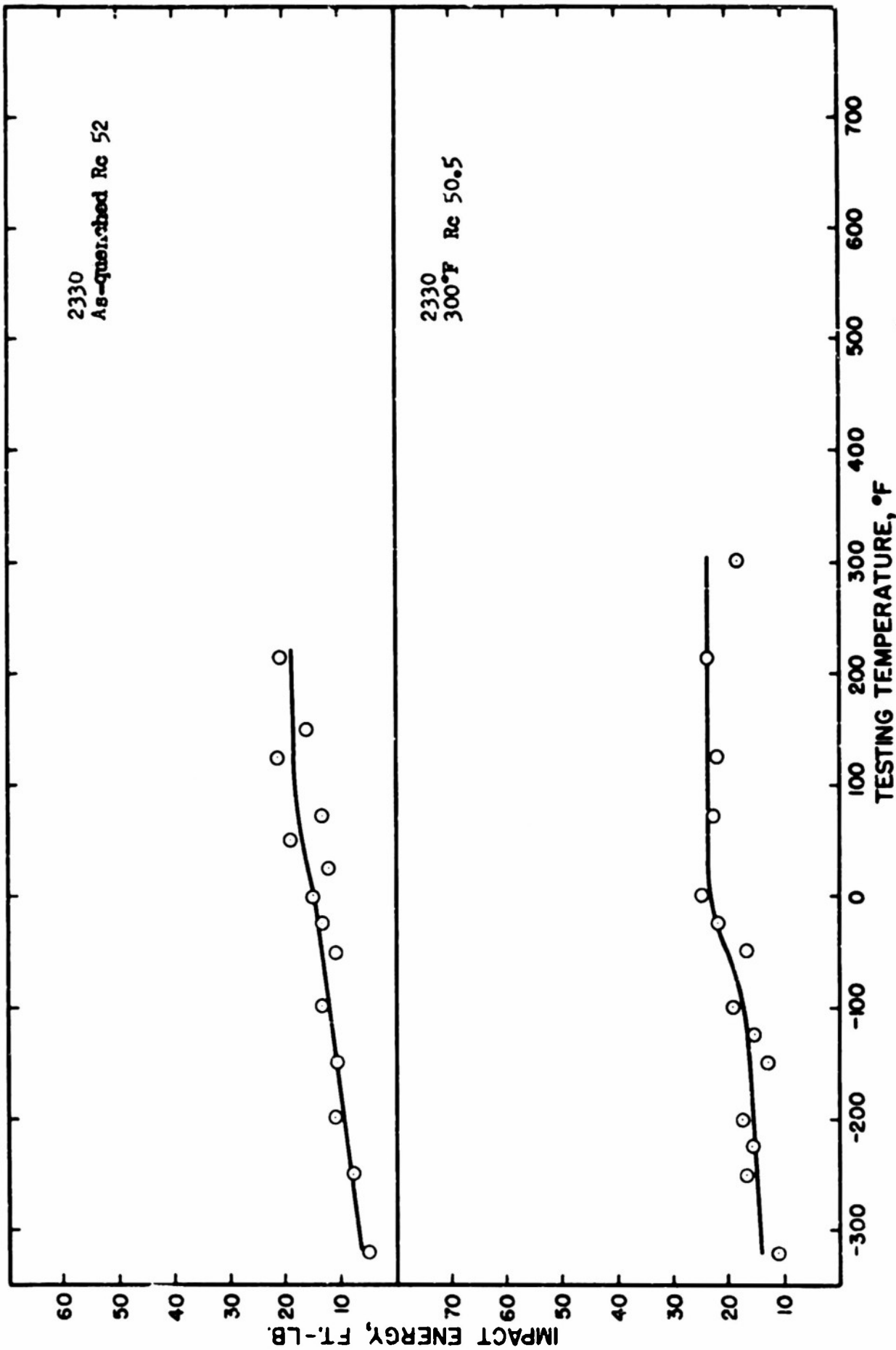


Fig. 13 - App. I

Heat 2722, laboratory fine grain 2330; quenched in oil after 30 minutes at 1575°F; tempered for one hour at temperature indicated in graph and water quenched.

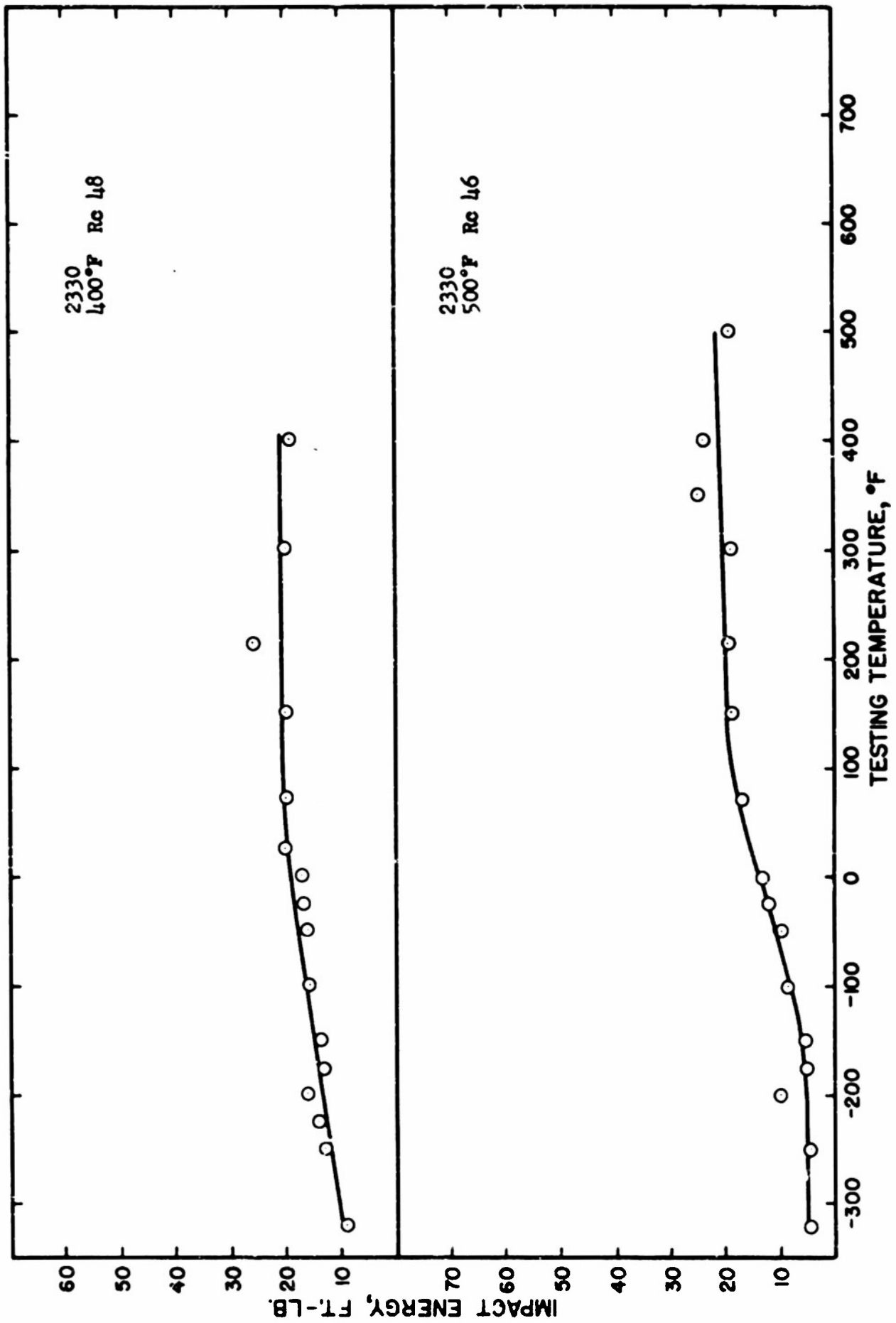


Fig. 14 - App. I

Heat 2722, laboratory fine grain 2330; quenched in oil after 30 minutes at 1575°F; tempered for one hour at temperature indicated in graph and water quenched.

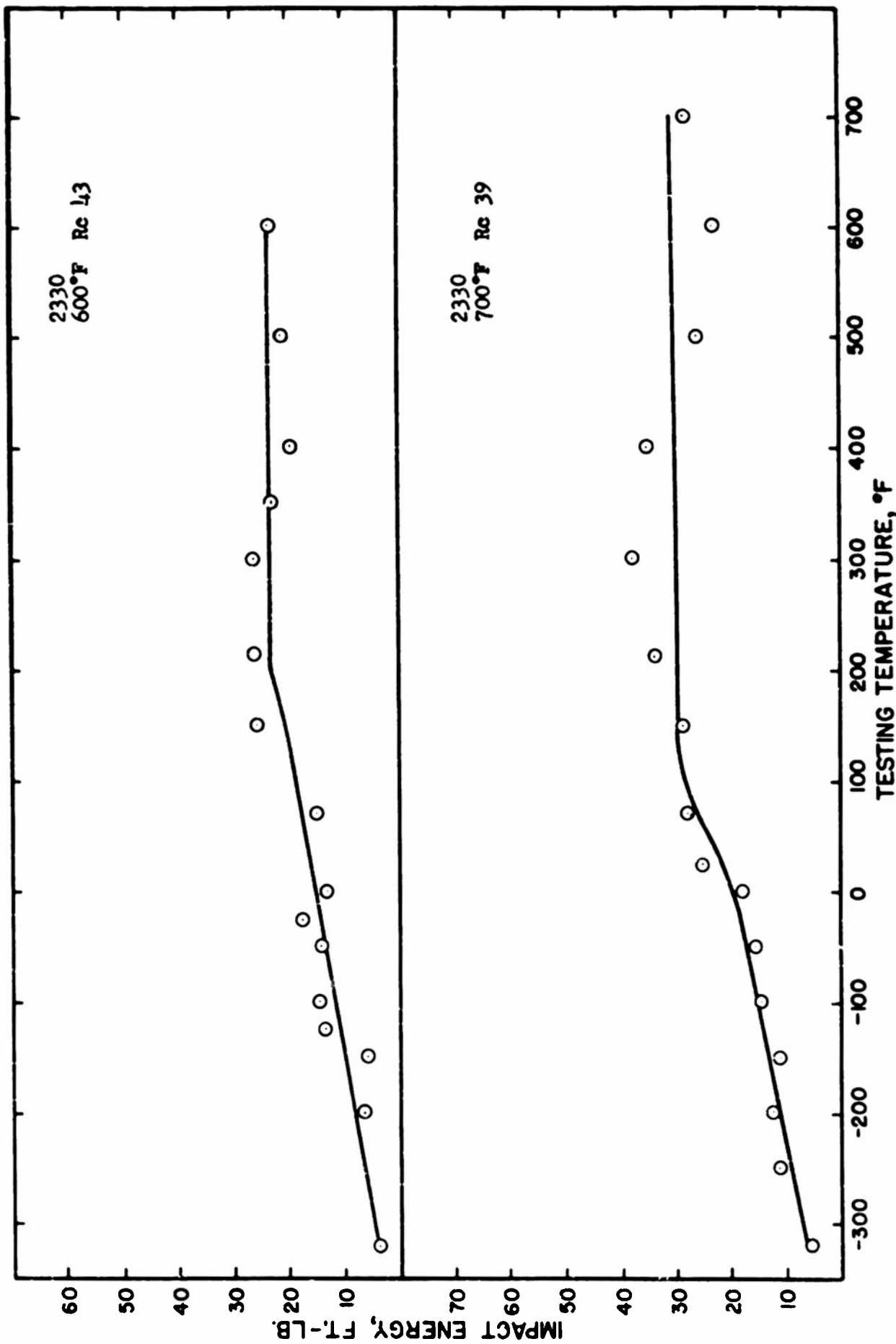


Fig. 15 - App. I

Heat 2722, Laboratory fine grain 2330; quenched in oil after 30 minutes at 1575°F; tempered for one hour at temperature indicated in graph and water quenched.

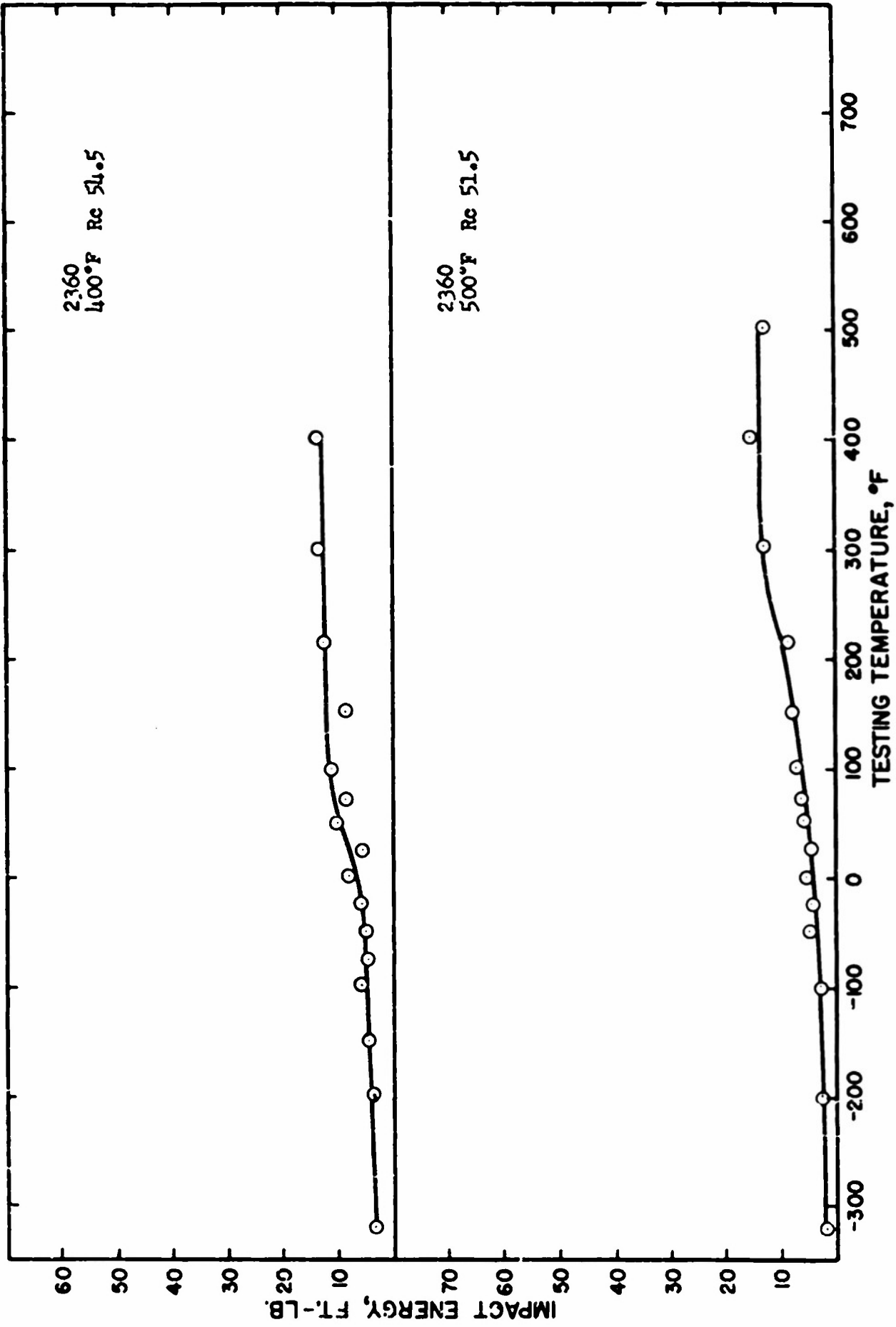


Fig. 16 - App. I

Heat 2725, laboratory fine grain 2360; quenched in oil after 30 minutes at 1475°F; tempered for one hour at temperature indicated in graph and water quenched.

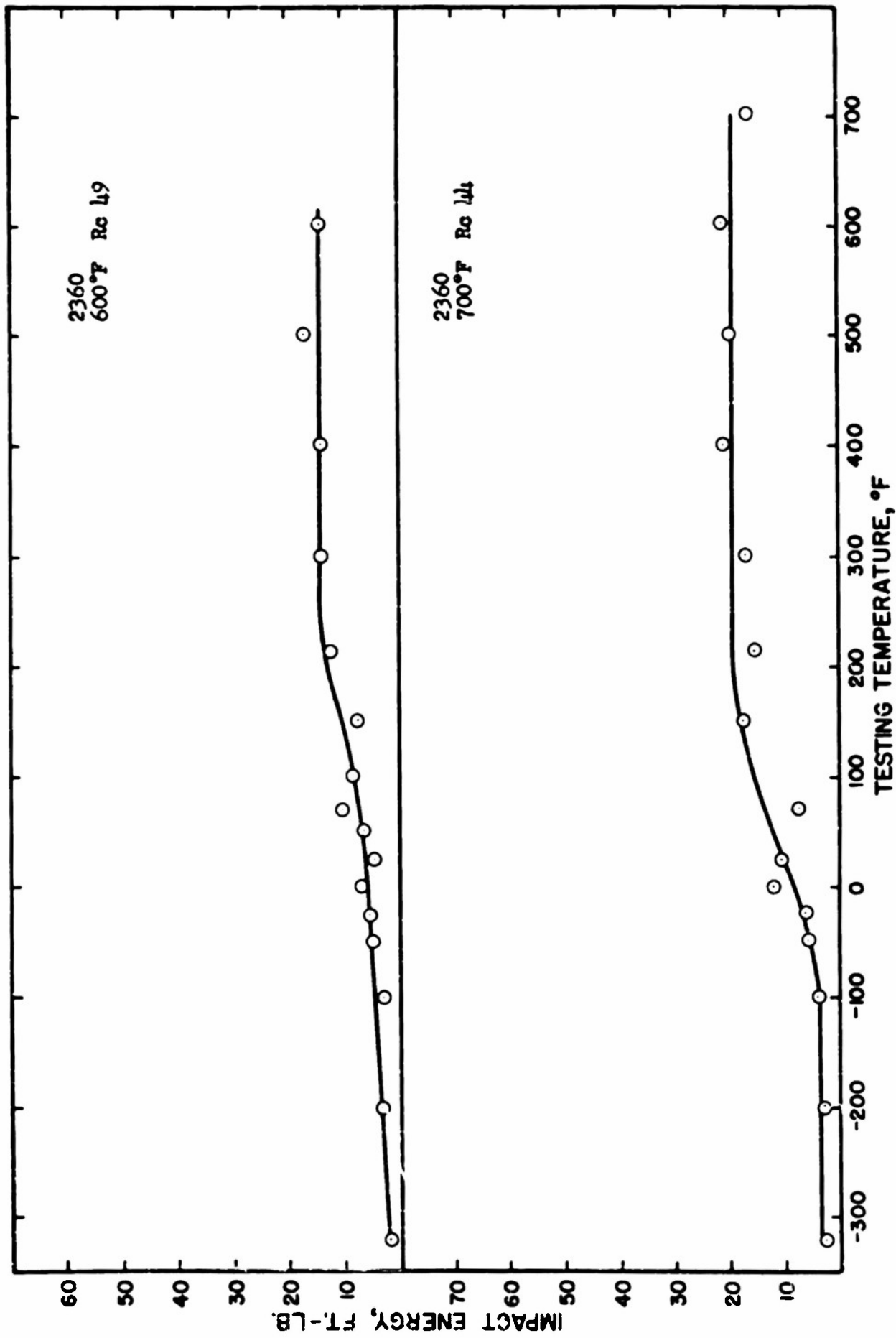


Fig. 17 - App. I

Heat 2725, laboratory fine grain 2360; quenched in oil after 30 minutes at 1475°F; tempered for one hour at temperature indicated in graph and water quenched.

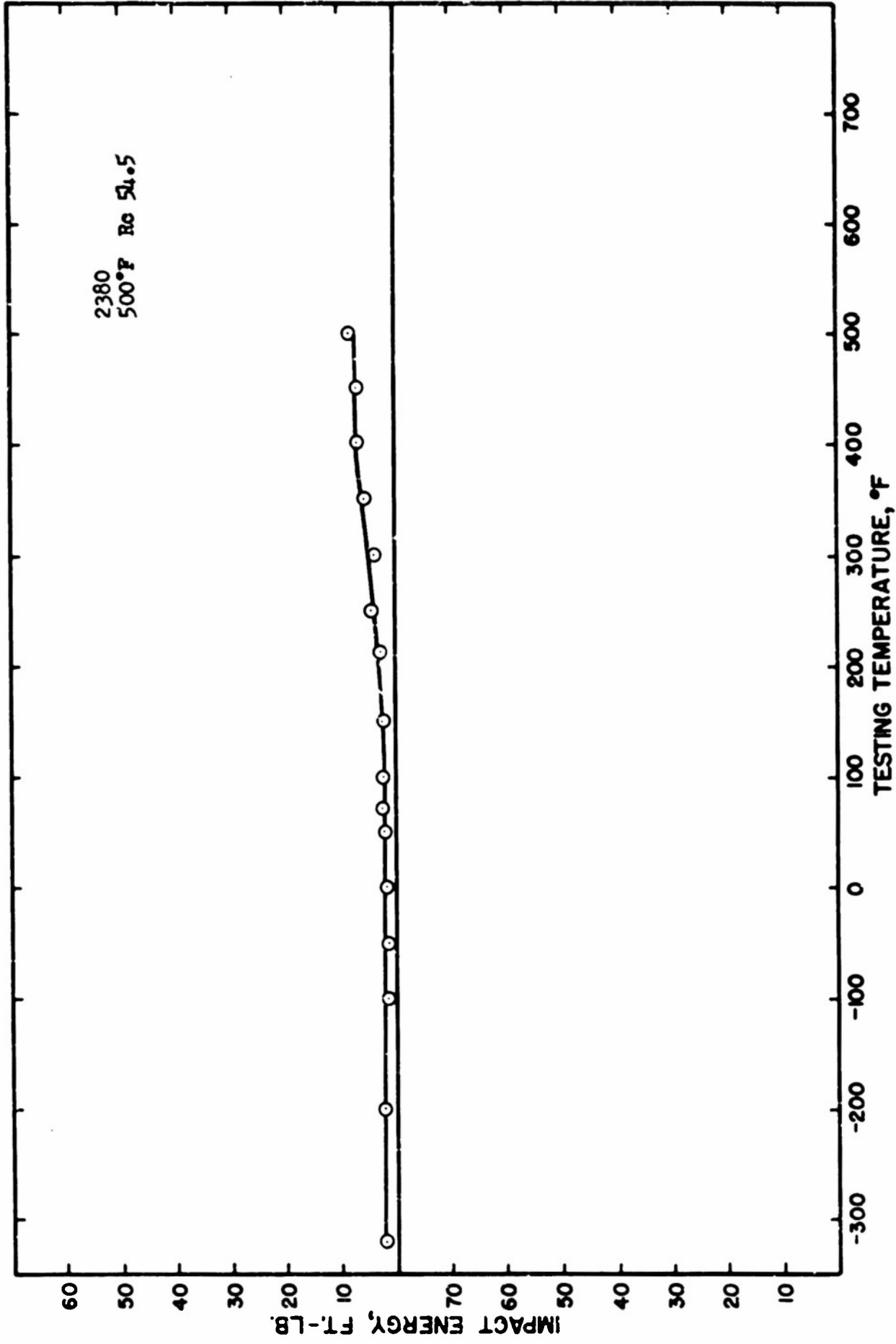


Fig. 18 - App. I

Heat 2727, laboratory fine grain 2380; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

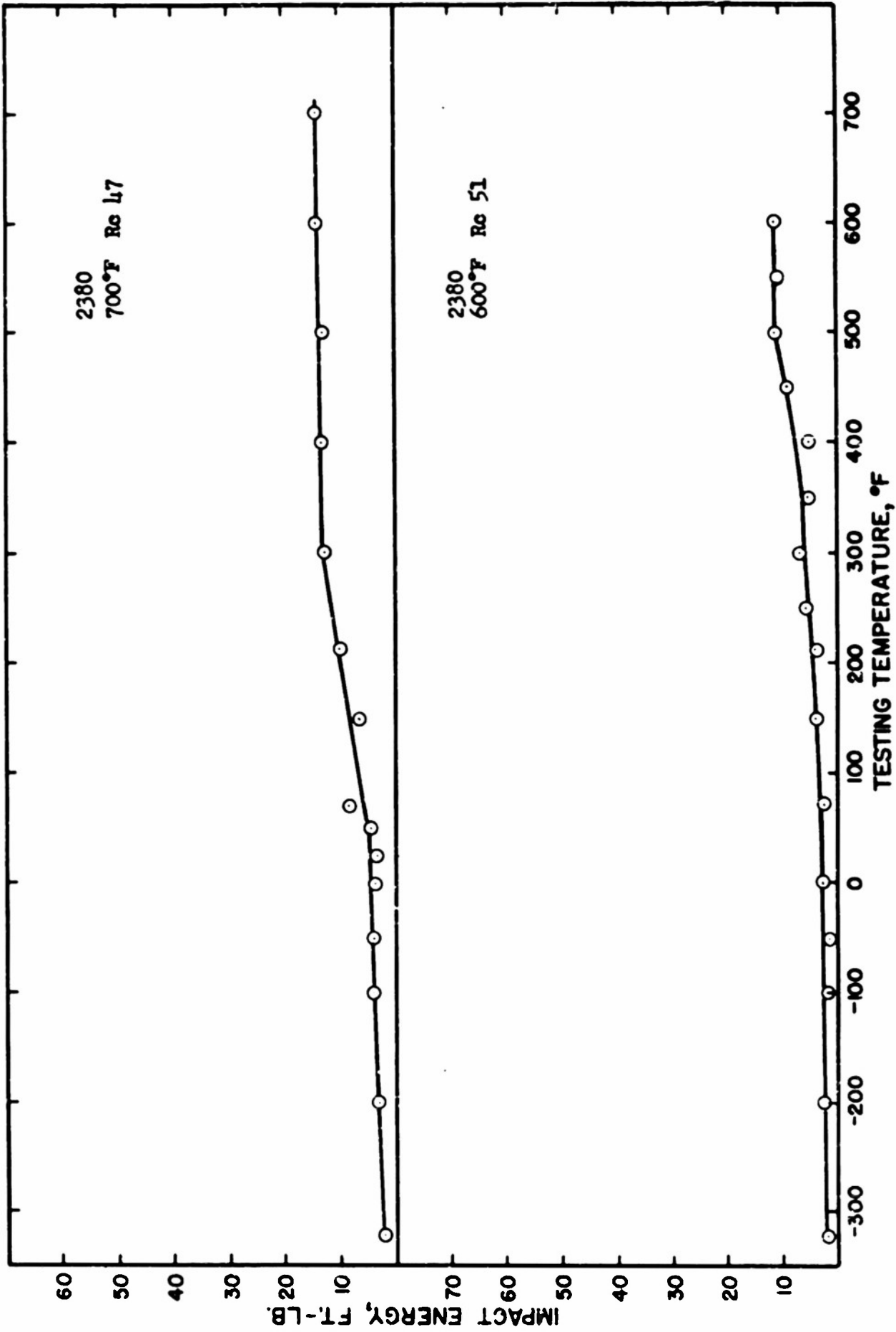


Fig. 19 - App. I

Heat 2727, laboratory fine grain 2380; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

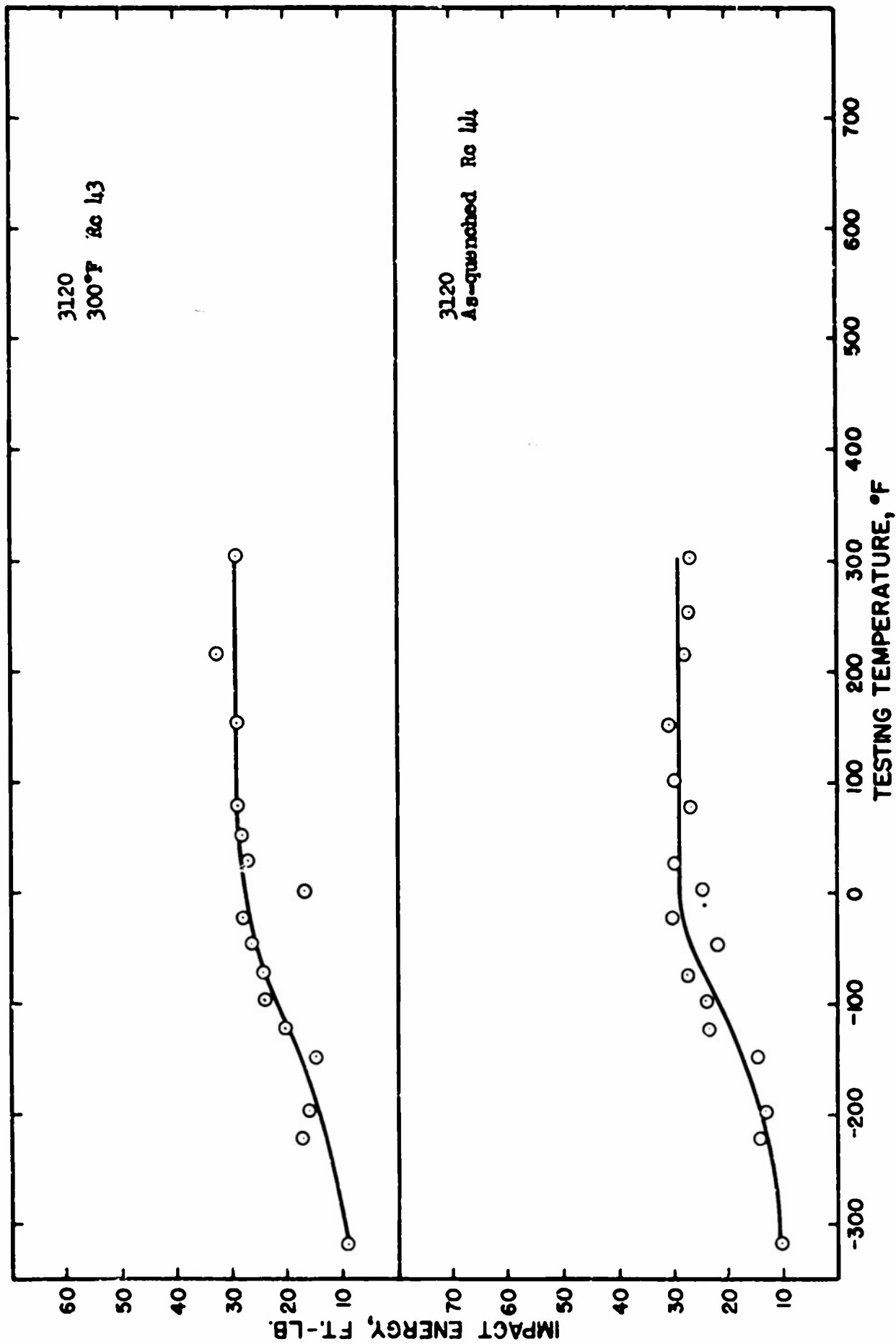


Fig. 20 - App. I

Heat 3745, laboratory fine grain 3120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

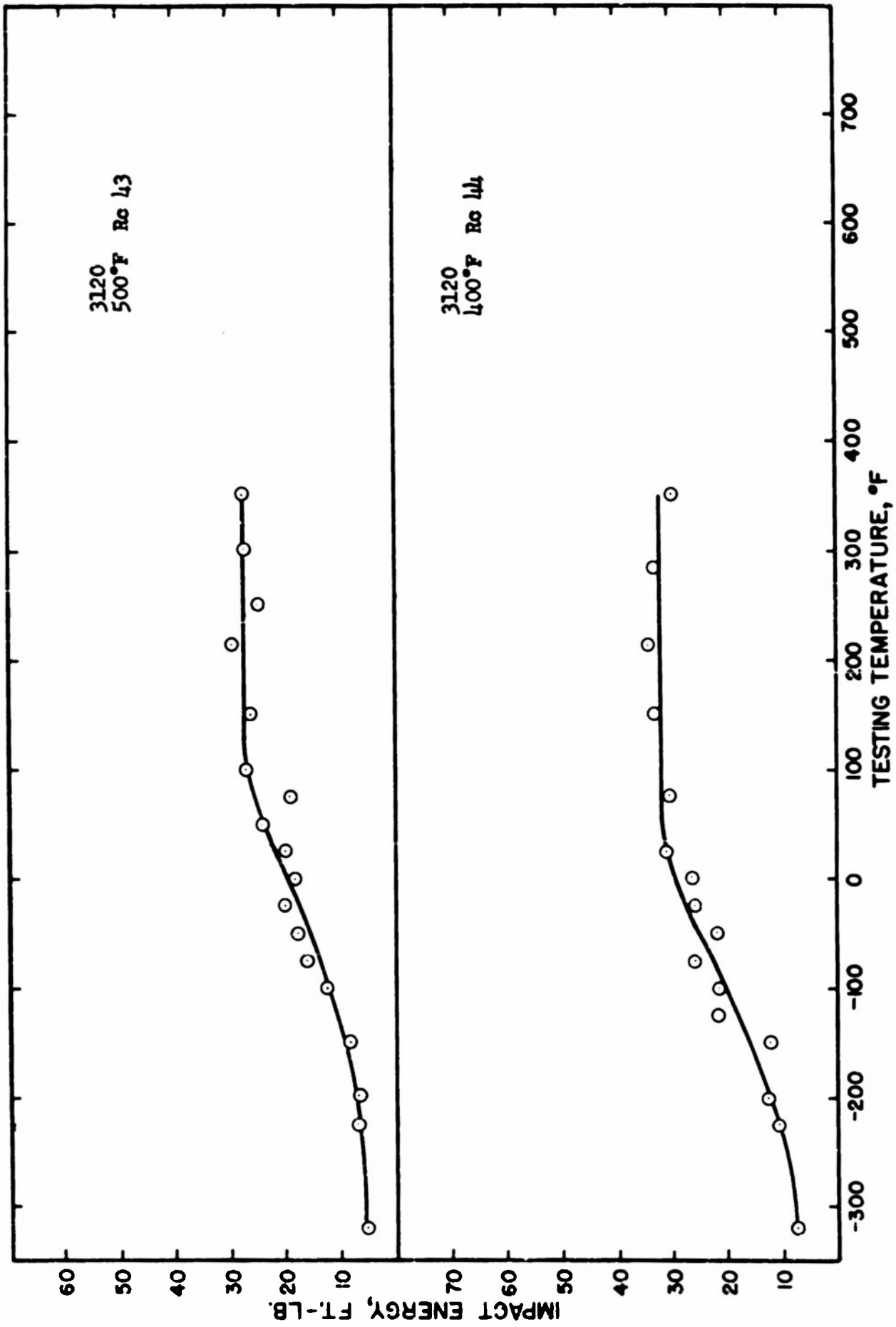


Fig. 21 - App. I

Heat 3745, laboratory fine grain 3120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

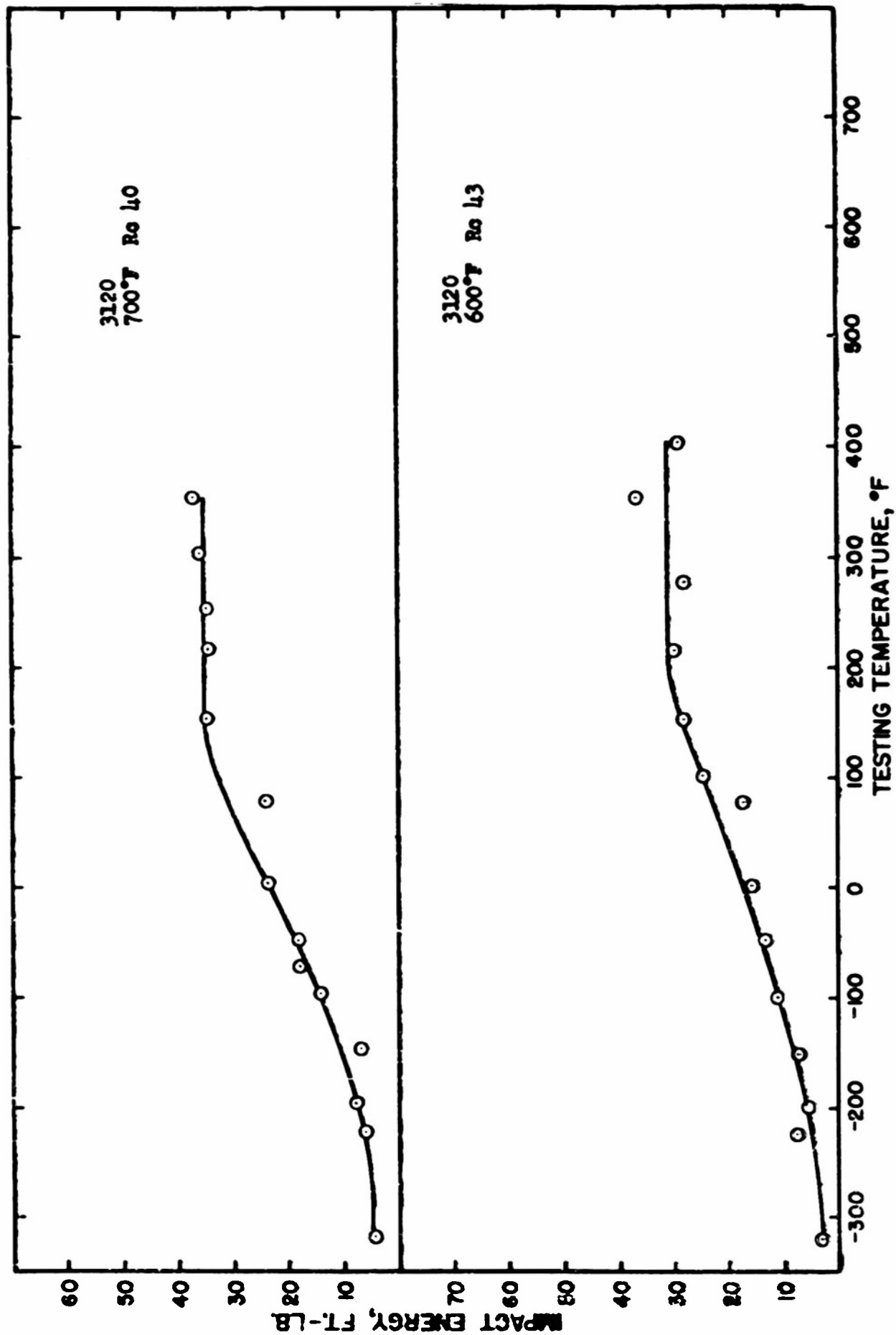


Fig. 22 - App. I

Heat 3745, Laboratory fine grain 3120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

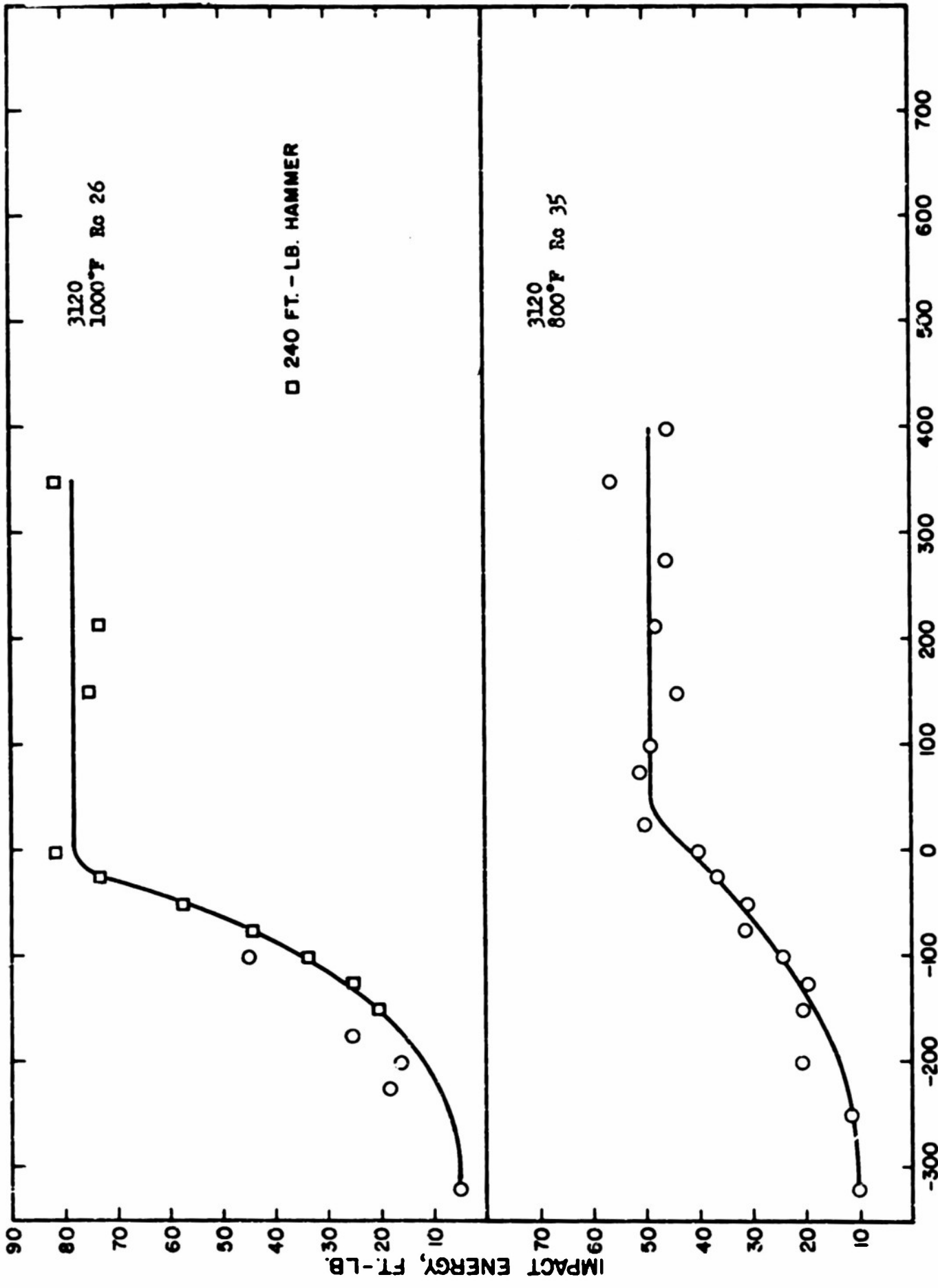


Fig. 23 - App. I. Heat 3745, Laboratory Heat 3120, quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

