WADC TECHNICAL REPORT 56-395
PART I.
ASTIA DOCUMENT No. AD 110637

DESIGN PROPERTIES OF HIGH STRENGTH STEELS IN THE PRESENCE OF STRESS CONCENTRATIONS

Part I. Dependence of Tension and Notch-Tension Properties of High-Strength Steels on a Number of Factors

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DECEMBER 1956

MATERIALS LABORATORY
CONTRACT No. AF 33(616)-2362, S/A 4(56-445)
PROJECT No. 7360

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
600 - February 1957

FOREWORD

This report was prepared by Syracuse University under USAF Contract No. AF 33(616)-2362, S/A 4(56-445). The contract was initiated under Project No. 7360, "Materials Analysis and Evaluation Techniques," Task No. 73605, "Design and Evaluation Data for Structural Metals". The project was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. A. W. Brisbane as project engineer. This work was performed in the period between September 1, 1955 and August 31, 1956.

ABSTRACT

In this report are presented the results of tension and notch-tension tests performed on hot rolled sections from commercial, electric furnace heats of 4340, V-Mod. 4330, 98B40, Tricent (Inco), Super Hy-Tuf, Hy-Tuf and Super TM-2 steels. Tension tests were conducted on 0.28 in. dia. specimens. An exception was a single test completed on a smooth 0.9 in. dia. 4340 steel specimen in order to examine the effect of section size on the tension properties of this steel. Notch-tension tests were performed on 0.3, 0.5 and 0.9 in. dia. specimens that were heat treated to strength levels ranging between 180,000 and 300,000 psi approximately. These specimens were provided with notches leading to stress-concentration factors, K, of 3, 5 and 10. In both instances (tension and notch-tension tests) longitudinal and transverse specimens were examined. Furthermore, information from the literature pertaining to the effects of as-processed section size is considered and evaluated.

In general, the tensile strength was found to be independent of the specimen orientation, but to decrease gradually with increase in the specimen size. The ductility of smooth specimens, however, was observed to depend on both specimen orientation and specimen size.

The notch strength decreased with increase in stress concentration, specimen diameter and as-processed section size. It also decreased as the specimen orientation was changed from longitudinal to transverse. These effects were pronounced at high strength levels and diminished, with decrease in the tensile strength, to insignificant values at strength levels below 200,000 psi.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
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INTRODUCTION**

The present design trends in the aircraft industry, leading to a high strength-to-weight ratio, necessitate extensive testing of aircraft steels that are heat treated to strength levels ranging between 200,000 and 300,000 psi. Previous investigations (1 - 6)* have demonstrated that steels heat treated to such high strength values are subject to design criteria which, for the most part, are different from those applicable at lower strength levels. The work presented in this report, therefore, was aimed at examining the strength properties of such high strength steels when subjected to a variety of testing and loading conditions.

The test data presented and discussed in this report complement the test results presented in a previous report (6). This report deals with the static tension properties of smooth and notched specimens.

The effects of numerous variables on the tension properties of high-strength steels were again examined. The studies included an evaluation of the effects of a) testing direction, b) as-tested section size, c) notch sharpness or stress concentration, d) strength level or tempering temperature, and e) steel composition.

In regard to the as-tested section size the previous investigation revealed that increasing the size of the notch-tension specimen from 0.3 to 0.5 in. dia. resulted in an appreciable decrease in the notch strength which varied considerably from steel to steel (6). In the present work notch-tension specimens up to 0.9 in. dia. were studied in order to establish more definitely some of the effects observed previously.

Furthermore, the strength level was extended to include one value below 200,000 psi for some steels, in order to establish with certainty some of the transitions that occur in the notch sensitivity when the strength level is changed from above to below 200,000 psi. The strength range examined here generally extended from approximately 180,000 to 300,000 psi.

The specimen dimensions were appropriately scaled to yield the same stress concentration factors used in the previous investigation, namely, K = 3, 5 and 10. For all testing conditions involved in this program specimens were oriented both parallel (longitudinal) and perpendicular (transverse) to the direction of rolling. The seven steels tested were: 4340, V-Mod. 4330, 98B40, Tricent (Inco), Super Hy-Tuf, Hy-Tuf and Super TM-2.

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*Numbers in parentheses pertain to the bibliography appended to the end of this report.

**Manuscript released by authors August 17, 1956 for publication as a WADC Technical Report.

EXPERIMENTAL PROCEDURE

1. Materials:

The steels examined in this investigation were hot rolled sections from commercial electric-furnace heats. The chemical analyses and section sizes of these steels are presented in Table I.

2. Test Specimen:

The tension and notch-tension specimens used in this investigation are presented in Figure 1. These were rough machined to 0.015 inch oversize on each surface and were finished after heat treatment. Smooth specimens were finish ground, while notches were machined by means of a properly ground carbide tool.

In the previous investigation (6) the position of the specimen in the steel section was found to produce an insignificant effect on the properties. For this reason the 0.3 and 0.5 in. dia. specimens were randomly located in the steel section with no attention being paid to their exact position in the cross section. The location of the 0.9 in. dia. specimen was 3/4 to 1-1/2 inch and zero to 1-1/2 inch from the center of the bar for the longitudinal (symbol L) and transverse (symbol T) directions respectively.

The specimens were heated to the recommended austenitizing temperature for each steel. The 0.3 and 0.5 in. dia. specimens were maintained at this temperature for a period of one hour and the 0.9 in. dia. specimens for a period of two hours. The specimens were oil quenched and tempered for a period of four hours and then air cooled.

3. Tension and Notch Tension Tests:

The tension specimens used in this program are illustrated in Figures 1(a) and 1(b), and the notch tension specimens are shown in Figures 1(c), 1(d) and 1(e). Concentricity of loading was ensured, in all instances, by using the concentric fixtures previously described (6).

The smooth 0.9 in. dia. specimens, see Figure 1(b), were made to a rather short gage length, in order to allow determining both longitudinal and transverse properties. However, the small fillet radius which had to

TABLE I

COMPOSITION AND SIZE OF THE VARIOUS STEELS INVESTIGATED

Alloy	Size & Shape	Percent of Alloying Elements									
		C	Mn	P	S	Si	Ni	Cr	Mo	V	Cu
4340	4-1/4 in.rd.	0.41	0.79	0.013	0.016	0.31	1.83	0.77	0.23		
V-Mod. 4330	4 in. sq.	0.32	0.88	0.012	0.018	0.26	1.79	0.84	0.355	0.07	
98B40	4-1/2 in. rd.	0.46	0.79	0.017	0.017	0.35	0.86	0.81	0.19		
Tricent (Inco)	4-1/4 in. sq.	0.39	0.74	0.014	0.014	1.54	1.83	0.83	0.38	0.07	
Super Hy-Tuf	3 in. rd.	0.41	1.28	0.014	0.024	1.77		1.26	0.33	0.17	
Hy-Tuf	3 in. rd.	0.285	1.29	0.019	0.015	1.58	1.87	0.24	0.40		
Super TM-2	3 in. rd.	0.41	0.72	0.012	0.014	0.61	2.08	1.15	0.44		0.14

be used in connection with the concentric fixture resulted in failure of all transverse and of a few longitudinal specimens under the head, rather than in the cylindrical test section. A few preliminary longitudinal tests were also made on much larger specimens, having a cylindrical length of about 4 in., and stepped buttonheads of 2 and 3-1/8 in. dia., respectively, which fitted an available larger fixture.

The notch used in this study was of the 60-degree, 50-percent type, where the 50 percent represents the area removed by notching. Three different stress concentration factors were employed, namely, K = 3, 5 and 10. The radii at the notch root, corresponding to these stress-concentration factors, were computed by Neuber's theory according to Peterson (7) and are given in Table II. An optical comparator with 62.5 diameter magnification was used to measure the notch radii and the notch diameters before and after the test.

The tensile, 0.2% yield and notch strengths and ductility were obtained in the conventional manner.

TABLE II

STRESS-CONCENTRATION FACTORS AND CORRESPONDING NOTCH RADII FOR NOTCH-TENSILE SPECIMENS

D - in.	d - in.	r - in.	K
0.300	0.212	0.0110 0.0035 0.0008	3 5 10
0.500	0.353	0.0180 0.0060 0.0013	3 5 10
0.900	0.636	0.0342 0.0100 0.0023	3 5 10

D = unnotched diameter

d = notch diameter

r = notch root radius

EXPERIMENTAL RESULTS

A. Properties of 4340 Steel:

4340 steel was investigated in this program more thoroughly than the other steels and the results of these tests are, therefore, discussed in some detail. In this section, Section A, are emphasized the facts and relations which had not been definitely established in the previous study.

In general, the conclusions drawn from the tests on 4340 steel apply qualitatively to the other alloy steels investigated. Therefore, the individual properties for the remaining steels will be presented but not discussed in this section. Unexpected phenomena that were encountered will be pointed out, evaluated and compared in Section B.

1. Effects of Directionality on Tension Characteristics:

Figure 2 presents the tensile properties and hardness of 4340 steel* in both the longitudinal and transverse directions. The yield strength and tensile strength in both directions were the same. Regarding the reduction of area, it appears that the difference between longitudinal and transverse ductility is large and remains nearly constant at lower tempering temperatures. However, this directionality decreases considerably as the tempering temperature increases above a certain value. This temperature is about 900°F in the case of 4340, corresponding to a tensile strength of about 190,000 psi.

In general this conclusion is in agreement with earlier test data (4). However, there is not as yet sufficient information available to fully evaluate the dependence of this effect of directionality on 4340, or any other steel.

2. Effect of Section Size on Tension Characteristics:

The effect of section size on the properties of smooth specimens has not yet been investigated systematically. The tension data given in Figure 2 relate to specimens having a diameter of 0.28 inches. The results of tests on smooth 0.9 in. dia. 4340 steel test bars are given in Figure 3,

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*The fact that 4 hours tempering time was used at 1000°F but only 1 hour at the other temperatures has an insignificant effect on the test results.

with solid lines representing the trend lines for the 0.28 in. dia. section. Only the tensile strength and reduction of area (ductility) are plotted in this graph. The yield strength and elongation were also determined, but they aré not reported. Because of the short gage length, which was less than 1-1/2 diameters, the standard autographic extensometer could not be used and the yield-strength values determined by means of a less sensitive strain gage were found to scatter excessively. The elongation of the short gage length was generally considerably higher than that of the 0.28 in. dia. specimens, which related to 3/4 inch, or about 3 diameters; otherwise the elongation of the larger section followed the same trend as that of the smaller.

Figure 3 illustrates that the tensile strength of the two section sizes agreed, within the limits of accuracy. However, the ductility (reduction of area) is found to decrease, in most instances, by an amount of 10 ± 5 percent, as the section diameter increases from 0.28 to 0.9 in. Such an effect is in agreement with previous test data (8).

Furthermore, if the steel had been heat treated to a particularly high strength, the section-size effect is found to be considerably greater. For the case of 4340 steel, Figure 3 shows that one of the two tests yielded a very low ductility, while the other value was within the range mentioned above. As, however, several of the other steels investigated also exhibited extremely low ductility values for their highest strength levels, see Figures 16 and 17, such a section size effect appears definitely established.

Previous investigations show that certain low-alloy steels, when heat treated to a very high tensile strength, may already be brittle in the normal smaller test sections (4). The change in ductility with tempering temperature is generally rather abrupt, and large scattering is generally observed in the transition range. It appears from Figure 4, in which the ductility is plotted vs. tensile strength, and which incorporates some additional test data from previous tests on 4340 steel (8) (9), that an increase in the test section distinctly shifts the range of brittle failures to lower strength levels.

It is difficult to say whether this section-size effect is due to differences in structure, i.e., as-quenched section size, or due to a true (as-tested) section-size, or to a combination of both. The last assumption is the most probable, namely that the strength and ductility of large specimens are adversely affected both by metallurgical factors and by the probability of an increased number of flaws, as postulated by Weibull (10) and by Irwin (11).

3. Effects of Directionality on Notch Strength:

The notch strength of a heat-treated steel has been observed to depend upon the direction of loading relative to the fiber direction (5)(12).

This investigation supplies further data which are in general agreement with the results of the previous evidence.

The results presented in Figures 5 and 6 for 4340 steel indicate that specimens taken parallel to the direction of rolling (longitudinal) may possess a notch strength superior to that of specimens taken perpendicular to the direction of rolling (transverse), when heat treated to strength values above 200,000 psi. The notch strength of transverse specimens may be as much as 25% lower than that of longitudinal specimens.

The magnitude of this effect remains approximately constant for tempering temperatures between 400 and 700°F, see Figure 5. As the temperature further increases the transverse notch strength gradually approaches the longitudinal notch strength. After tempering at 1000°F only a slight difference between longitudinal and transverse notch strength is retained, if both the stress concentration is high and the test section is large. Under less severe conditions the maximum value of notch strength, i.e. about 1.5 times the tensile strength, which indicates insensitivity to notching (13), is usually reached.

However, it is evident from Figures 5 and 6 that the effect of tempering temperature is fundamentally different for longitudinal and transverse specimens. In either case, all curves for different specimen diameters and different stress concentrations represent practically one family of curves. These, however, are for the transverse specimens more nearly parallel than for the longitudinal specimens. The curves for the longitudinal specimens converge in a more pronounced manner, i.e. lead to earlier fading out of the notch sensitivity, as the tempering temperature increases.

This also means that the effects of the other two factors investigated, namely increasing section size and stress concentration, are very similar.

4. Effect of Section Size on Notch Strength:

Previous evidence indicates that even a small change in section size, namely from 0.3 to 0.5 inch in the diameter of the cylindrical section, considerably reduces the notch strength of a low-alloy steel, if heat treated to a high strength level (5) (6). Further work at Syracuse University on a Navy Bureau of Aeronautics contract reveals that the notch strength is progressively lowered as the section size further increases (15). In addition, the rate of this decrease was found to become smaller as the tensile strength was lowered, so that no effect of section size could be expected at a tensile strength below about 170,000 psi, for section diameters up to 1.1 inches. However, similar tests with specimens ranging in diameter from 0.3 to 0.75 inches (8) disclose only a size effect considerably smaller than that observed at Syracuse University.

The results obtained in this program fully confirm the results of the previous investigations at Syracuse University. The values of notch strength of 4340 steel for the three specimen sizes investigated are presented in Figure 5 as a function of tempering temperature. This graph clearly reveals the pronounced reduction in the notch strength of the high strength levels with increasing section size.

As the tempering temperature increases the section-size effect progressively decreases, as further illustrated in Figure 7. On tempering at 800°F, and particularly at 1000°F, only part of the conditions studied are still subject to a pronounced section-size effect.

This is explained by the fact that the lowering of strength due to increasing the section also depends upon the stress concentration and the direction of testing. For any particular temper, the strength curves appear to belong to a single family, e.g., the curve for longitudinal specimens having a high stress concentration is found to be practically identical to another one of a transverse specimen with a lower stress concentration. However, this relation changes considerably with increasing tempering temperature. At low temperatures, the stress-concentration effect is much larger than the directionality effect, while the reverse is true for high tempering temperatures.

The dependence of notch strength ratio* on the specimen diameter is illustrated in Figure 9 for both longitudinal and transverse specimens with a stress concentration, K = 10. Values for lower stress concentrations were generally found to respond in a manner similar to those of K = 10. The results presented in Figure 9 clearly reveal that the sensitivity to notching is enhanced with increase in the specimen diameter and decrease in the tempering temperature as discussed previously. Furthermore, this effect is observed to be more pronounced with transverse than with longitudinal specimens. However, both types of specimens (longitudinal and transverse) appear to belong to one single universal family of curves. In view of the large scattering of the test results usually encountered with transverse specimens, these curves were established entirely on the basis of longitudinal test values.

Figure 10 includes in addition to the present data some obtained in previous investigations for large as-tested sections (5), (6), (9). These illustrate the general agreement between the results of various studies of the notch strength of 4340 steel.

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*Notch strength ratio is the ratio of strength of notched to that of smooth specimens.

5. Effect of Stress Concentration:

Certain universal functions can be expected to relate the notch-strength ratio to other variables, as concluded from the results of a previous program (6). If, for instance, the notch strength ratio is plotted as a function of the stress concentration, it was found that all curves for longitudinal specimens presented one family, and all curves for transverse specimens another family.

The results of the added tests on 0.9 in. dia. specimens agree, in this respect, well with those previously reported for 0.3 and 0.5 in. dia. specimens. It is again clearly noted from Figure 11 that transverse specimens, in contrast to longitudinal specimens, remain notch sensitive at rather low strength levels.

As already apparent from the above discussion the 0.9 in. dia. specimens are considerably more notch sensitive than the smaller specimens. However, as long as the stress concentration is kept reasonably low, even 0.9 in. dia. specimens exhibit rather good notch strength properties, particularly in the longitudinal direction, up to strength levels of 280,000 psi, see also Figure 6.