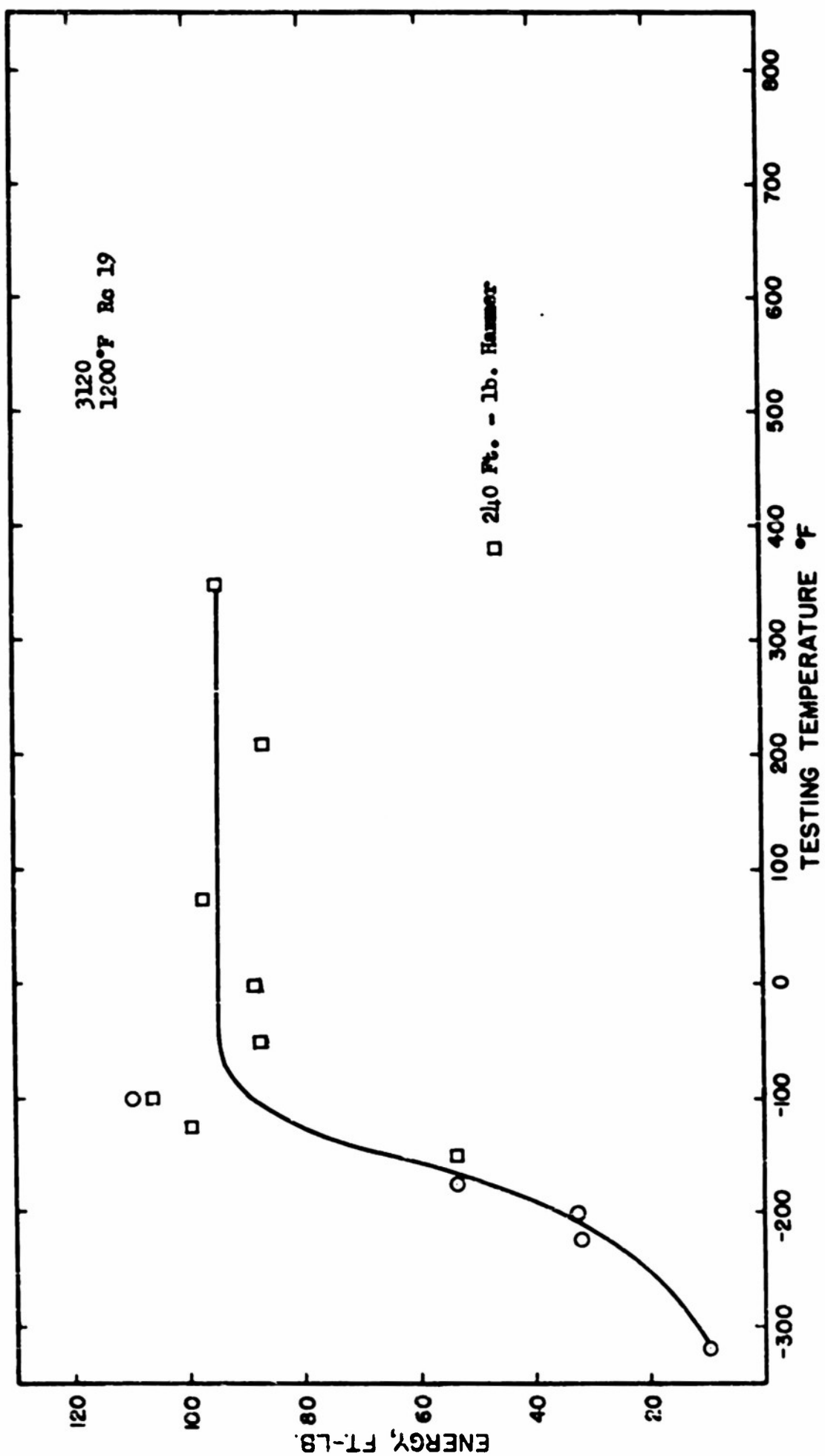


Fig. 24 - App. I

Heat 3745, Laboratory fine grain 3120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

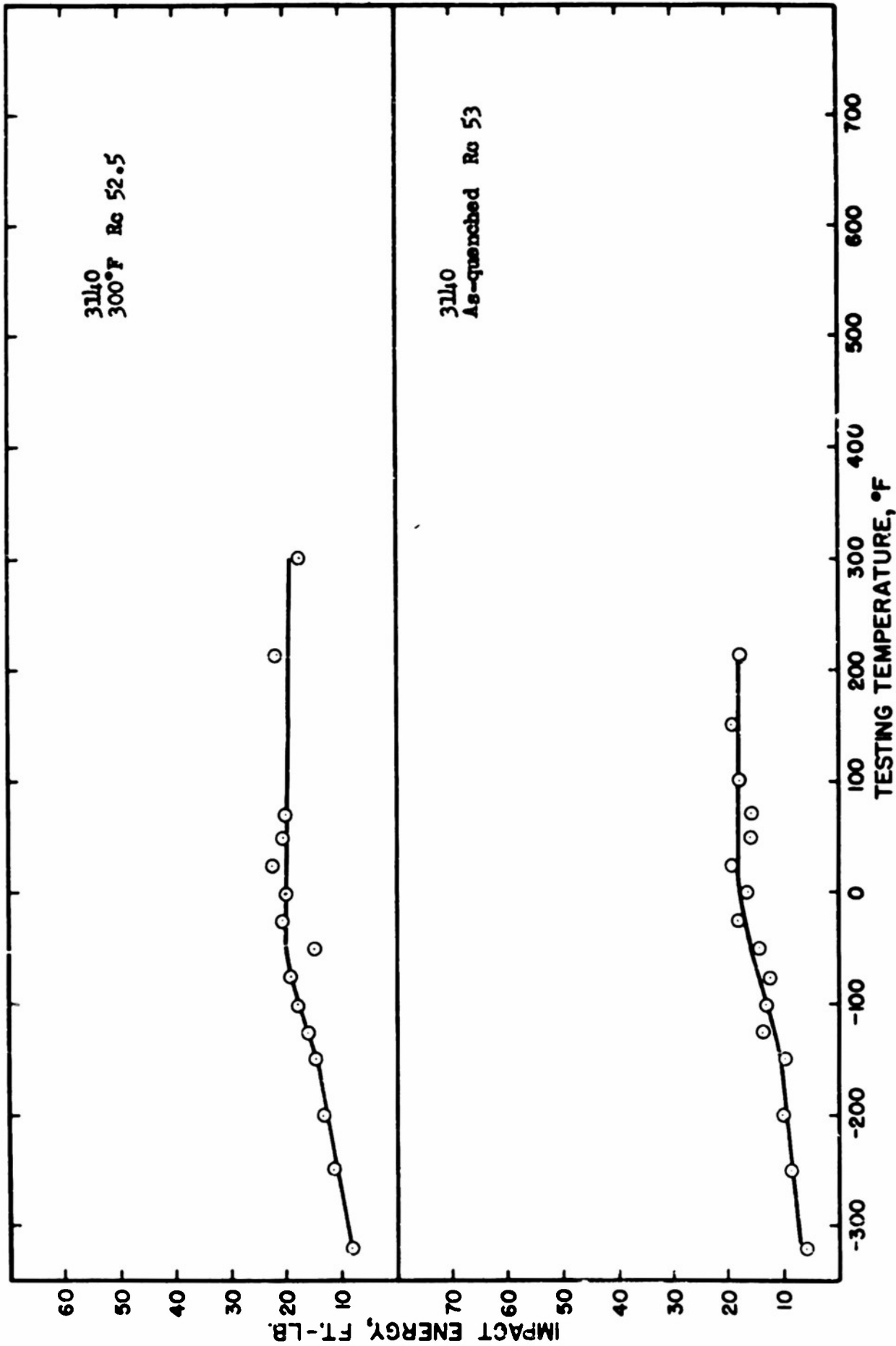


Fig. 25 - App. I

Heat J, laboratory fine grain 3140; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

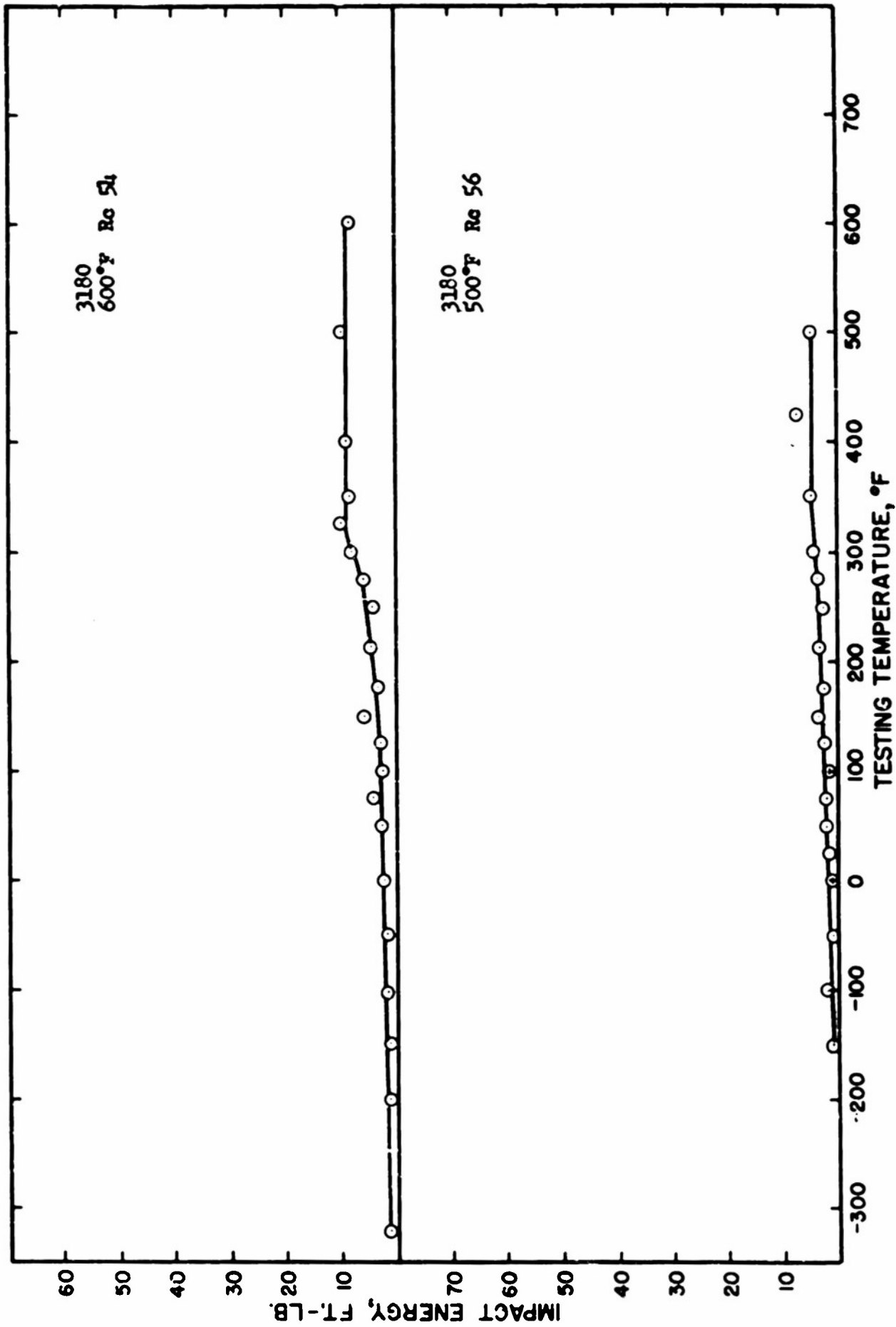


Fig. 26 - App. I

Heat 3781, laboratory fine grain 3180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

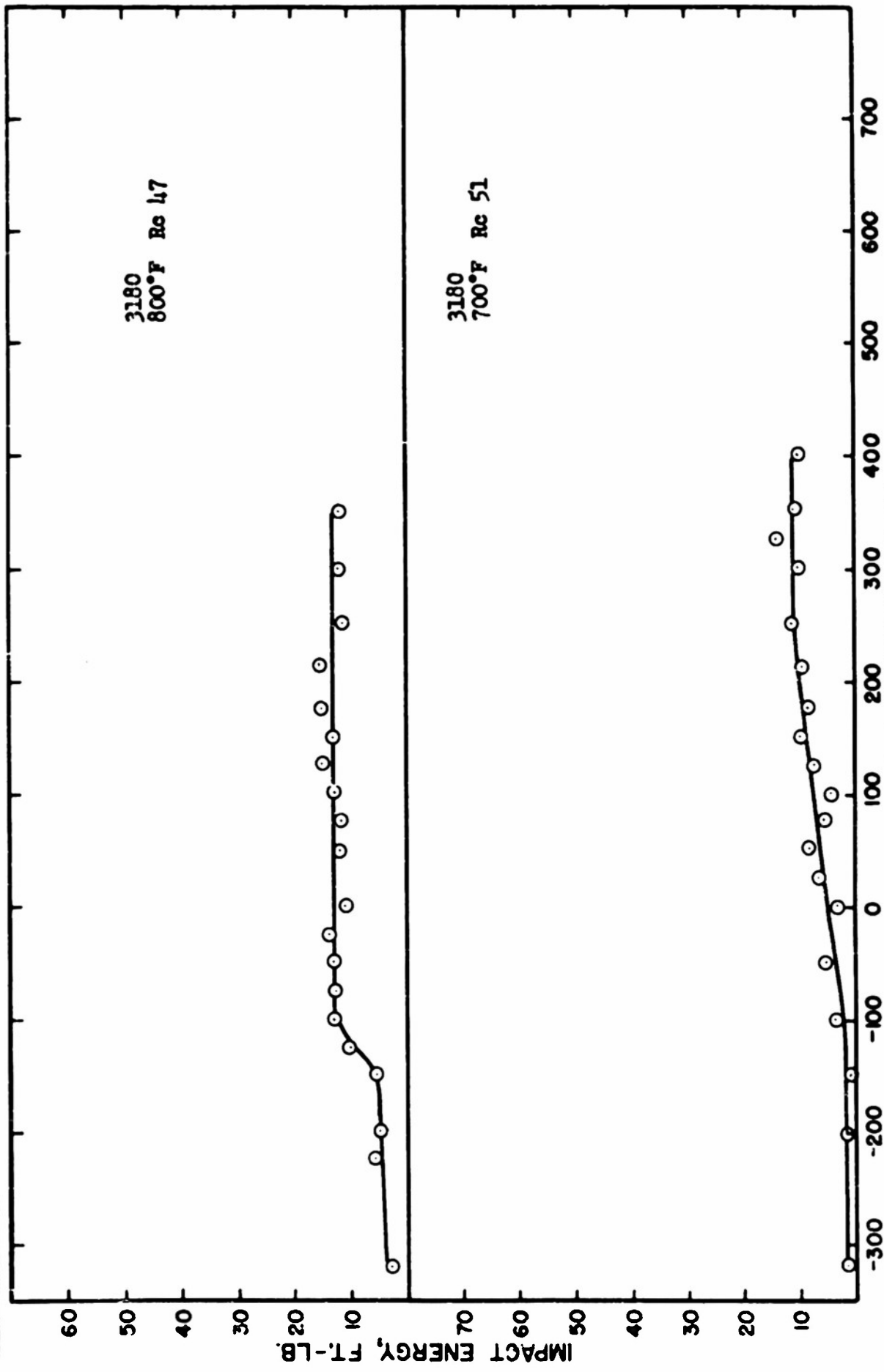


Fig. 27 - App. I

Heat 3781, laboratory fine grain 3180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

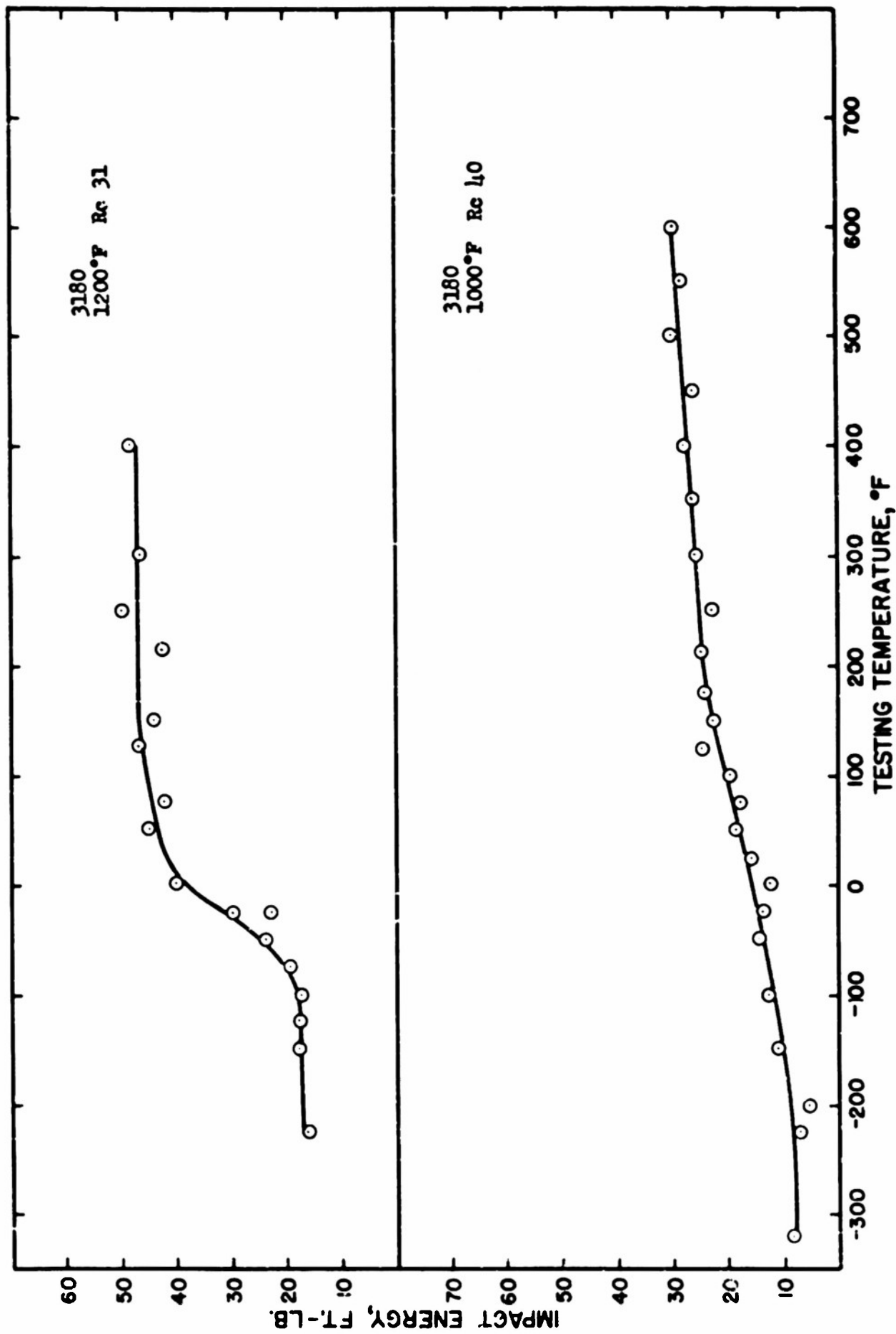


Fig. 28 - App. I

Heat 3781, laboratory fine grain 3180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

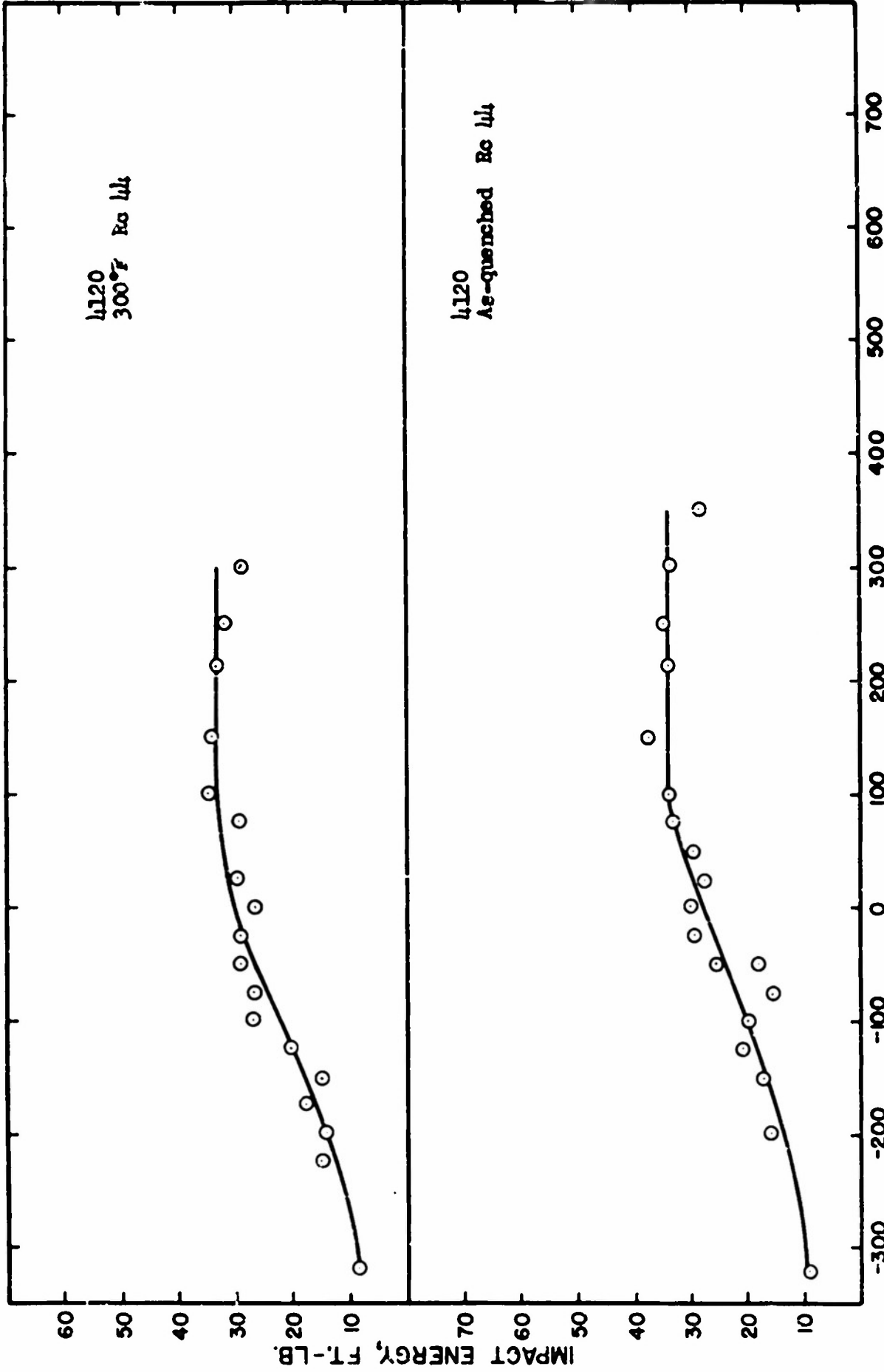


Fig. 29 - App. I

Heat 3808-3, laboratory fine grain 4120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

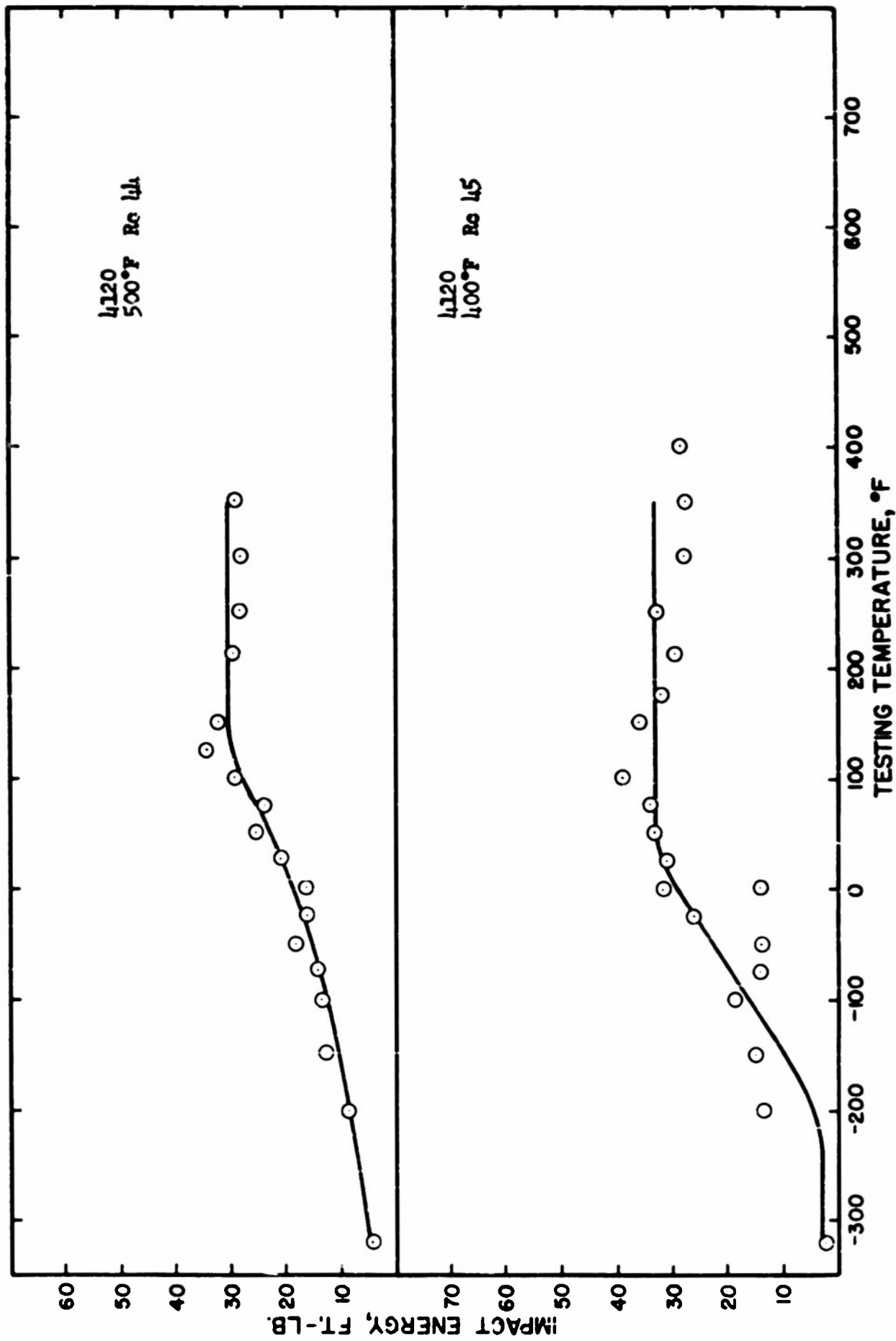


Fig. 30 - App. I

Heat 3808-3, laboratory fine grain 4120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

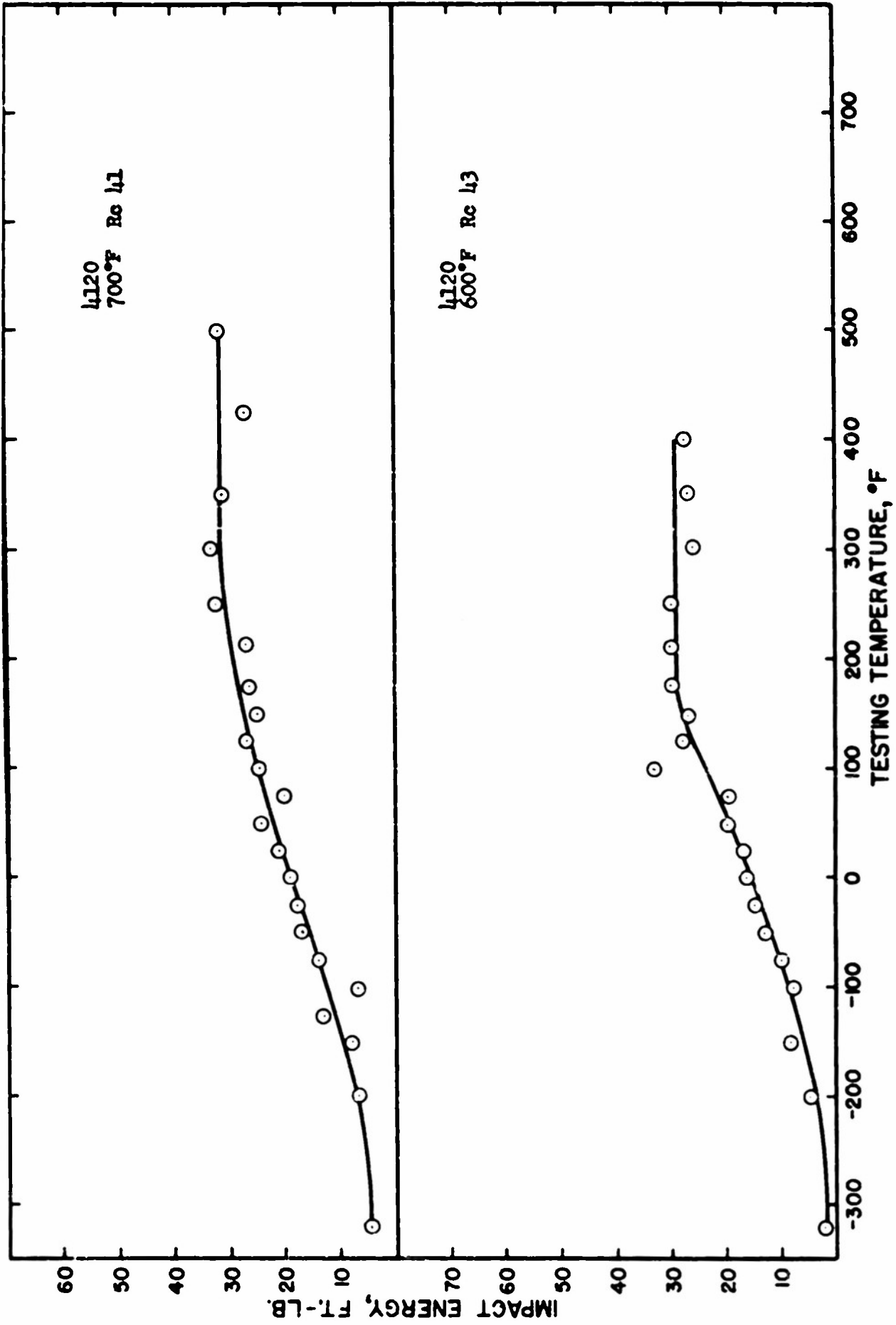


Fig. 31 - App. I

Heat 3808-3, Laboratory fine grain 4120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

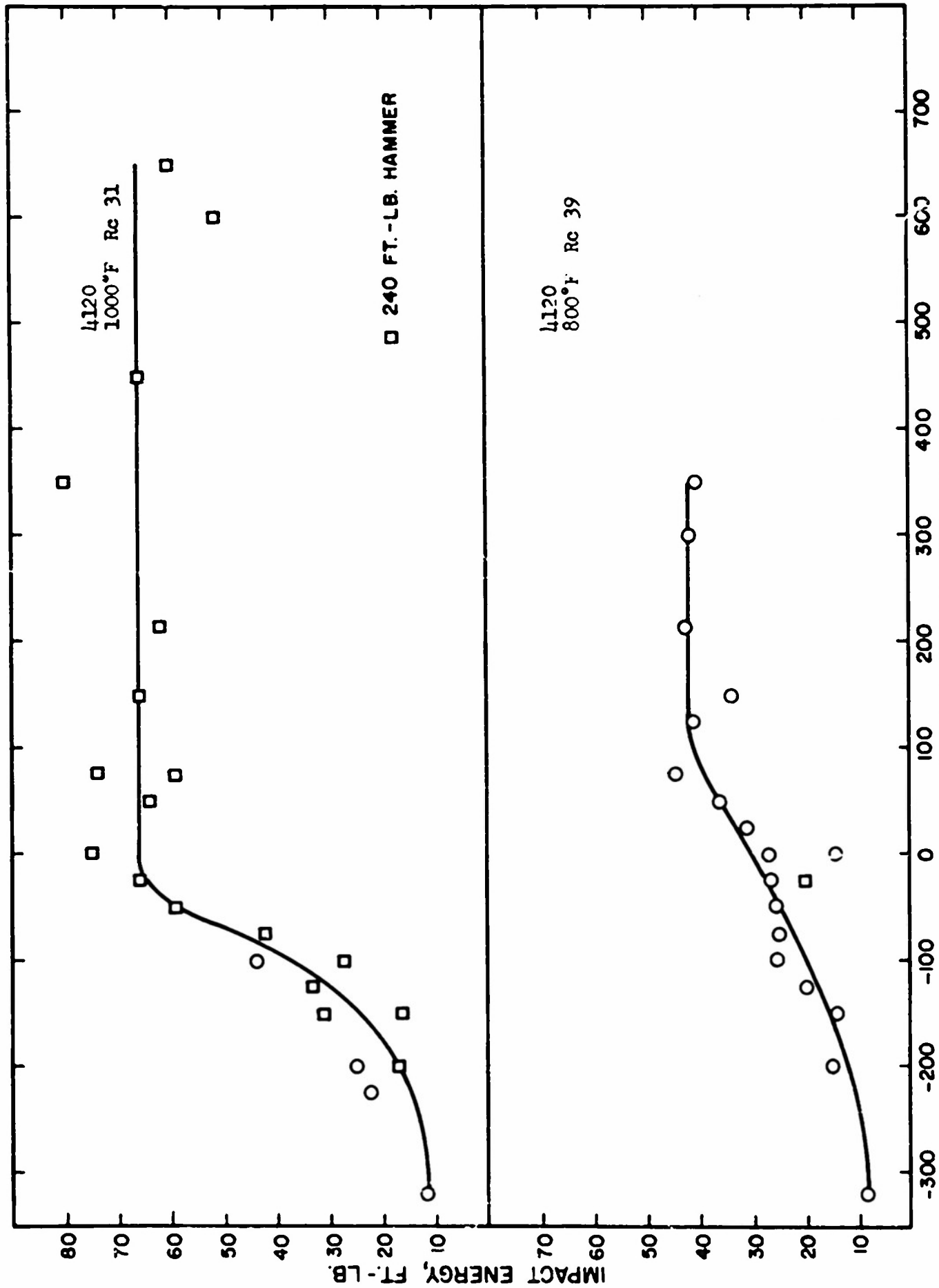
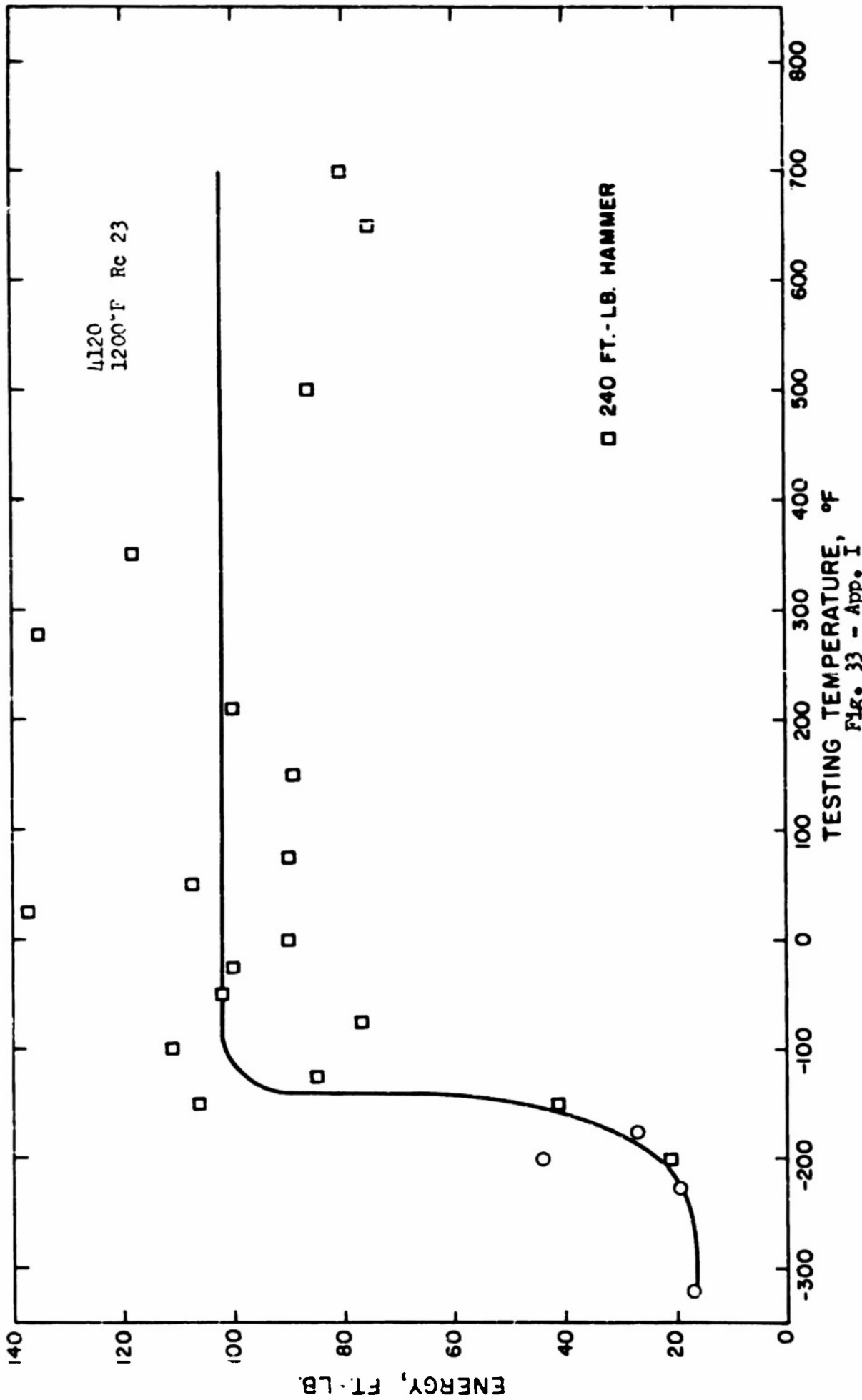


Fig. 32 Heat 3808-3, laboratory fine grain 4120; quenched in oil after 30 minutes at 1650°F; App. I tempered for one hour at temperature indicated in graph and water quenched.



Heat 3808-3, laboratory fine grain L120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

Fig. 33 - App. I

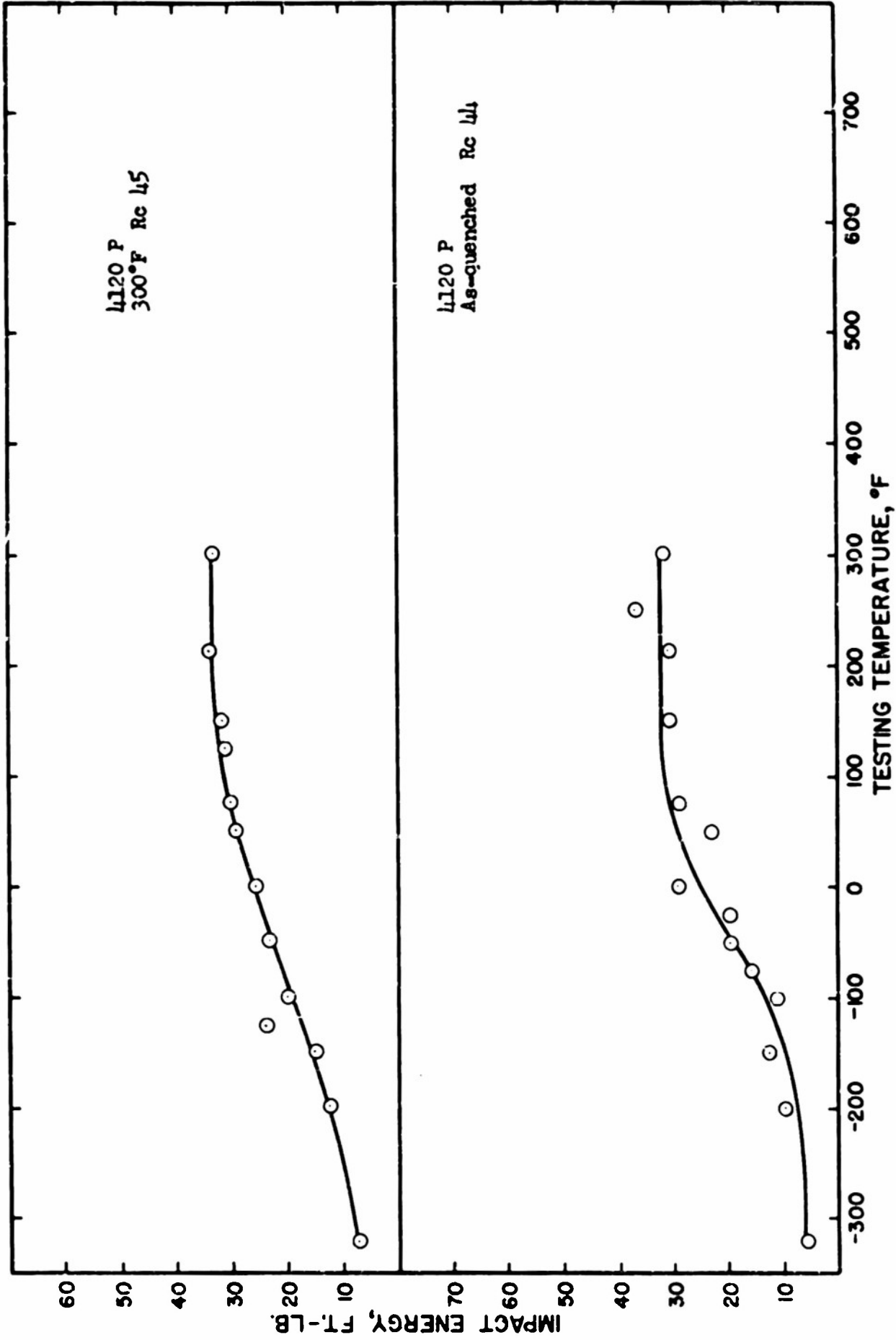


Fig. 34 - App. I

Heat 3808-6, Laboratory fine grain 4120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

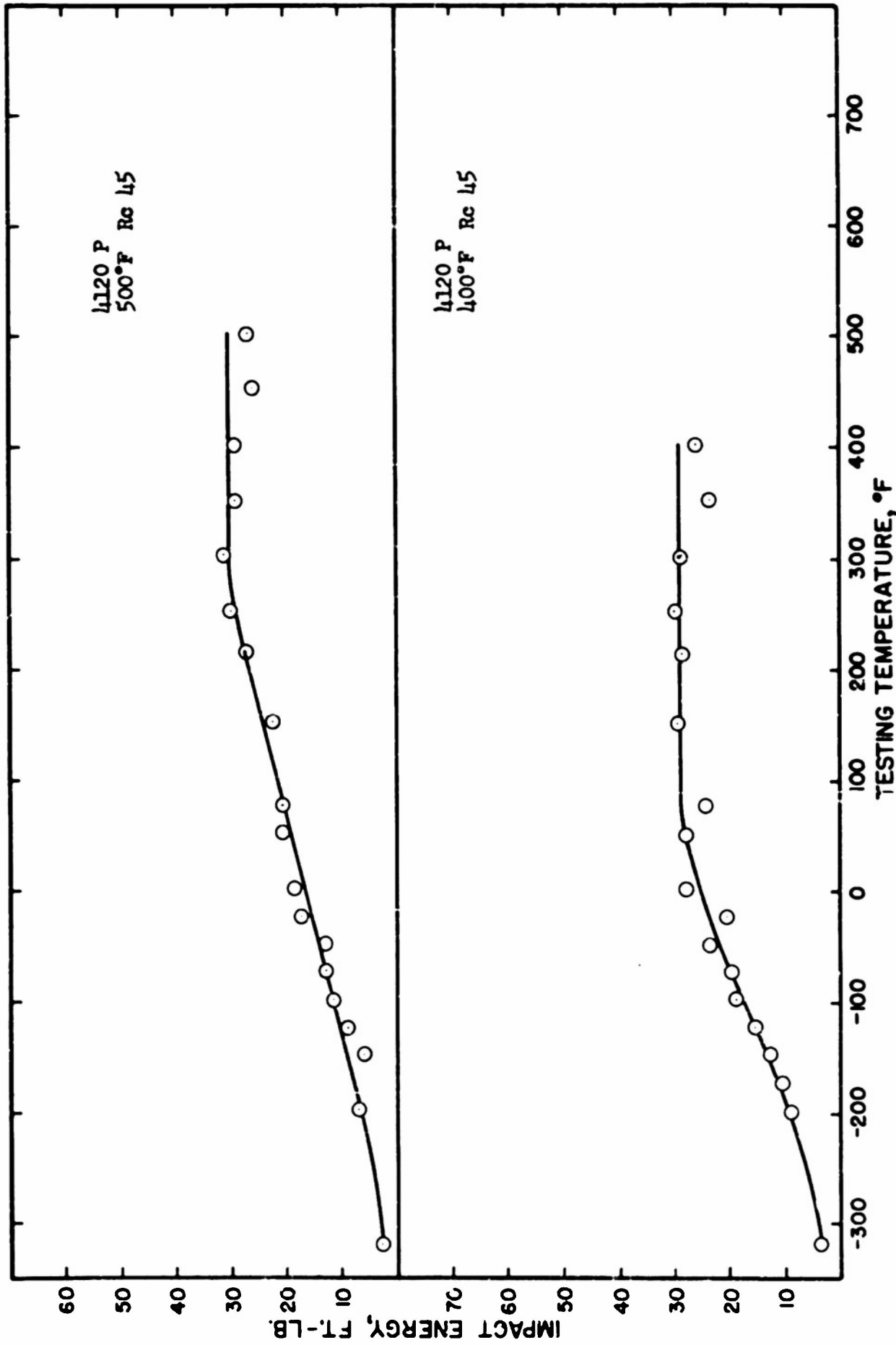


Fig. 35 - App. I

Heat 3908-6, laboratory fine grain 4120 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

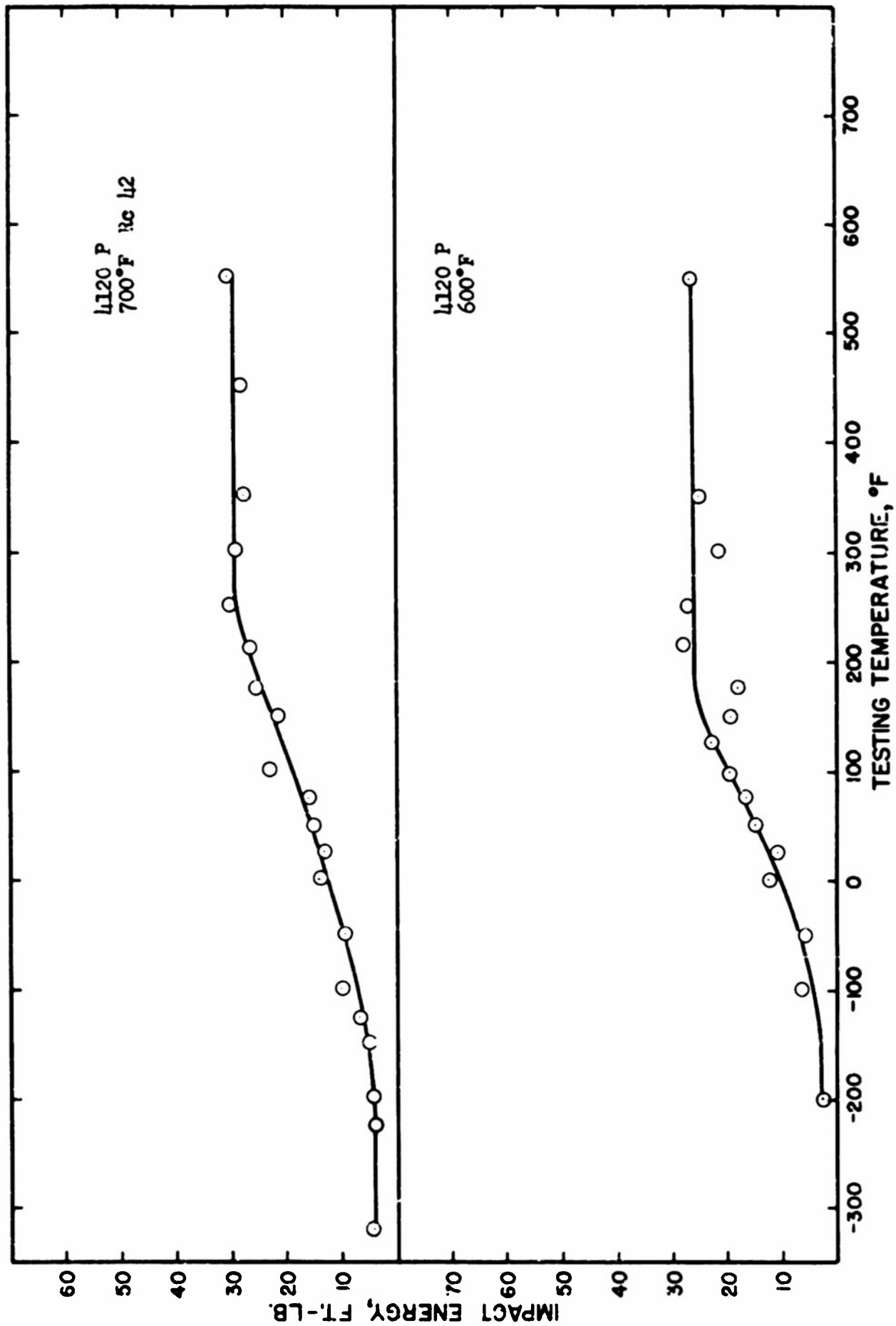


Fig. 36 - App. I

Heat 3808-6, laboratory fine grain 4120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

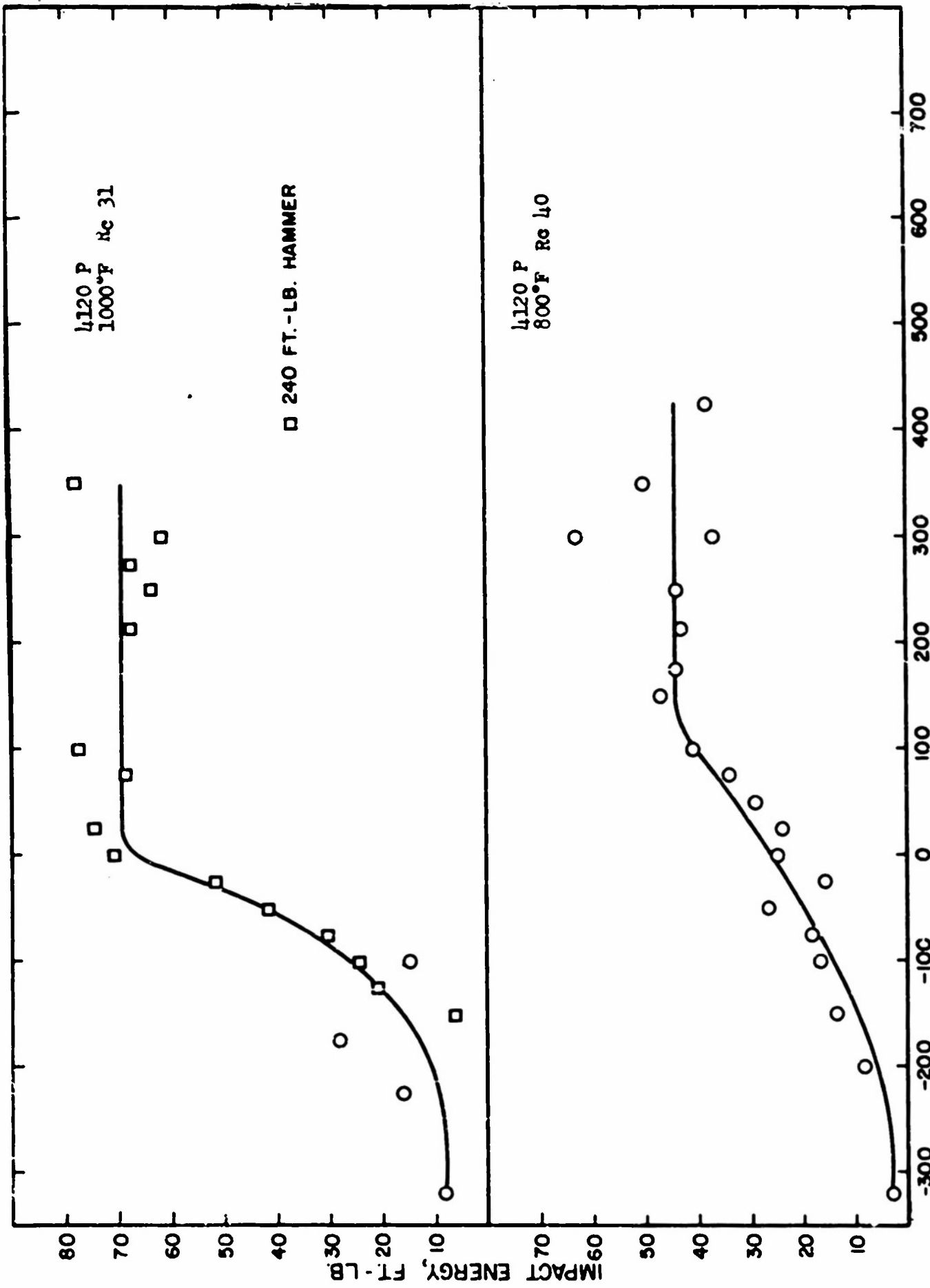


Fig. 37 - App. I. Heat 3808-6, laboratory fine grain 4120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

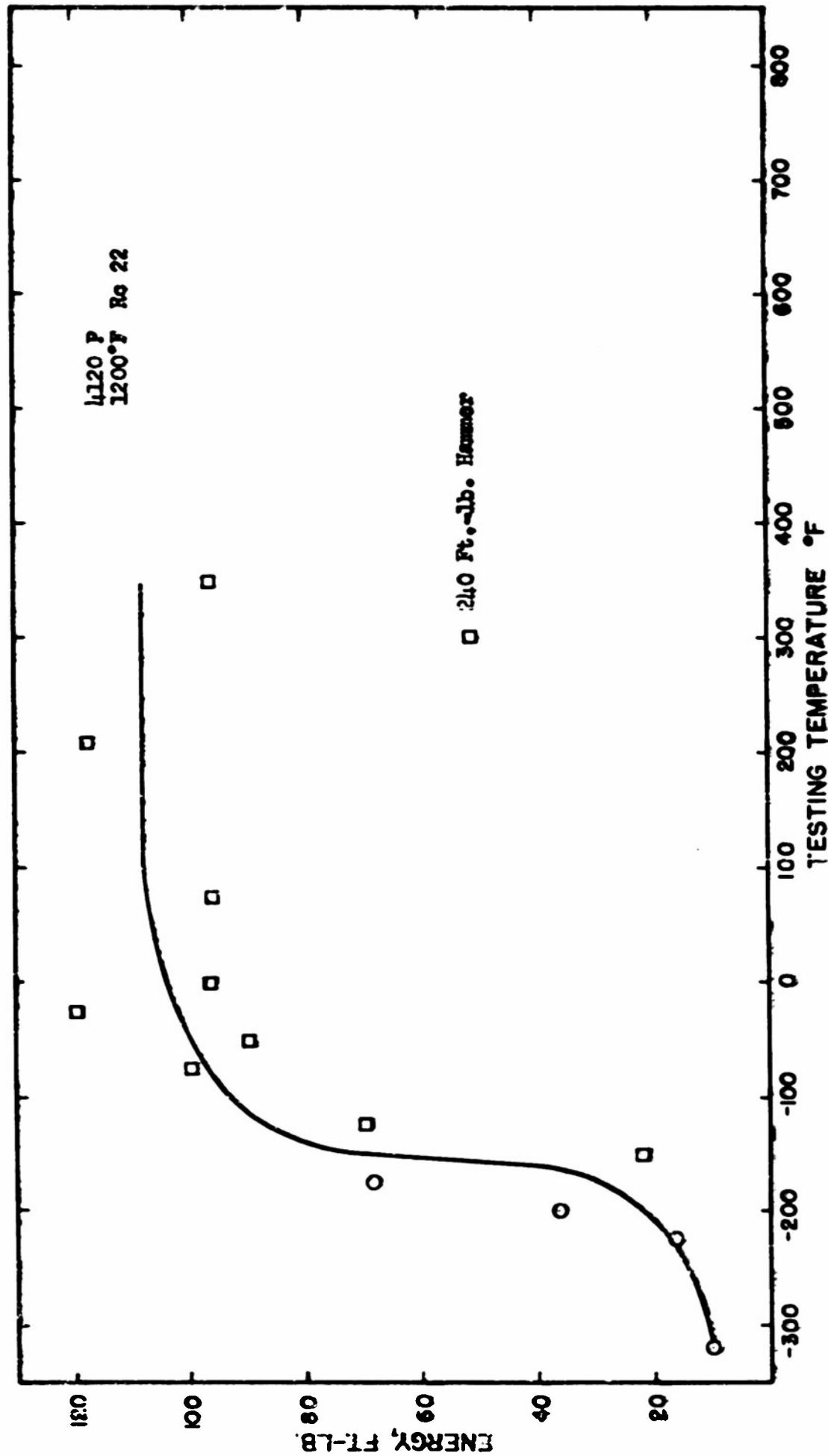


Fig. 38 - App. I

Heat 3808-6, laboratory fine grain 4L20 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

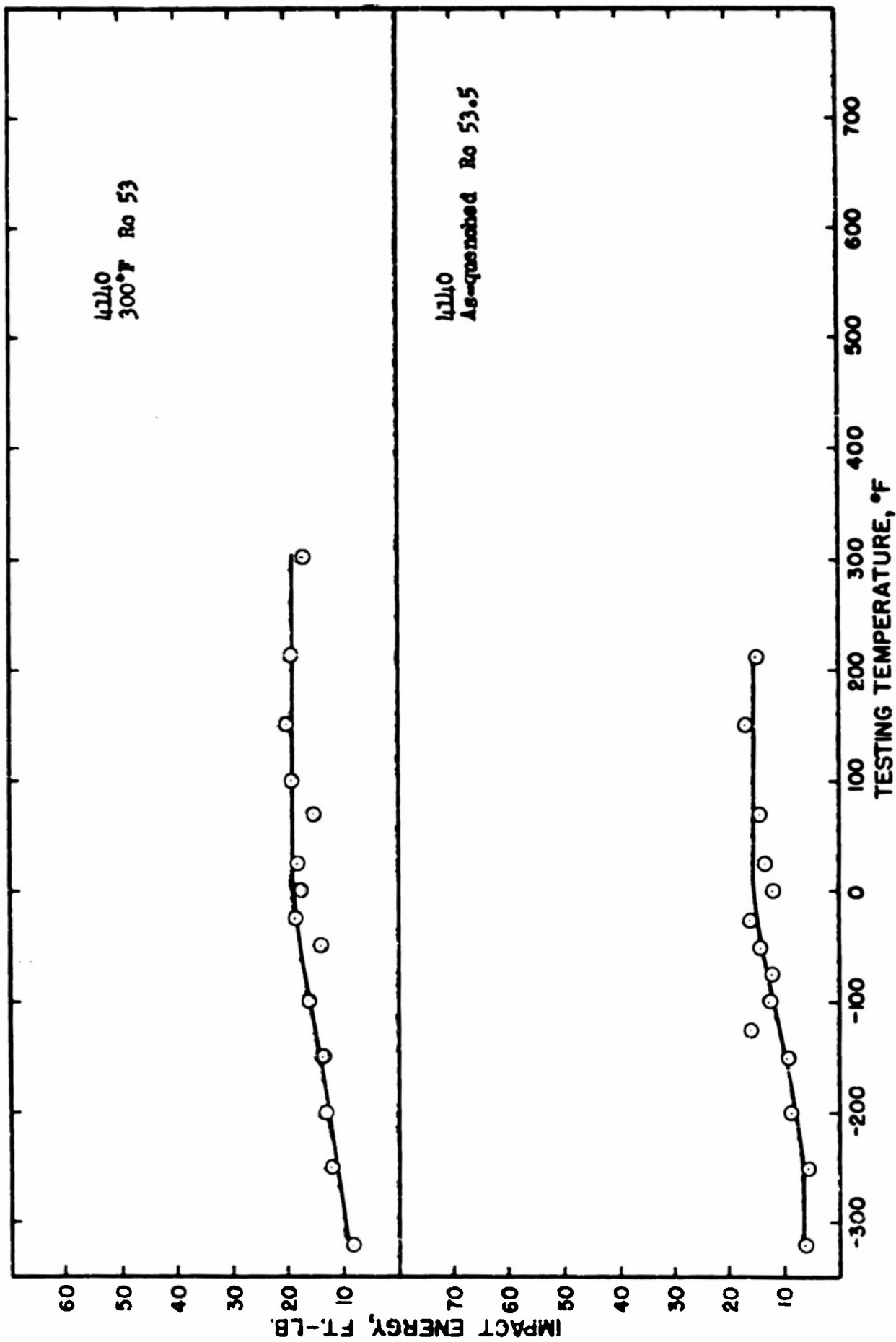


Fig. 39 - App. I

Heat K, Laboratory fine grain 4140; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

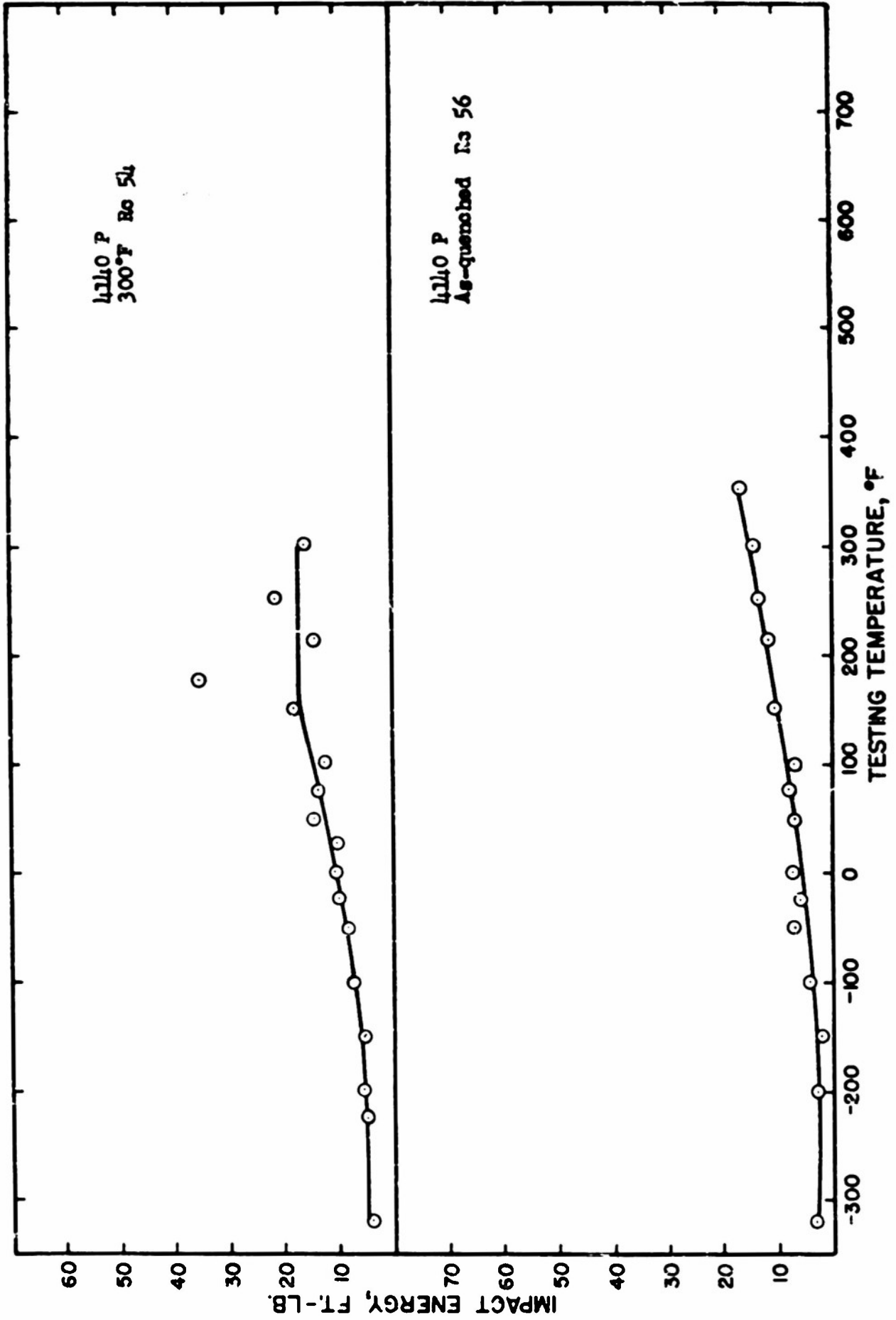


Fig. 40 - App. I

Heat 3729, laboratory fine grain 4140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

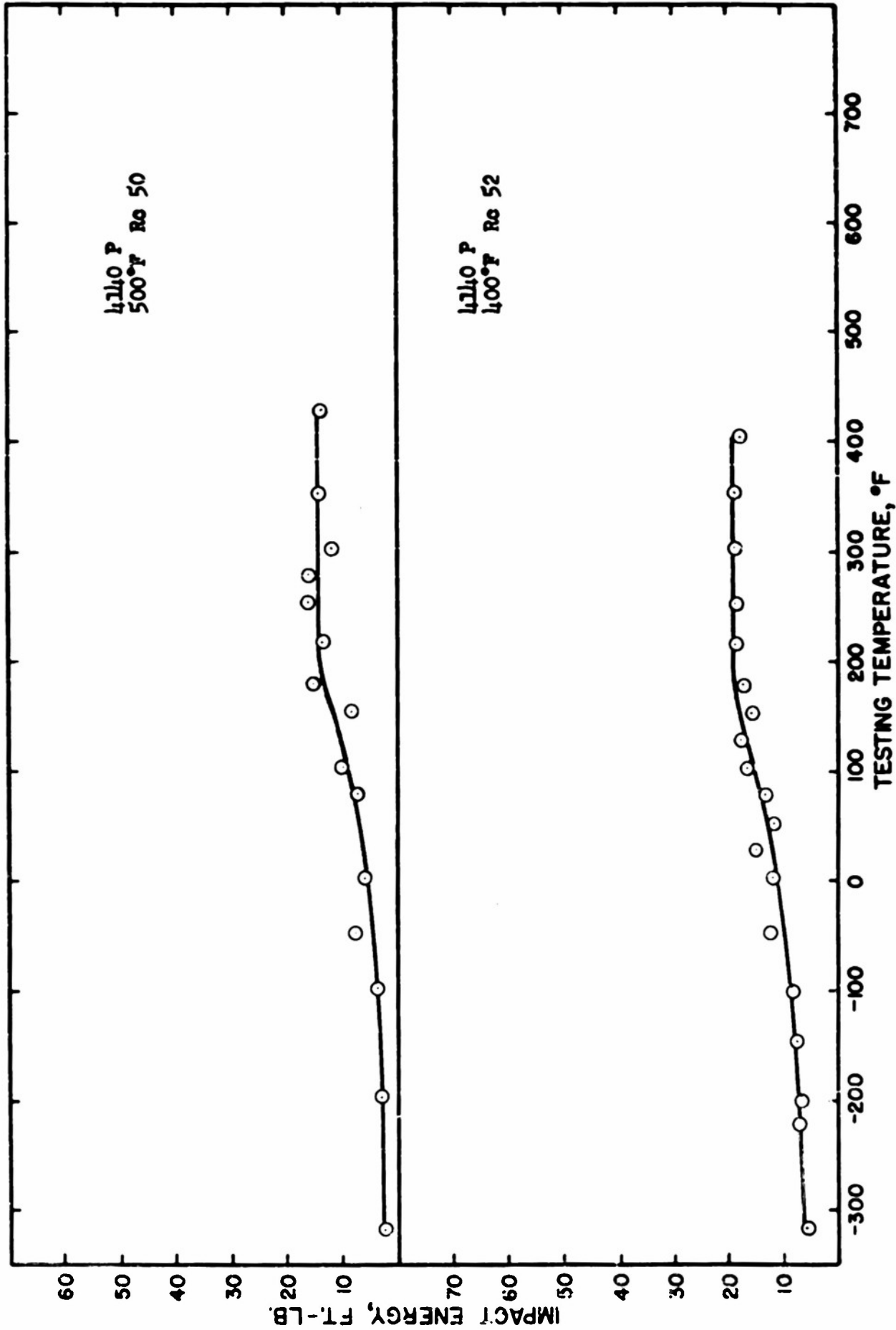


Fig. 41 - App. I

Heat 3729, laboratory fine grain 4140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

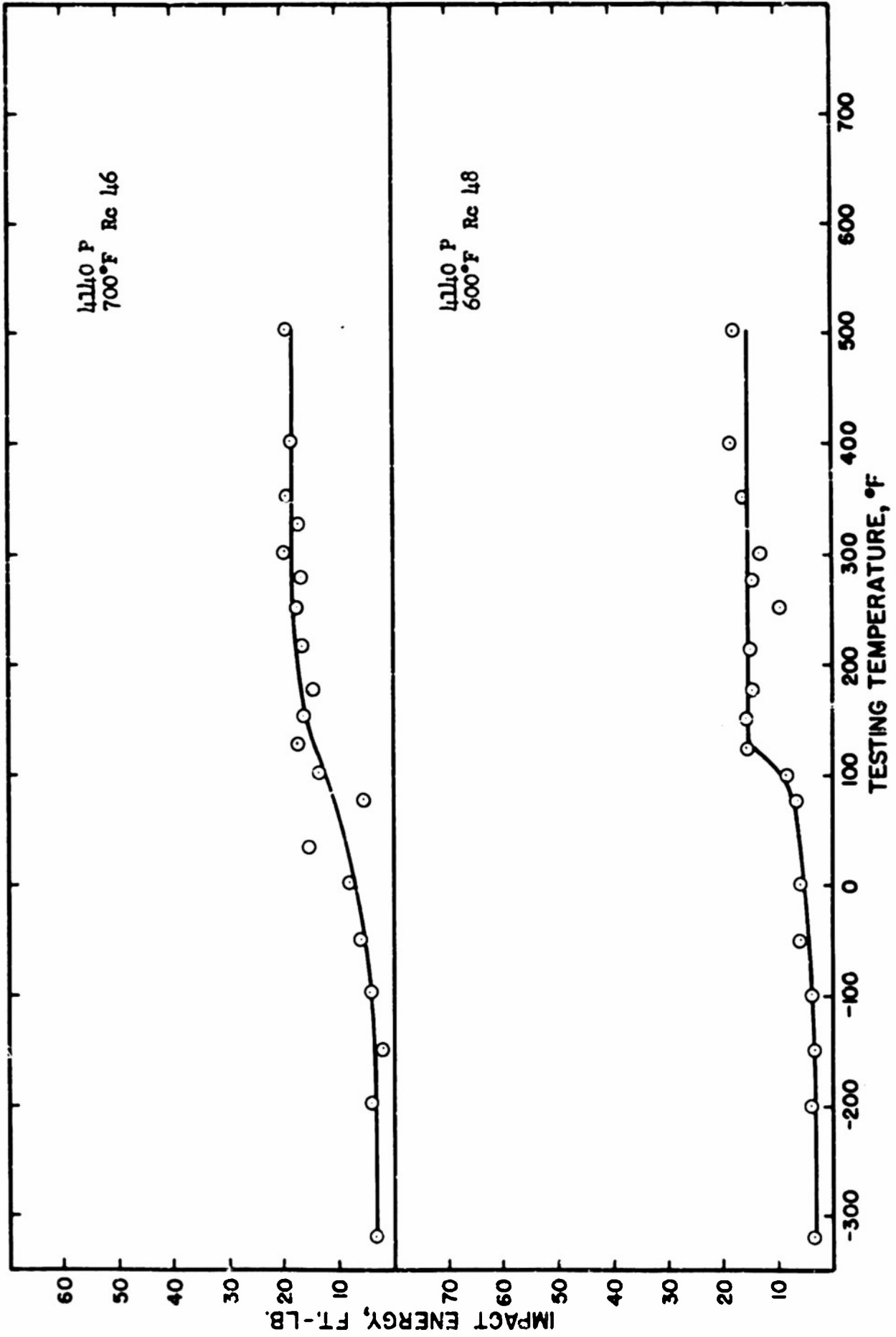


Fig. 42 - App. I

Heat 3729, laboratory fine grain 4140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

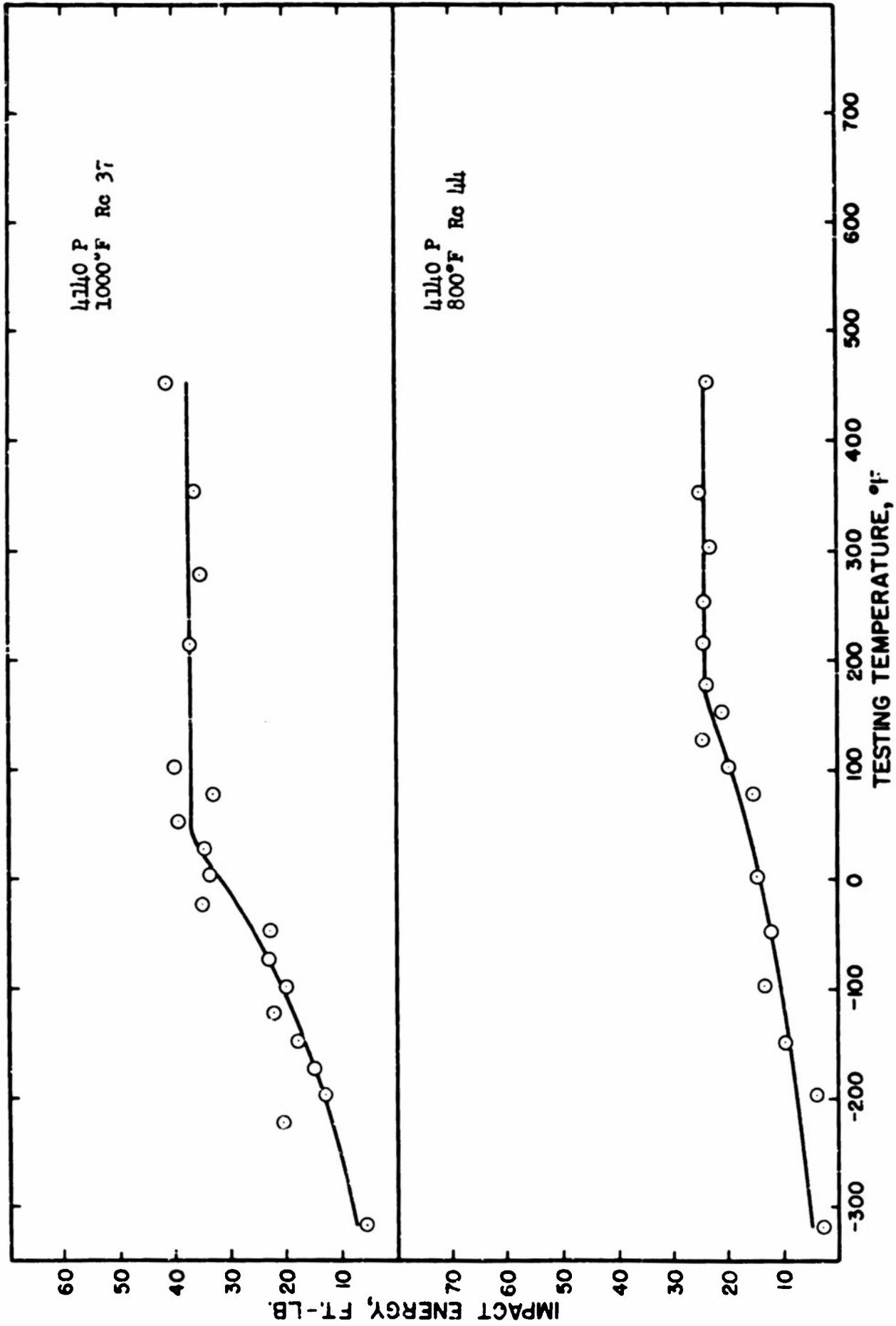


Fig. 43 - App. I

Heat 3729, Laboratory fine grain 4140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

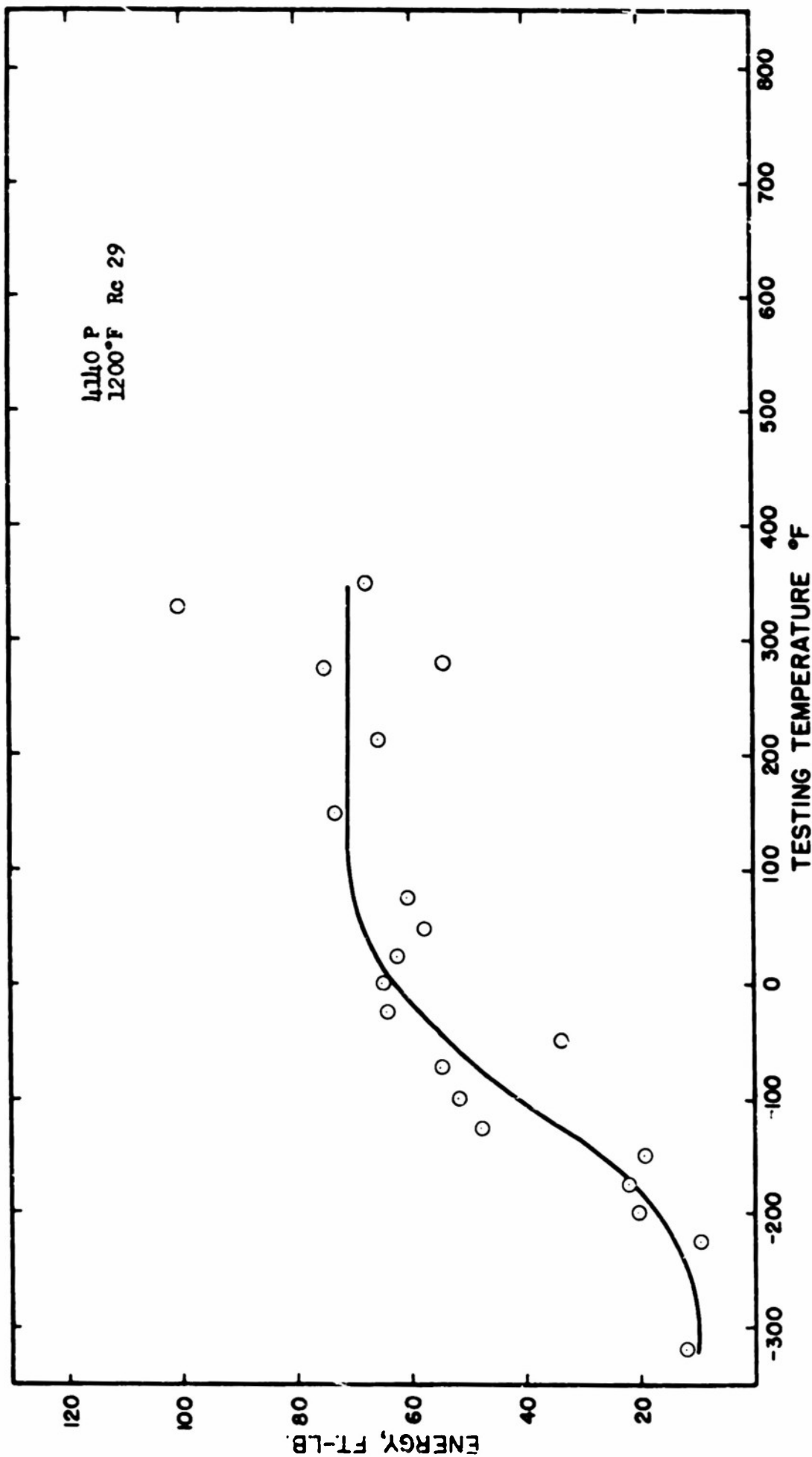


Fig. 44 - App. I

Heat 3729, laboratory fine grain 4140 with high phosphorus; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

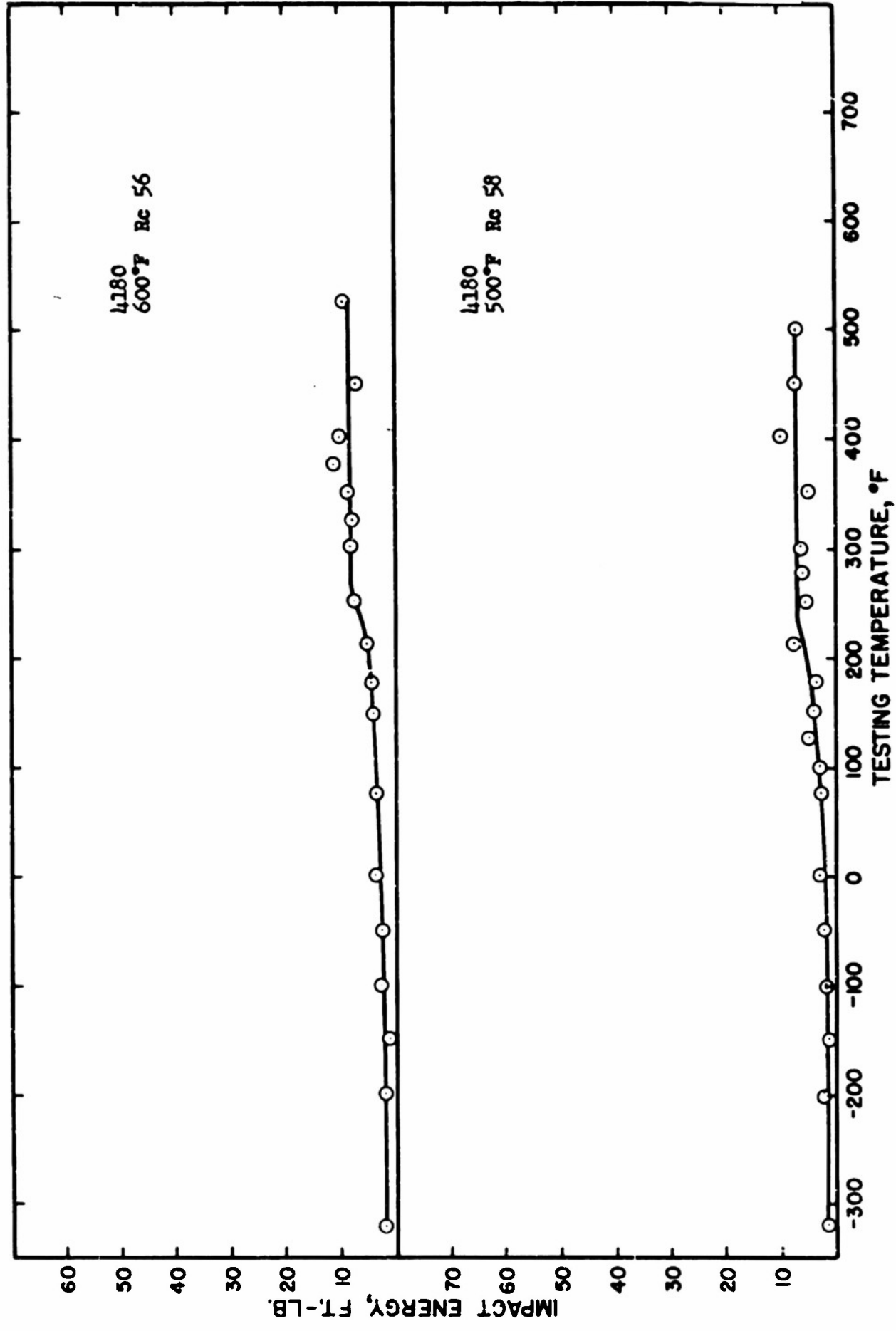


Fig. 45 - App. I

Heat 3811.-3, laboratory fine grain 4180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