6. Effect of As-Processed Section Size on Notch Strength:

No attempt was made in this program to investigate the effects associated with changes in the dimensions of the section from which the test specimens are machined. However, the data now available in the literature (5), (6), (12), (15) permit a more thorough evaluation of these effects than was possible before.

The results of notch tension tests on 0.3 and 0.5 in. dia. specimens derived from a number of sources are illustrated in Figure 11. This graph illustrates the dependence of the notch strength of 4340 steel specimens (longitudinal) having a stress concentration, $K \geq 10$ on the as-processed section size for both 0.3 and 0.5 in. dia. specimens. It is observed that the notch strength is appreciably lowered as the as-processed section size is changed from small sections (3/4 to 1-1/2 in. dia.) to large sections (2-3/4 to 12 in. dia.). Furthermore, this effect is observed to be insignificant at strength levels below 200,000 psi, and to increase as the strength level increases above 200,000 psi, the largest strength reduction occurring between 250,000 and 300,000 psi. These observations apply equally to both 0.3 and 0.5 in. dia. specimens.

The reduction in the notch strength due to the increase of specimen diameter from 0.3 and 0.5 inches has already been discussed in the previous paragraphs.

7. Presentation of Properties of Various Alloy Steels:

As previously mentioned, the trends established for 4340 steel apply equally well, in a qualitative manner, to the other alloy steels examined. Any deviations from the general trends will be examined and discussed in Section B of this report, which also compares, quantitatively, the differences that exist between the various steels. In this section, therefore, the results of tension and notch tension tests on V-Mod. 4330, 98B40, Tricent (Inco), Super Hy-Tuf, Hy-Tuf and Super TM-2 are presented in graph form and no discussion of their performance is advanced.

The tensile characteristics of these alloys, for 0.28 in. dia. specimens, are presented as functions of the tempering temperature in Figures 13 to 15, and those for the 0.9 in. dia. specimens in Figures 16 and 17. The notch strength is presented as a function of the tempering temperature in Figures 18 to 23.

B. Comparison of Various Alloy Steels:

In this section the performance of the various alloy steels is discussed in more detail. Furthermore, their tension and notch tension characteristics are compared and evaluated on the basis of their longitudinal properties. Regarding the transverse properties, the data obtained in this investigation, as well as those available in the literature, still comprise a rather insignificant volume of information when compared to that relating to longitudinal properties. In addition, it is generally observed that transverse test values depend upon certain factors and scatter considerably more than longitudinal values and that, therefore, their reliability is frequently not sufficient to establish definitely a particular effect.

1. General Remarks Regarding the Performance of Various Alloy Steels:

The modified 4330 steel is characterized by a low carbon content and slightly higher alloying content than 4340. This combination, among other results, promotes high ductility, particularly in the transverse direction, Figure 13. On tempering at 1000°F to a strength level of 175,000 psi the transverse reduction of area reaches a value of more than one-half of the longitudinal value. At this low strength level the effects of both the section size and the stress concentration have faded out for longitudinal specimens, but they retain a considerable magnitude in the transverse direction, Figure 18.

Tempering of the 98B40 steel at 900°F for 4 hours resulted in a tensile strength of 195,000 psi. At this strength the transverse compared to the longitudinal ductility is still low, Figure 13. Regarding the notch strength of 98B40 steel in the transverse direction, it was observed that the 0.9 in. dia. specimen yielded, on the average, only slightly different but considerably more consistent values than the 0.5 in. dia. specimens previously studied (6). It appears, therefore, that the section length used in the previous 0.5 in. dia. tests was inferior regarding its transverse notch strength than the section length used in the complementary 0.9 in. dia. tests. It is interesting to note that the longitudinal notch strength of 98B40 steel for the 0.5 in. dia. specimen (reported previously (6)) was found to be rather close to that of the 0.9 and much below that of the 0.3 in. dia. specimens, see Figure 19. When compared to the behavior of other alloy steels in this respect it is found that the longitudinal 0.5 in dia. values of the 98B40 steel are rather low. This leads to the conclusion that low transverse properties also adversely affect the longitudinal properties, in the presence of stress concentrations.

The results presented for Super Hy-Tuf in Figure 21 indicate an effect of specimen size contrary to the trends exhibited by all other steels: for the majority of conditions examined the 0.9 in. dia. specimens yielded higher notch strength than the 0.5 in. dia. specimens. The tentative explanation offered for this behavior is that Super Hy-Tuf appears to respond to longer tempering time much more favorably than the other steels examined.

The results of notch-tension tests on Tricent (Inco), Hy-Tuf and Super TM-2 steels, Figures 20, 22 and 23 respectively, indicate trends very similar to those discussed for 4340 steel.

2. Effects of Directionality and Section Size on Various Alloy Steels:

The primary effect of directionality on the characteristics of smooth tension specimens (Figures 13 to 15) is that the transverse ductility is generally lower than the longitudinal. All steels investigated exhibited a very large such effect.

The directionality effect disclosed by notch tests in Figures 18 to 23, however, differed greatly for the different steels, without any definite relation to the smooth-bar ductility. In one instance, namely, for Tricent (Inco), the transverse notch strength was only slightly lower than the longitudinal, roughly 20,000 psi, on the average, while for another alloy, namely Super TM-2, this difference was much larger and over 100,000 psi for the 0.9 in. dia. specimens. In most instances, the directionality effect increased as the section diameter became larger.

The tension-test data for the smooth 0.9 in. dia. specimens, Figures 16 and 17, reveal that all the steels containing 0.4 percent or more carbon apparently retained a comparatively high ductility in this section size to a strength of well over 250,000 psi. On the other hand, 98B40 steel exhibited a very low ductility when heat treated to a strength of about 290,000 psi. Furthermore, V-Mod. 4330 steel already developed rather pronounced brittleness at a strength of 265,000 psi obtained by tempering at 250°F. This inferiority of the lower carbon steel is somewhat surprising and further tests in this respect are indicated.

Regarding the dependence of the notch strength upon the section size, several of the alloy steels revealed a trend which may be considered normal, while several other steels behaved in an extremely irregular manner. Normal performance is exemplified by 4340, Figure 5, and also by Tricent (Inco), Figure 20, possibly Hy-Tuf, Figure 22 and Super TM-2, Figure 23. The notch strength of these steels was reduced, on the average, by the same amount when increasing the diameter from 0.3 to 0.5 in., as from 0.5 to 0.9 in. Examination of the behavior of Tricent, Hy-Tuf and Super TM-2 according to the trends established for 4340 steel in Figure 9 revealed very good agreement. V-Mod. 4330 steel, Figure 18, deviated slightly from this trend in that the notch strength of 0.5 in. dia. specimens was distinctly closer to the 0.3 in. dia. than to the 0.9 in. dia. values. In the case of 98B40 steel, Figure 19, however, the 0.5 in. dia. notch strength was, on the average, only slightly higher than that for the 0.9 in. dia. specimens. Finally, the 0.9 in. dia. notch strength of Super Hy-Tuf, Figure 21, was found, in four out of six tested conditions, to be higher than that of the 0.5 in. dia. specimens. The only one of the last three alloy steels mentioned that was thoroughly investigated is 98B40, and this steel was found to exhibit larger scattering of the 0.5 in. dia. values than was encountered under any other condition.

3. Tension Characteristics of Various Alloy Steels:

Figure 24 illustrates the yield strength and reduction of area of the various alloy steels as functions of their tensile strength. It can be seen that these steels can be grouped into two different categories.

The one group comprises 4340, V-Mod. 4330 and 98B40, Figure 24(a). Their yield strength is nearly the same up to a tensile strength of 200,000 psi. At higher tensile strength the yield strength, however, may differ considerably. The general trend apparent from Figure 24(a) has been previously established as an effect of the carbon content (4). The higher the carbon, the higher is the maximum yield strength. In the case of binary alloy steels (2300 and 5100 steels) quenched in oil, maximum yield strength values are obtained on tempering at about 500°F, and the values decrease slightly both at higher and at lower tempering temperatures. This fact, and the actual maximum values, for a given carbon content, are found here to be nearly the same for the complex alloy steels mentioned above. These steels are characterized by a low silicon content. The reduction of area of these steels is also a function of the carbon content, being high for low carbon contents and low for high carbon contents.

In the other group of steels, Figure 24(b), which all contain more than the normal amount of silicon, the yield strength follows a rather different trend. If steels of the two groups having about the same carbon content are compared, such as 4340 with Super Hy-Tuf, or V-Mod. 4330 with Hy-Tuf, it is noted that as the tensile strength increases up to a certain value, the second group develops a lower yield strength than the first group. At still higher strength levels, however, maximum yield strength values are reached which are distinctly higher and occur at higher tensile strength for alloys of the second group. At the same time, the reduction of area of the second group decreases with increasing silicon content, as well as with increasing carbon content.

4. Notch Strength of Various Alloy Steels:

From the large amount of notch strength data available only those in the longitudinal direction for the stress concentration, K = 10 are used here for a comparison of the properties of the different steels examined. Values for lower stress concentrations were generally observed to respond in the same manner as, but to be less sensitive to all variables than, those for the highest (K = 10) stress concentration.

An exception is the fact that transverse specimens respond to stress concentration fundamentally differently than longitudinal test bars. While the effect of many variables on the longitudinal notch strength becomes insignificant as the stress concentration decreases to K = 3, a considerable fraction of the notch sensitivity is usually retained at this stress concentration in the transverse direction.

Regarding the actual notch strength values in the transverse direction it appears premature to base a comparison and evaluation of different steels on this strength characteristic. The tests reported previously for 4340 (6) showed that these values considerably varied from heat to heat. They also depended upon the as-processed section size, and presumably also upon ingot size and other metallurgical variables. In addition, the data obtained for 98B40 indicate that transverse properties may materially change with the location of the particular section tested.

The notch strength of the various steels examined, as determined by tests on 0.3, 0.5 and 0.9 in. dia. specimens, is presented in Figure 25. The notch strength of the different steels is found to depend upon their tensile strength in different manners. Up to the maximum tensile strength obtainable with V-Mod. 4330 (250,000 to 270,000 psi) this steel is superior to the other steels studied. It is followed by 4340 as long as the tensile strength does not exceed about 250,000 psi. At a tensile strength of 270,000 psi or higher the two steels, Super TM-2 and Tricent (Inco), become superior to 4340. 98B40, Hy-Tuf and Super Hy-Tuf are throughout inferior to the previously mentioned steels.

This rating of the steels is based primarily on the results obtained with 0.3 in. dia. specimens. For the more extensively investigated steels, 4340, V-Mod. 4330 and 98B40, the rating remains the same when based on tests with larger sections. The results of the few such tests on the other steels are in fair agreement with those on 0.3 in. dia. specimens, considering the limits of accuracy.

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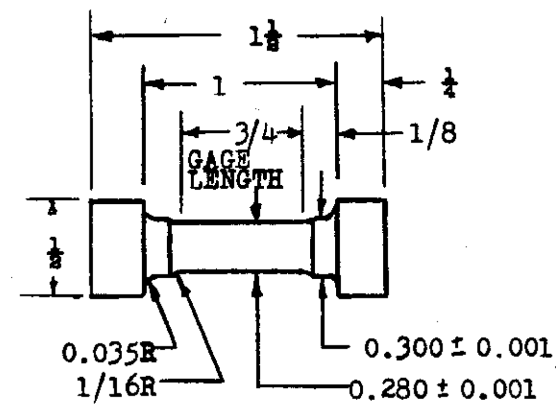
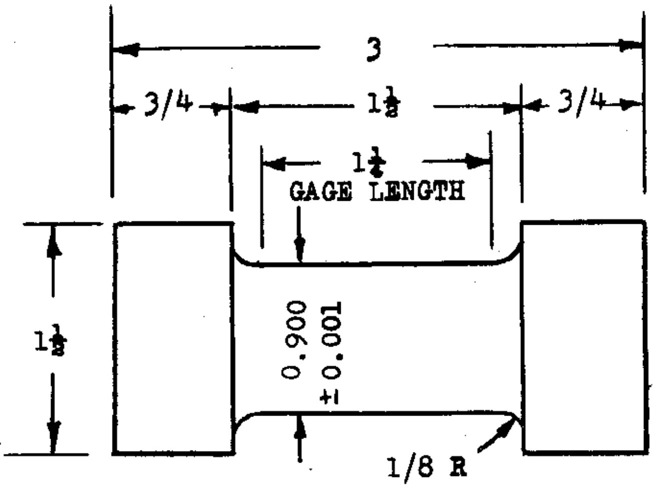
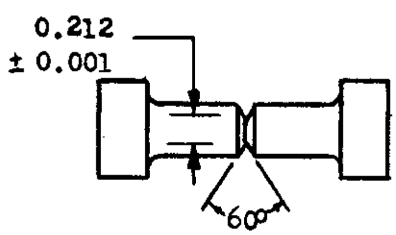


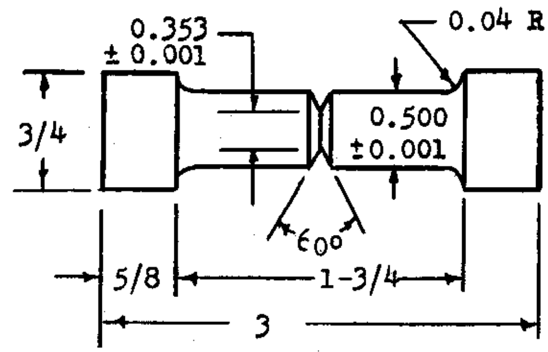
(a) 0.28 IN DIA. TENSION SPECIMEN



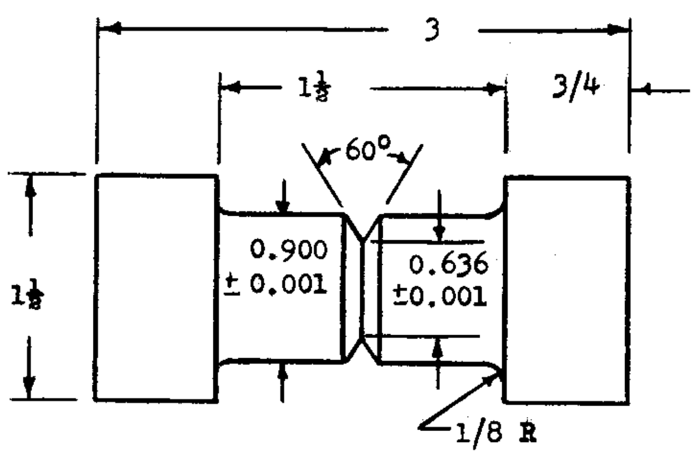
(b) 0.9 IN. DIA. TENSION SPECIMEN



(c) 0.3 IN DIA. NOTCH-TENSION SPECIMEN



(d) 0.5 IN. DIA. NOTCH-TENSION SPECIMEN



(e) 0.9 IN. DIA. NOTCH-TENSION SPECIMEN

FIG. 1 TEST SPECIMENS USED IN THIS PROGRAM.

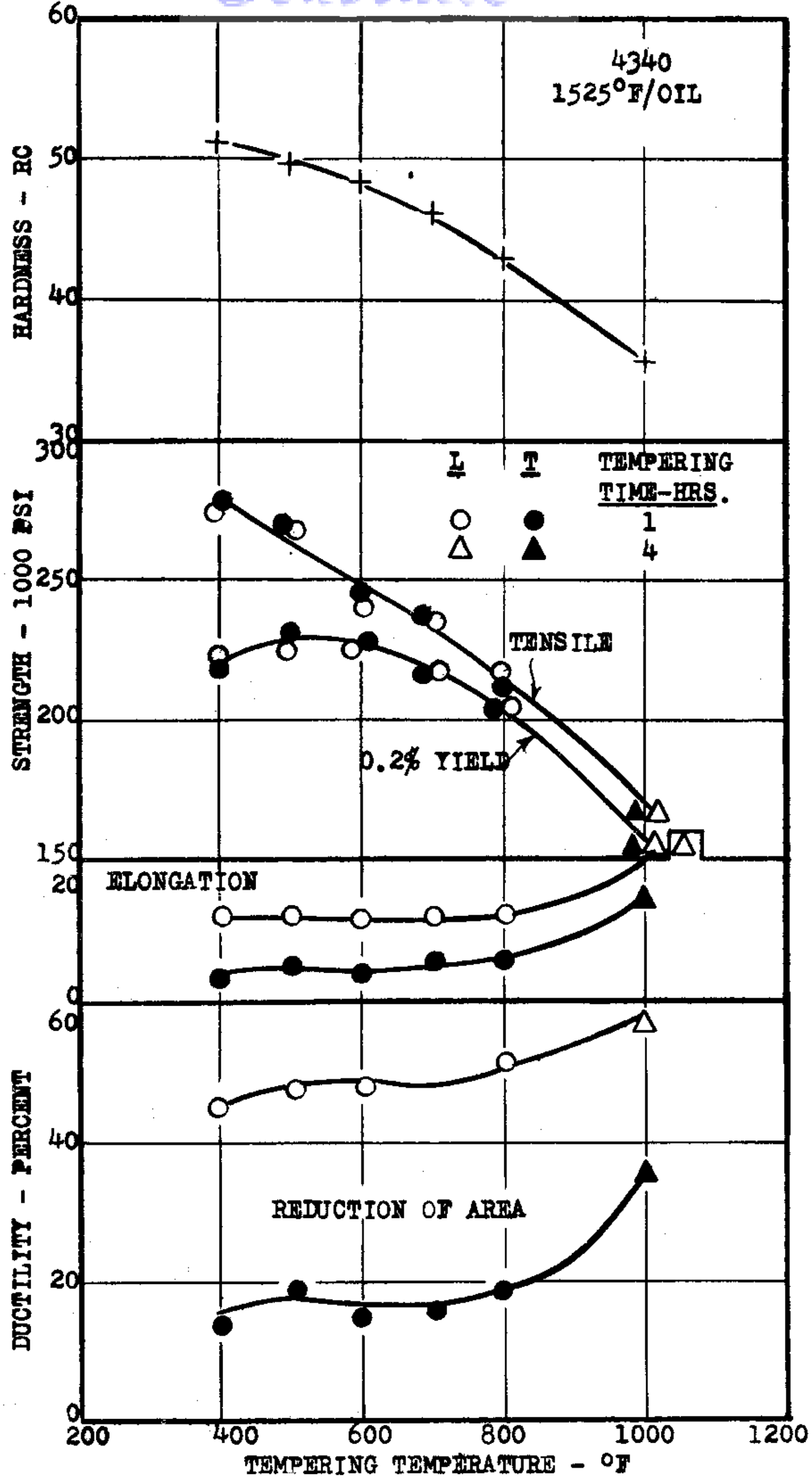


FIG. 2 HARDNESS, STRENGTH AND DUCTILITY OF 0.28 IN. DIA. 4340 STEEL SPECIMENS AS FUNCTIONS OF TEMPERING TEMPERATURE.

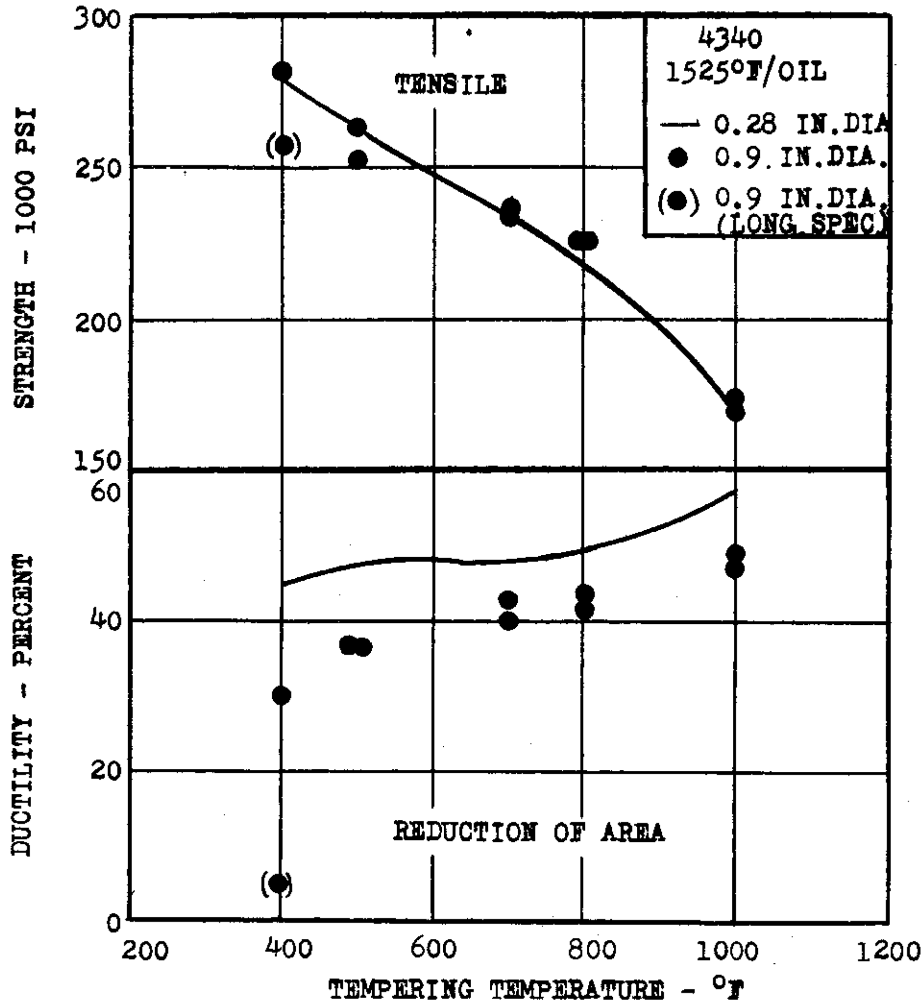


FIG. 3 STRENGTH AND DUCTILITY OF 4340 STEEL AS A FUNCTION OF TEMPERING TEMPERATURE FOR 0.9 IN. DIA. SPECIMENS.

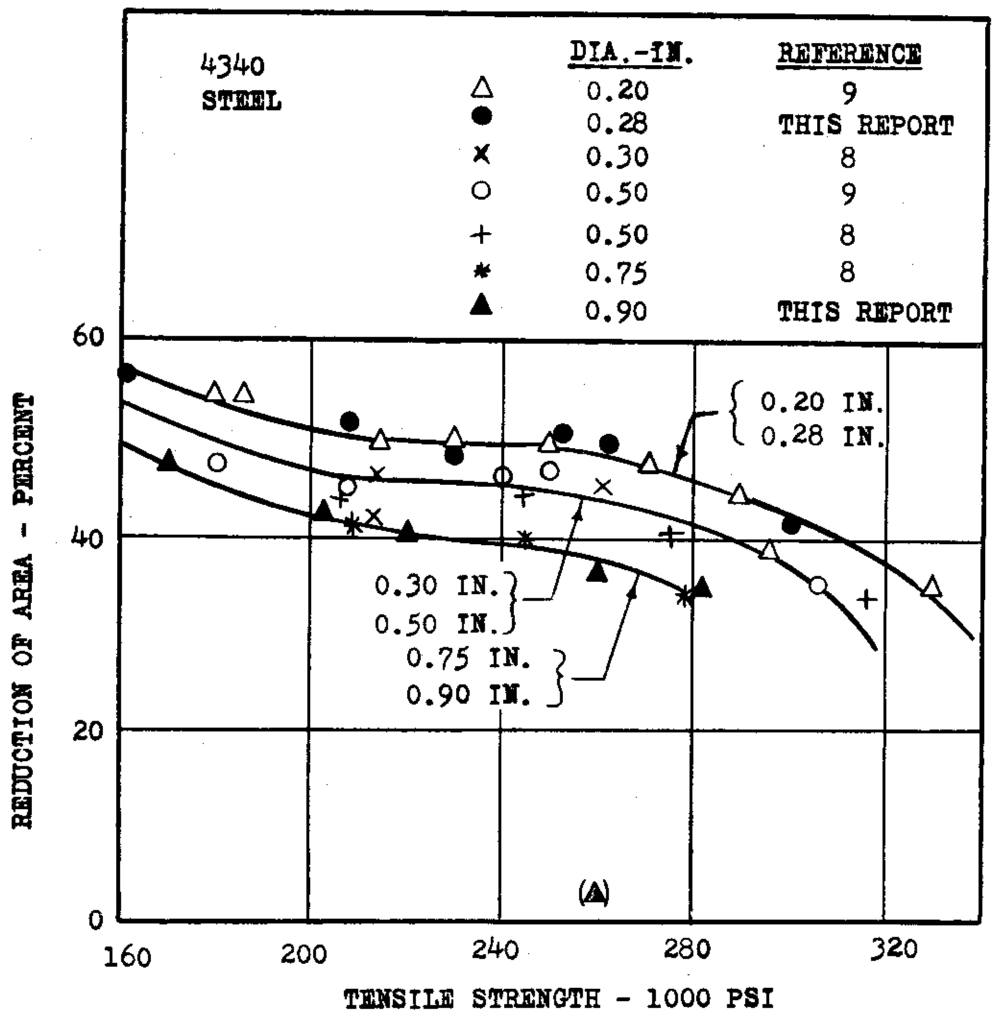


FIG. 4 RELATION BETWEEN TENSILE STRENGTH AND REDUCTION OF AREA FOR DIFFERENT TEST SECTIONS OF 4340 STEEL.

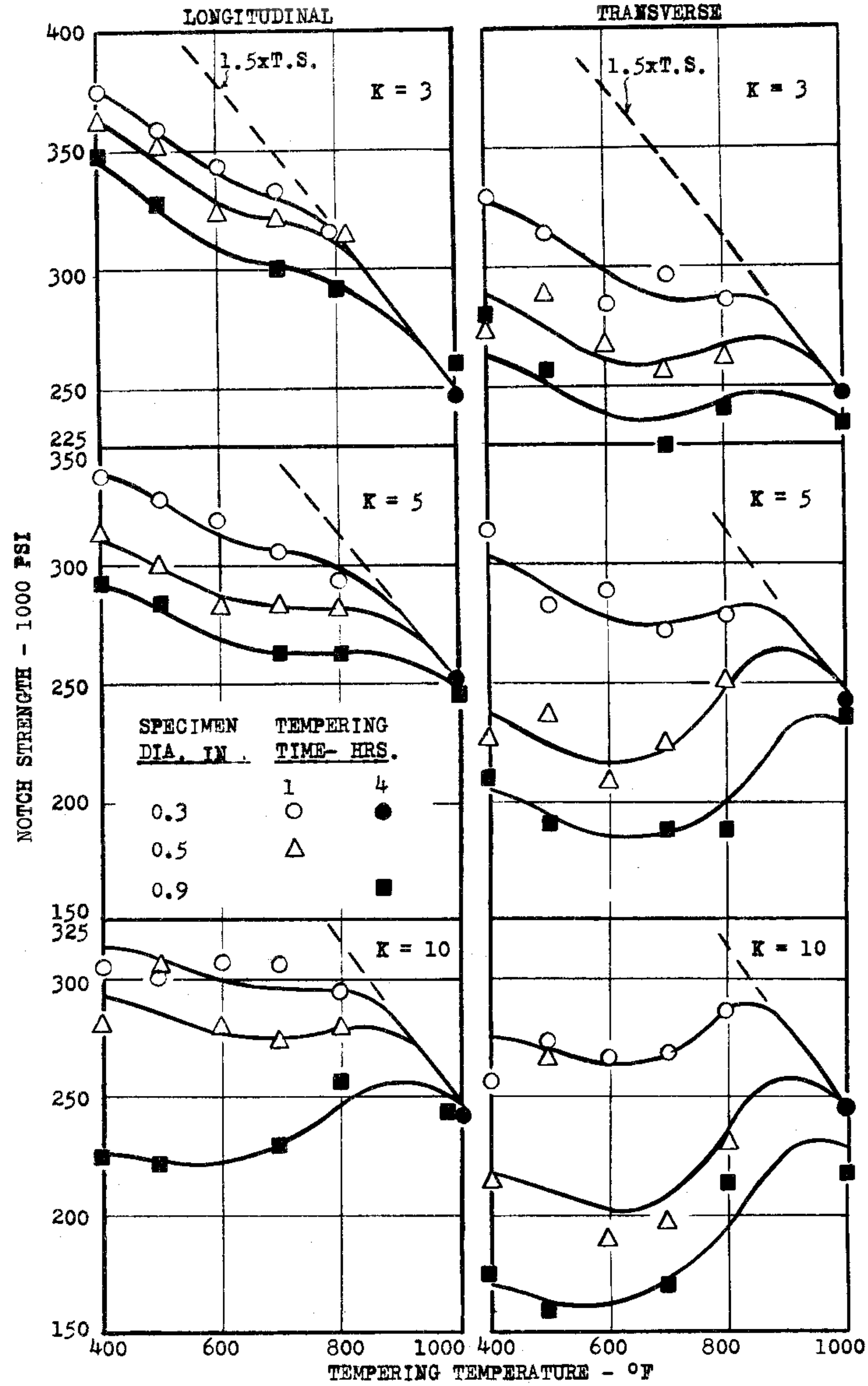


FIG. 5 NOTCH STRENGTH OF 4340 STEEL AS A FUNCTION OF TEMPERING TEMPERATURE WITH SPECIMEN DIAMETER AS PARAMETER.

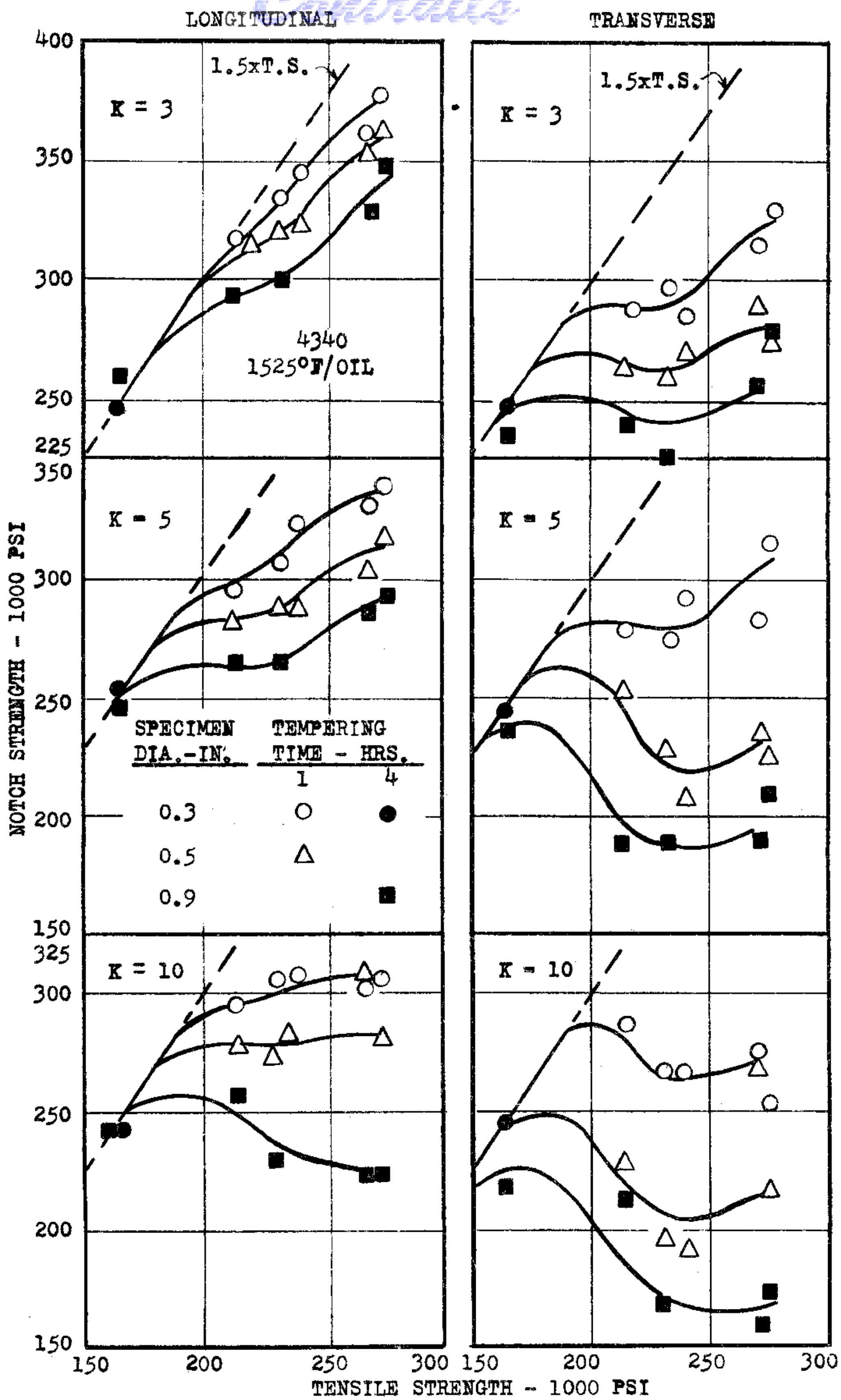


FIG. 6 NOTCH STRENGTH OF 4340 STEEL AS A FUNCTION OF TEMPERING TEMPERATURE WITH SPECIMEN DIAMETER AS PARAMETER.