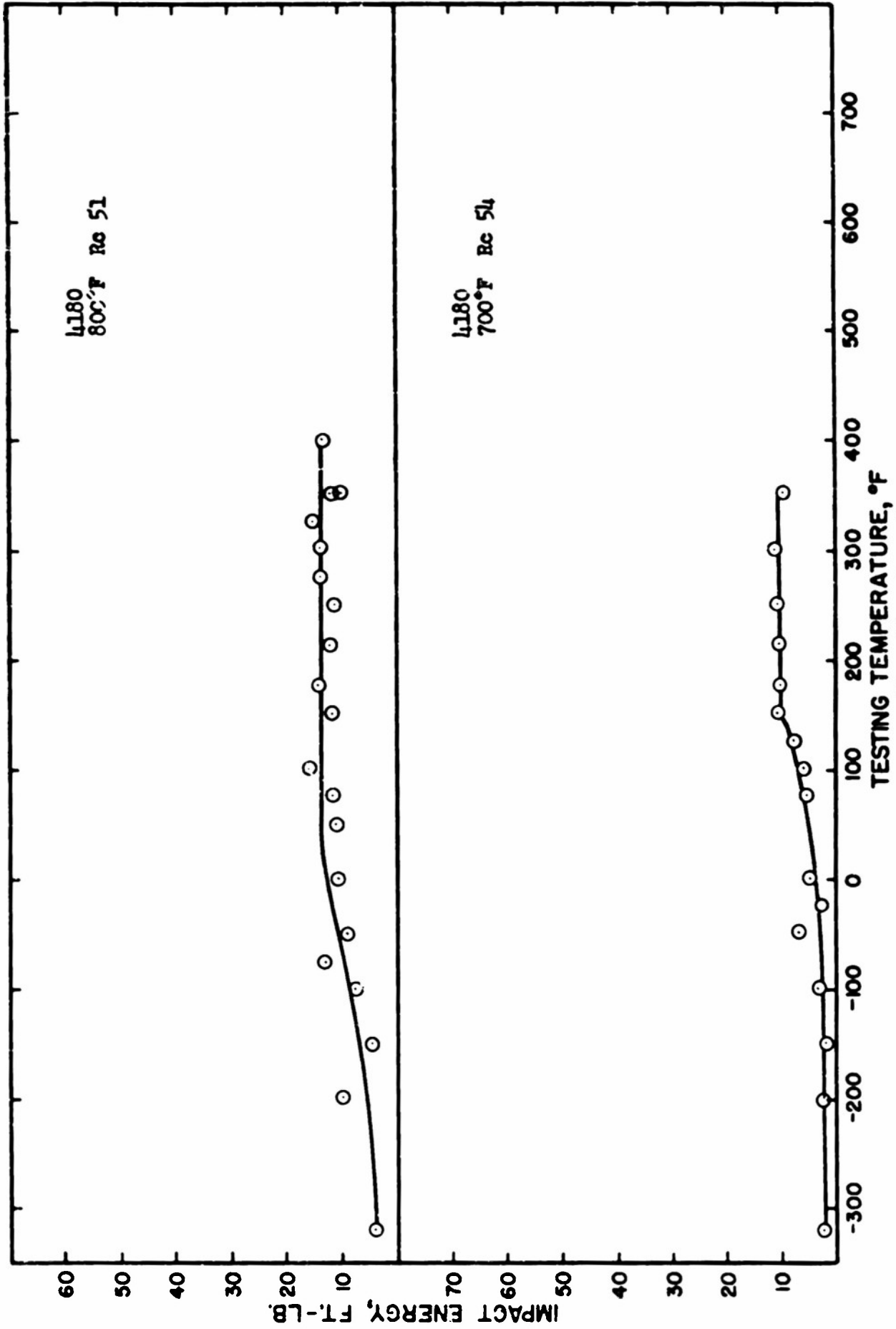


Fig. 46 - App. I

Heat 3814-3, Laboratory fine grain 4180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

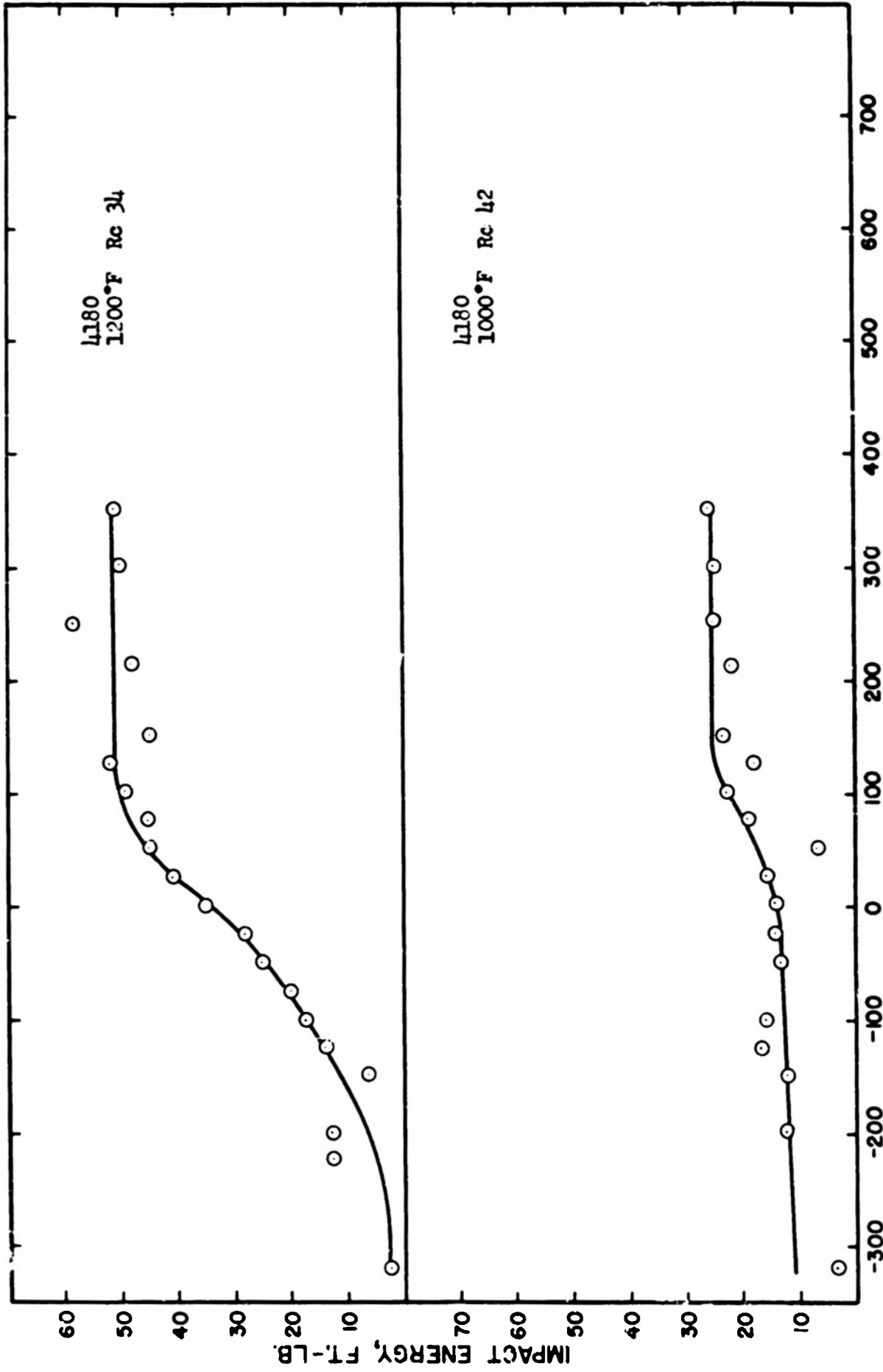


Fig. 47 - App. I

Heat 3811-3, laboratory fine grain 4180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

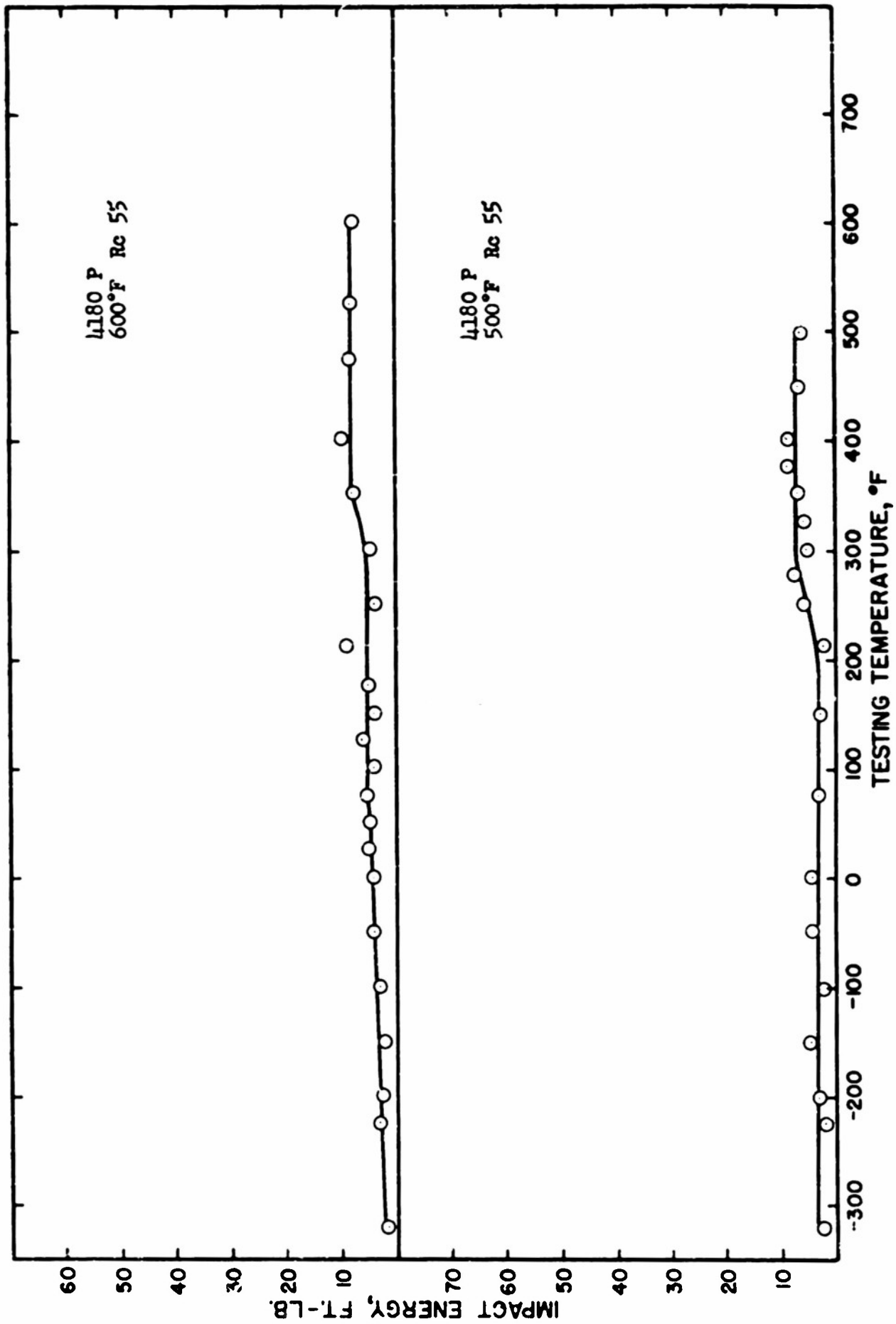


Fig. 48 - App. I

Heat 3814-6, Laboratory fine grain 4180 with high phosphorous; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

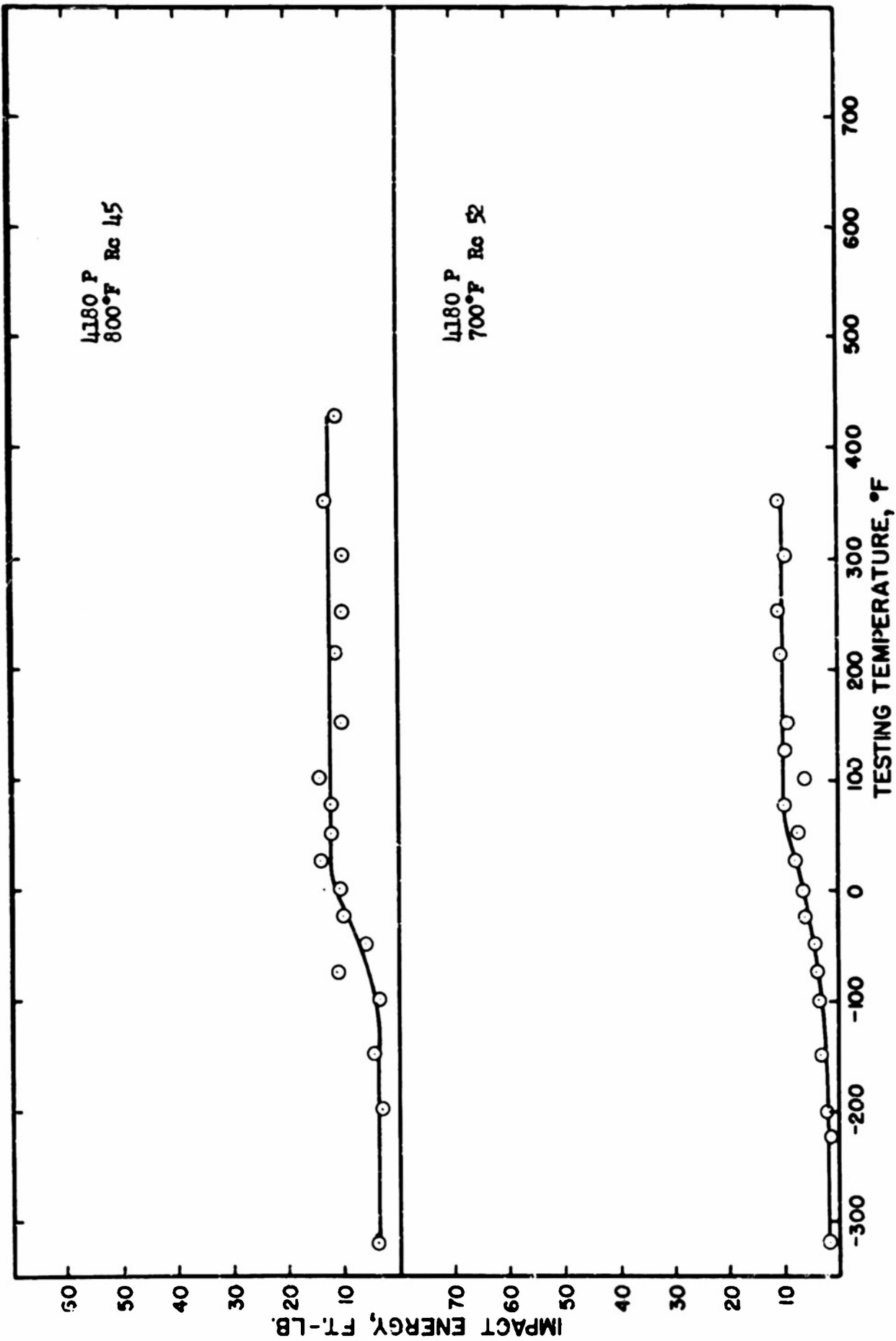


Fig. 49 - App. I

Heat 38111-6, laboratory fine grain 4180 with high phosphorous; quenched in oil after 30 minutes at 1150°F; tempered for one hour at temperature indicated in graph and water quenched.

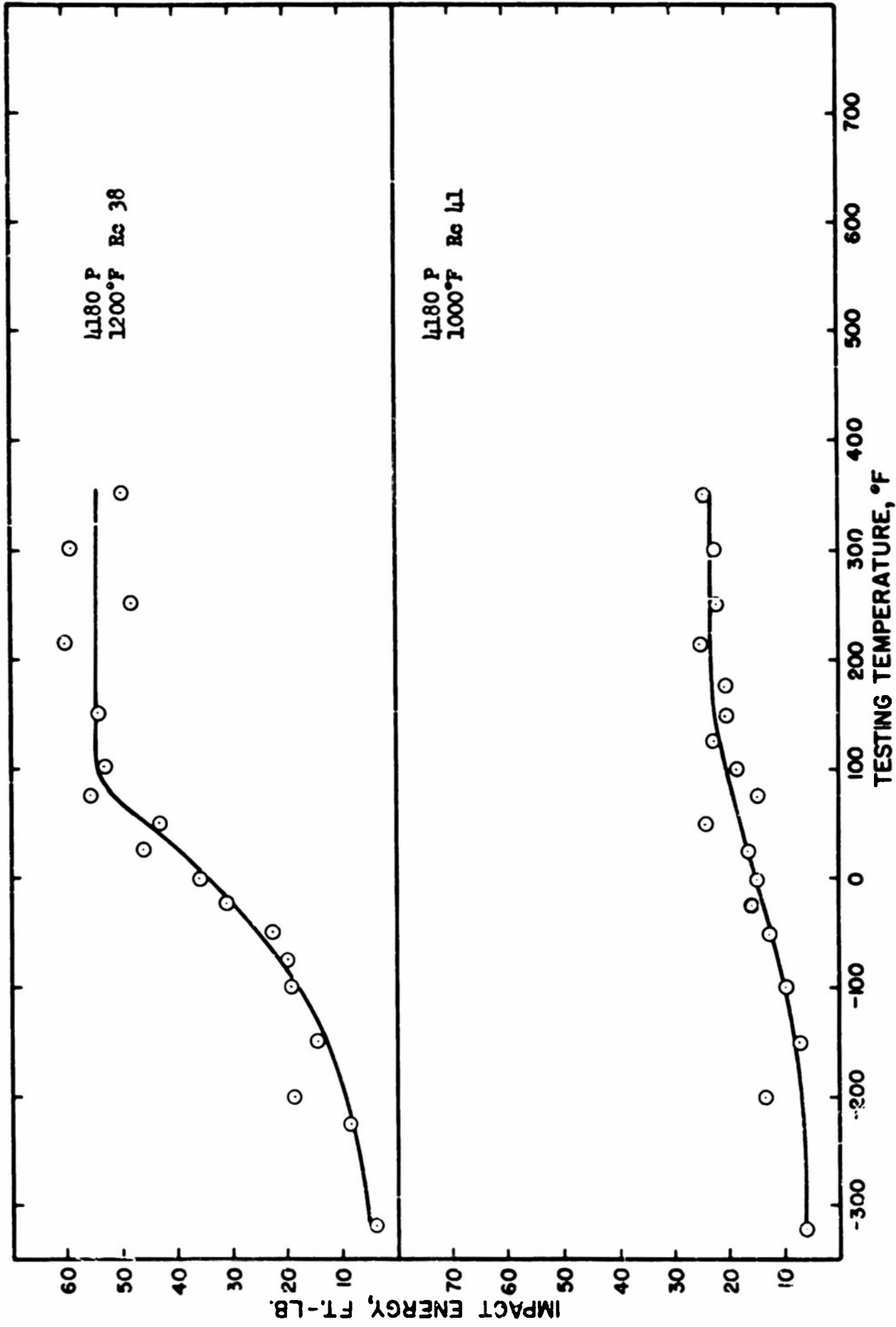


Fig. 50 - App. I

Heat 3811-6, Laboratory fine grain 4180 with high phosphorous; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

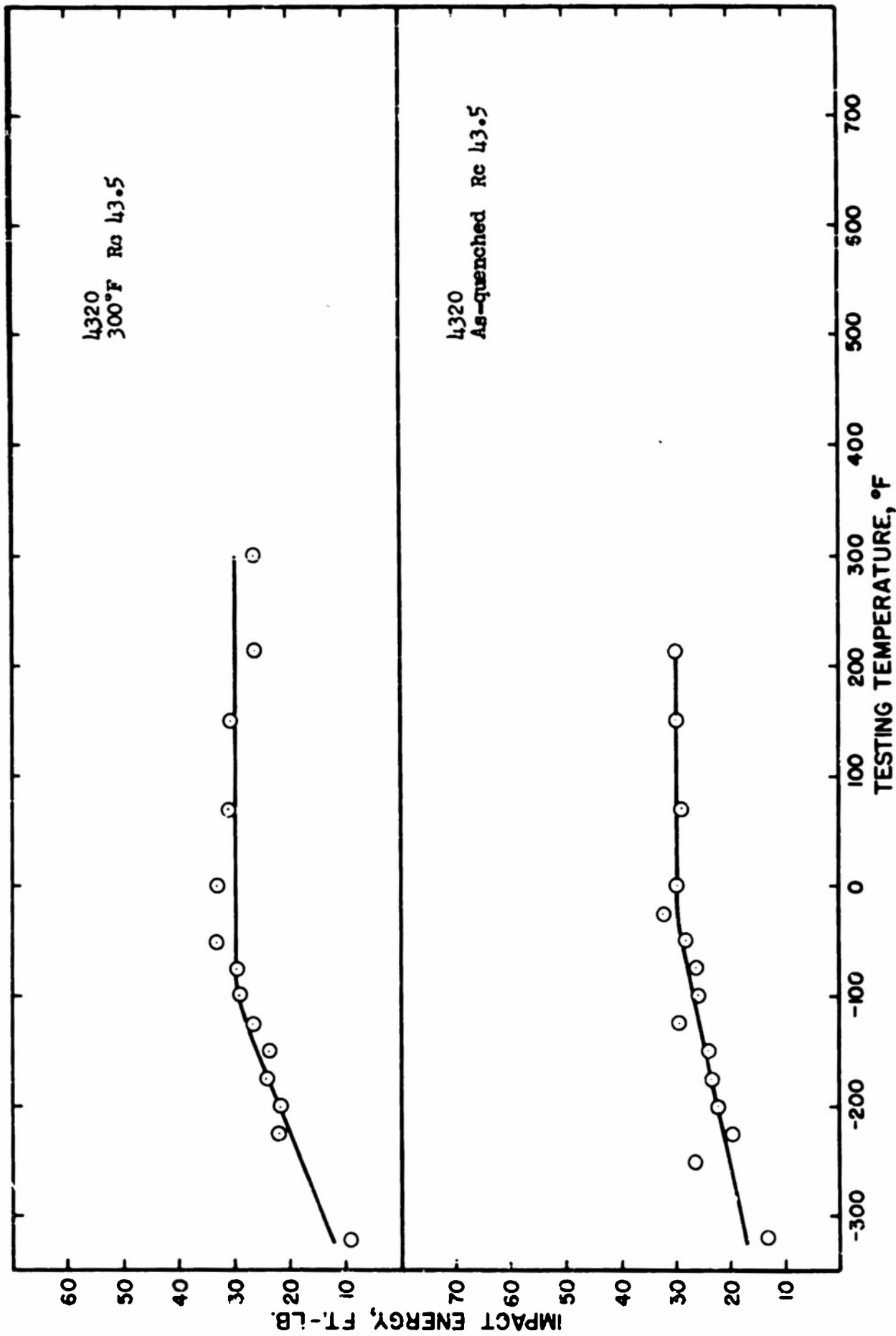


Fig. 51 - App. I

Heat 2921, laboratory fine grain 4320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

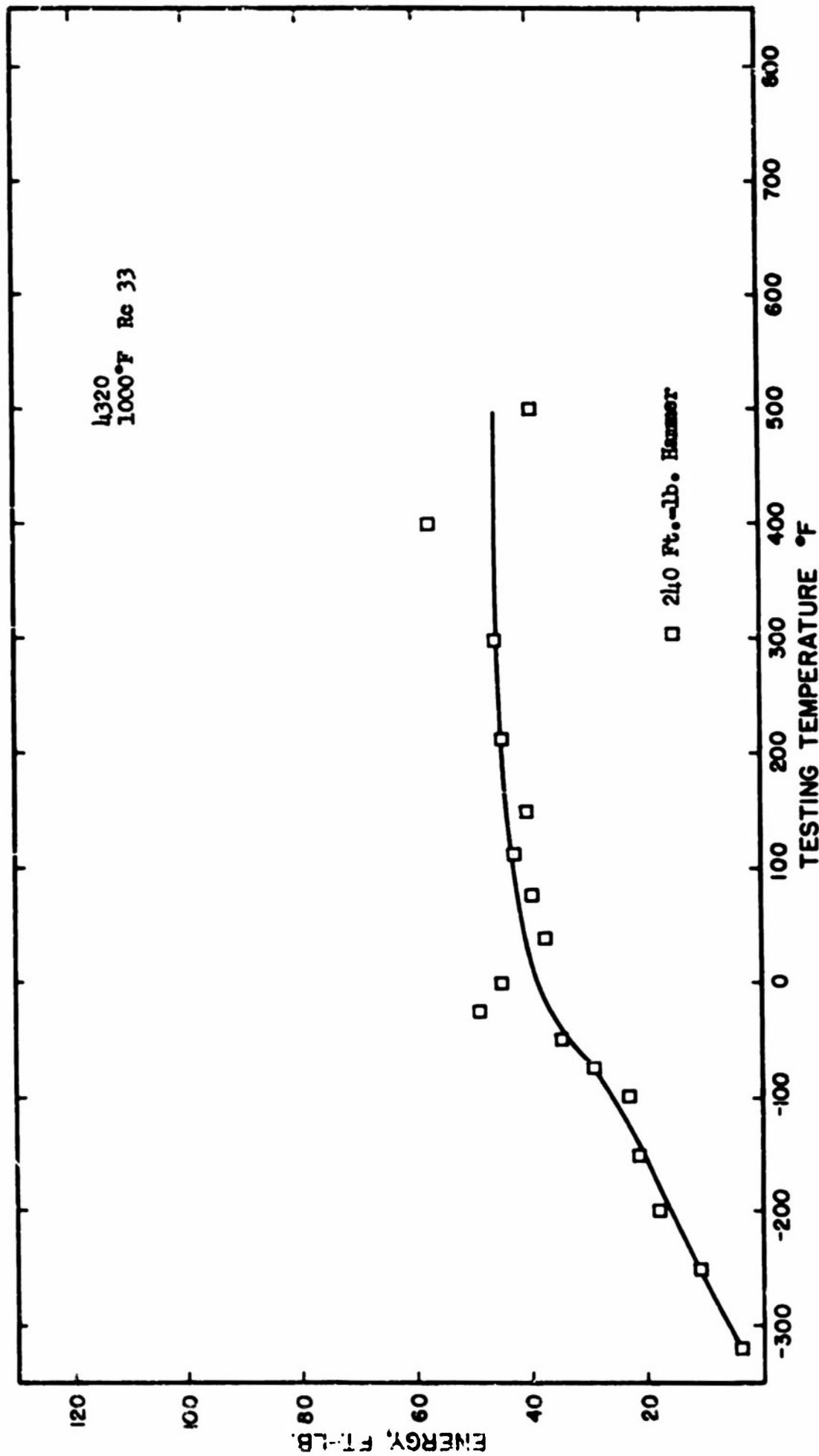


Fig. 52 - App. I

Heat 2921, laboratory fine grain 4320; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

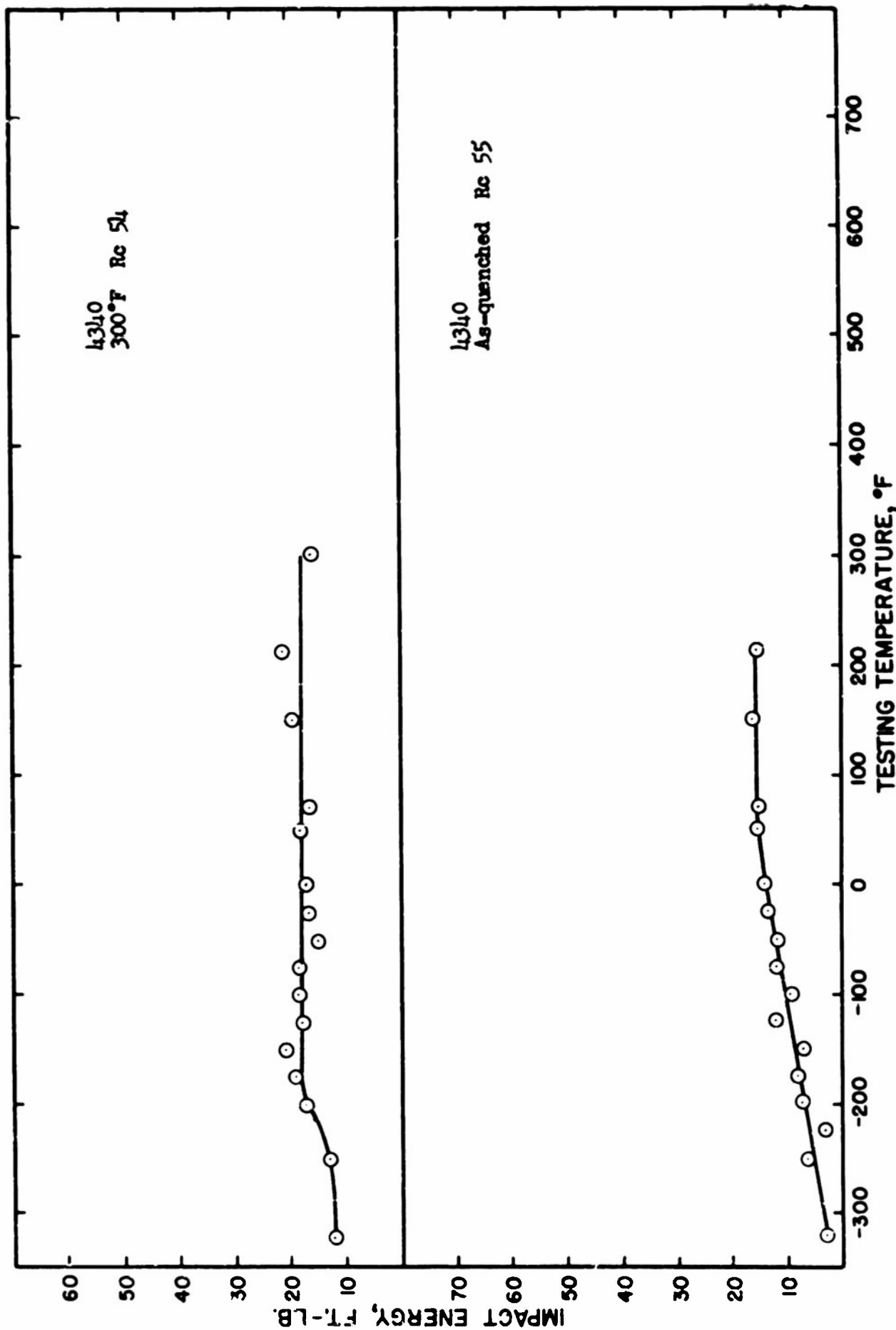


Fig. 53 - App. I

Heat M, laboratory fine grain 4340; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

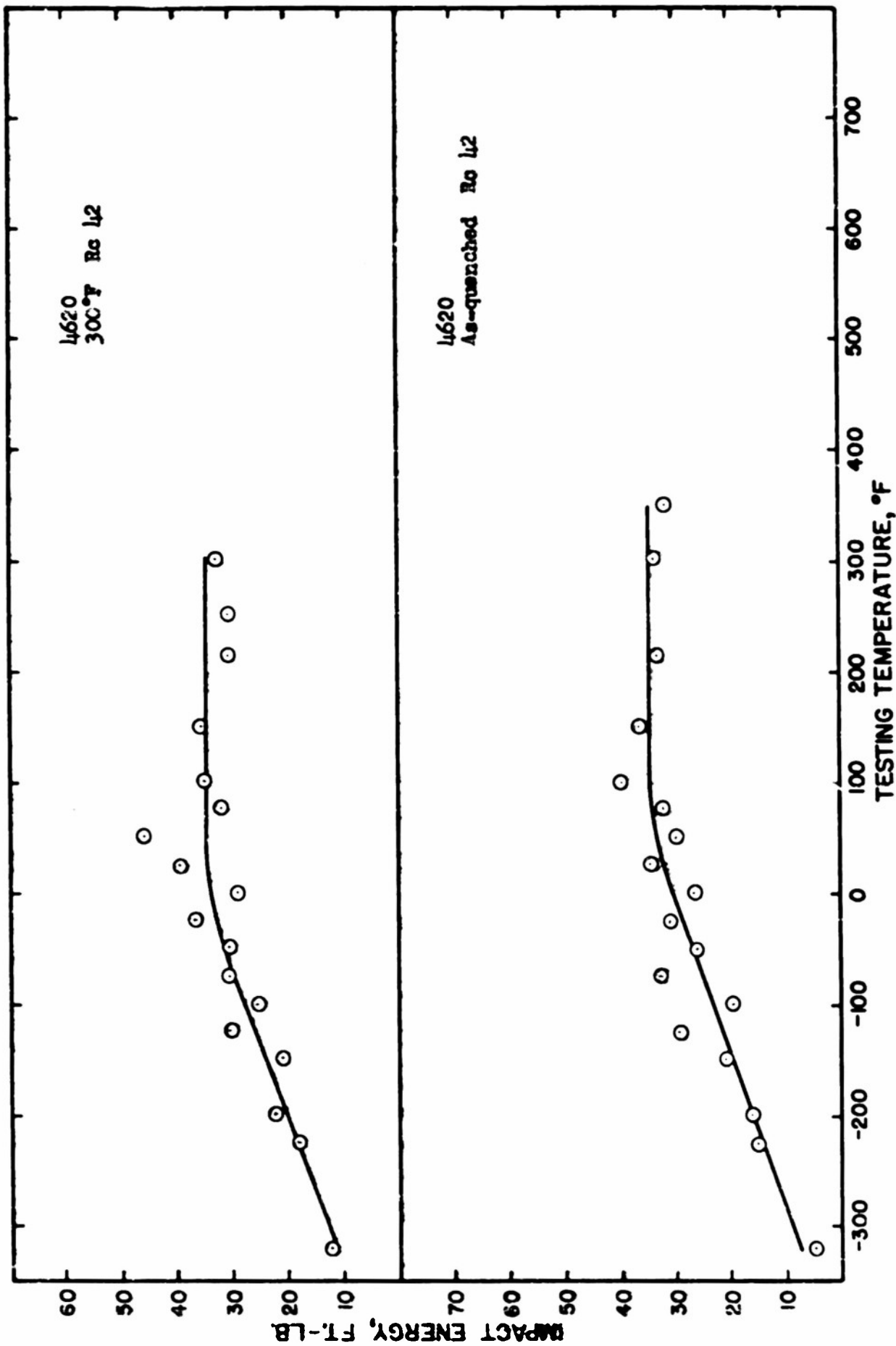


Fig. 54 - App. I

Heat 3751, Laboratory fine grain 4620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

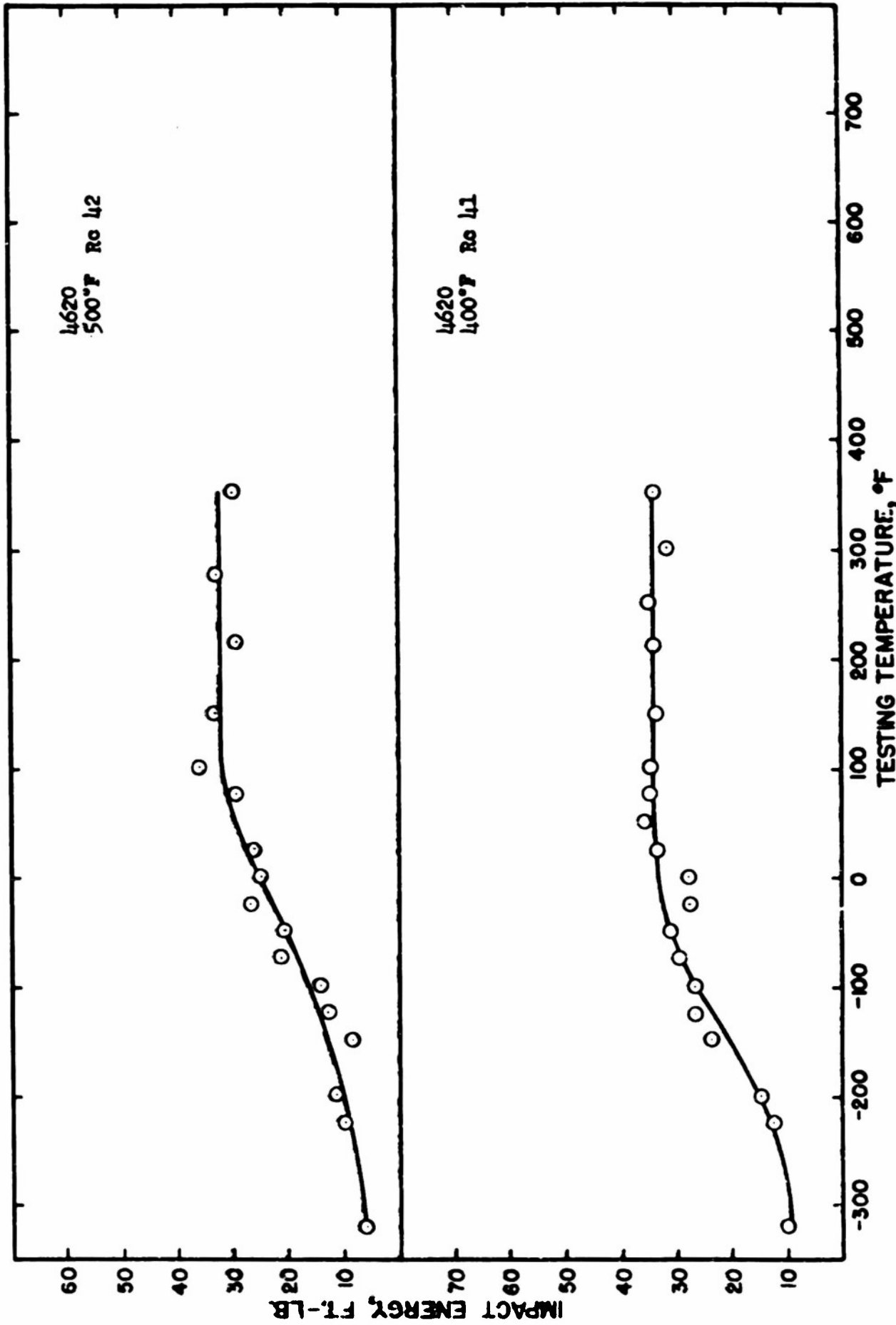


Fig. 55 - App. I

Heat 3751, Laboratory fine grain 4620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