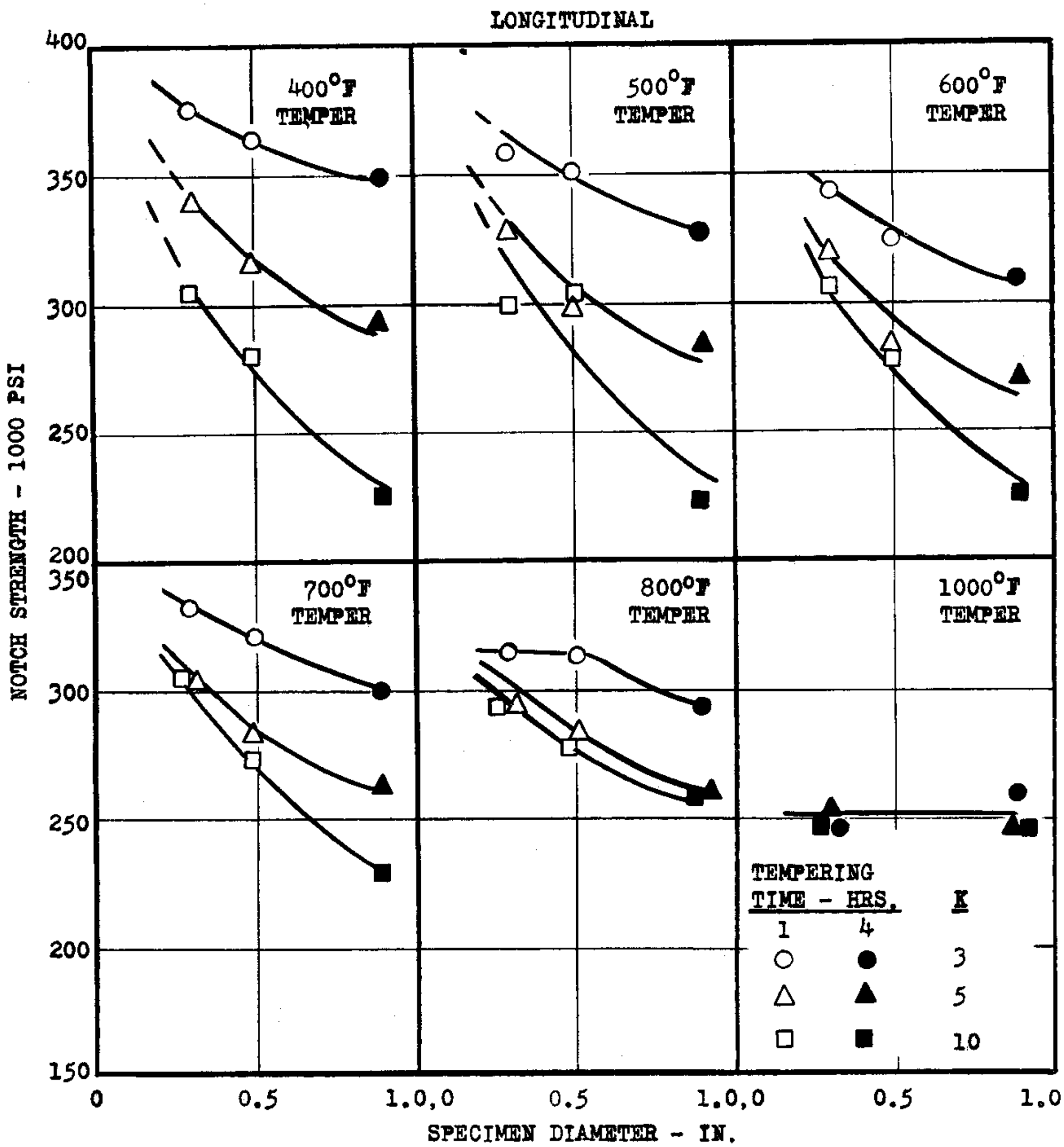


FIG. 7 EFFECT OF SPECIMEN DIAMETER ON NOTCH STRENGTH OF LONGITUDINAL 4340 STEEL SPECIMENS.

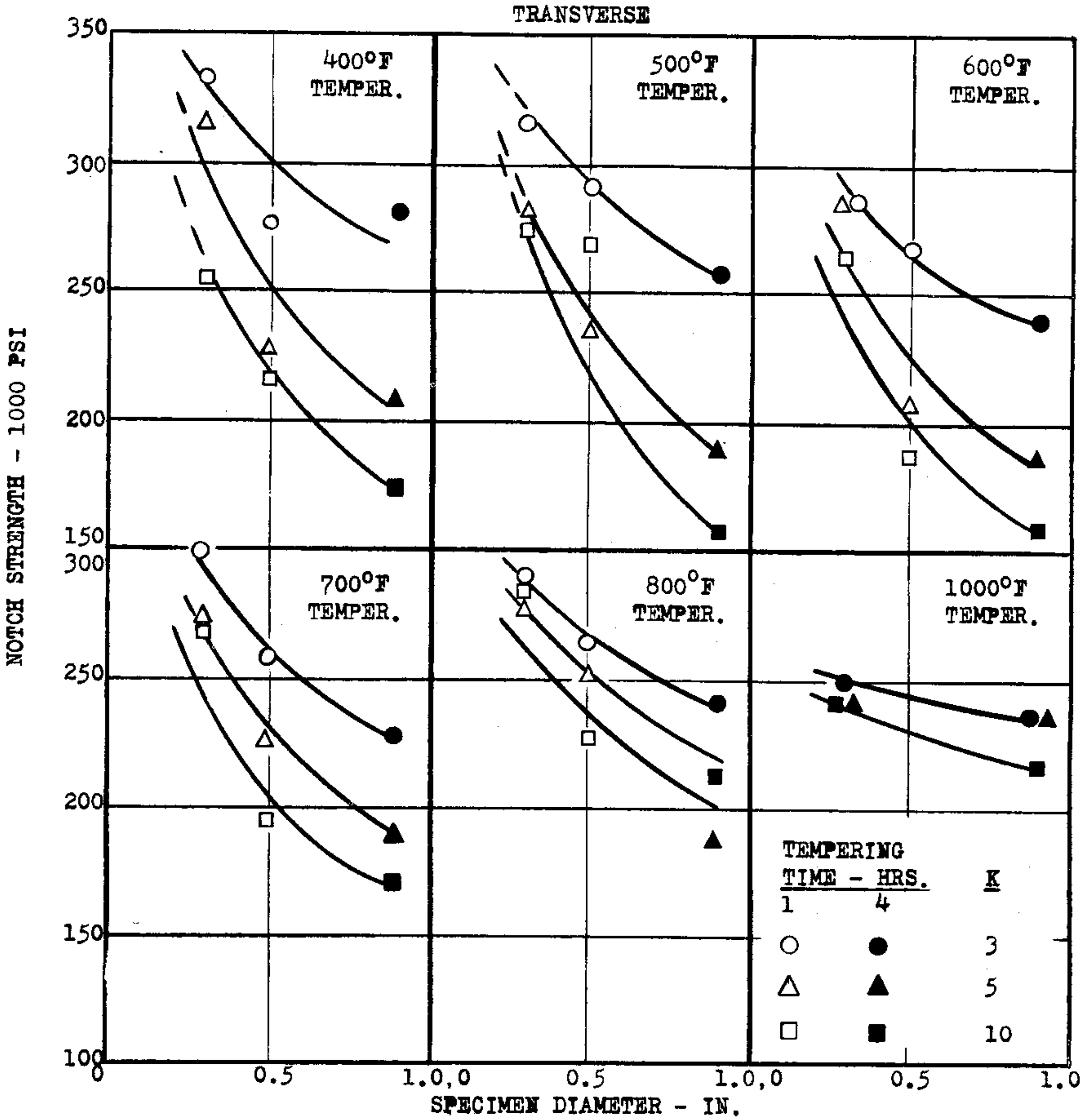


FIG. 8 EFFECT OF SPECIMEN DIAMETER ON NOTCH STRENGTH OF TRANSVERSE 4340 STEEL SPECIMENS.

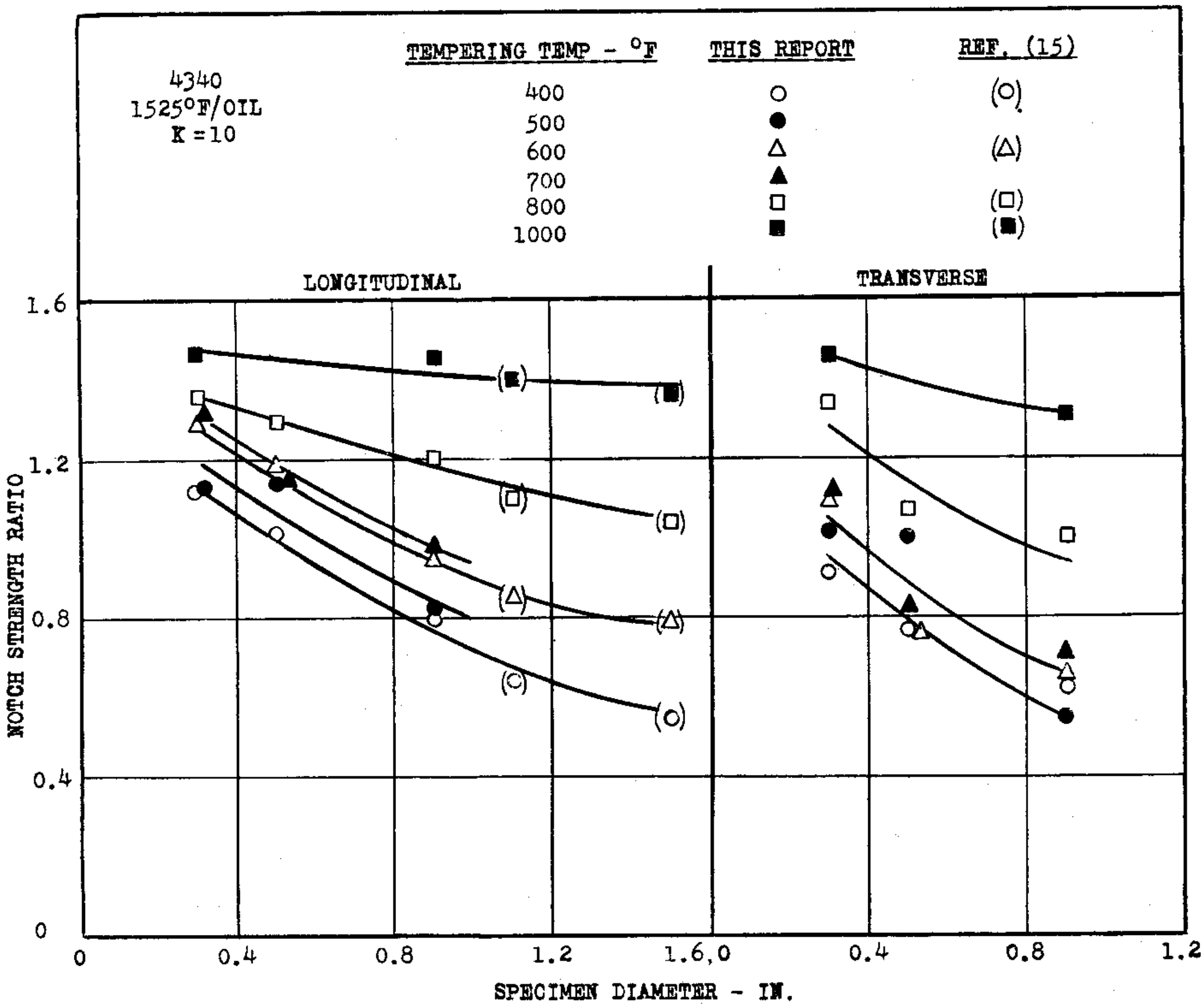


FIG. 9 NOTCH STRENGTH RATIO OF SHARPLY NOTCHED (K = 10) 4340 STEEL SPECIMENS AS A FUNCTION OF SPECIMEN DIAMETER.

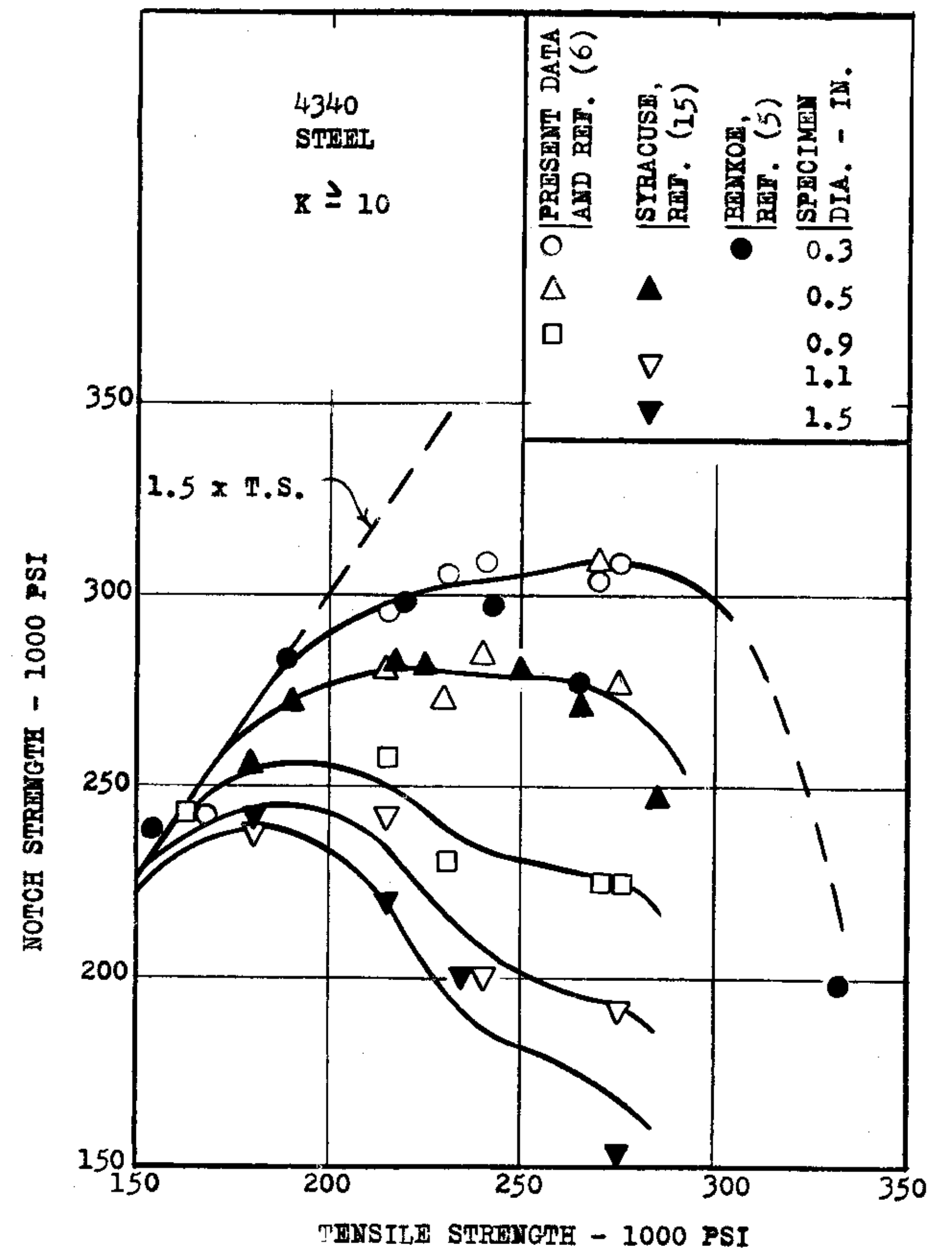


FIG. 10 NOTCH STRENGTH OF SHARPLY NOTCHED (K ≥ 10) 4340 STEEL SPECIMENS AS A FUNCTION OF TENSILE STRENGTH WITH SPECIMEN DIAMETER AS PARAMETER.

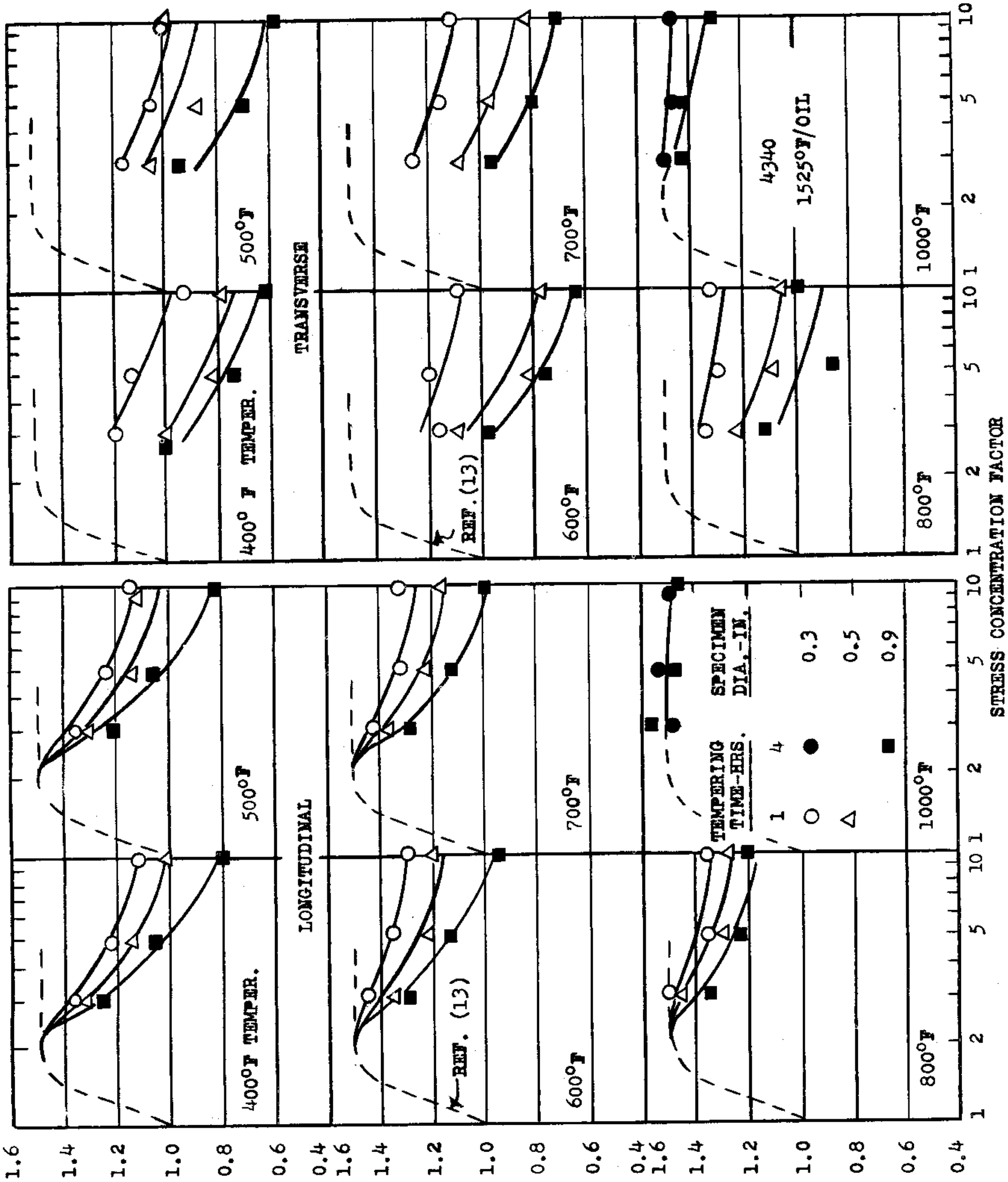


FIG. 11 DEPENDENCE OF NOTCH STRENGTH RATIO OF 4340 STEEL ON THE STRESS CONCENTRATION FACTOR.

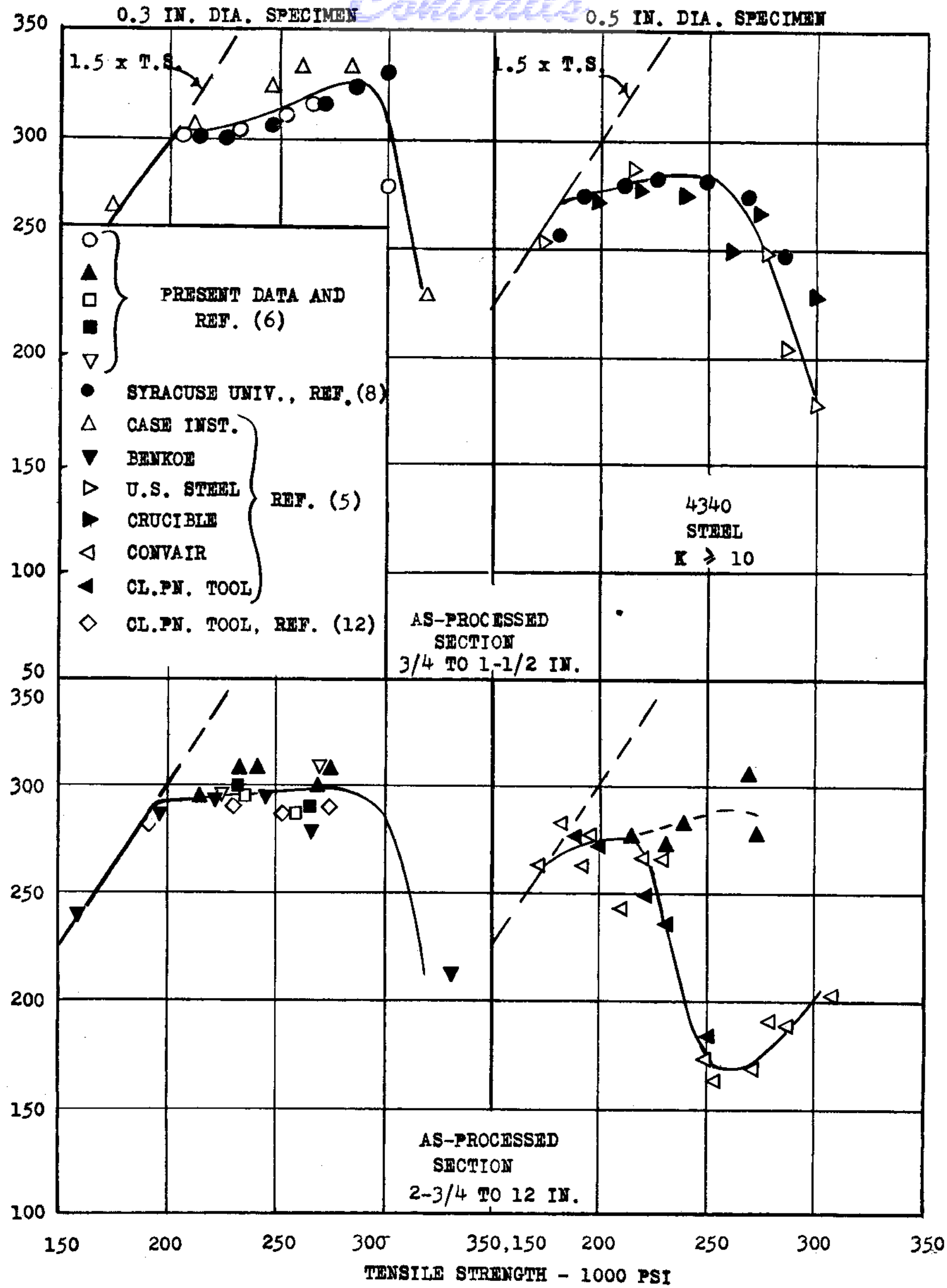


FIG. 12 EFFECTS OF AS-PROCESSED AND AS-TESTED SECTION SIZE ON NOTCH STRENGTH OF SHARPLY NOTCHED (K ⩾ 10) 4340 STEEL SPECIMENS.

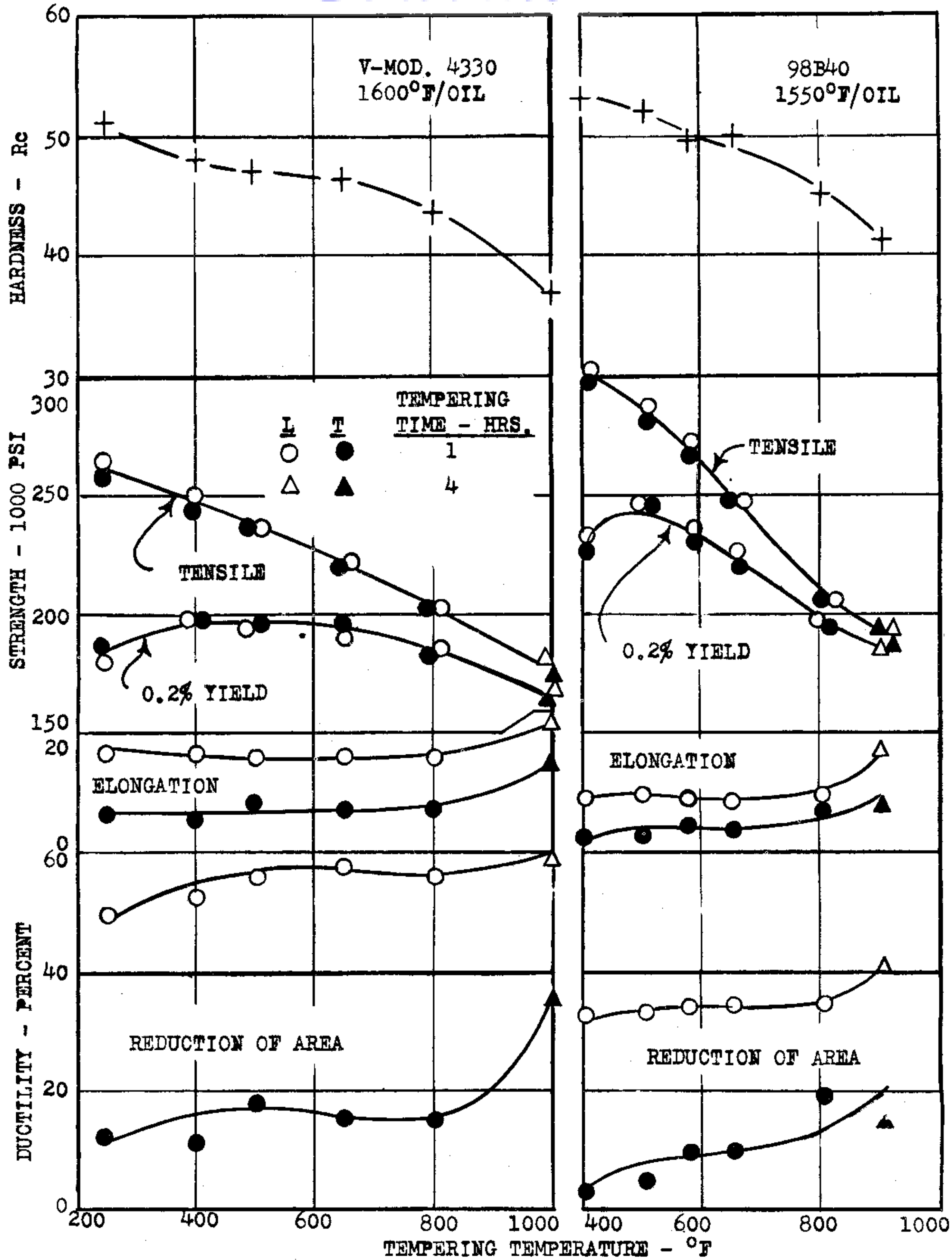


FIG. 13 HARDNESS, STRENGTH AND DUCTILITY OF V-MOD. 4330 AND 98B40 STEELS AS FUNCTIONS OF TEMPERING TEMPERATURE.

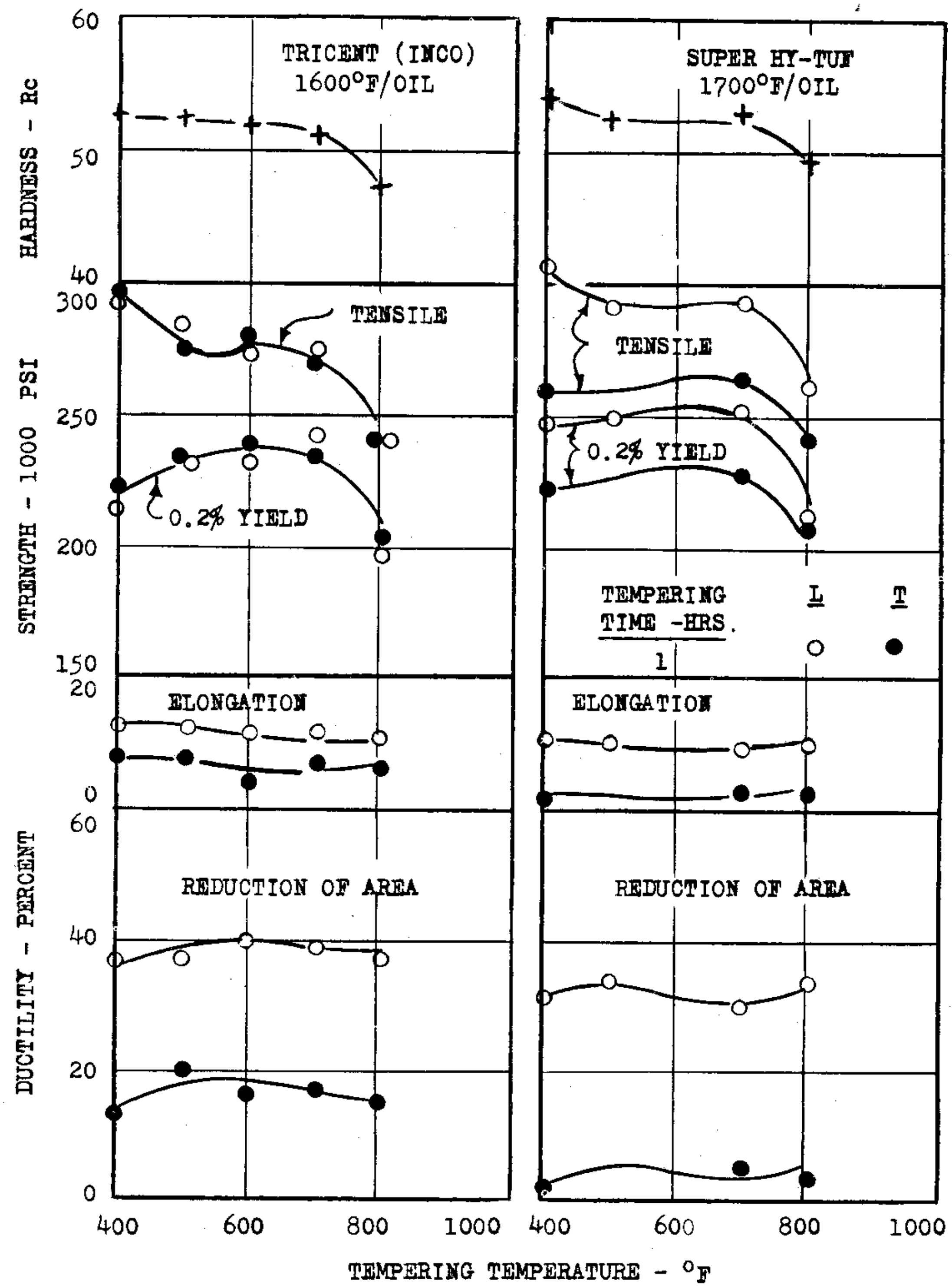


FIG. 14 HARDNESS STRENGTH AND DUCTILITY OF TRICENT AND SUPER HY-TUF STEELS AS FUNCTIONS OF TEMPERING TEMPERATURE.

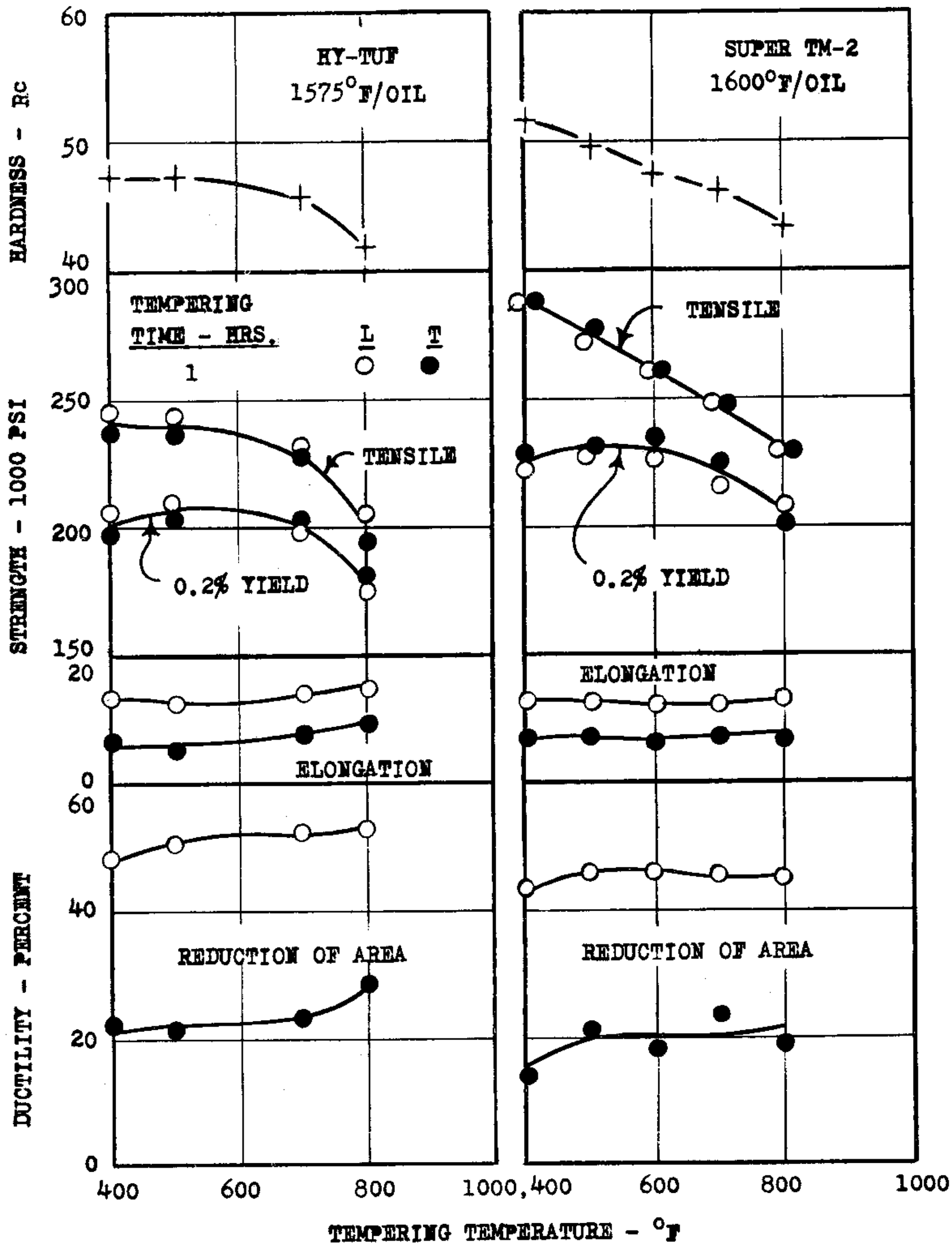


FIG. 15 HARDNESS, STRENGTH AND DUCTILITY OF HY-TUF AND SUPER TM-2 STEELS AS FUNCTIONS OF TEMPERING TEMPERATURE.