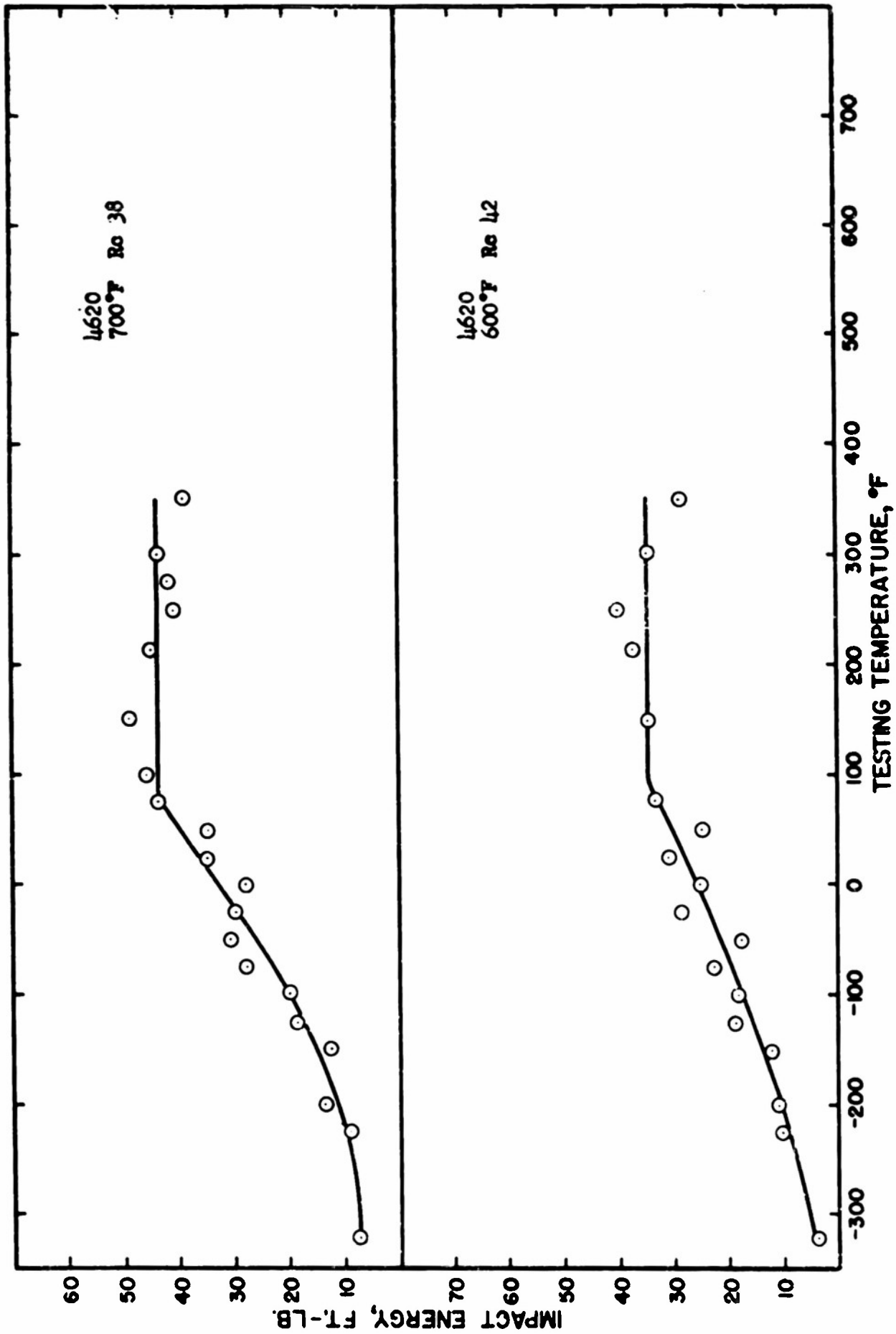


Fig. 56 - App. I

Heat 3751, laboratory fine grain 4620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

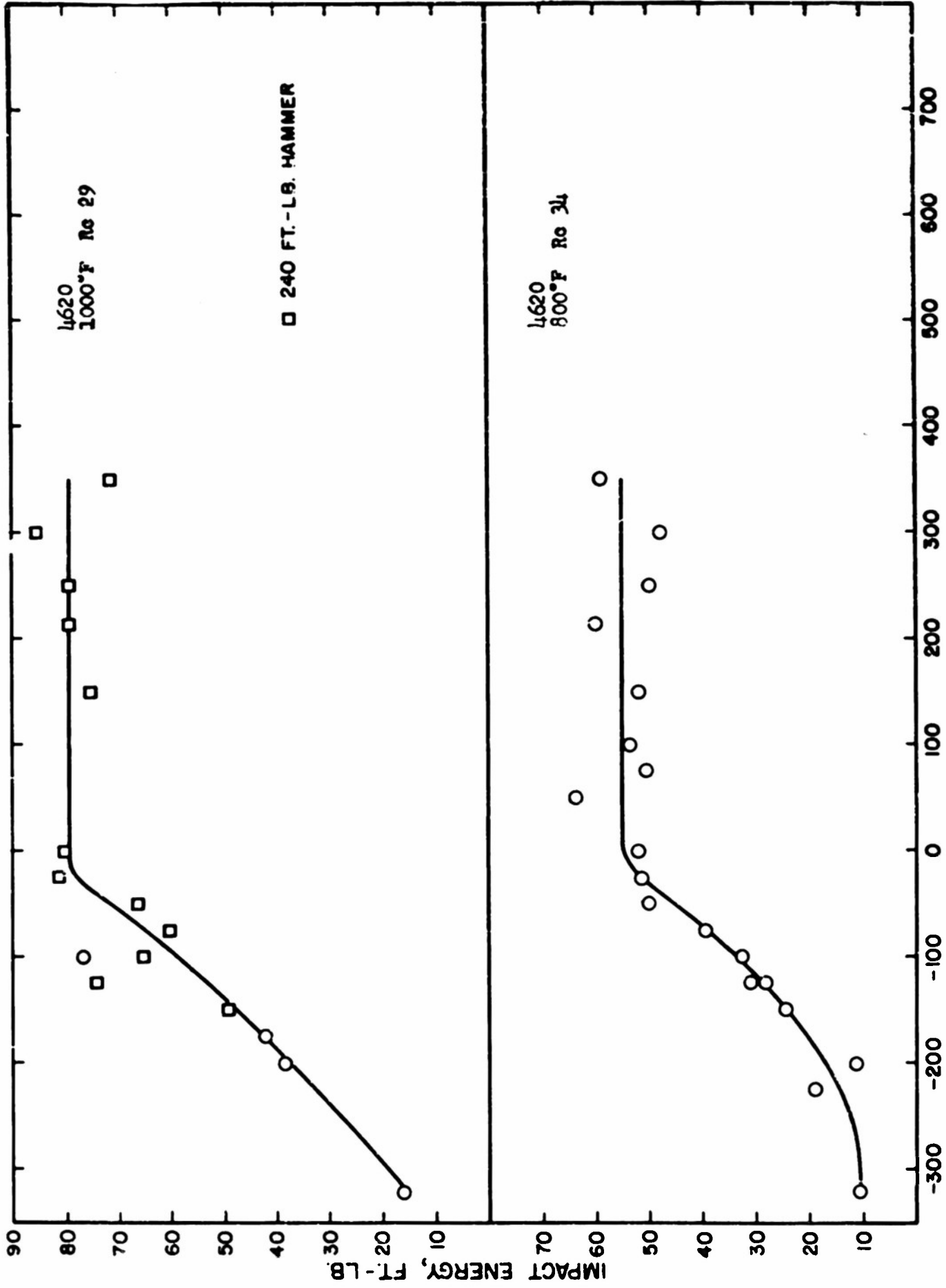


Fig. 57 - App. I. Heat 3751, laboratory fine grain 4620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

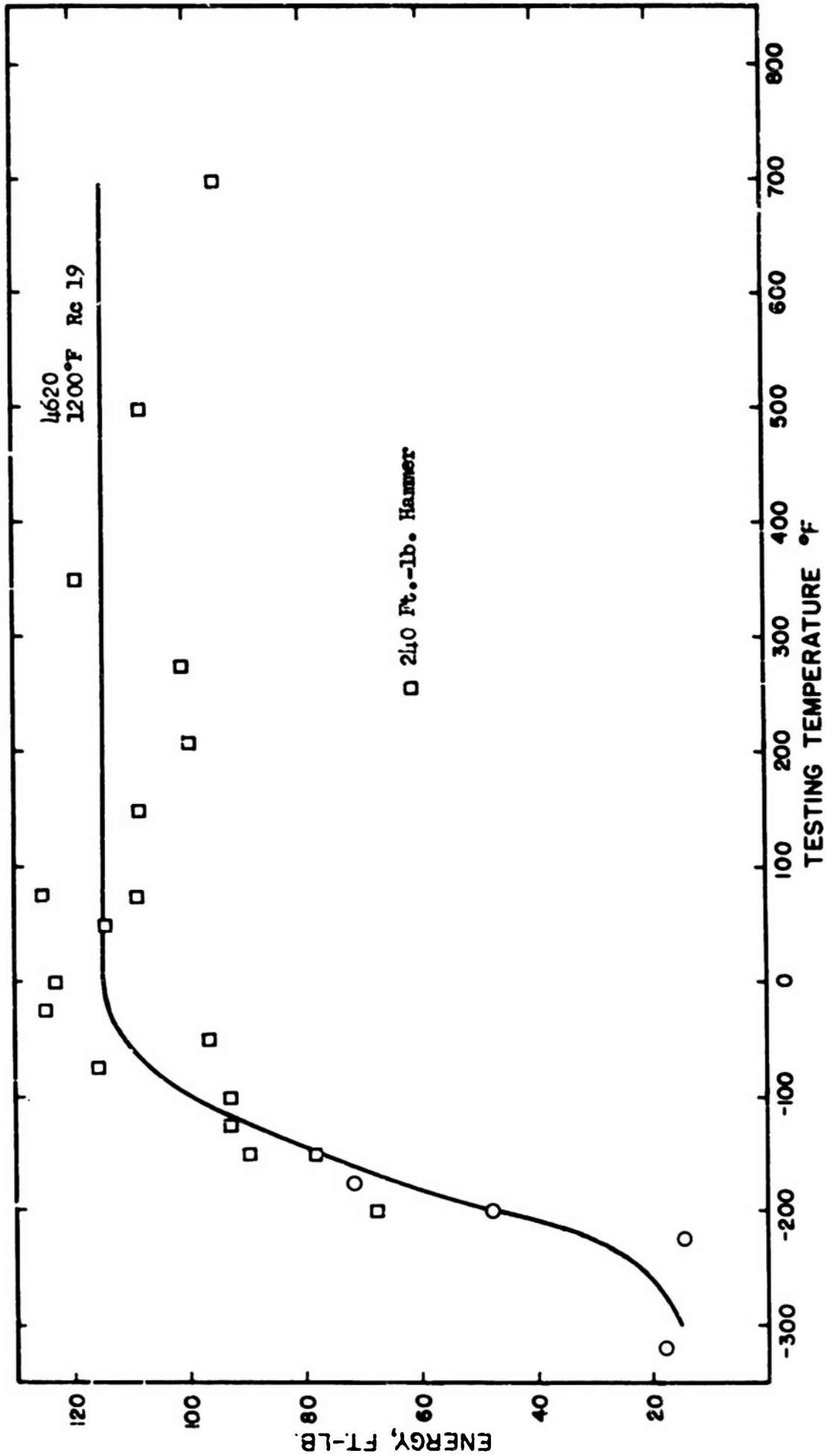


Fig. 58 - App. I

Heat 3751, laboratory fine grain 4620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

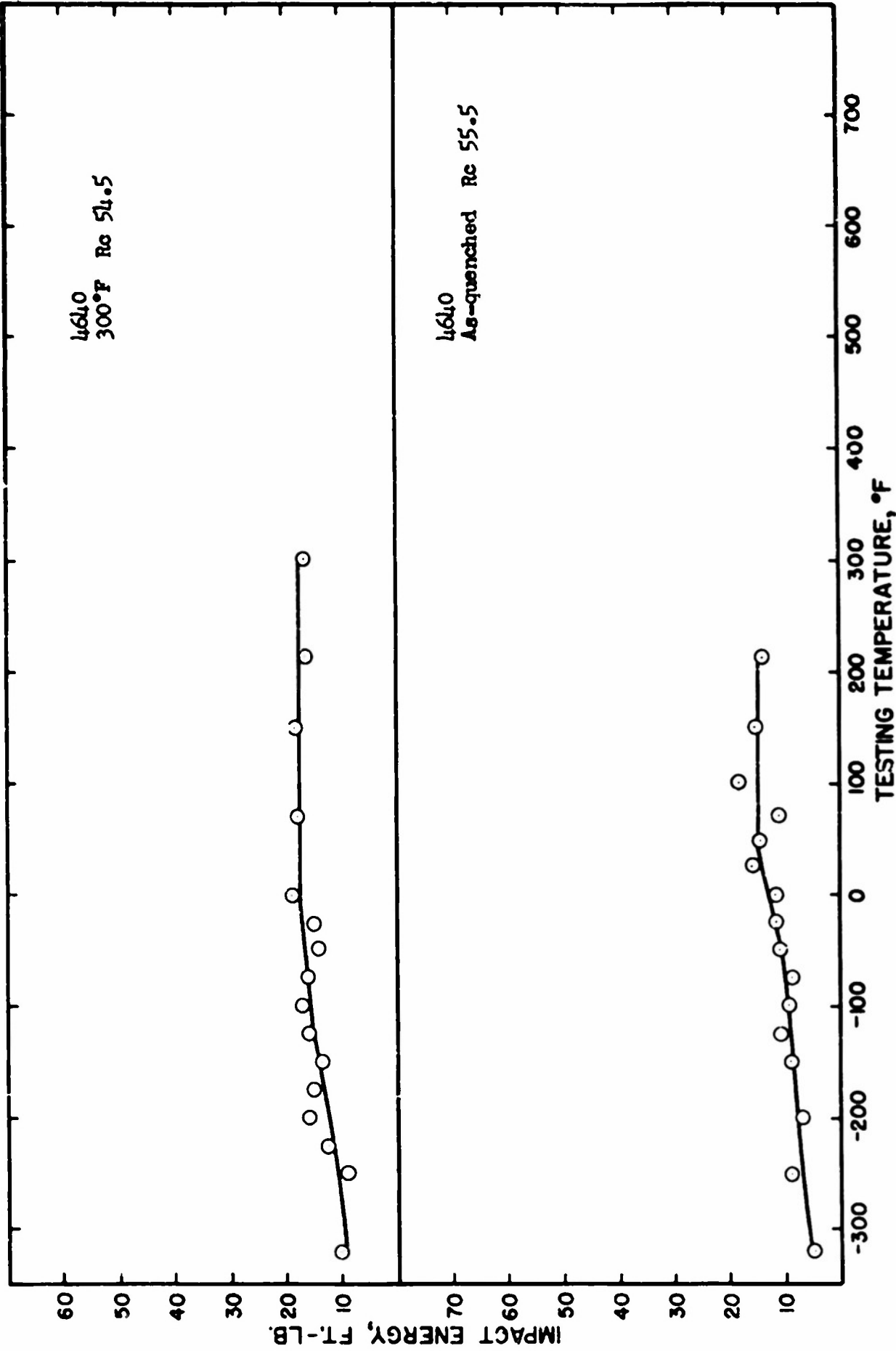


Fig. 59 - App. I

Heat L, laboratory fine grain 4640; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

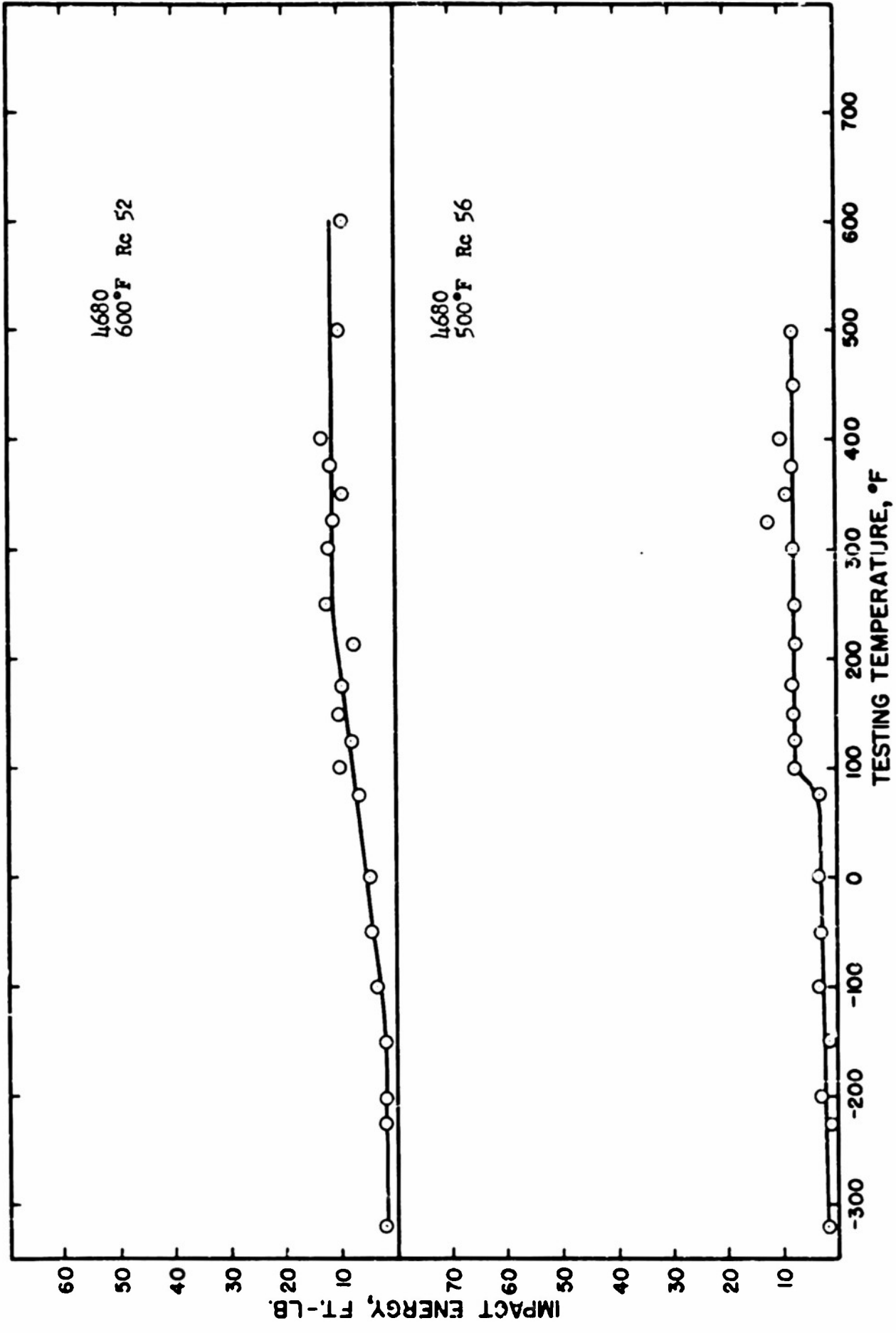


Fig. 60 - Apr. I

Heat 3792, laboratory fine grain 4680; quenched in oil after 30 minutes at 1450°F, tempered for one hour at temperature indicated in graph and water quenched.

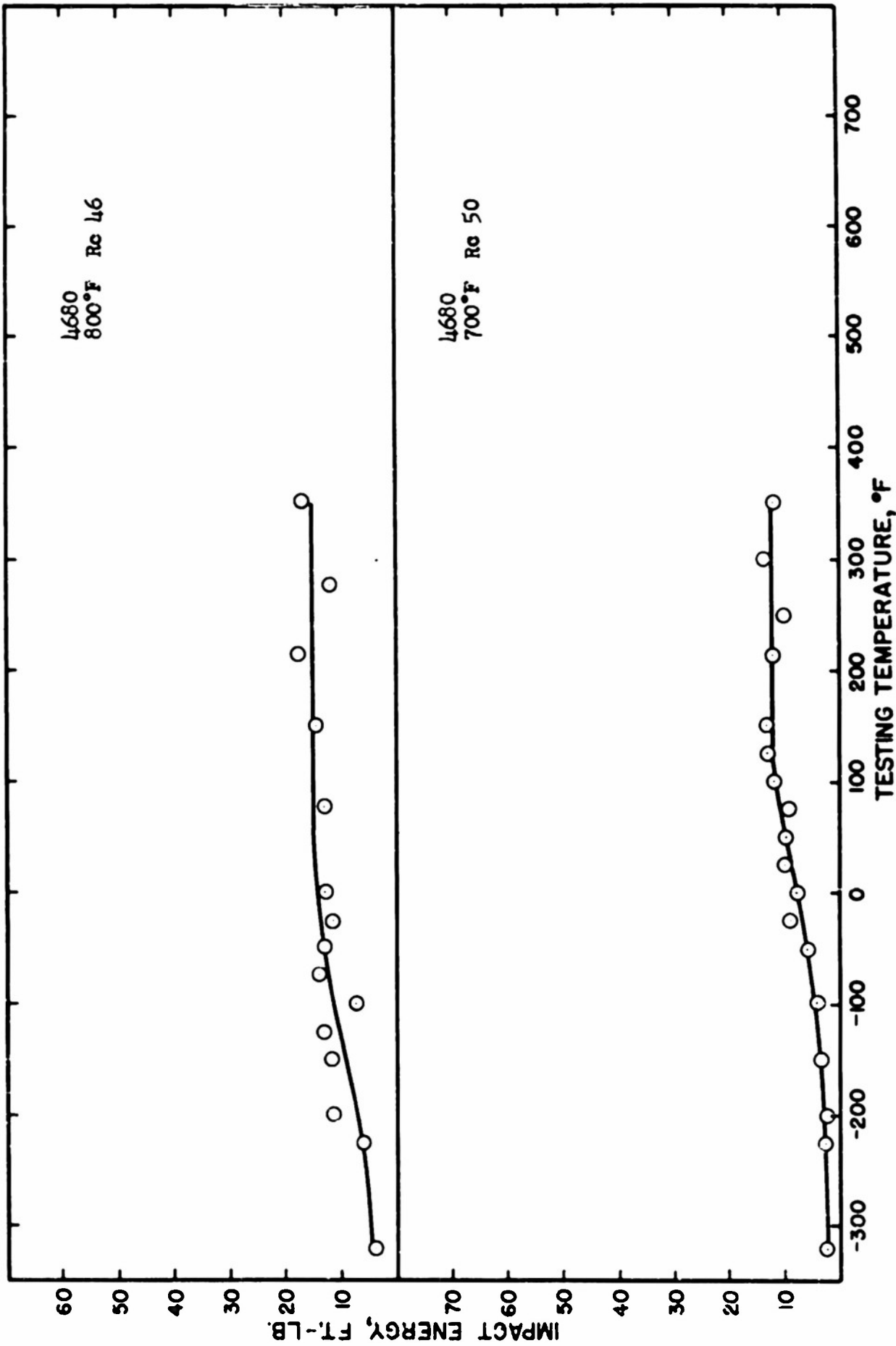


Fig. 61 - App. I

Heat 3792, laboratory fine grain 4680; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

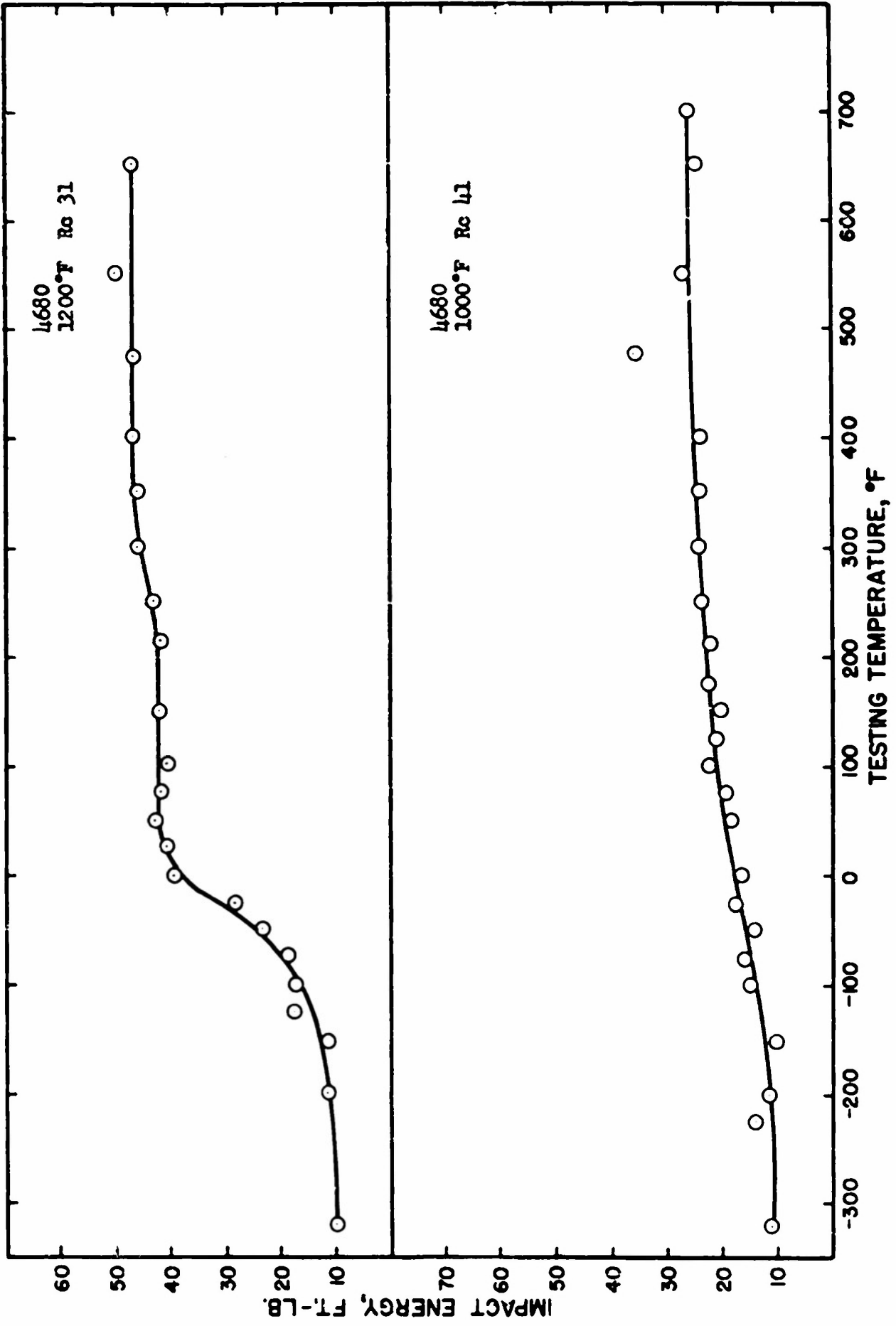


Fig. 62 - App. I

Heat 3792, laboratory fine grain 4680; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

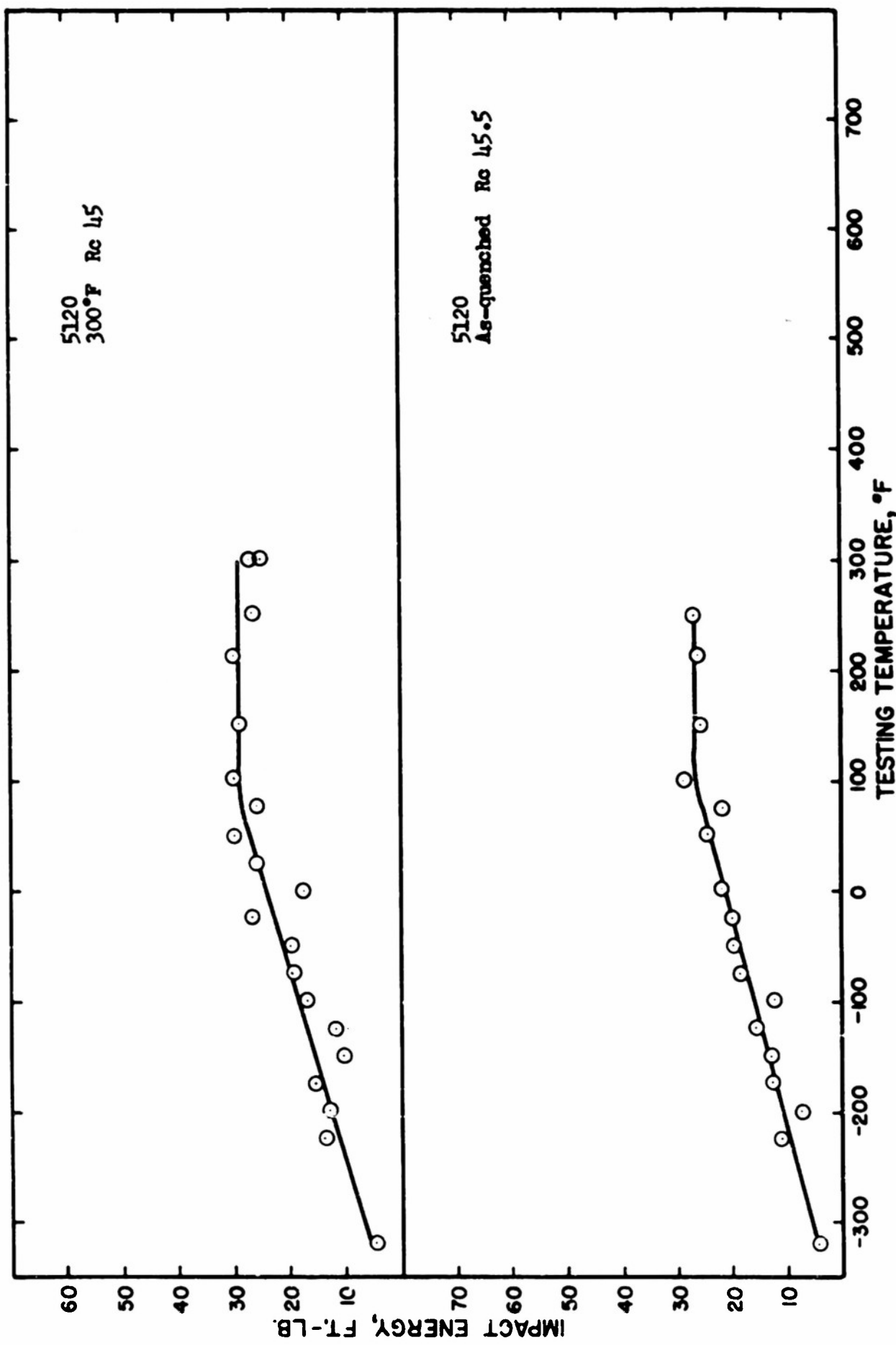


Fig. 63 - App. I

Feat 3798-3, Laboratory fine grain 5120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

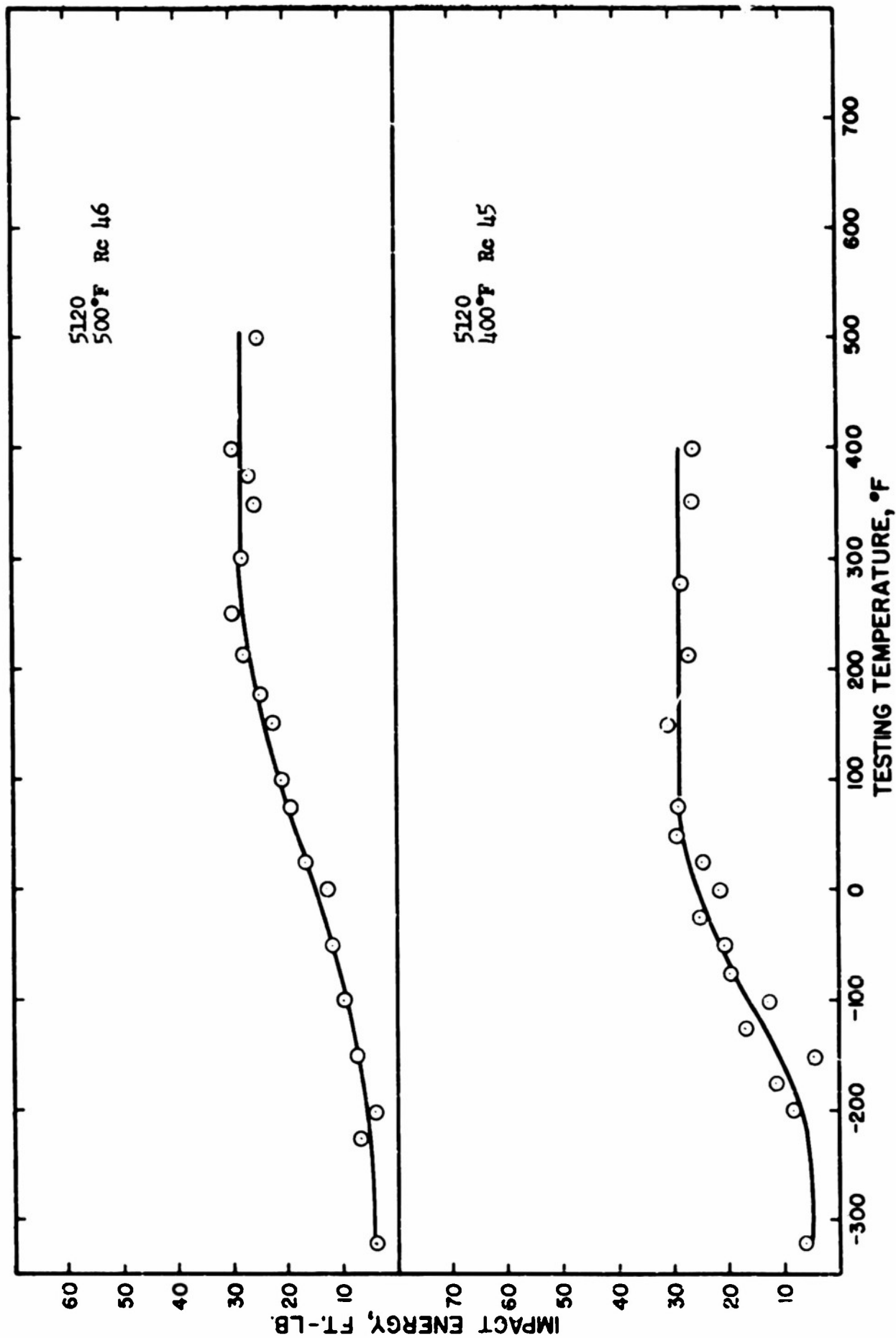


Fig. 64 - App. I

Heat 3798-3, laboratory fine grain 5120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

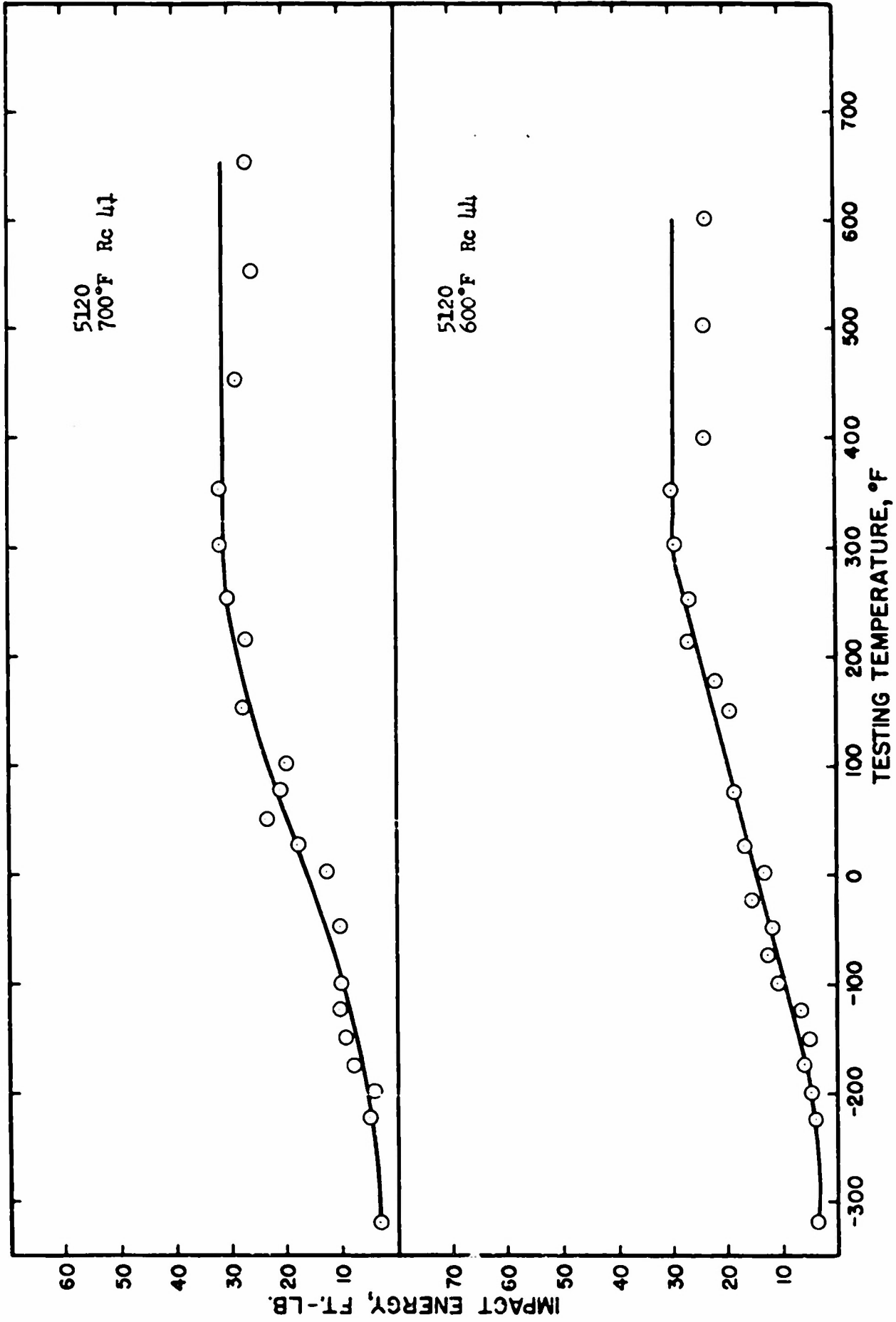


Fig. 65 - App. I

Heat 3798-3, laboratory fine grain 5120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

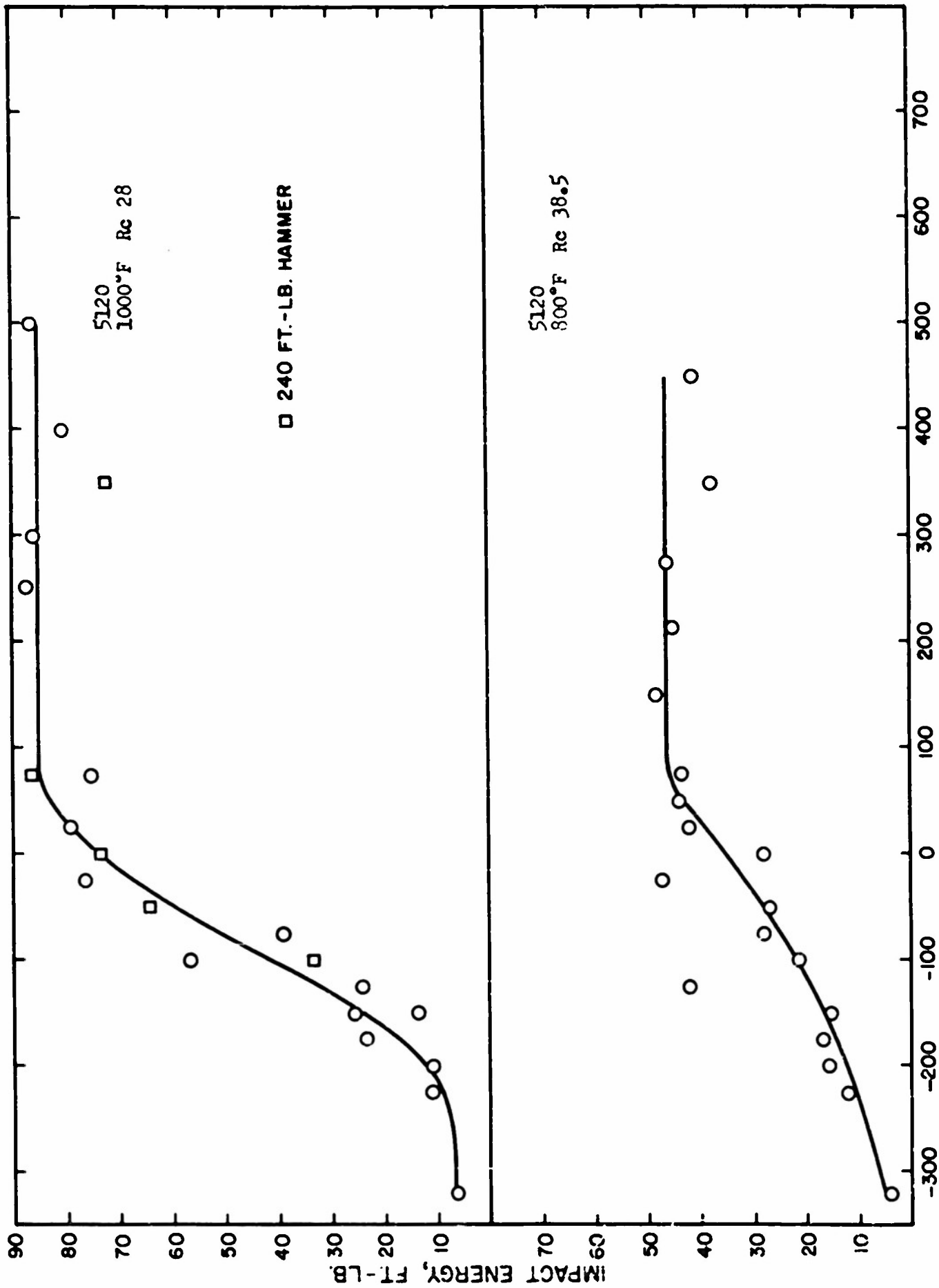


Fig. 66 - App. I. Heat 3798-3, Laboratory fine grain 5120; quenched in oil after 20 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