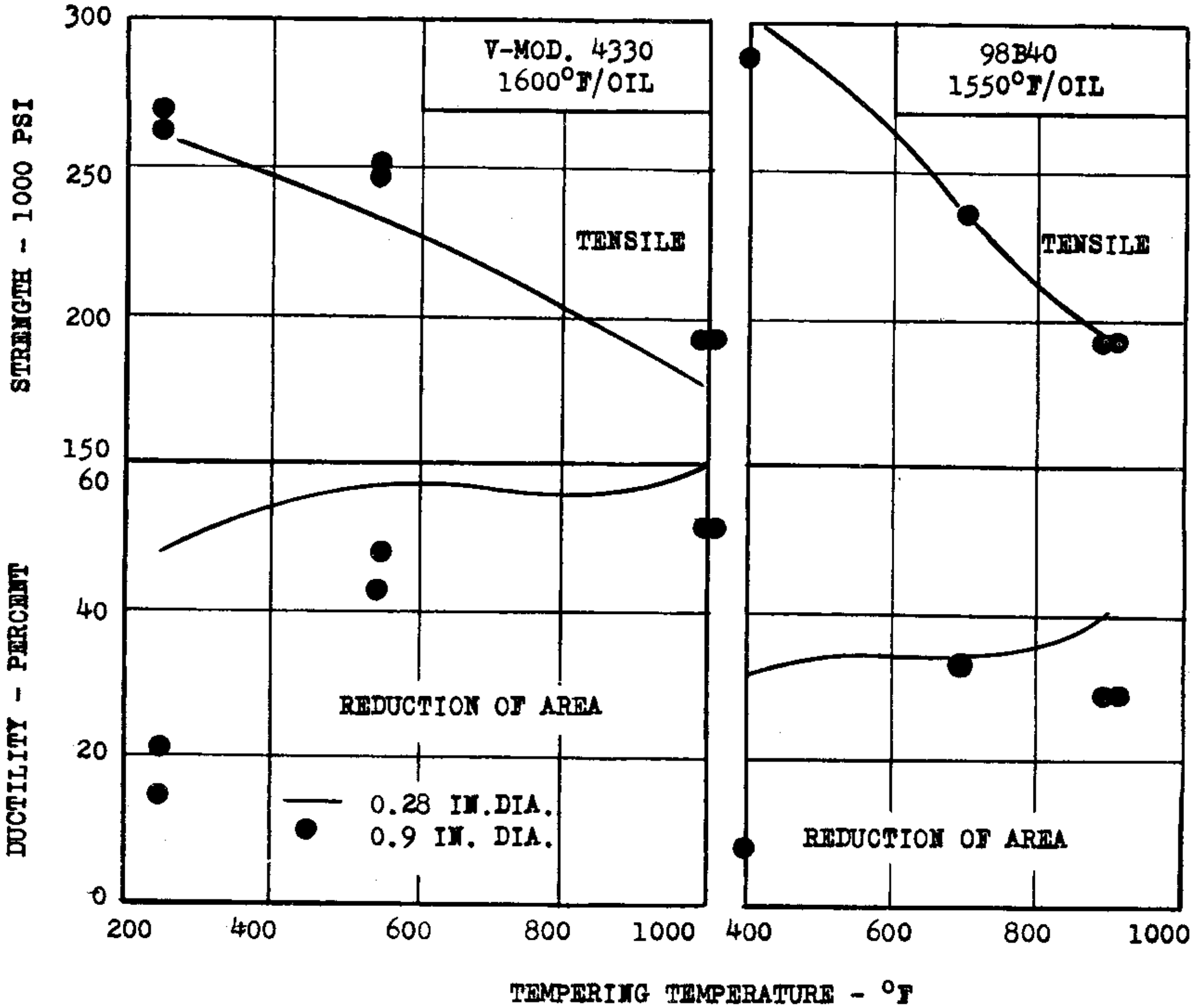


FIG. 16 STRENGTH AND DUCTILITY OF V-MOD. 4330 AND 98B40 STEELS AS FUNCTIONS OF TEMPERING TEMPERATURE FOR 0.9 IN. DIA. SPECIMENS.

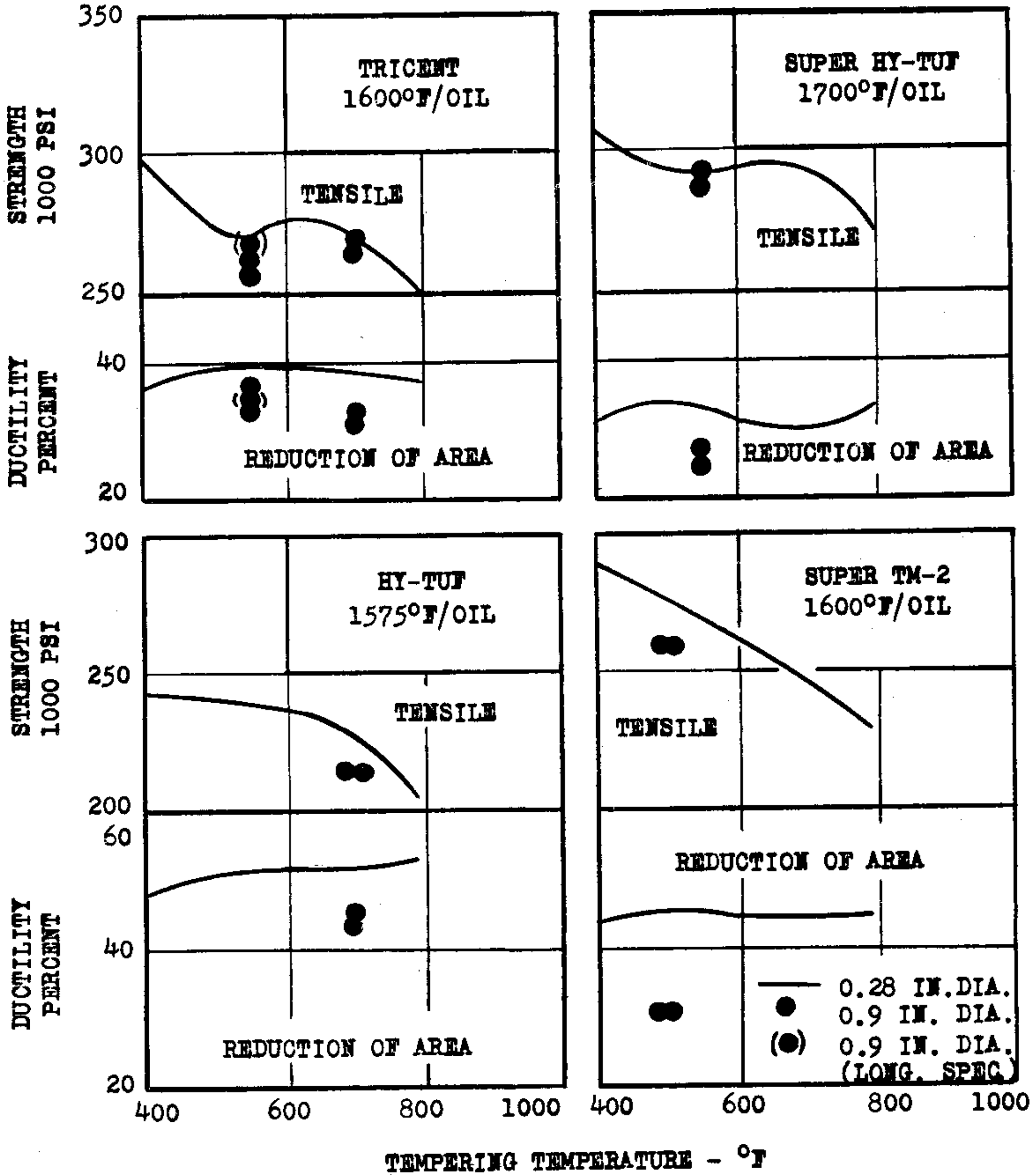


FIG. 17 STRENGTH AND DUCTILITY OF TRICENT SUPER HY-TUF, HY-TUF AND SUPER TM-2 STEELS AS FUNCTIONS OF TEMPERING TEMPERATURE FOR 0.9 IN. DIA. SPECIMENS.

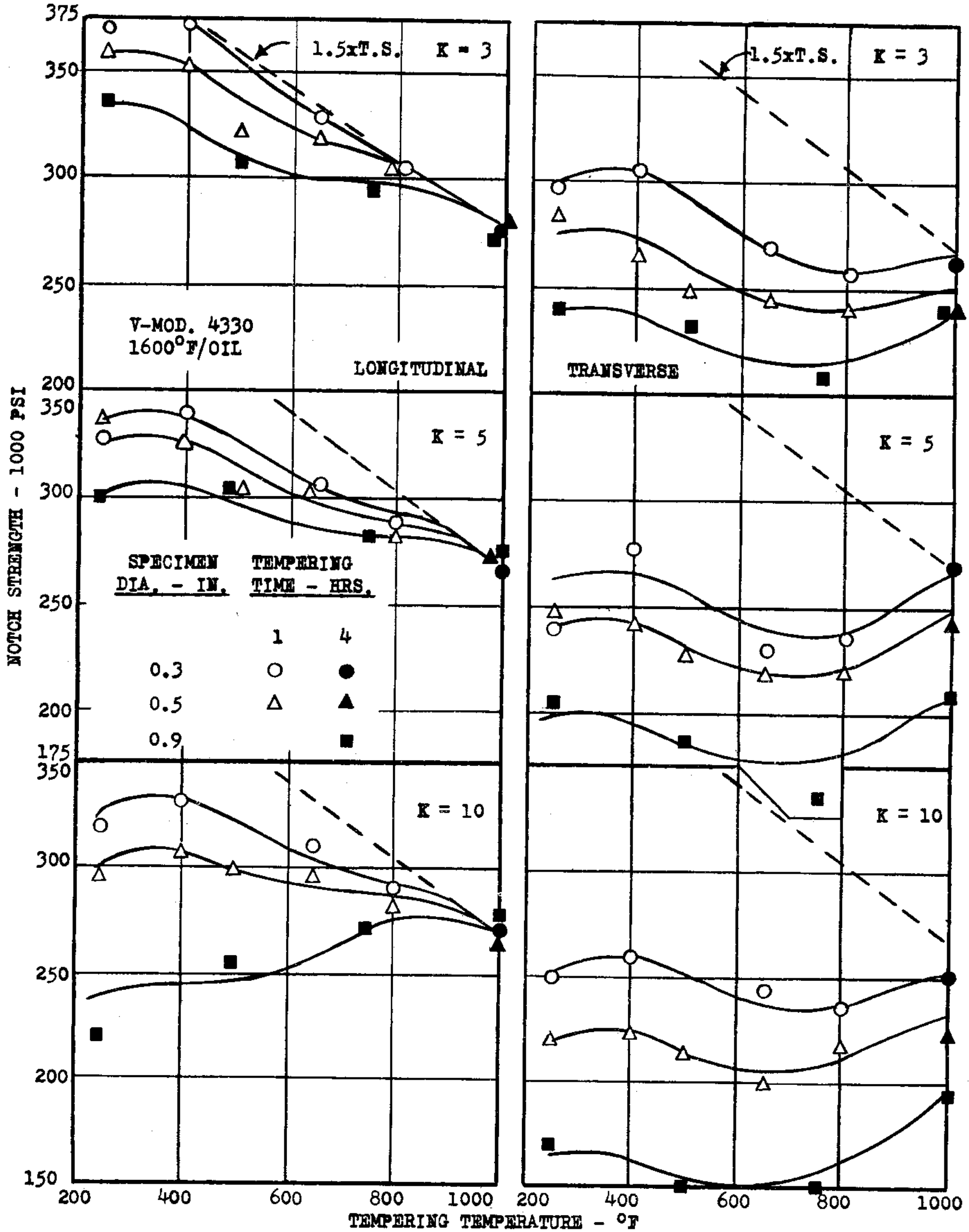


FIG. 18 DEPENDENCE OF NOTCH STRENGTH OF V-MOD. 4330 STEEL ON TEMPERING TEMPERATURE AND SPECIMEN DIAMETER.

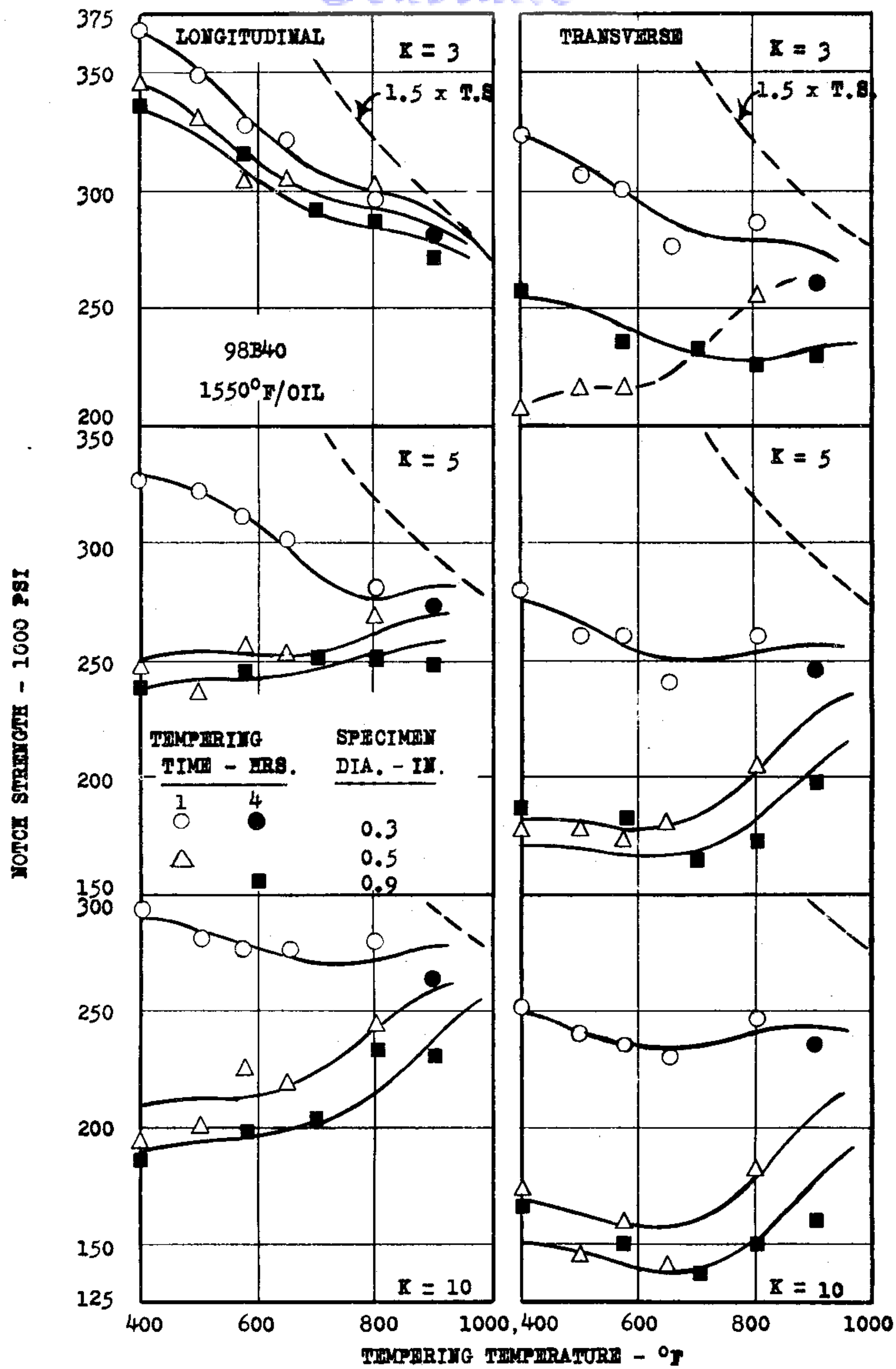


FIG. 19 DEPENDENCE OF NOTCH-STRENGTH OF 98B40 STEEL ON TEMPERING TEMPERATURE AND SPECIMEN DIAMETER.

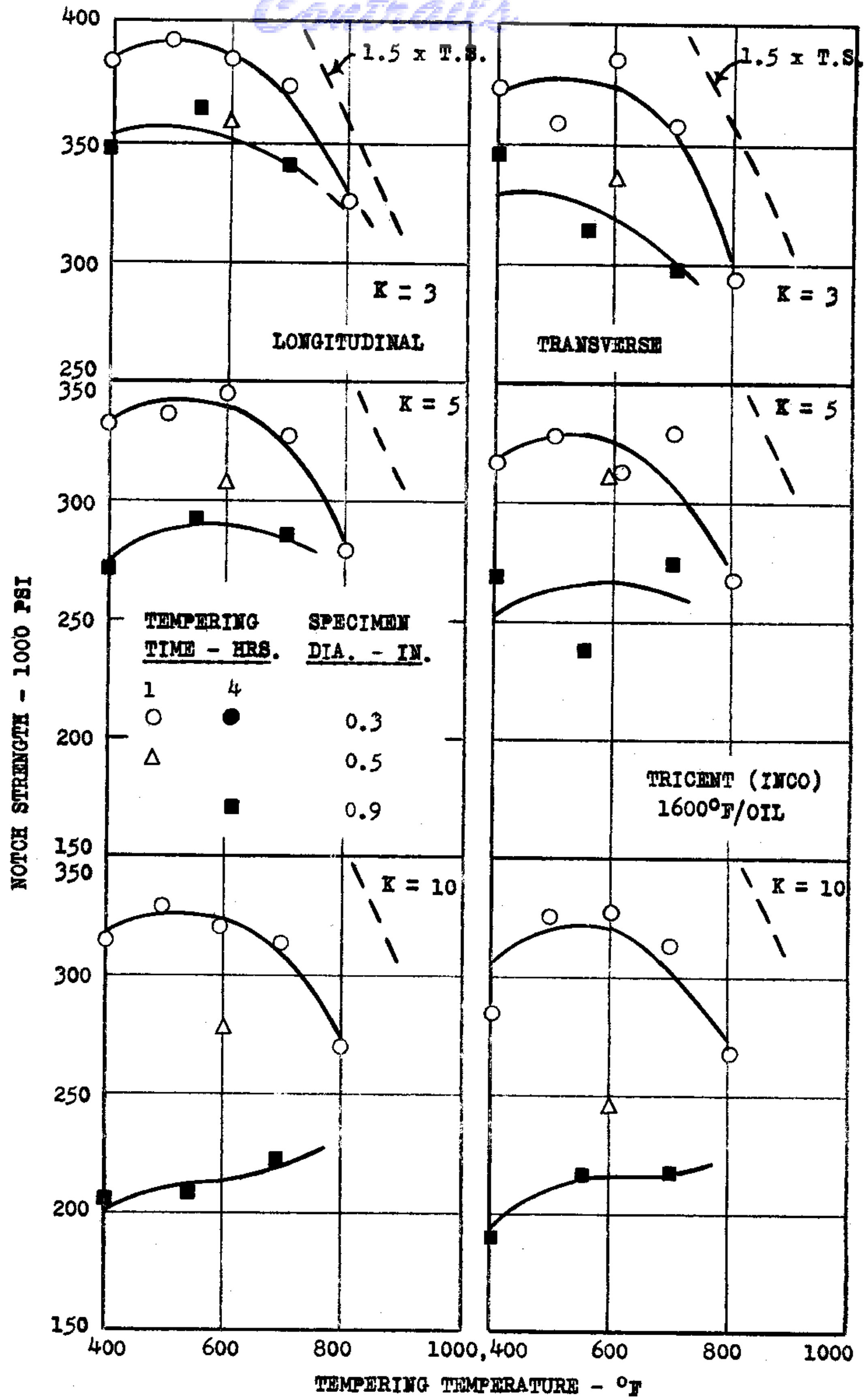


FIG. 20 DEPENDENCE OF NOTCH STRENGTH OF TRICENT STEEL ON TEMPERING TEMPERATURE AND SPECIMEN DIAMETER.

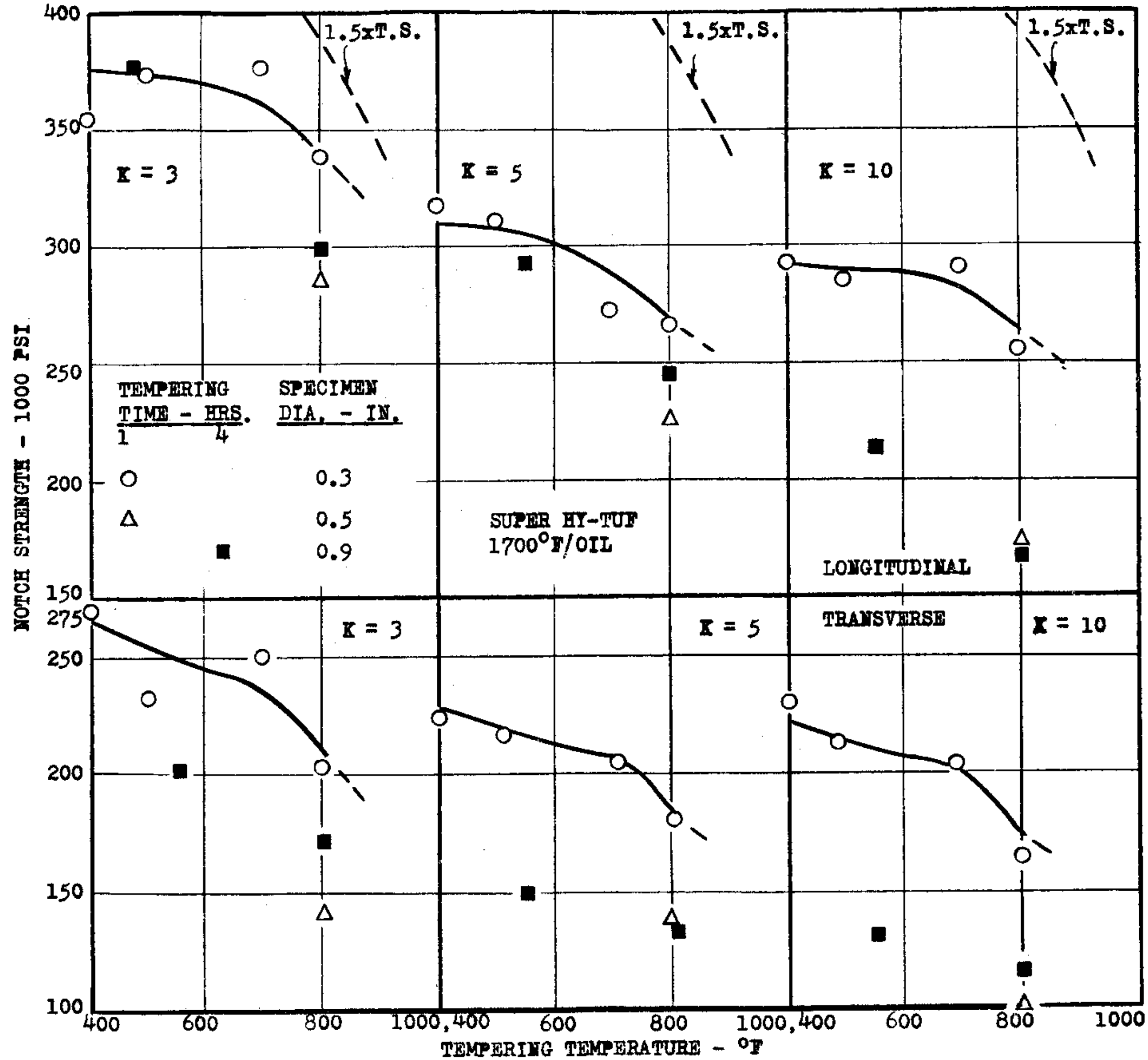


FIG. 21 DEPENDENCE OF NOTCH STRENGTH OF SUPER HY-TUF STEEL ON TEMPERING TEMPERATURE AND SPECIMEN DIAMETER.

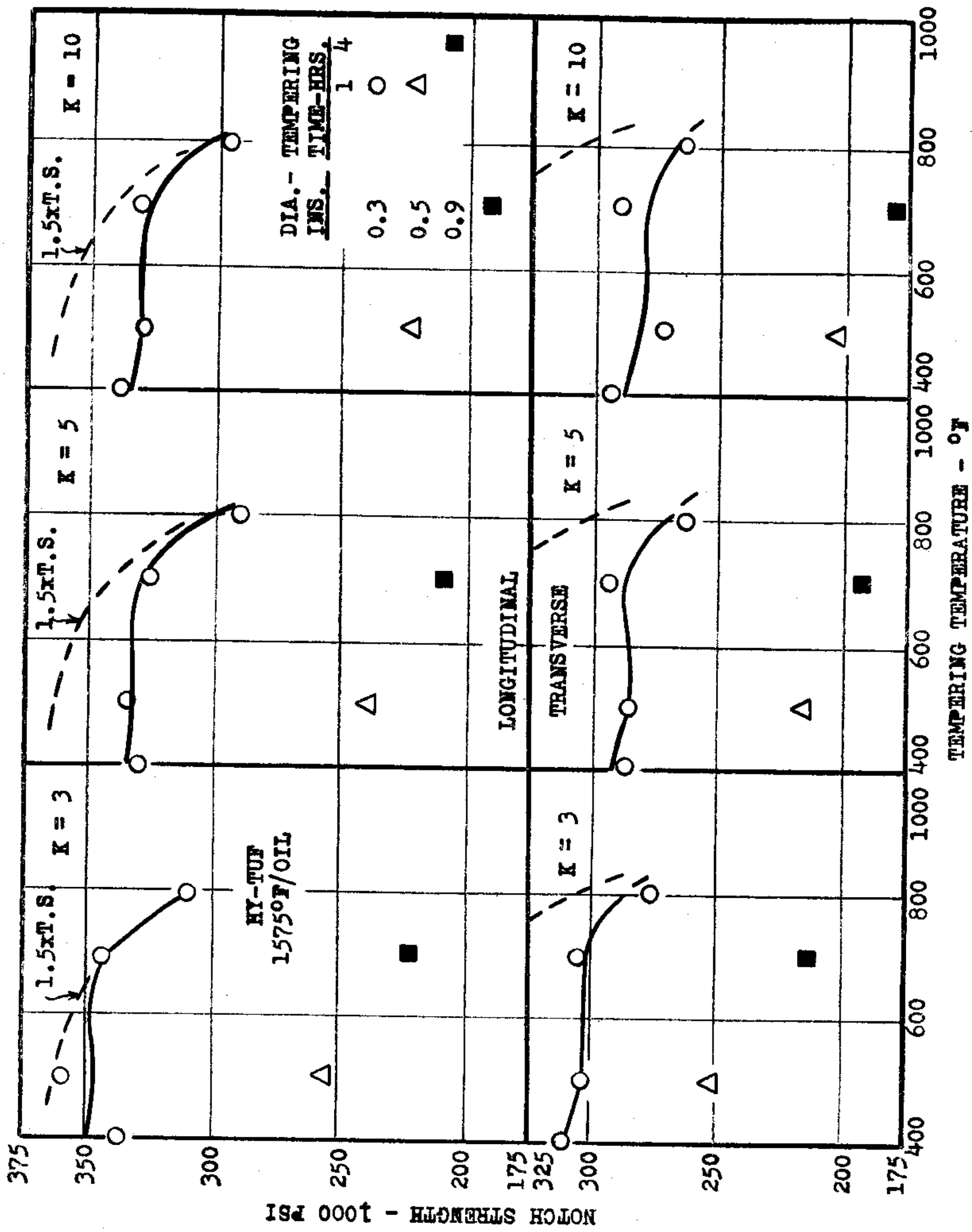


FIG. 22 DEPENDENCE OF NOTCH STRENGTH OF HY-TUF STEEL ON TEMPERING TEMPERATURE AND SPECIMEN DIAMETER.

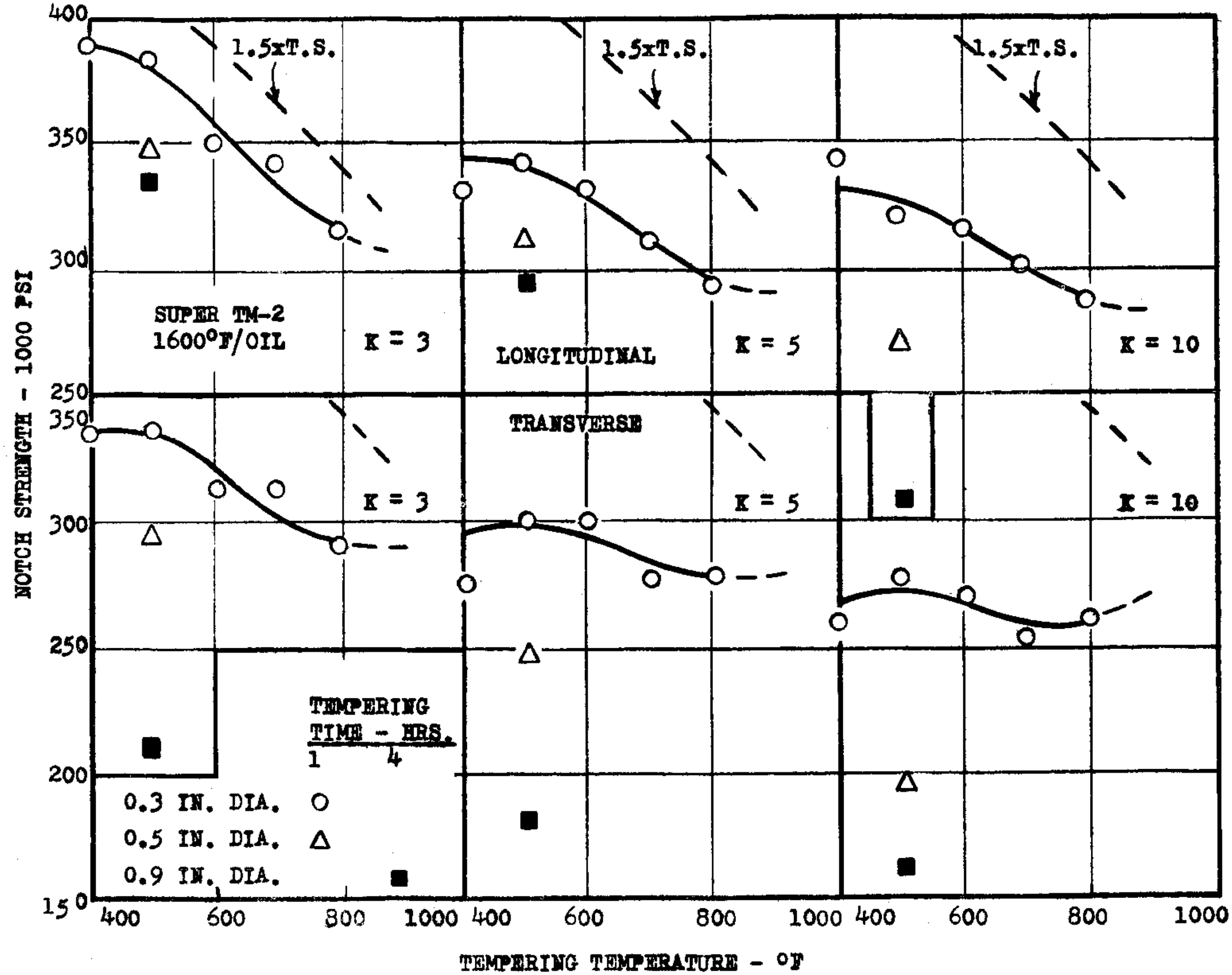


FIG. 23 DEPENDENCE OF NOTCH STRENGTH OF SUPER TM-2 STEEL ON TEMPERING TEMPERATURE AND SPECIMEN DIAMETER.