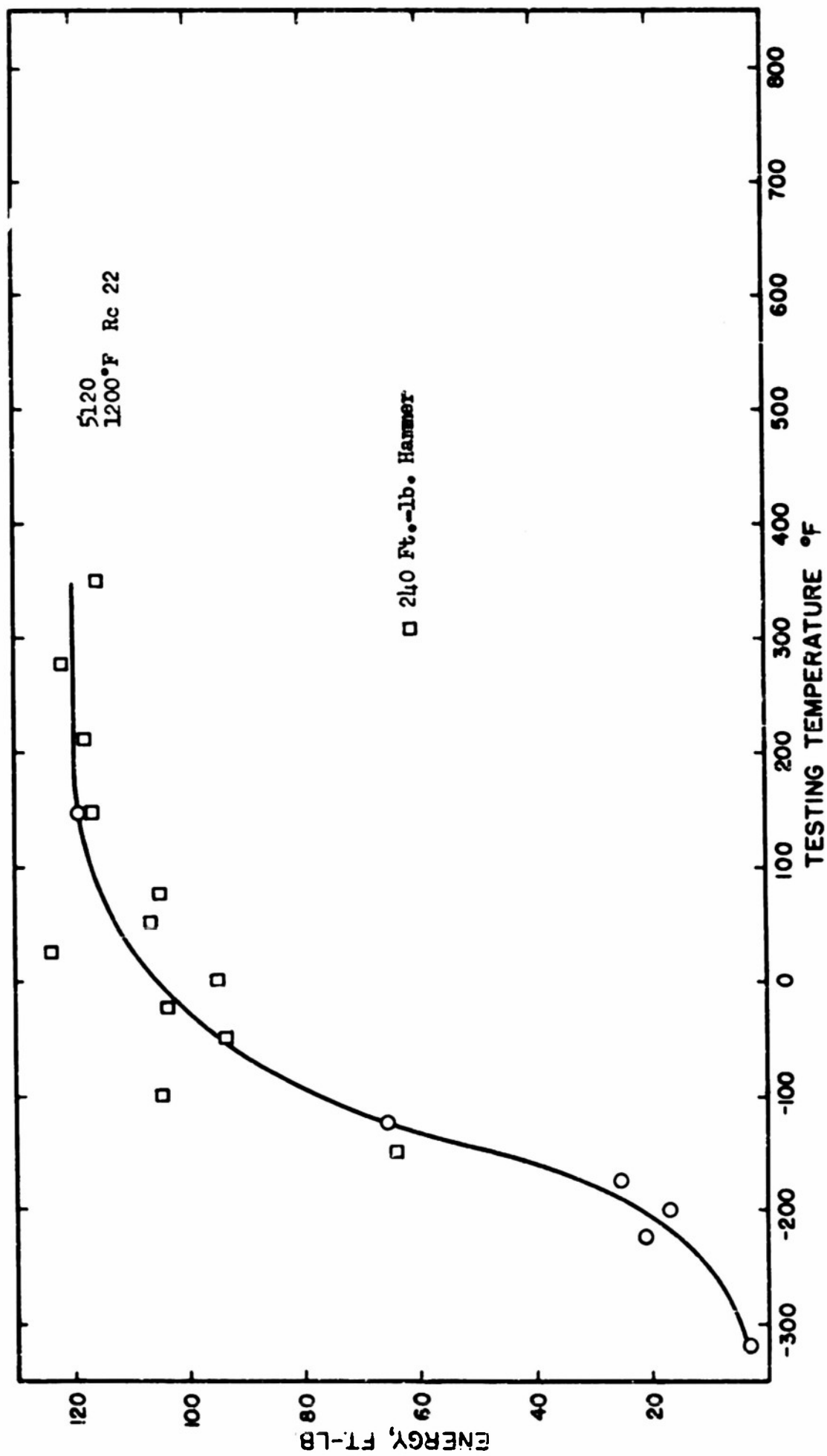


Fig. 67 - App. I

Heat 3798-3, laboratory fine grain 5120; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

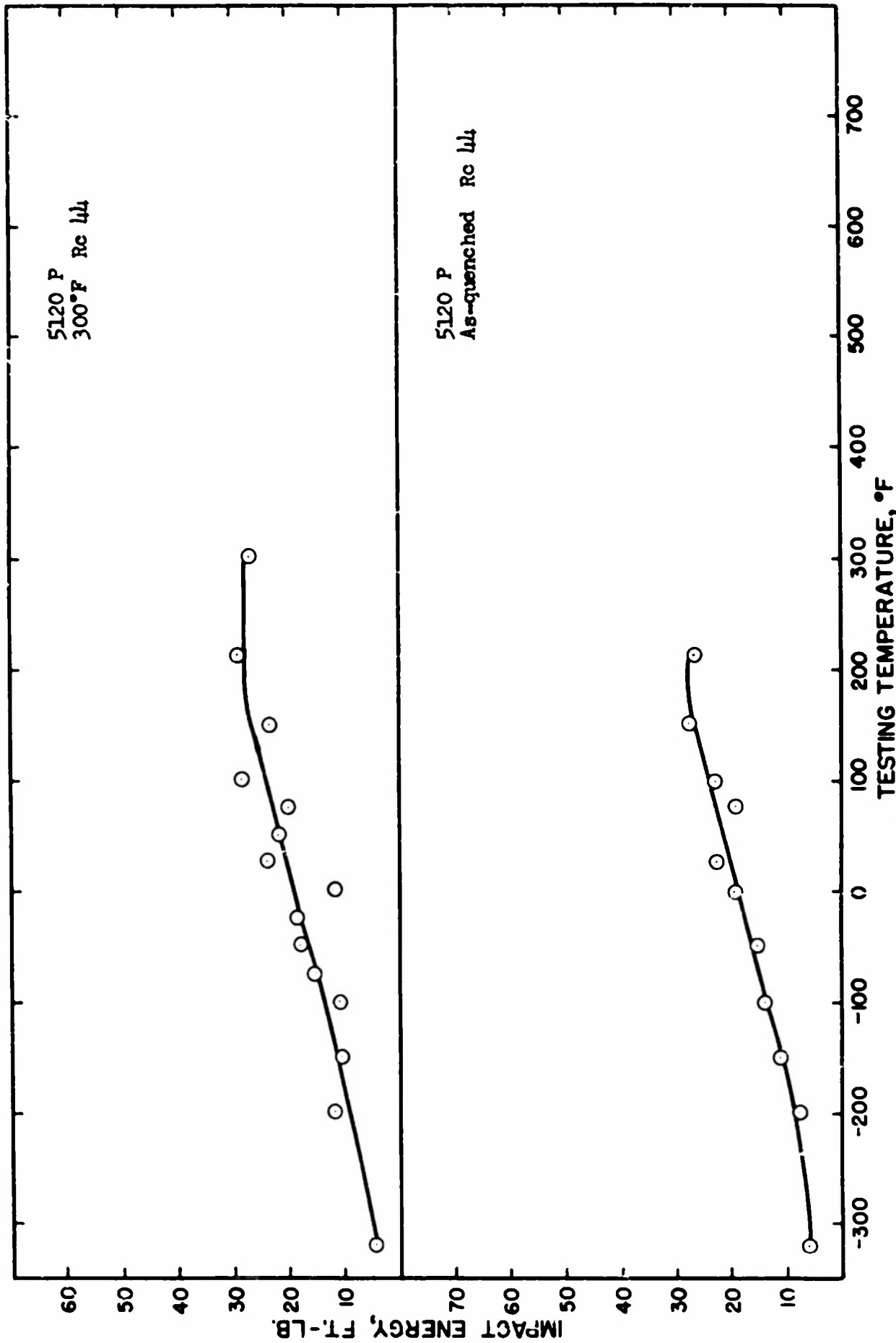


Fig. 68 - App. I

Heat 3798-6, laboratory fine grain 5120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

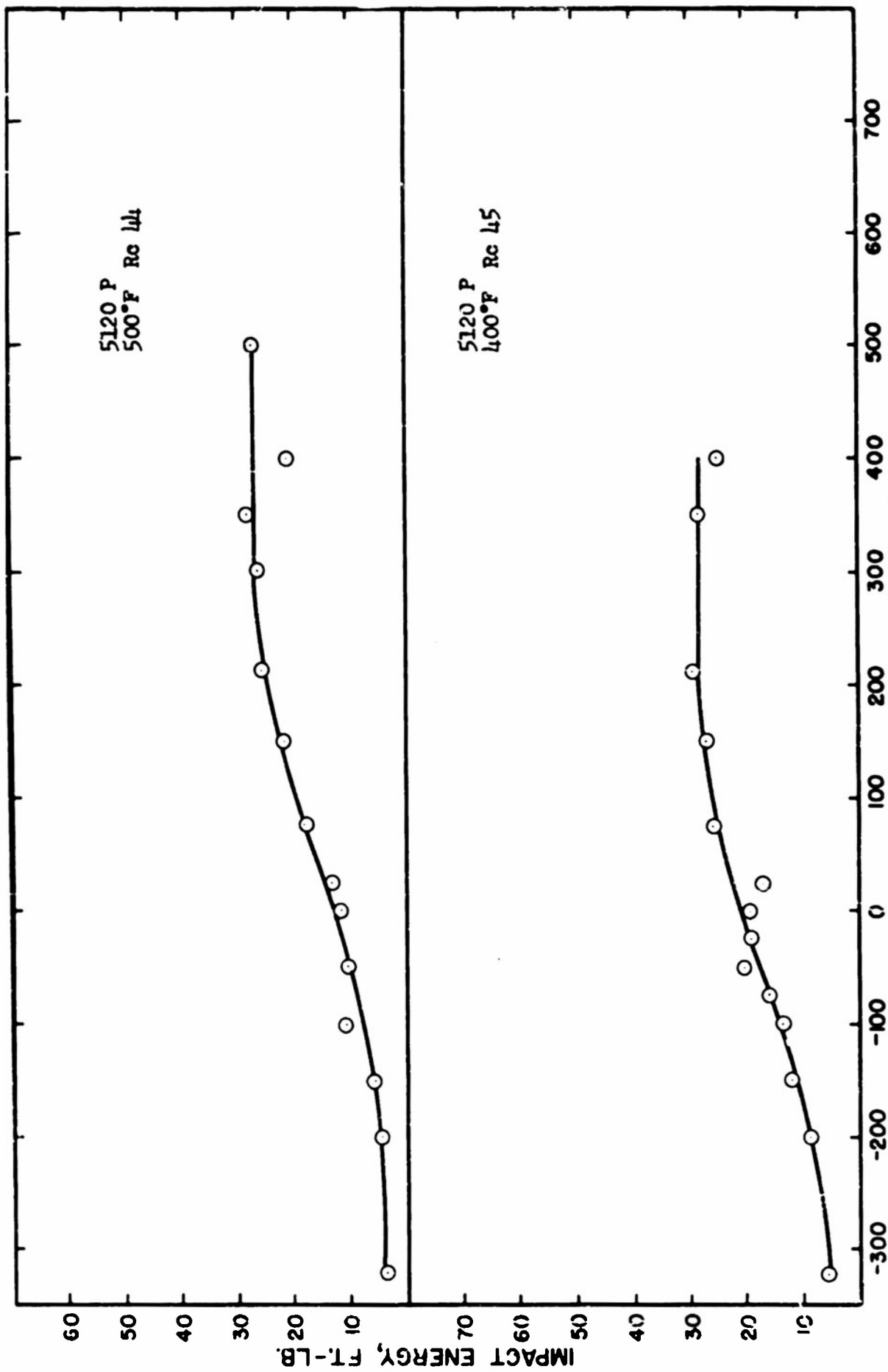


Fig. 69 - App. I

Heat 3798-6, Laboratory fine grain 5120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

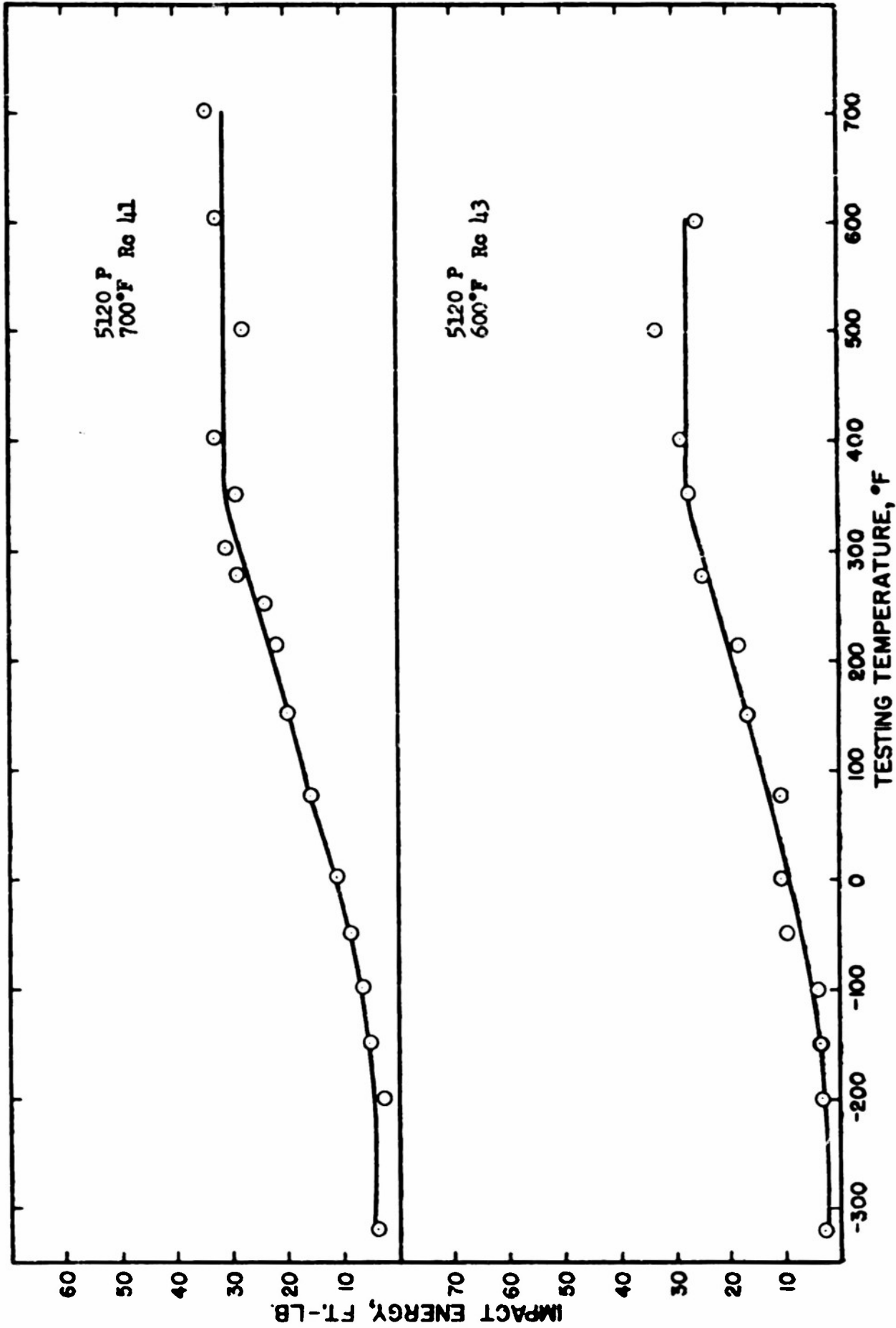


Fig. 70 - App. I

Heat 3798-6, Laboratory fine grain 5120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

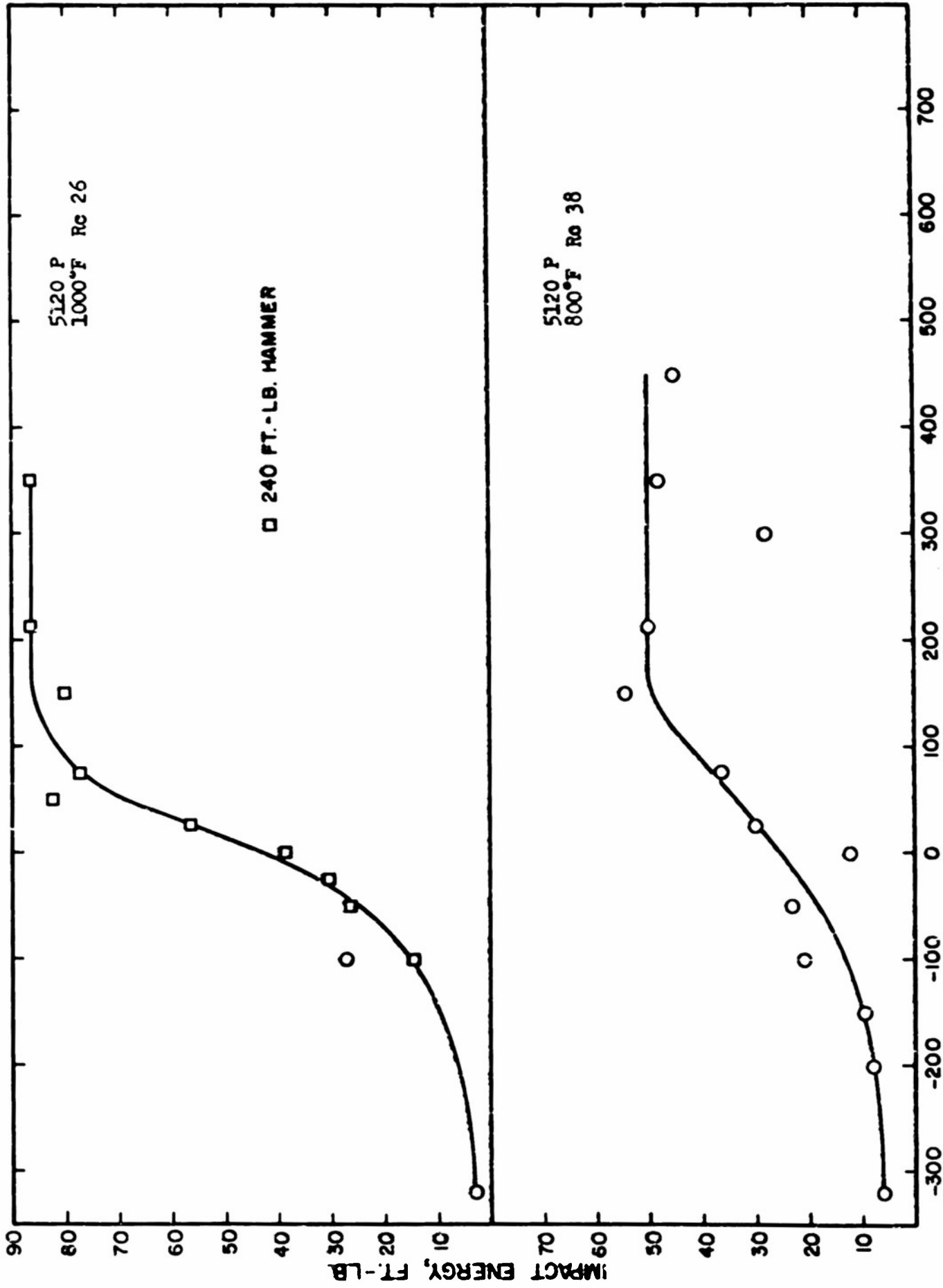


Fig. 71 - App. I. Heat 3798-6, Laboratory fine grain 5120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

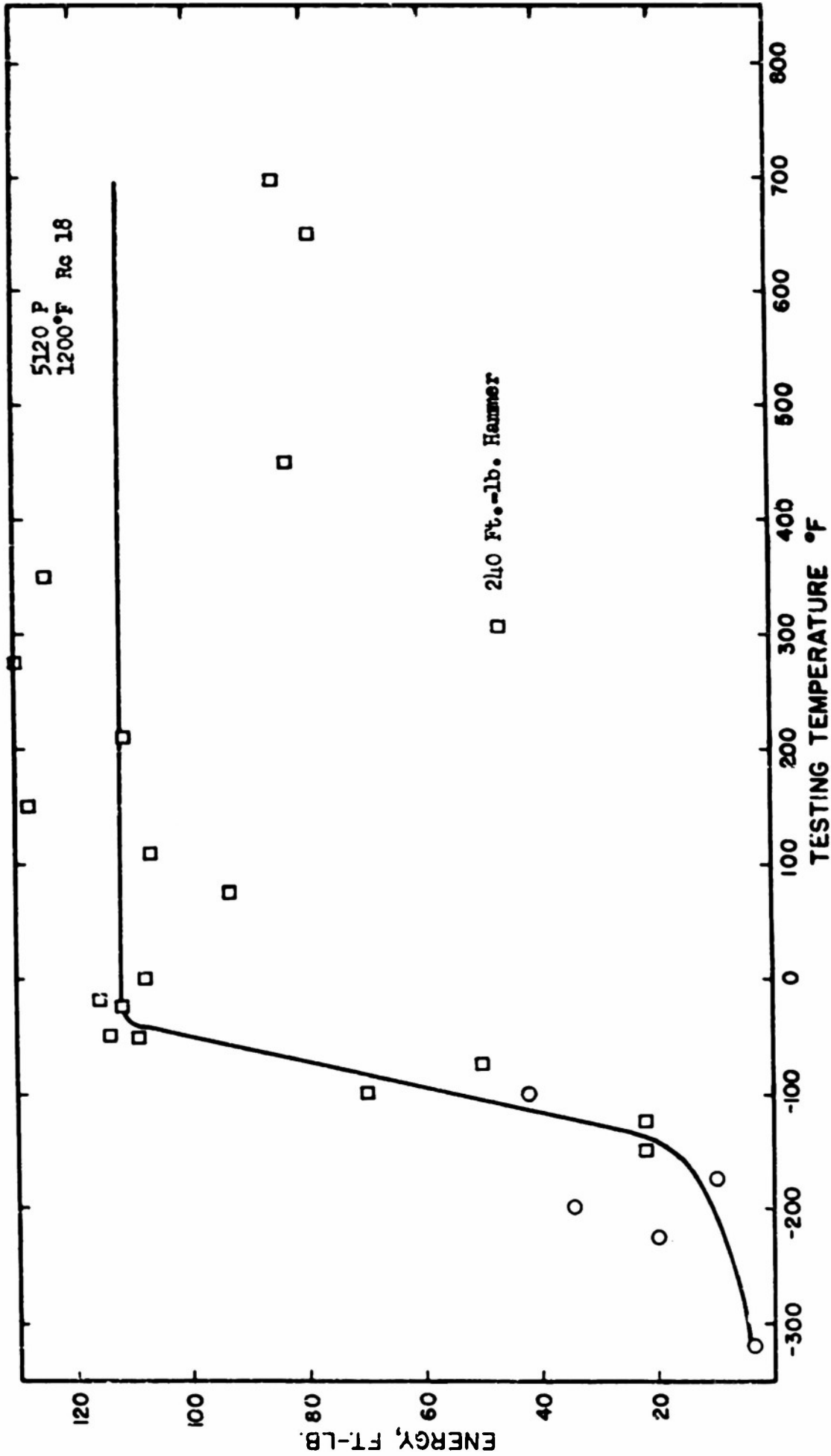


Fig. 72 - App. I

Heat 3798-6, laboratory fine grain 5120 with high phosphorous; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

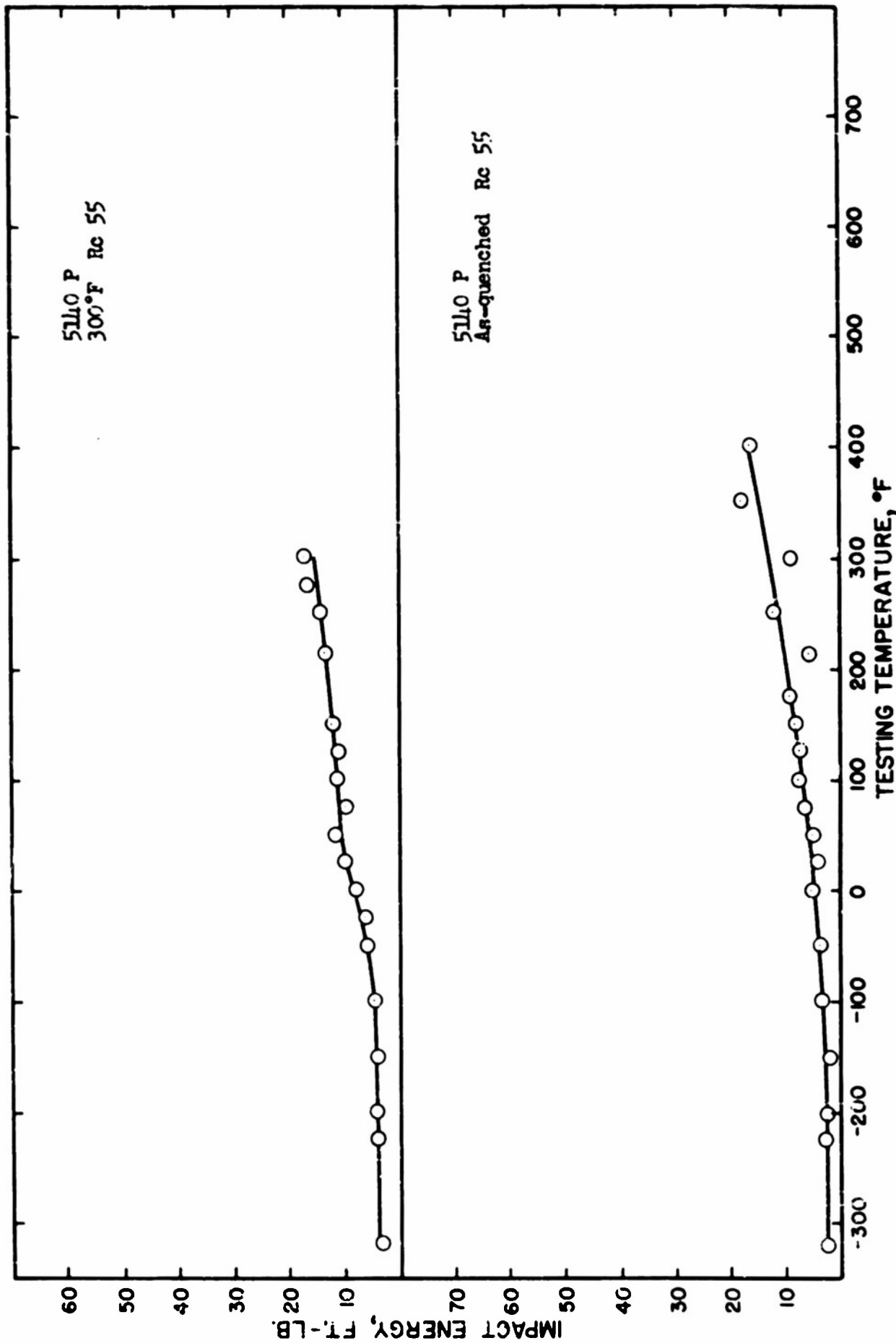


Fig. 73 - App. I

Heat 3816, Laboratory fine grain 5140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

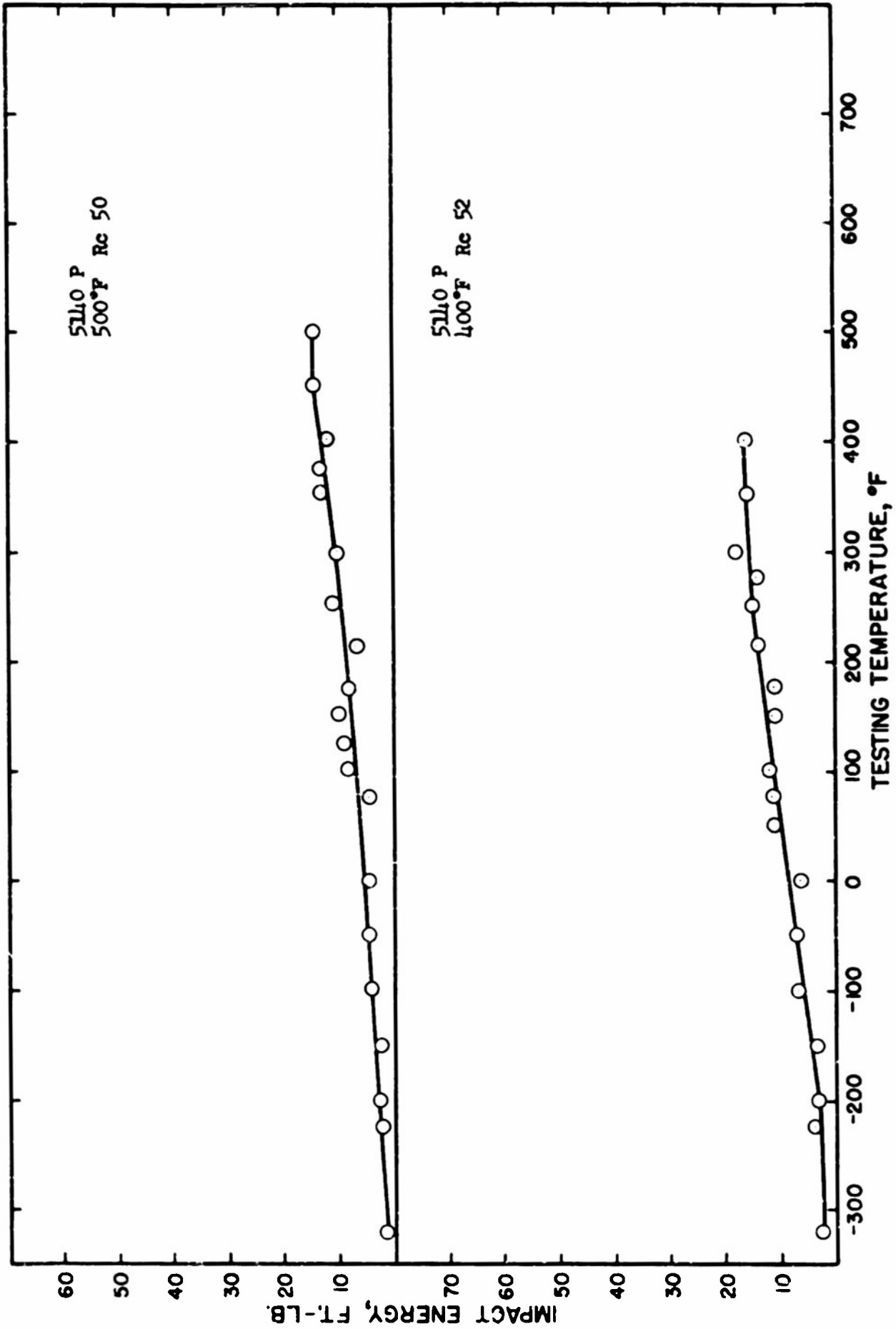


Fig. 74 - App. I

Heat 3816, laboratory fine grain 5140 with high phosphorus; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

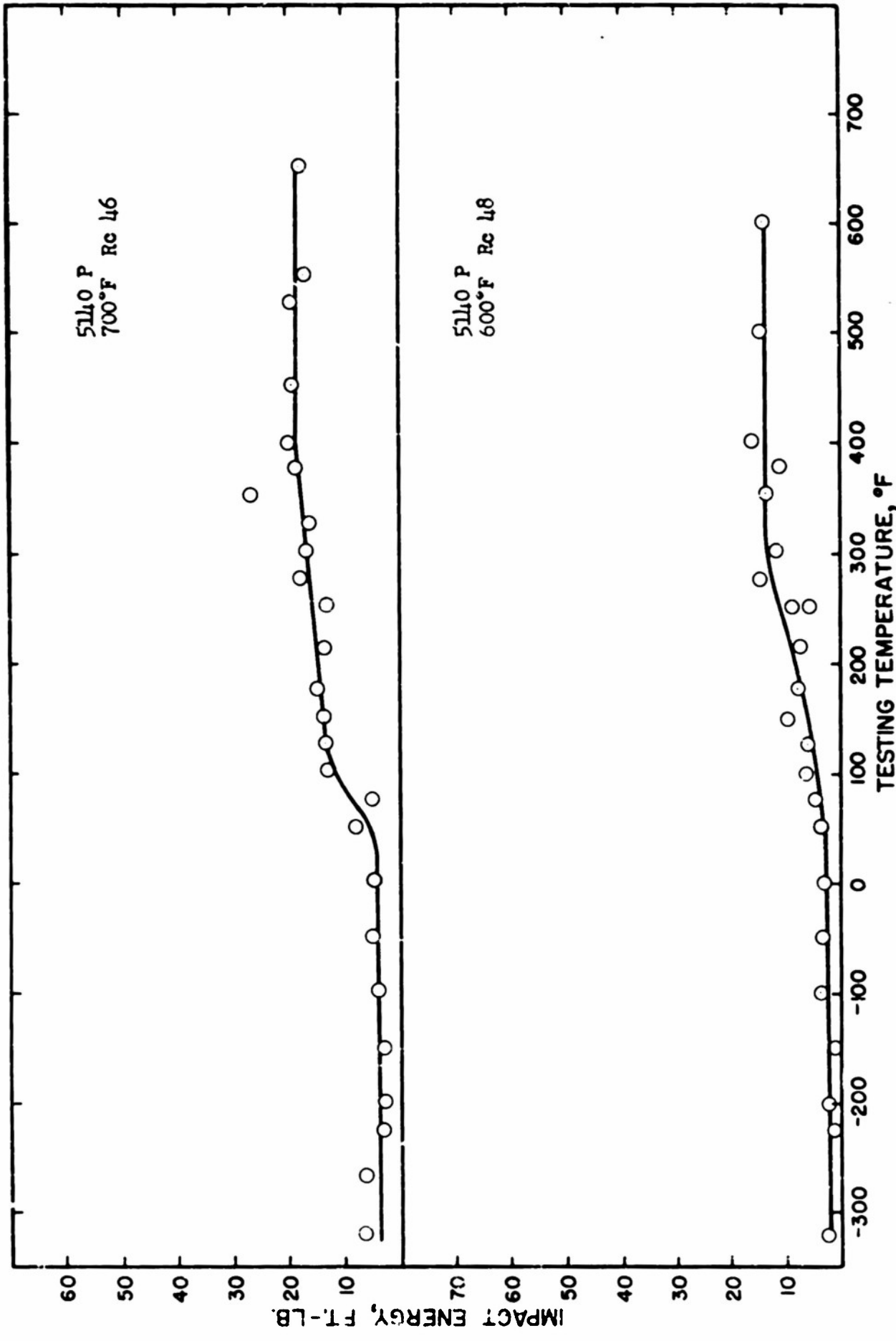


Fig. 75 - App. I

Heat 3816, laboratory fine grain 5140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

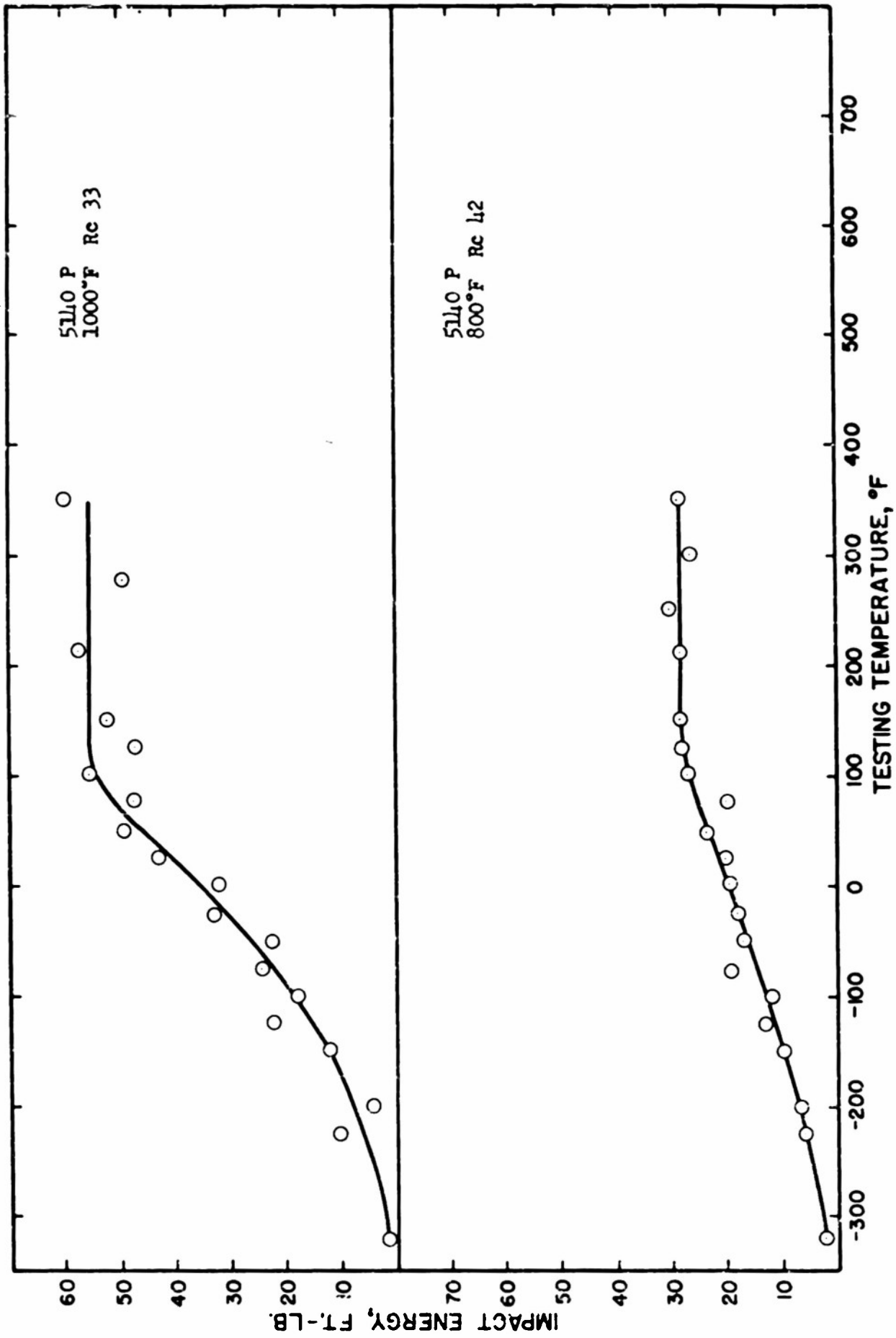


Fig. 76 - App. I

Heat 3816, laboratory fine grain 5140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

5140 P
1200°F Rc 26

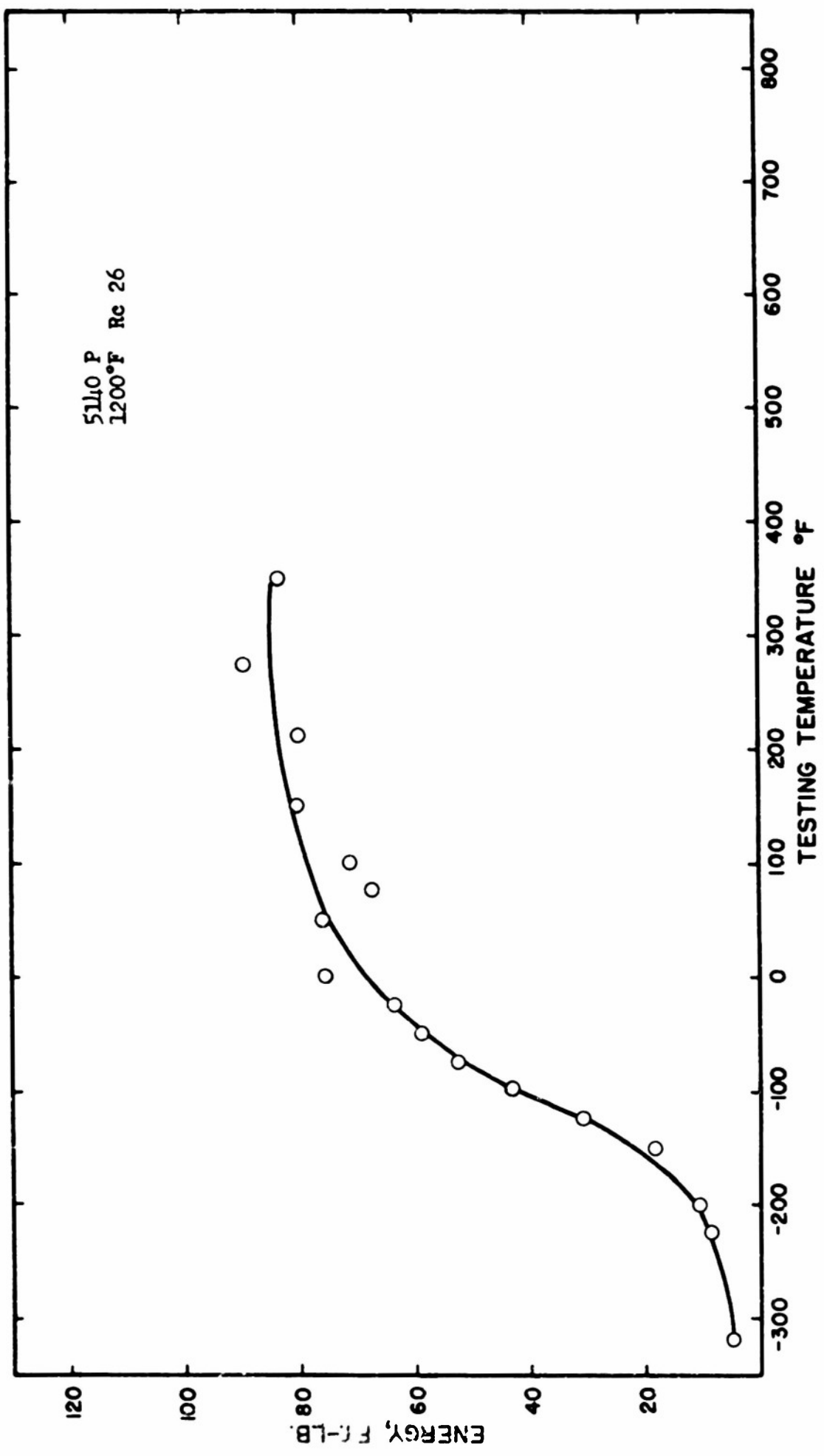


Fig. 77 - App. I

Heat 3816, laboratory fine grain 5140 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

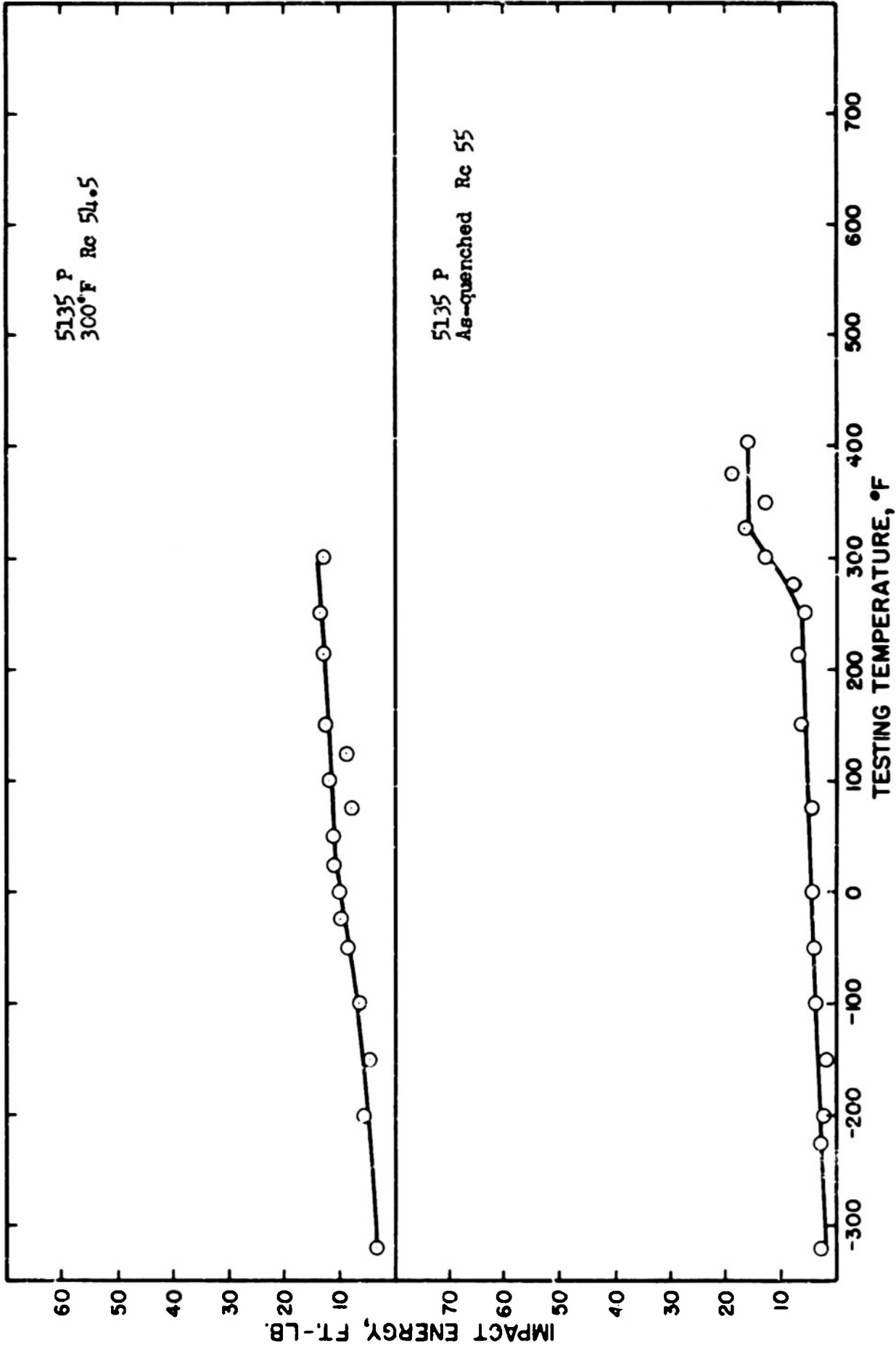


Fig. 78 - App. I

Heat 3717, Laboratory fine grain 5135 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

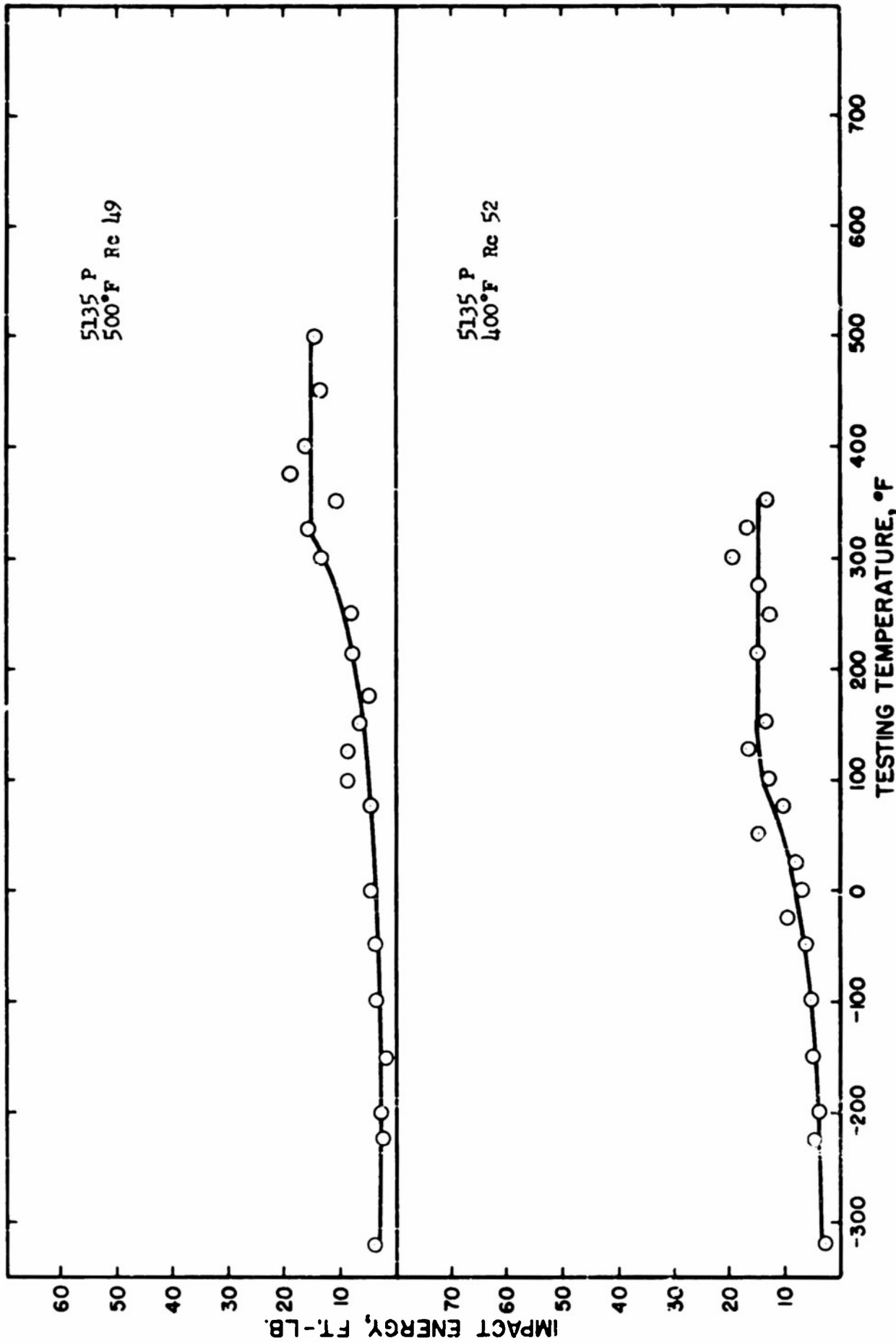


Fig. 79 - App. I

Heat 3717, laboratory fine grain 5135 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

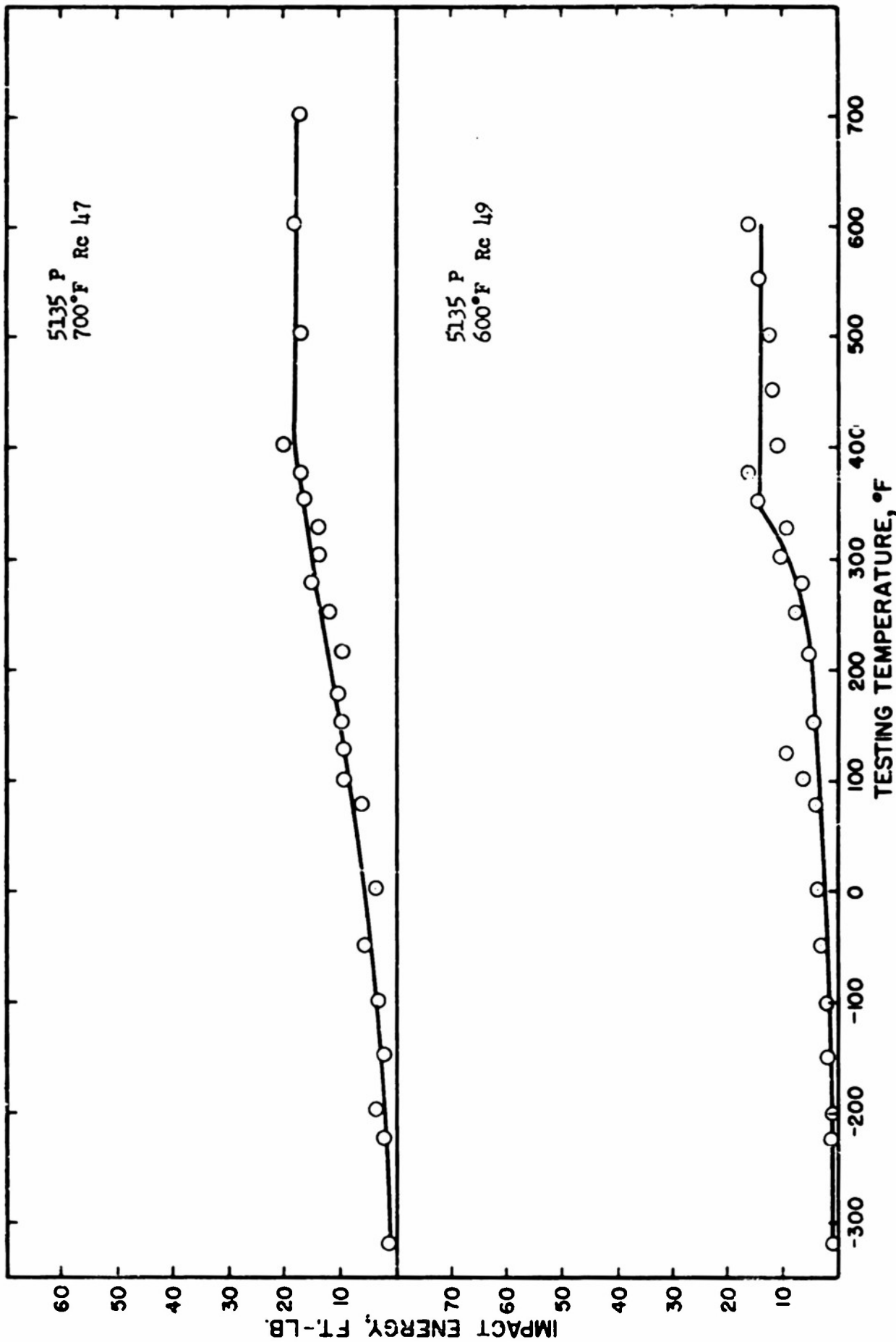


Fig. 80 - App. I

Heat 3717, laboratory fine grain 5135 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

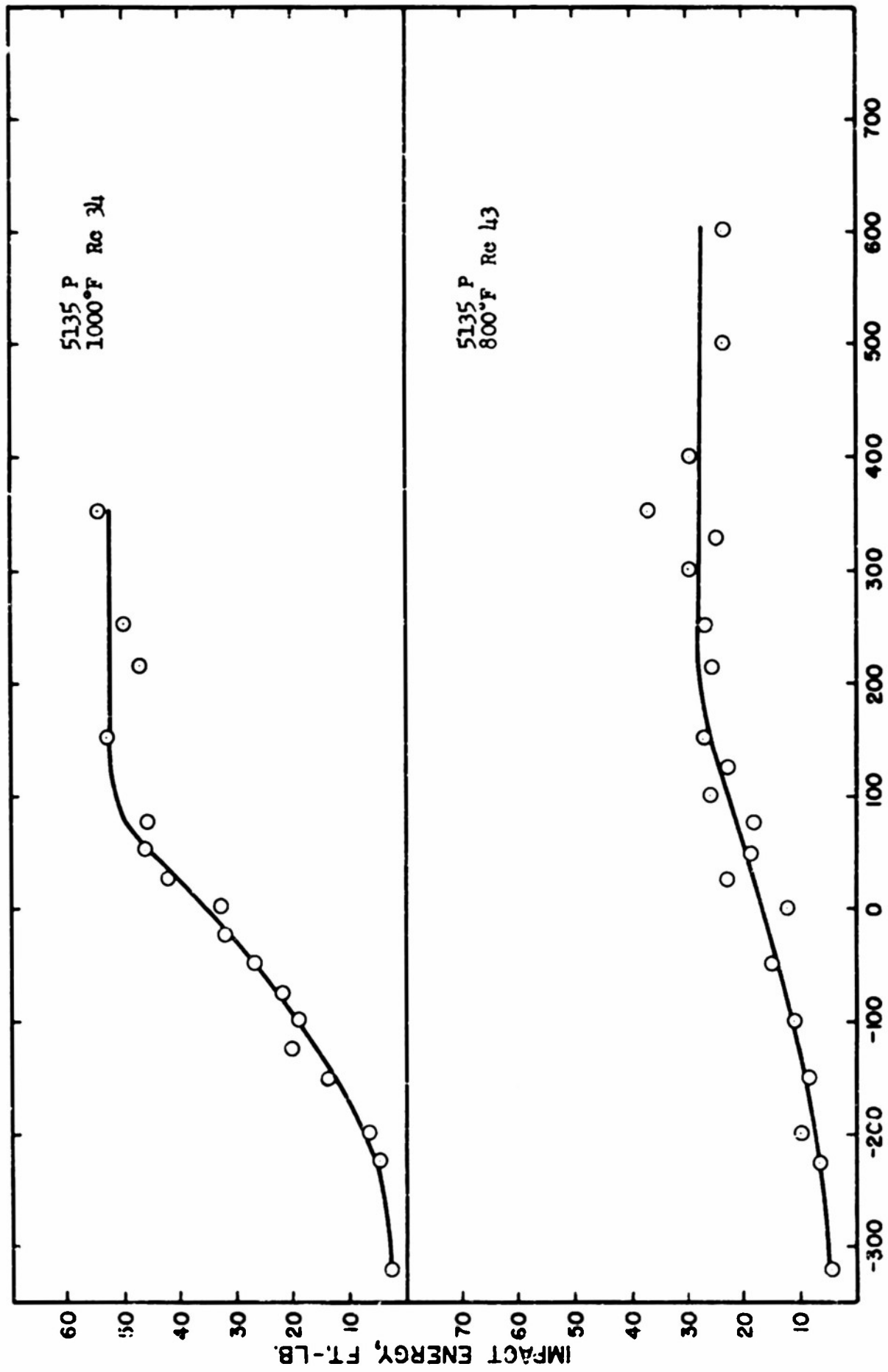


Fig. 81 - App. I

Heat 3717, laboratory fine grain 5135 with high phosphorus; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

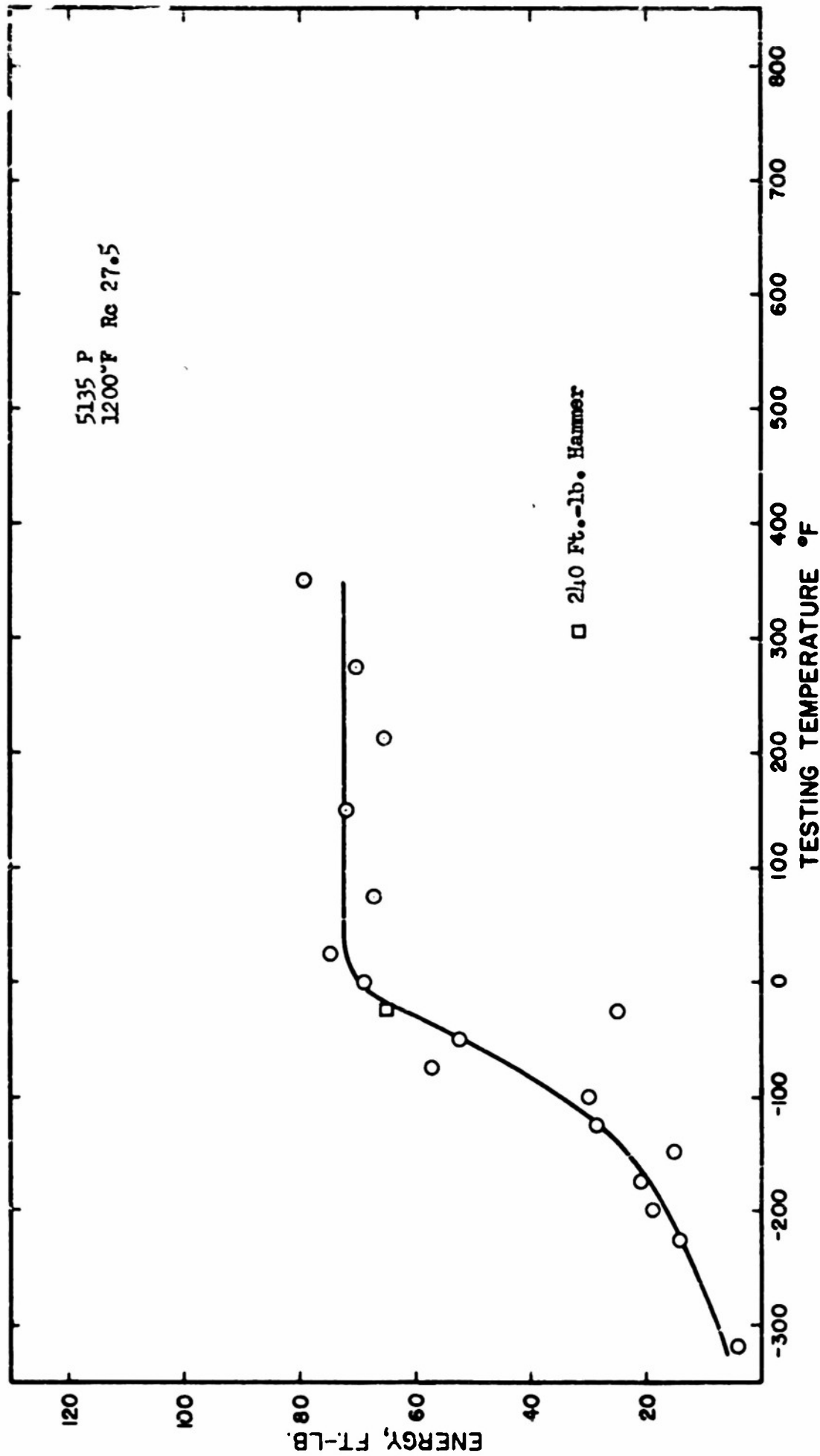


Fig. 82 - App. I

Heat 3717, laboratory fine grain 5135 with high phosphorous; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

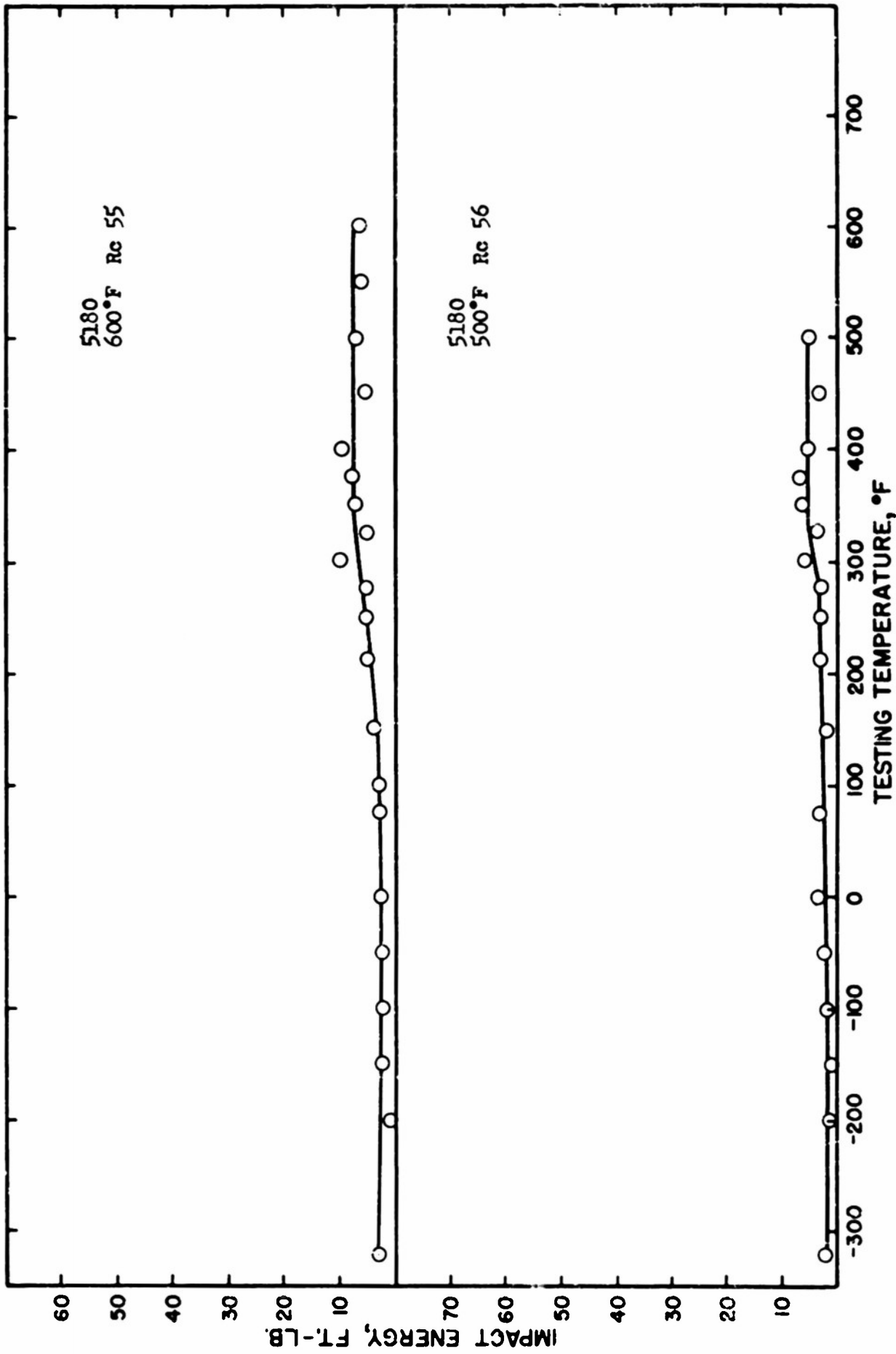


Fig. 83 - App. I

Heat 3813-3, Laboratory fine grain 5180, quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

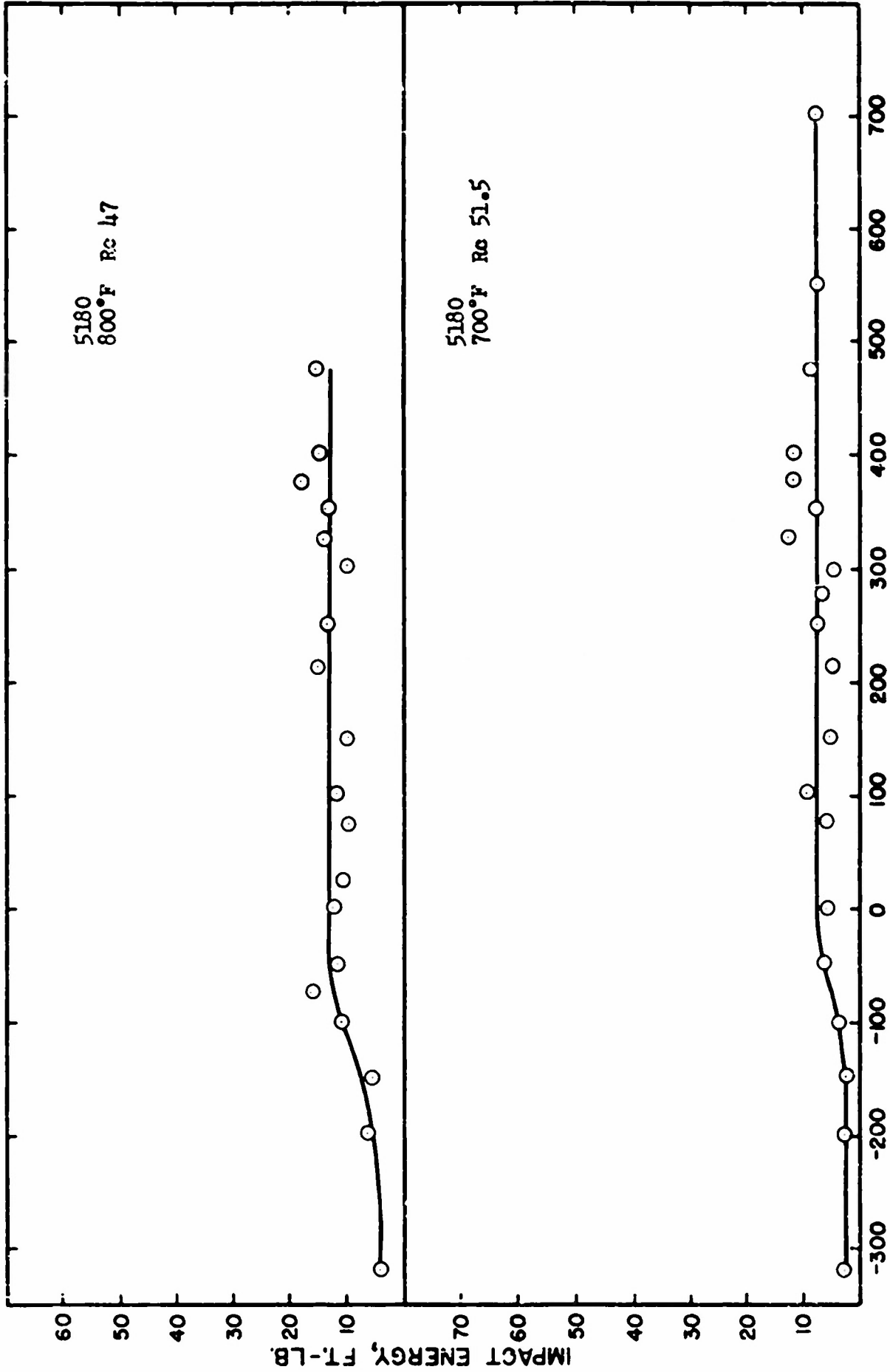


Fig. 84 - App. I

Heat 3813-3, Laboratory fine grain 5180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

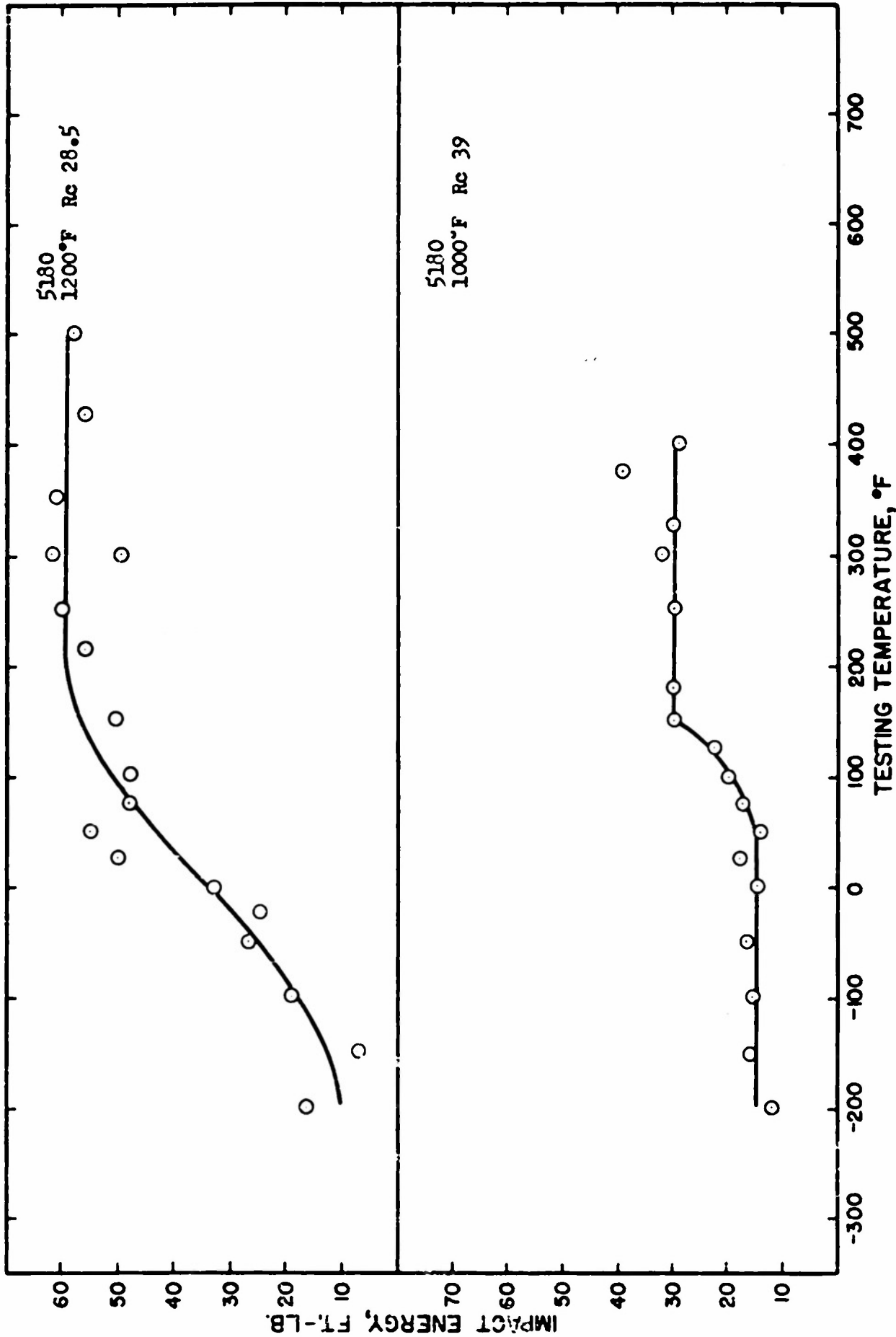


Fig. 85 - App. I

Heat 3813-3, Laboratory fine grain 5180; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

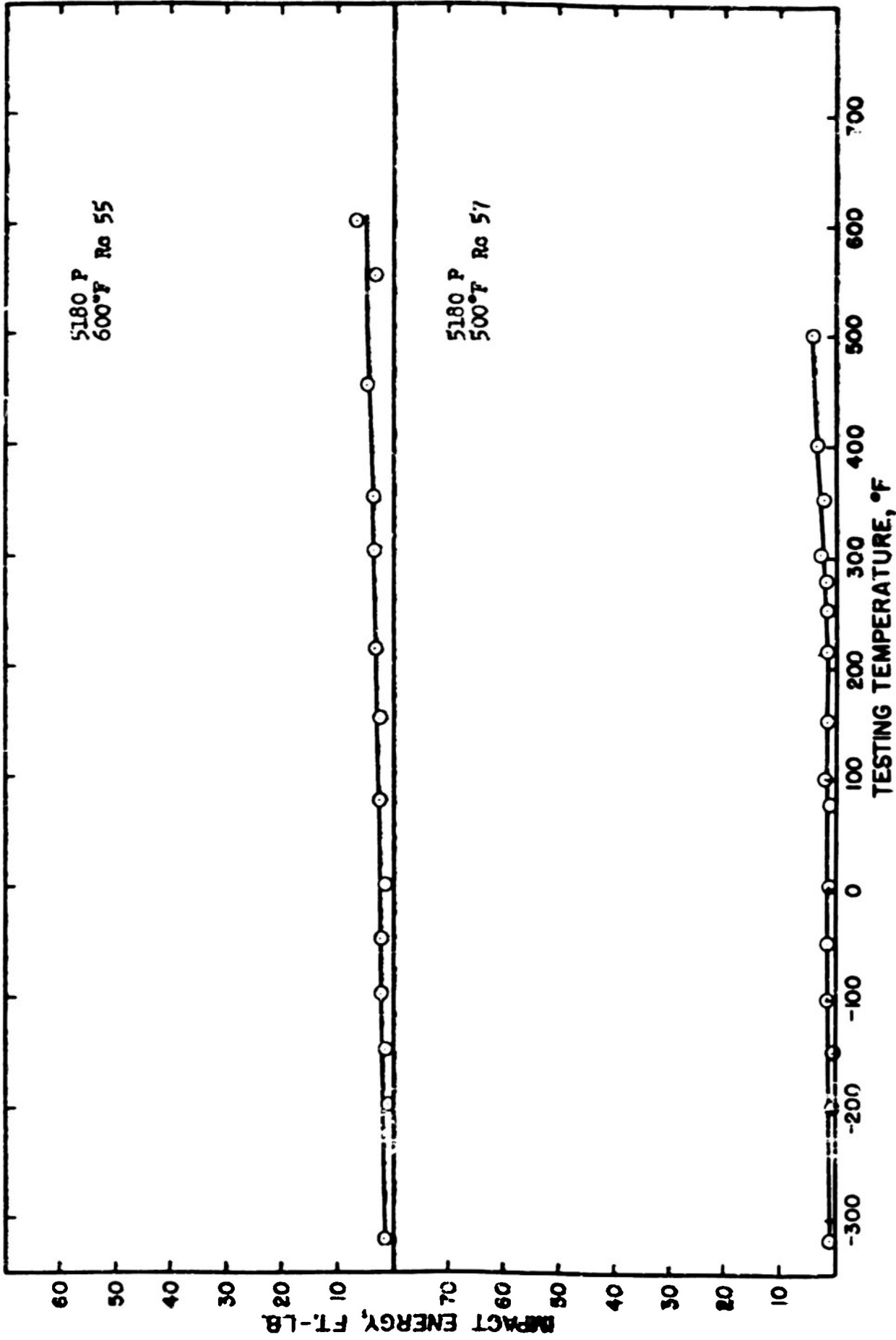
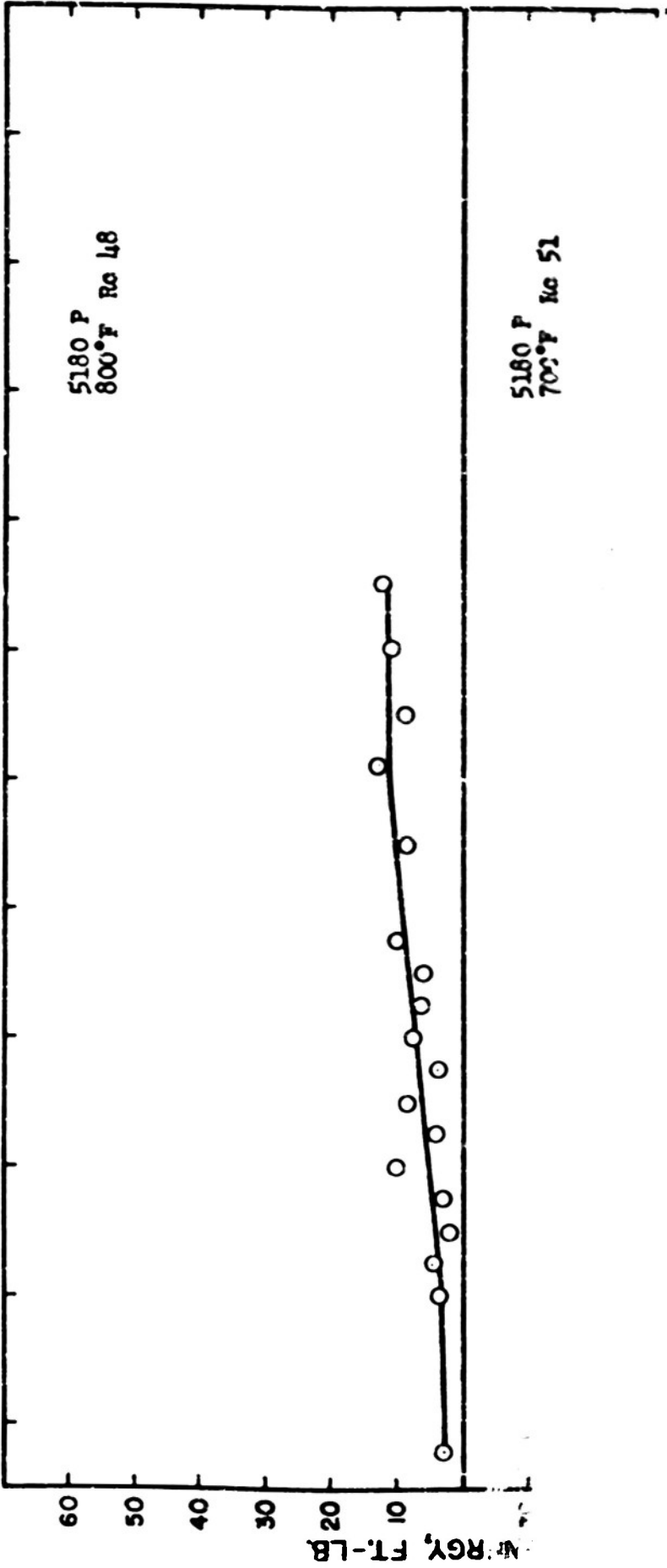


Fig. 86 - App. I

Heat 3813-6, Laboratory fine grain 5180 with high phosphorous; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.



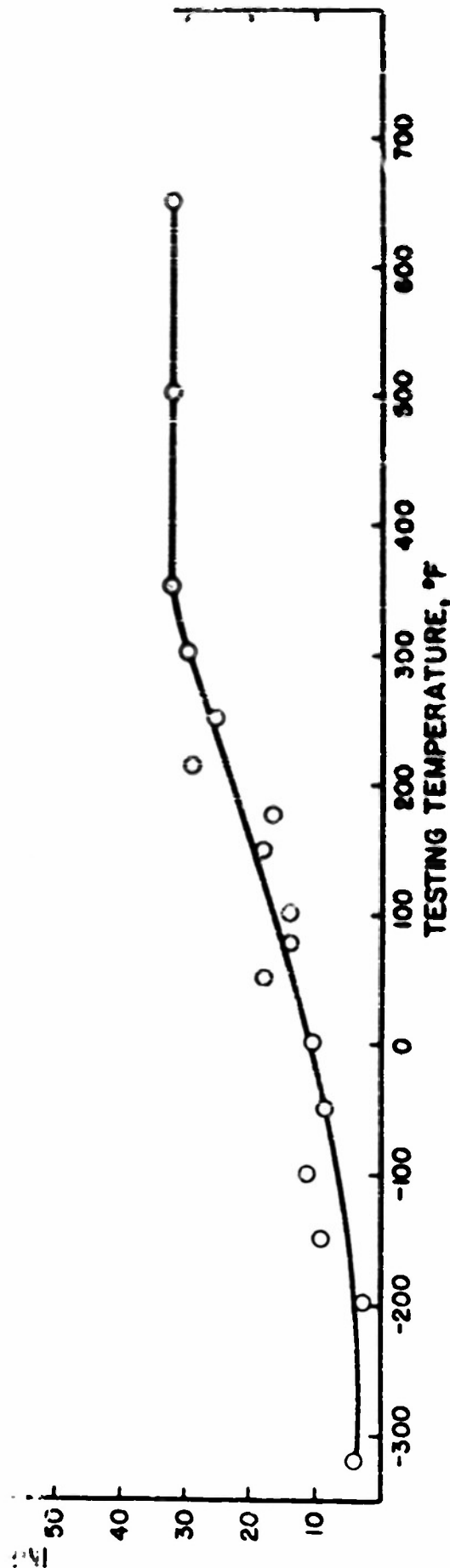


Fig. 58 -- App. I

Heat 3813-6, laboratory fine grain 5180 with high phosphorus; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

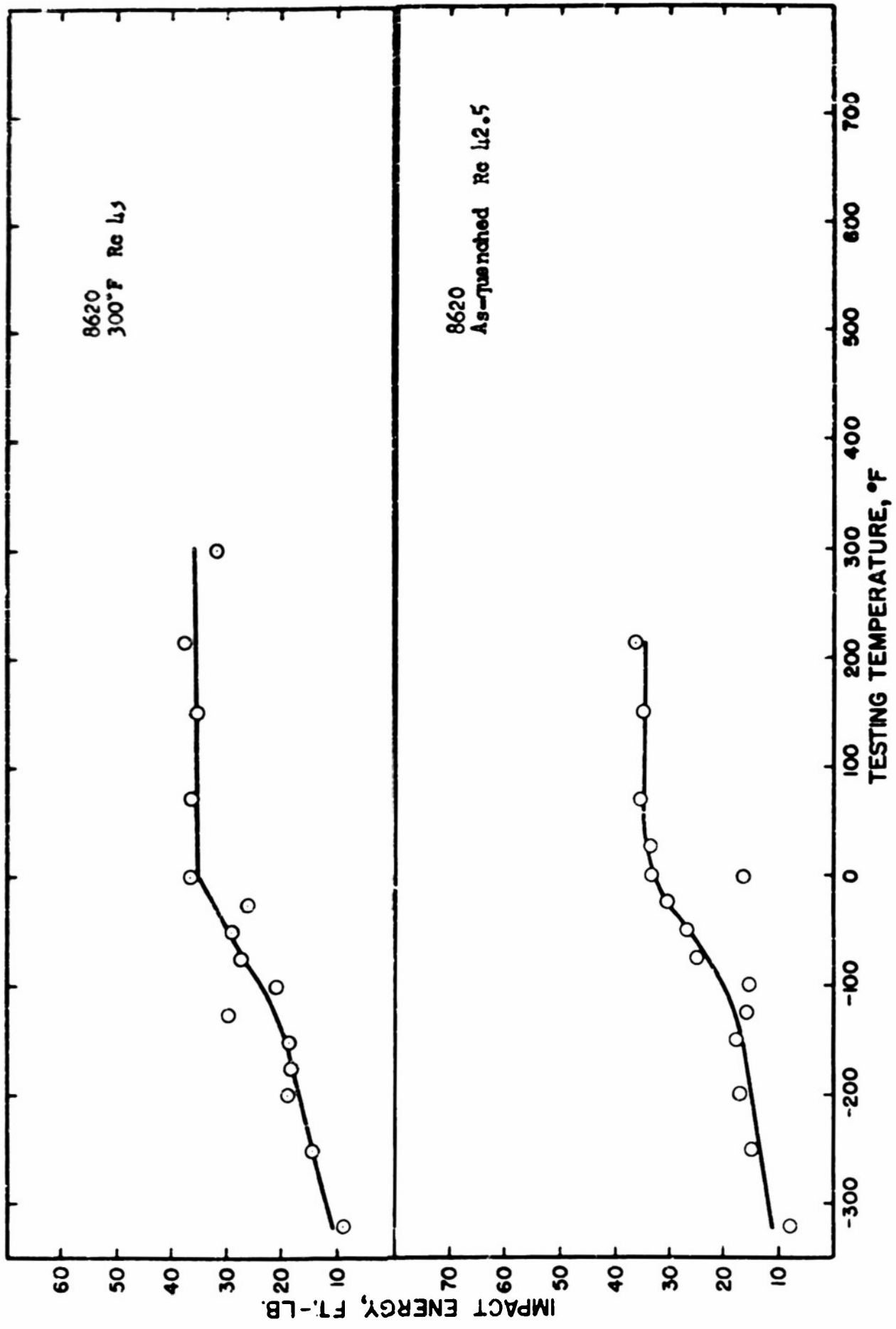


Fig. 89 - App. I

Heat 2730, laboratory fine grain 8620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

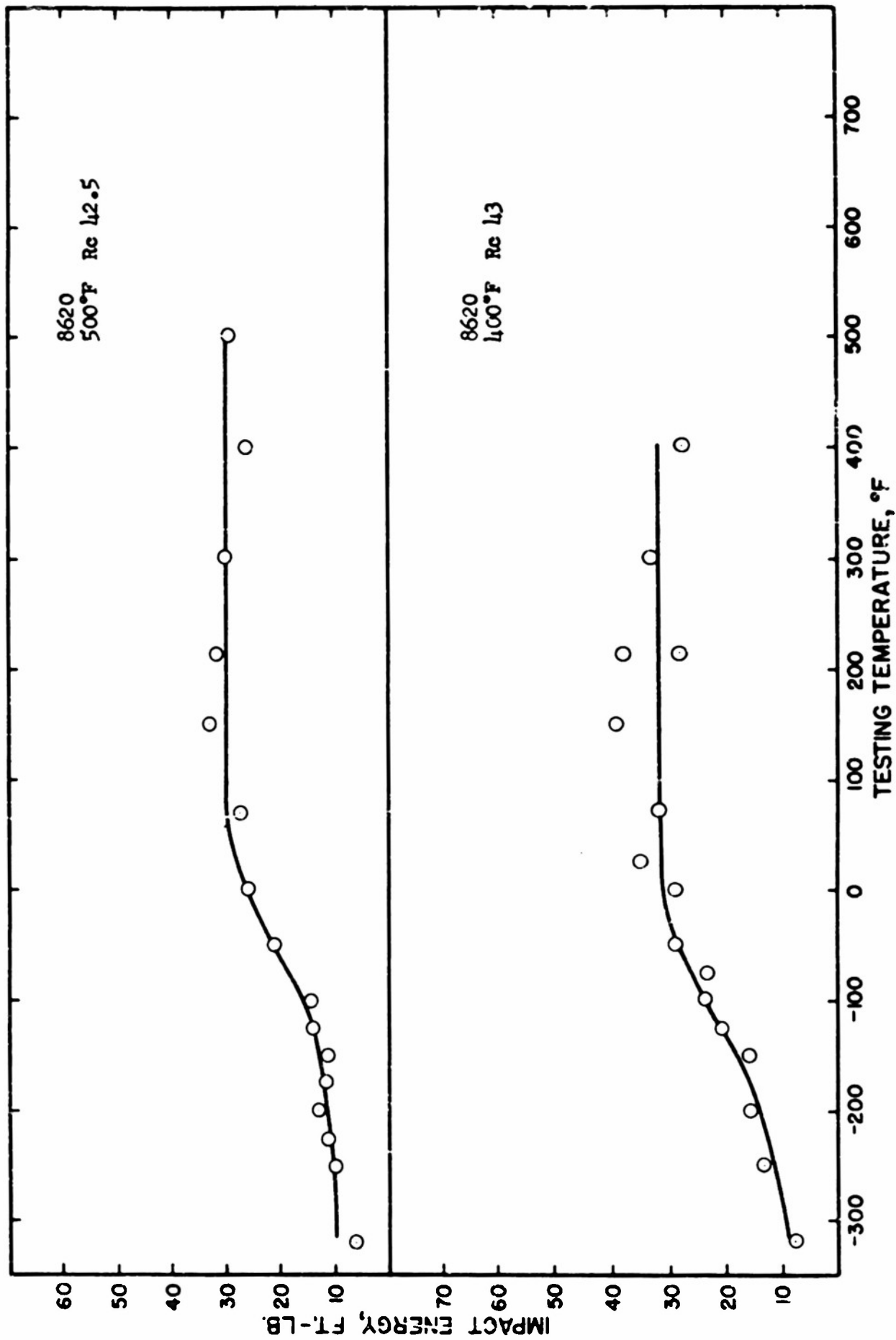


Fig. 90 - App. I

Heat 2730, laboratory fine grain 8620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

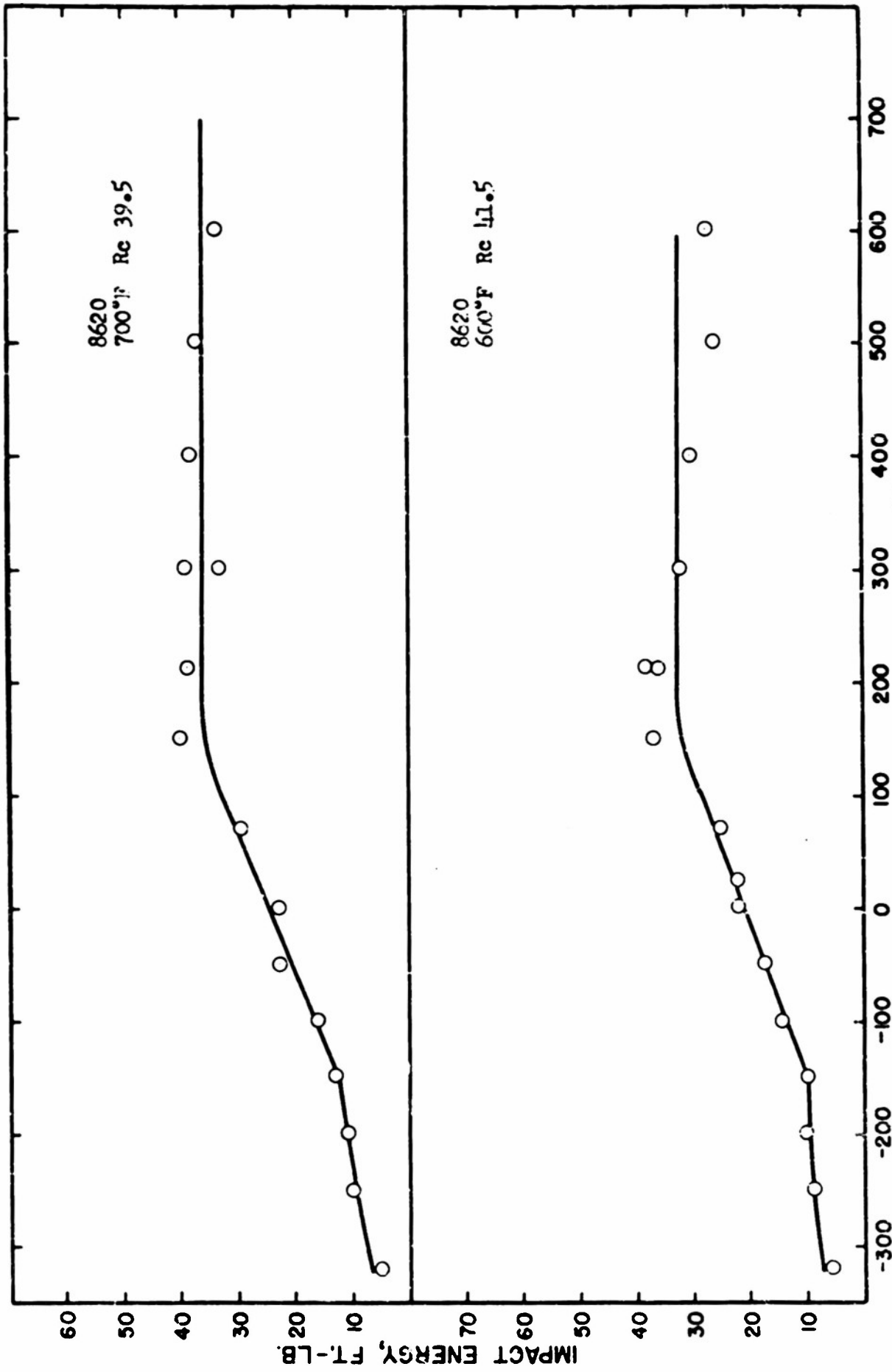


Fig. 91 - App. I

Heat 2730, laboratory fine grain 8620; quenched in oil after 30 minutes at 1650°F; tempered for one hour at temperature indicated in graph and water quenched.

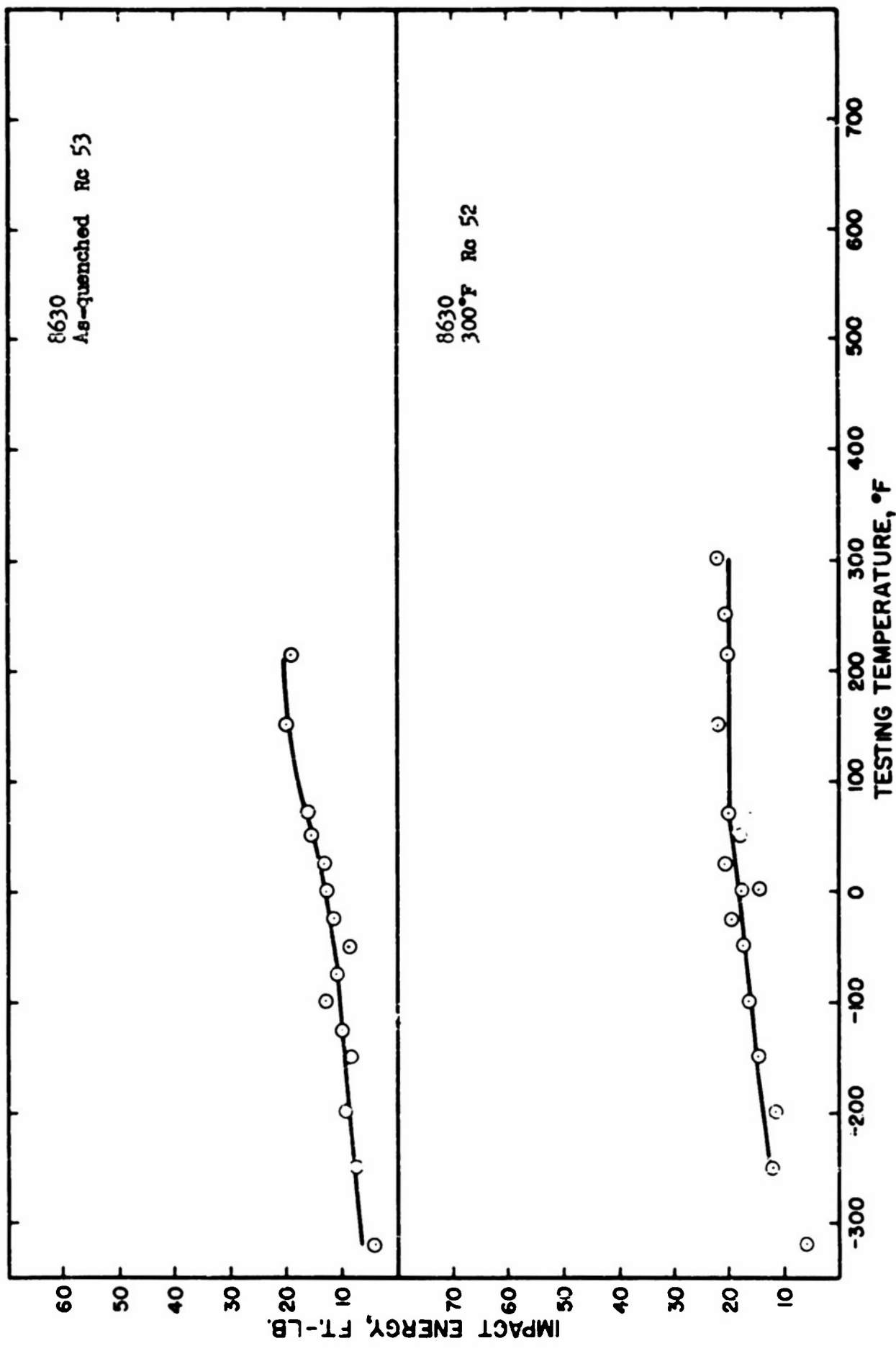


Fig. 92 - App. I

Heat 2820, Laboratory fine grain 8630; quenched in oil after 30 minutes at 1575°F; tempered for one hour at temperature indicated in graph and water quenched.

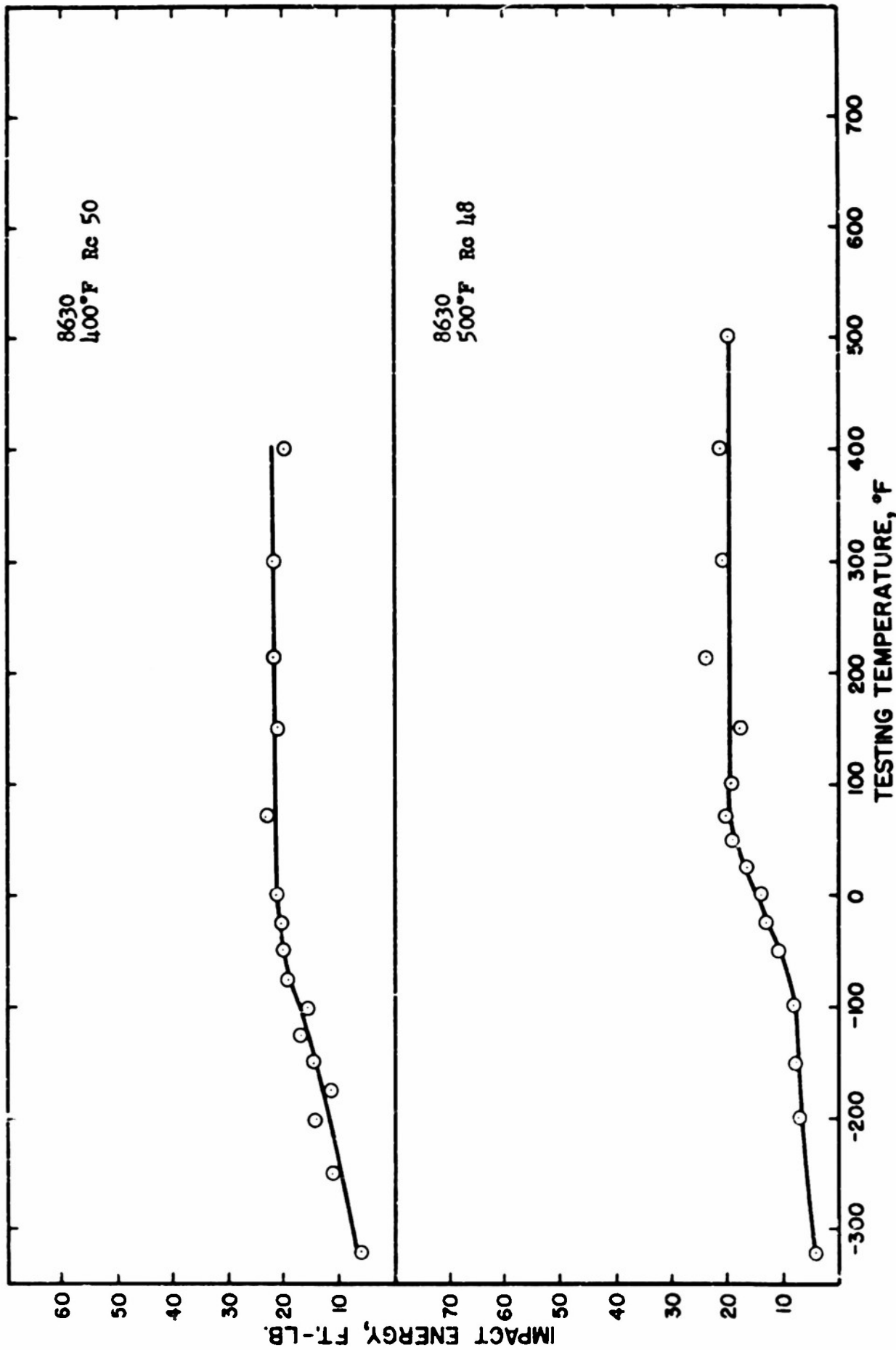


Fig. 93 - App. I

Heat 2820, laboratory fine grain 8630; quenched in oil after 30 minutes at 1575°F; tempered for one hour at temperature indicated in graph and water quenched.

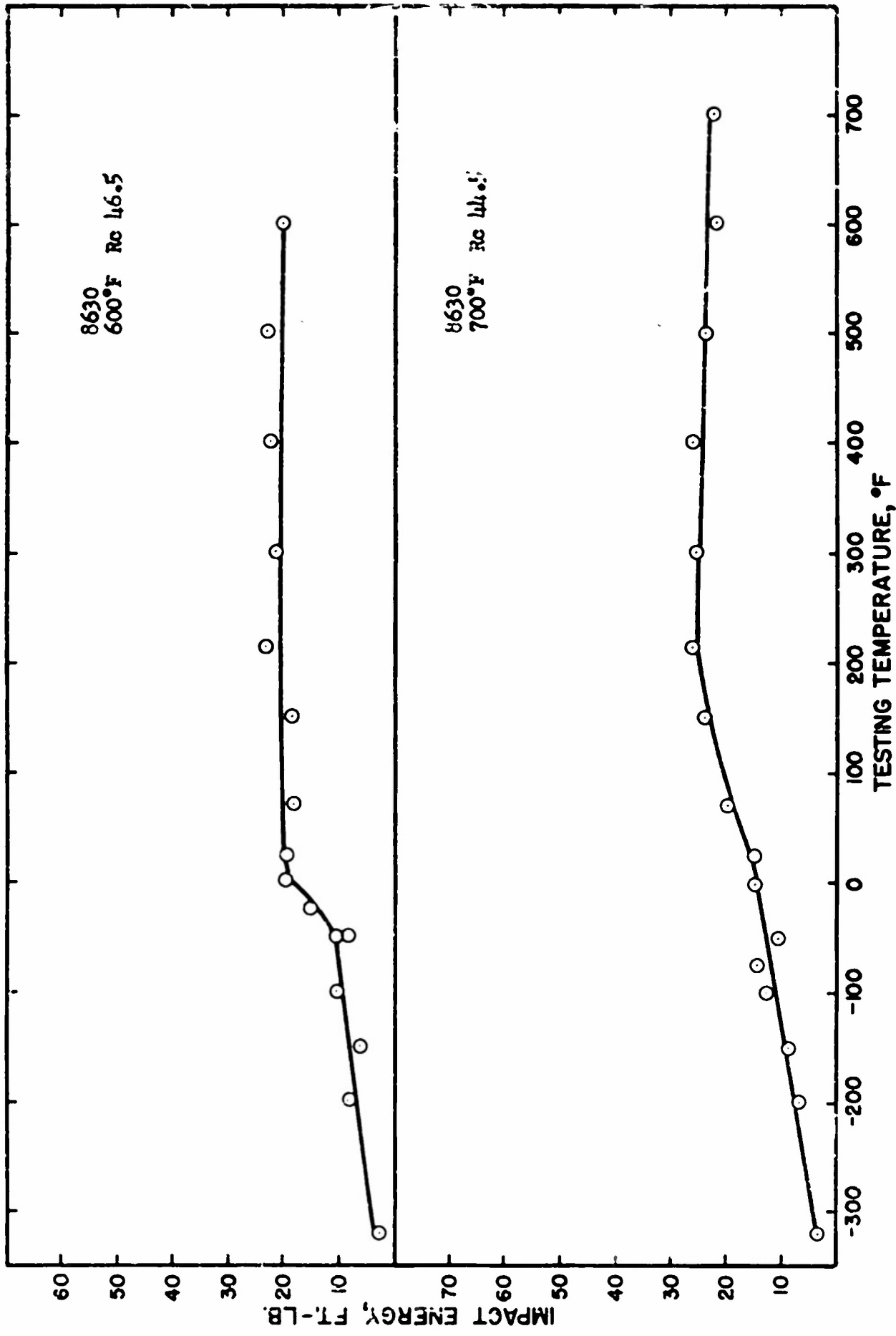


Fig. 94 - App. I

Heat 2820, laboratory fine grain 8630; quenched in oil after 30 minutes at 1575°F; tempered for one hour at temperature indicated in graph and water quenched.

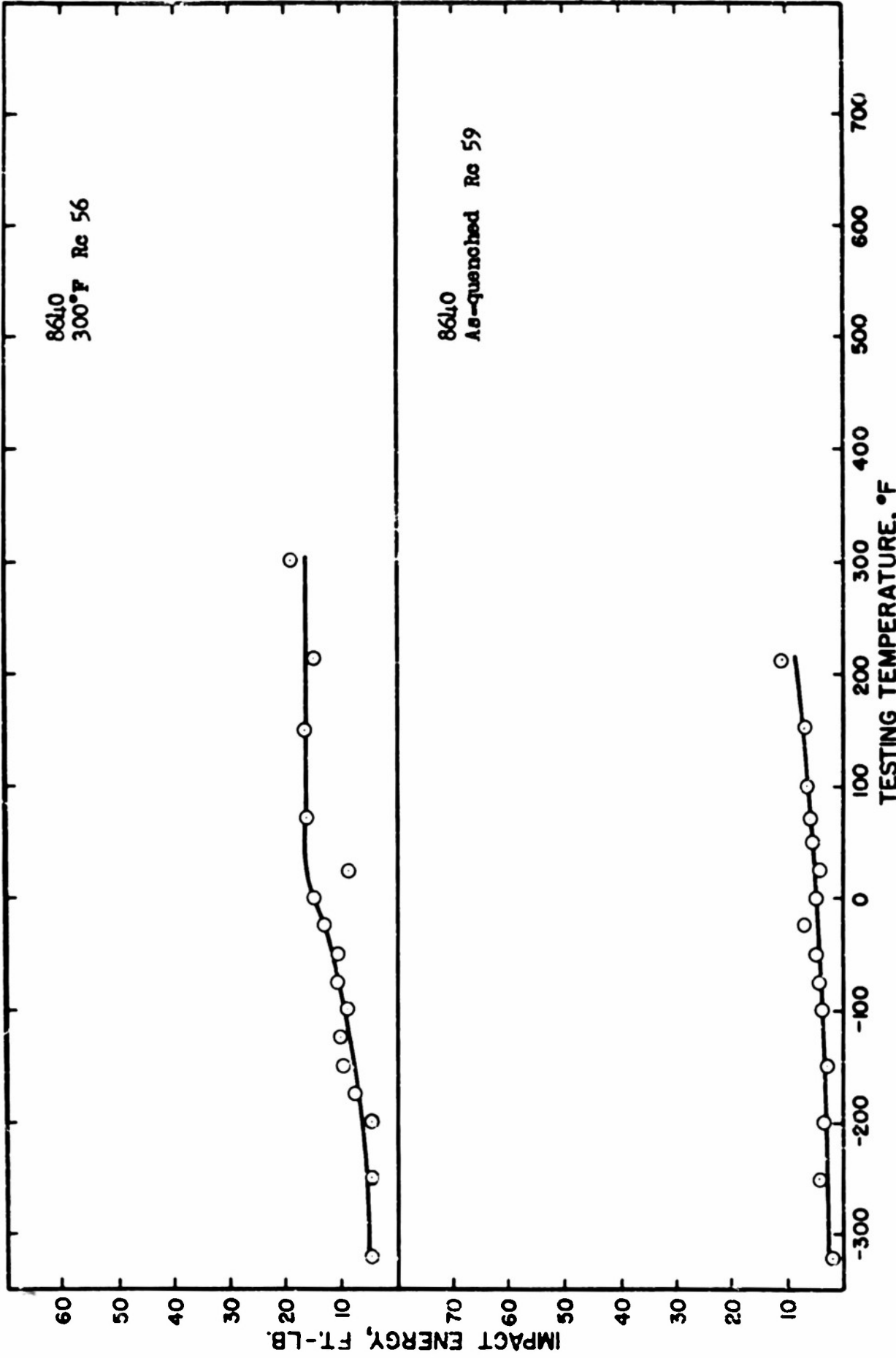


Fig. 95 - App. I

Heat N, laboratory fine grain 8640; quenched in oil after 30 minutes at 1550°F; tempered for one hour at temperature indicated in graph and water quenched.

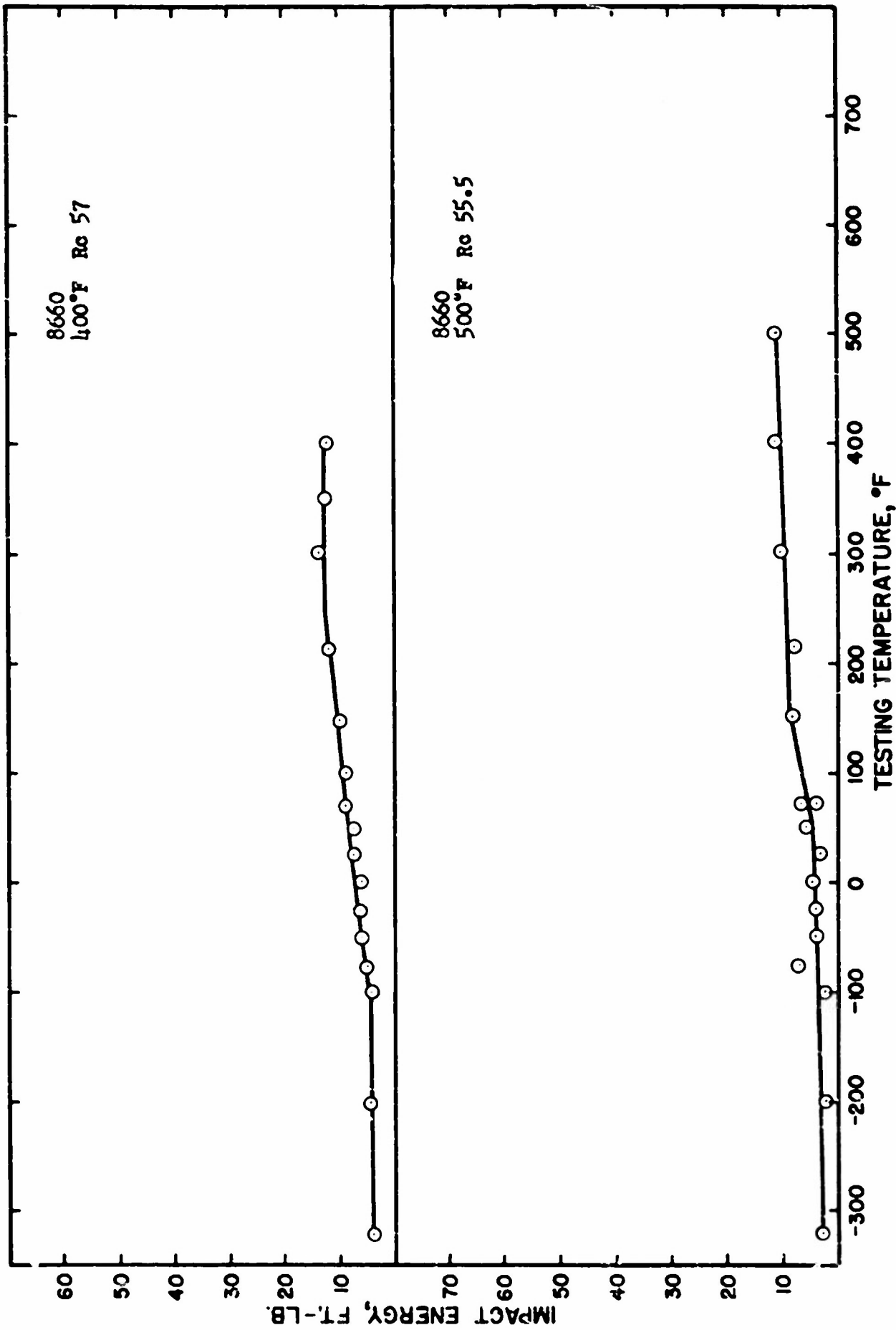


Fig. 96 - App. I

Heat 2928, laboratory fine grain 8660; quenched in oil after 30 minutes at 1475°F; tempered for one hour at temperature indicated in graph and water quenched.

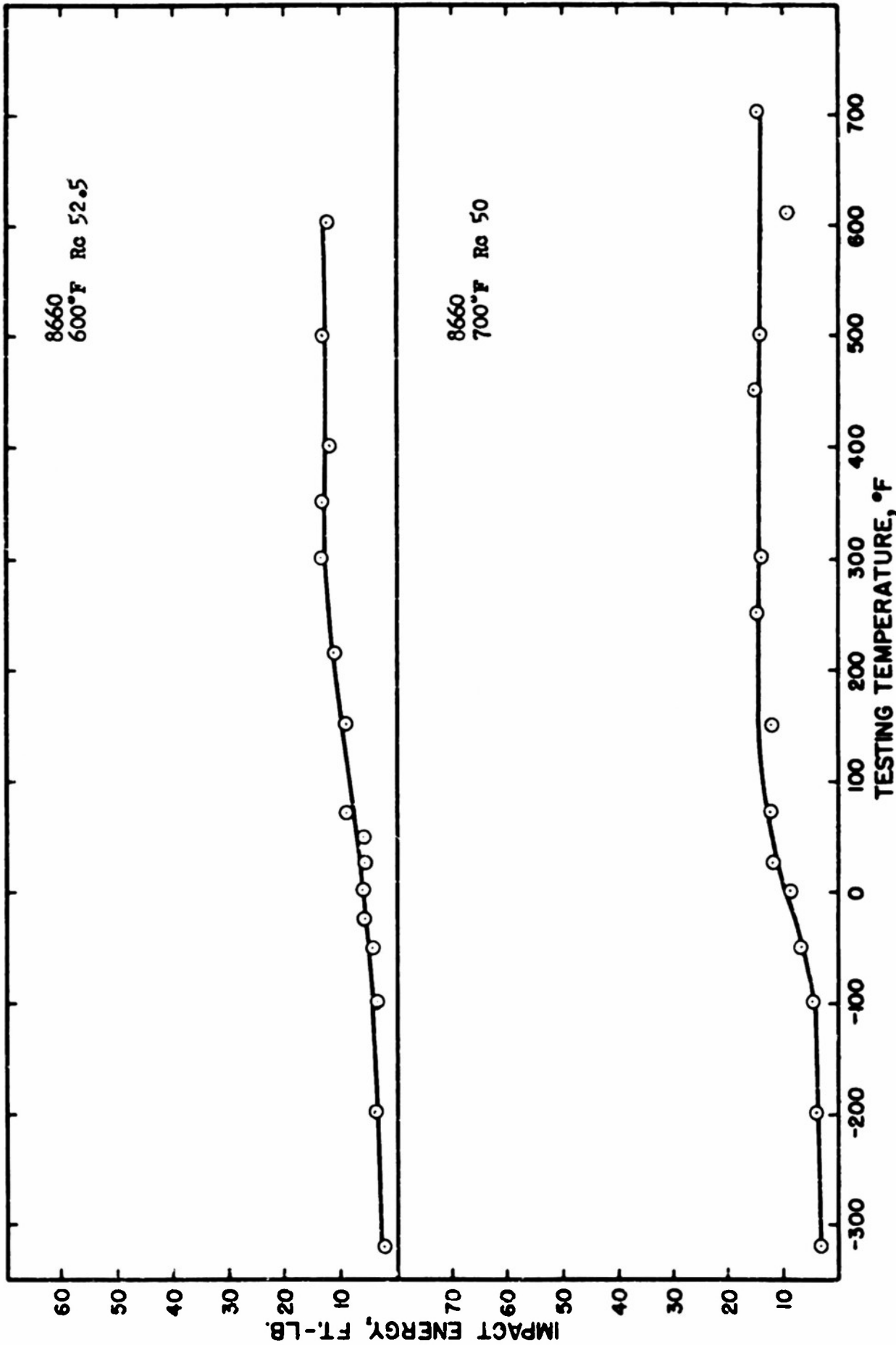


Fig. 97 - App. I

Heat 2928, laboratory fine grain 8660; quenched in oil after 30 minutes at 1475°F; tempered for one hour at temperature indicated in graph and water quenched.

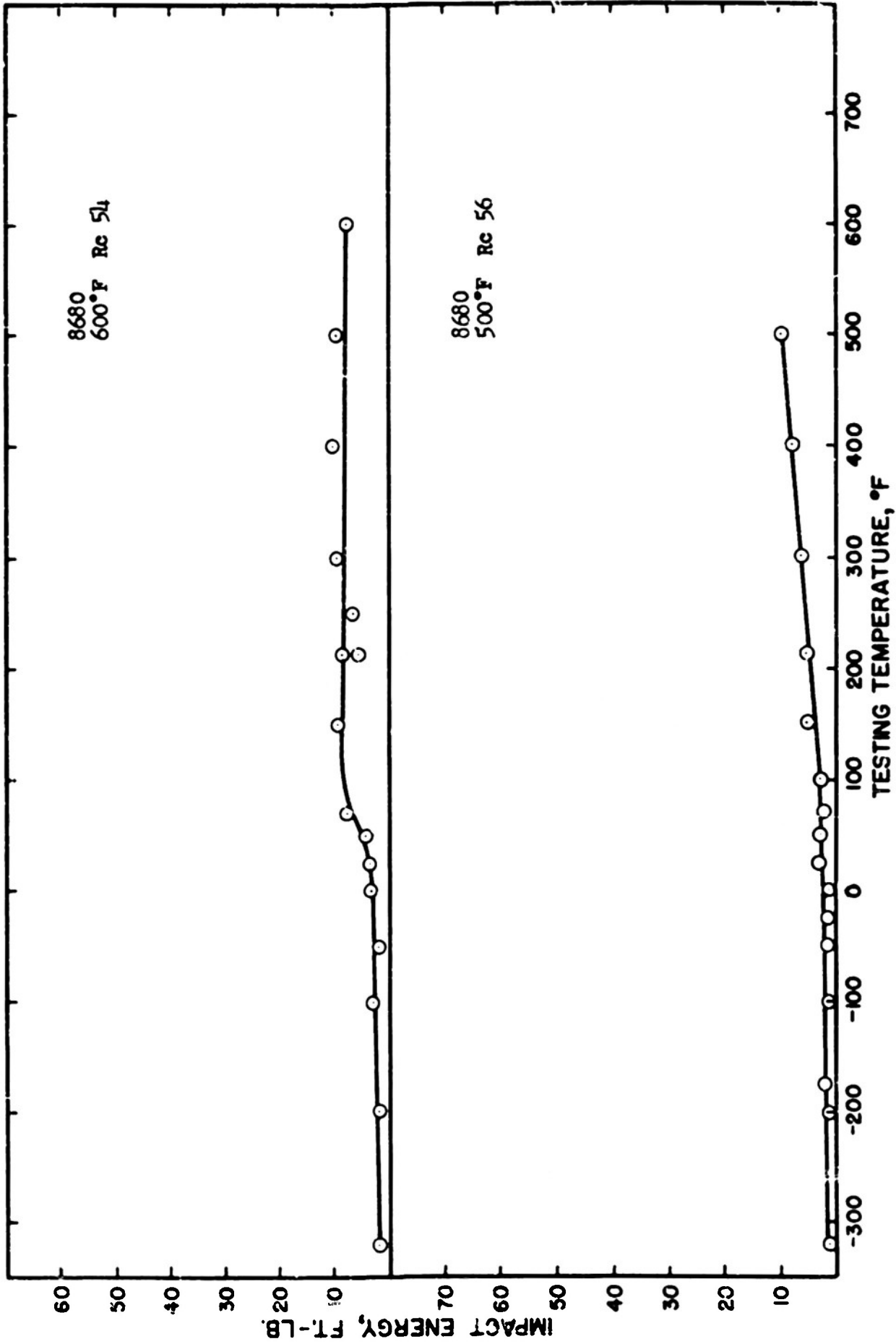


Fig. 98 - App. I

Heat 2817, Laboratory fine grain 8680; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.

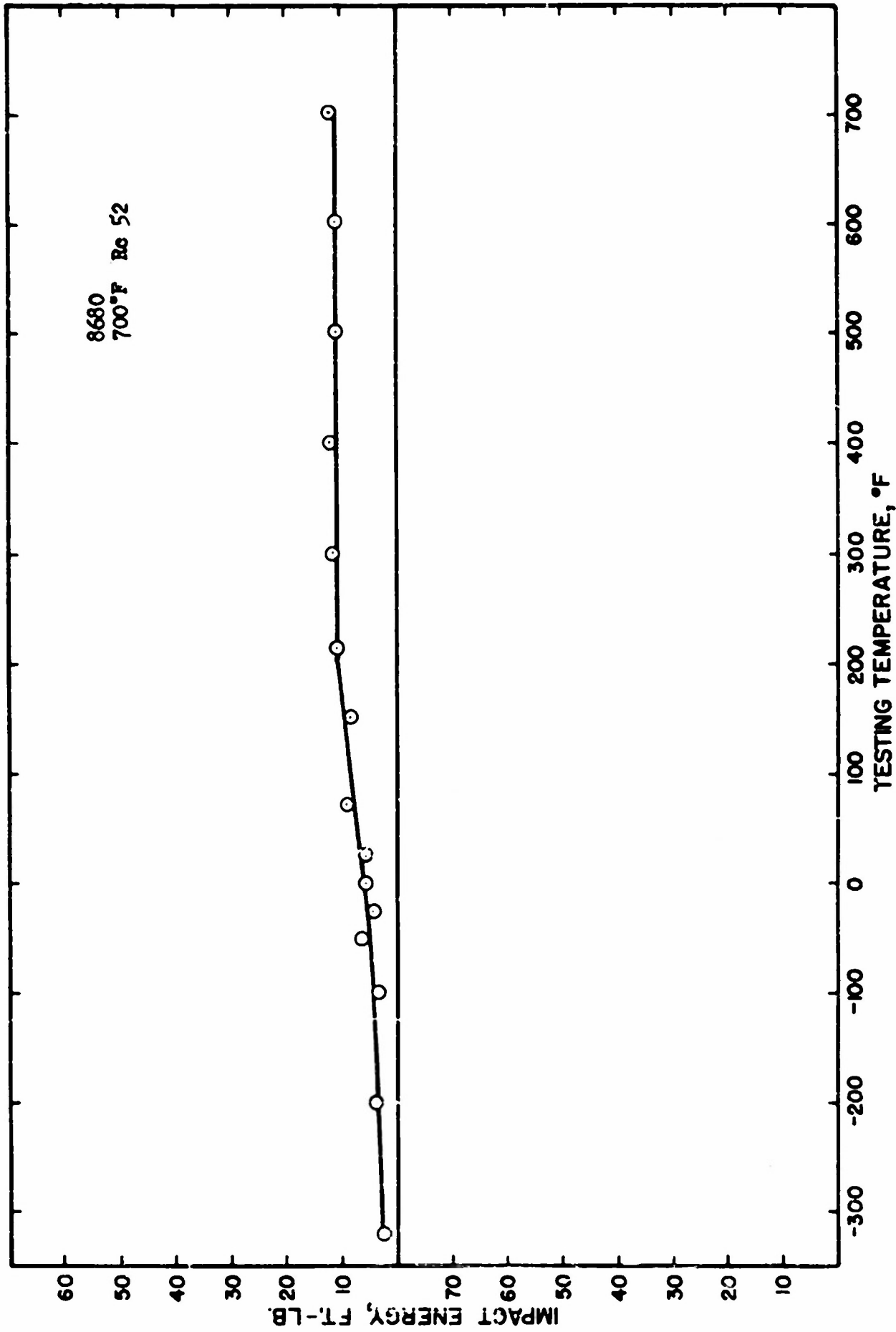


Fig. 99 - App. I

Heat 2817, laboratory fine grain 8680; quenched in oil after 30 minutes at 1450°F; tempered for one hour at temperature indicated in graph and water quenched.