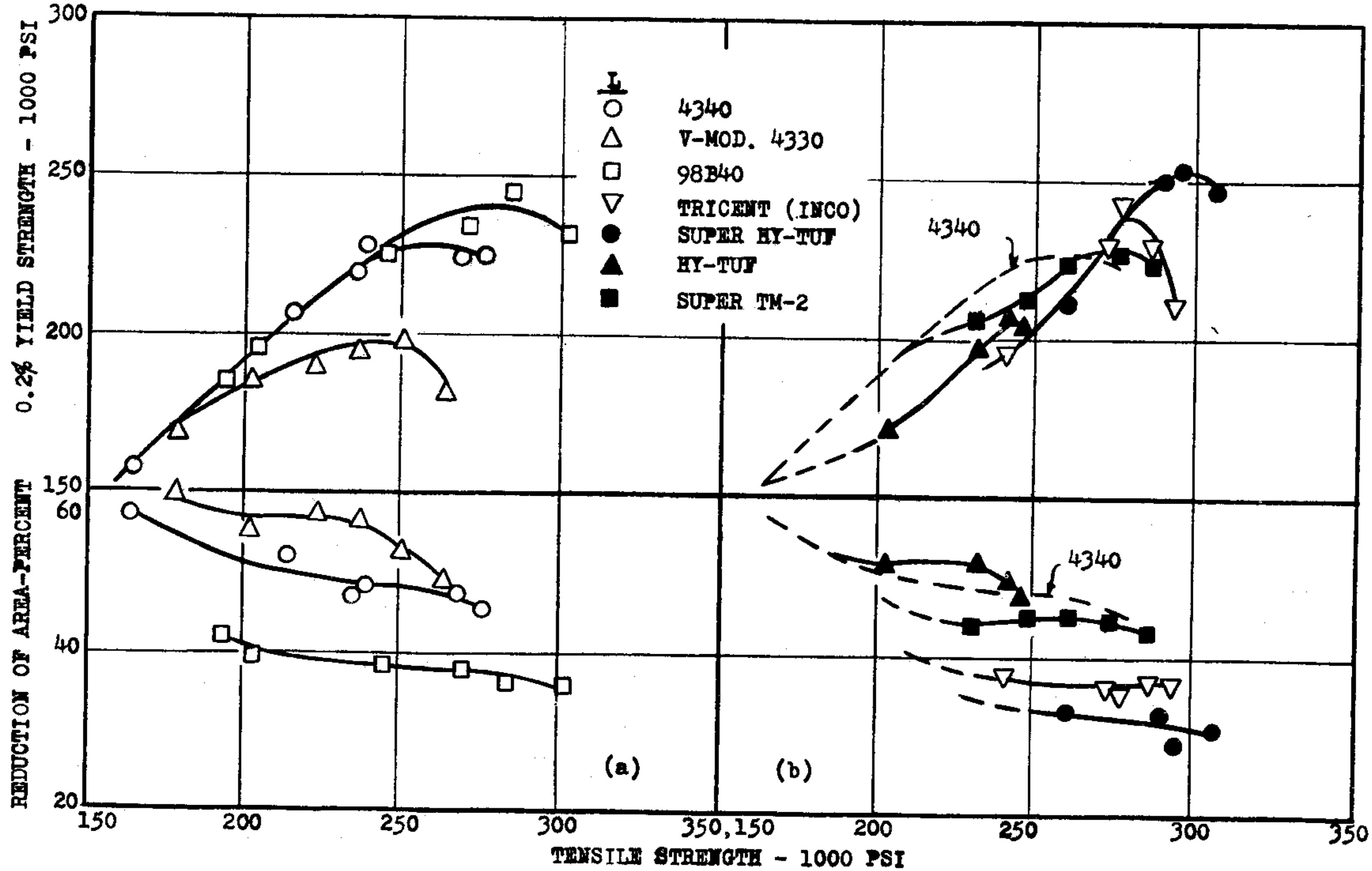


FIG. 24 YIELD STRENGTH AND REDUCTION OF AREA AS FUNCTIONS OF STRENGTH LEVEL FOR A NUMBER OF HIGH-STRENGTH STEELS.

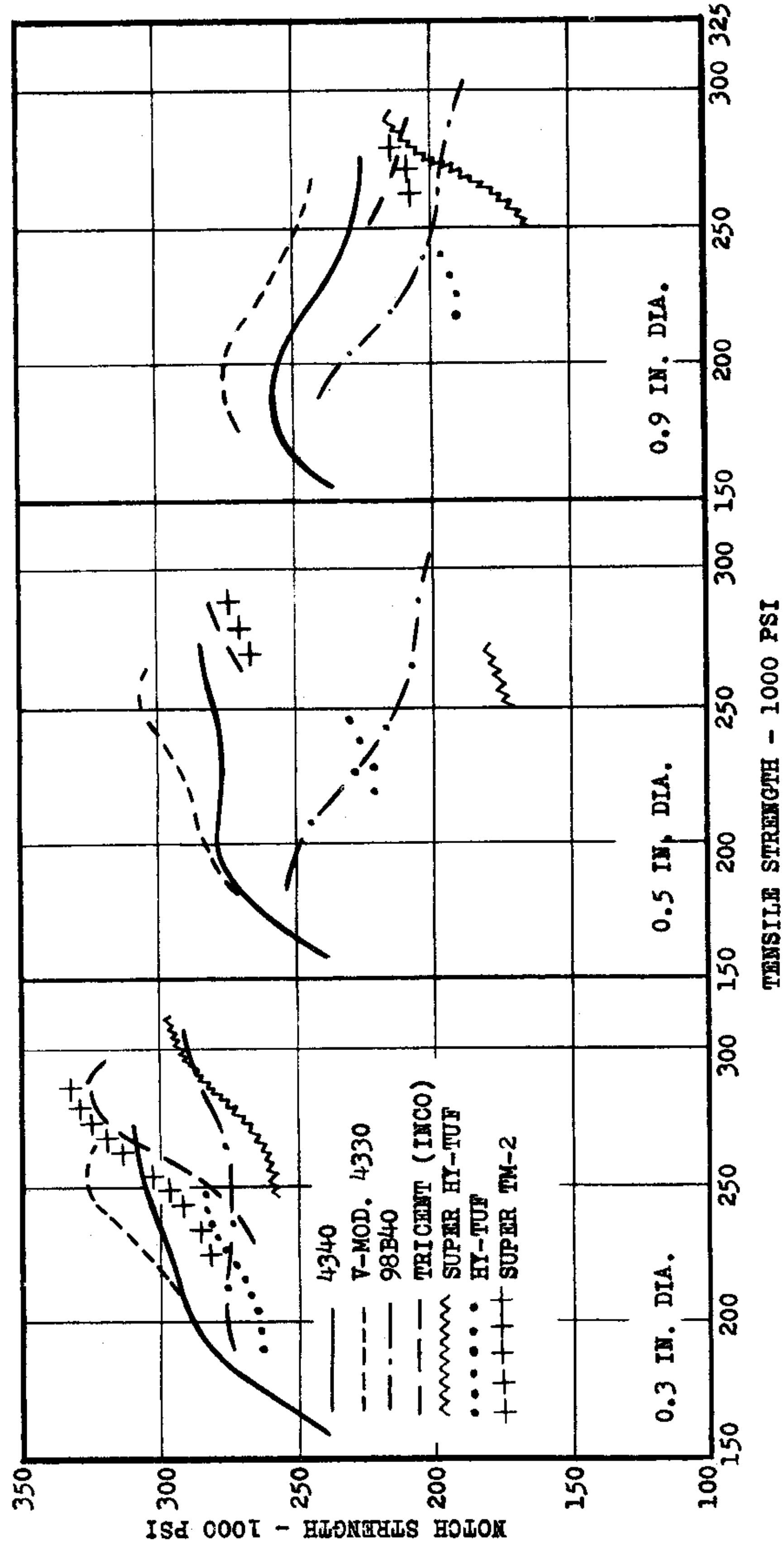


FIG. 25 DEPENDENCE OF NOTCH STRENGTH ON TENSILE STRENGTH FOR A NUMBER OF HIGH-STRENGTH STEELS.

APPENDIX

The numerical data presented in this appendix complement the information previously reported in WADC TR 55-103, Sup. 2. The data are given as individual and average values.

TABLE III

Results of Tension Tests (K = 1) on 0.28 in. dia.
4340 (1525°F/oil), V-Mod. 4330 (1600°F/oil) and 98B40 (1550°F/oil)

Steel and Temp. Temp. (°F)	Type of Speci-men	Tensile Strength 1000 psi		0.2% Yield Strength 1000 psi		% Reduction of Area		% Elongation	
			ave.		ave.		ave.		ave.
4340	L	166.0 164.5	165.3	158.0 156.0	157.0	54.5 56.7	55.6	21.0 23.0	22.0
1000	T	163.8 --	163.8	153.5 --	153.5	36.0 --	36.0	14.5 --	14.5
V-Mod. 4330	L	178.0 179.0	178.5	168.0 170.0	169.0	59.5 59.5	59.5	20.7 23.9	22.3
1000	T	175.0 174.0	174.5	168.0 166.0	167.0	35.5 35.5	35.5	14.9 14.9	14.9
98B40	L	194.0 194.0	194.0	185.5 184.5	185.0	41.3 41.8	41.6	18.2 18.2	18.2
900	T	195.0 194.5	194.8	187.0 186.0	186.5	13.5 13.2	13.4	9.0 6.7	7.9

TABLE IV

Results of Tension Tests (K = 1) on 0.9 in. dia. 4340 (1525°F/oil), V-Mod. 4330 (1600°F/oil), 98B40 (1550°F/oil), Tricent (1600°F/oil), Super Hy-Tuf (1700°F/oil), Hy-Tuf (1575°F/oil) and Super TM-2 (1600°F/oil) Longitudinal Specimens.

Steel and Tempering Temp. (°F)	Tensile Strength 1000 psi		Reduction of Area Percent	
		Average		Average
4340 400	283 260*	271.5	30.5 4.0	17.3
4340 500	252 263	258	36.4 36.7	36.6
4340 700	220 225	223	42.6 39.5	41.1
4340 800	203 202	202.5	42.2 44.4	43.3
4340 1000	171 173	172	47.6 49.3	48.4
V-Mod. 4330 250	270 264	267	14.5 20.2	17.6
V-Mod. 4330 500	249 255	252	42.7 47.5	45.1
V-Mod. 4330 1000	193 192	192.5	51.0 51.5	51.3
98B40 400	289 ---**	289	7.7 ----	7.7
98B40 700	237 ---**	237	33.0 ----	33.0
98B40 900	194 195	195	29.2 29.0	29.1
Tricent 550	259.5 257 264*	260	33.2 36.1 35.1	34.5
Tricent 700	268 264	266	32.1 31.1	31.8
Super Hy-Tuf 550	273 280	276.5	25.0 27.2	26.1
Hy-Tuf 700	212 211	211.5	44.0 43.0	43.5
Super TM-2 500	259 259	259	29.5 30.0	29.8

*Long. Specimen
**Broke in fillet

TABLE V

Results of Notch Tension Tests (K = 3) on 0.9 in. dia. 4340 Steel Specimens (1525°F/oil)

Tempering Temp. -°F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
400	L	348.0 345.9	347.0	1.9 3.8	2.8	1.26
	T	269.6 289.3	279.5	1.9 2.5	2.2	1.00
500	L	327.6 328.1	327.9	1.9 2.2	2.0	1.22
	T	257.9 254.7	256.3	1.9 1.3	1.6	0.95
700	L	295.6 305.3	300.5	2.5 3.1	2.8	1.28
	T	240.5 213.0	266.8	1.3 1.9	1.6	0.96
800	L	289.1 288.4	288.8	6.3 4.4	5.3	1.34
	T	252.4 228.0	240.2	2.6 3.1	2.9	1.13
1000	L	251.6 267.3	259.5	6.8 6.3	6.6	1.57
	T	234.4 234.9	234.7	4.4 3.8	4.1	1.43
1000* (0.5 in. dia.)	L	350.0 322.2	336.1	10.0 8.1	9.1	2.03
	T	332.3 321.4	331.9	4.1 4.1	4.1	2.01
1000 (0.3 in. dia.)	L	249.1 242.3	245.7	11.2 14.0	12.6	1.48
	T	253.5 242.3	247.9	5.0 8.9	7.0	1.50

*Results not used in evaluation presented in this report because they are doubtful.

TABLE VI

Results of Notch Tension Tests (K = 5) on 0.9 in. dia. 4340 Steel Specimens (1525°F/oil)

Tempering Temp.- °F	Type of Specimen	Notch Strength 1000 psi	Notch Strength 1000 psi average	% Reduction of Area	% Reduction of Area average	Notch Strength Ratio
400	L	296.5 288.0	292.3	3.5 2.5	3.0	1.06
	T	196.8 219.4	208.1	0.9 1.3	1.1	0.75
500	L	286.6 286.0	286.3	2.8 --	2.8	1.06
	T	189.0 188.5	188.8	0.6 0.9	0.8	0.70
700	L	251.0 277.0	264.0	2.6 --	2.6	1.12
	T	193.5 180.3	186.9	1.3 1.3	1.3	0.79
800	L	268.5 256.0	262.3	2.5 2.5	2.5	1.22
	T	187.0 183.5	185.3	1.3 1.9	1.6	0.87
1000	L	250.0 242.9	246.5	3.8 5.4	4.5	1.49
	T	220.8 226.1	223.5	2.2 2.6	2.4	1.37
1000* (0.5 in. dia.)	L	329.6 329.6	329.6	5.1 7.2	6.2	1.99
	T	299.0 330.9	315.0	3.1 2.1	2.6	1.91
1000 (0.3 in. dia.)	L	253.1 253.5	253.3	8.0 9.1	8.6	1.53
	T	240.6 241.7	241.2	4.5 5.4	5.0	1.46

* Results not used in evaluation presented in this report because they are doubtful.

TABLE VII

Results of Notch Tension Tests (K = 10) on 0.9 in. dia. 4340 Steel Specimens (1525°F/oil)

Tempering Temp. -°F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
400	L	215.2 227.8	221.5	0.6 1.3	0.95	0.80
	T	173.5 170.9	172.2	3.2 0.6	1.90	0.62
500	L	220.8 220.8	220.8	1.0 1.3	1.12	0.82
	T	156.7 157.7	157.2	0.9 1.0	0.944	0.58
700	L	231.5 227.1	229.3	1.3 0.6	0.96	0.98
	T	179.8 157.7	168.8	1.3 1.0	1.11	0.71
800	L	256.3 258.7	257.5	3.2 2.8	3.0	1.20
	T	215.9 208.2	212.1	1.9 3.5	2.69	1.00
1000	L	242.1 242.1	242.1	4.1 3.5	3.77	1.46
	T	220.1 208.9	214.5	1.9 1.6	1.72	1.31
1000* (0.5 in. dia.)	L	305.2 287.6	296.4	6.2 5.2	5.7	1.79
	T	296.0 266.3	281.2	5.1 2.0	3.6	1.70
1000 (0.3 in. dia.)	L	241.7 242.8	242.3	9.7 8.6	9.2	1.47
	T	236.6 246.9	241.8	8.9 6.3	7.6	1.46

* Results not used in evaluation presented in this report because they are doubtful.

TABLE VIII

Results of Notch Tension Tests (K = 3) on 0.9 in. dia. V-Mod. 4330 Steel Specimen (1600°F/oil)

Tempering Temp. - °F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
250	L	328.0 340.0	334.0	3.2 2.9	3.1	1.27
	T	236.0 244.0	240.0	1.9 4.4	3.2	0.93
500	L	302.0 313.0	307.5	4.8 4.5	4.7	1.30
	T	226.0 237.0	231.5	3.8 2.2	3.0	0.98
750	L	302.0 288.0	295.0	3.8 3.5	3.7	1.35
	T	197.5 216.0	206.5	1.6 2.2	1.9	0.96
1000	L	275.0 337.0	306.0	4.1 5.3	4.7	1.54
	T	224.0 255.5	239.5	3.5 1.9	2.7	1.38
1000 (0.5 in. dia.)	L	279.0 279.2	279.1	10.5 8.4	9.5	1.56
	T	255.0 219.0	237.0	4.9 2.3	3.6	1.36
1000 (0.3 in. dia.)	L	272.0 281.5	276.7	11.5 10.7	11.1	1.55
	T	264.0 256.0	260.0	6.5 4.9	5.7	1.49

TABLE IX

Results of Notch Tension Tests (K = 5) on 0.9 in. dia. V-Mod. 4330 Steel Specimens (1600°F/oil)

Tempering Temp. - °F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
250	L	300.0 300.5	300.0	3.8 1.9	2.9	1.14
	T	200.5 207.0	203.5	1.0 0.9	1.0	0.79
500	L	301.0 304.0	302.5	1.9 2.8	2.4	1.28
	T	182.0 187.0	184.5	0.9 0.9	0.9	0.78
750	L	285.0 279.0	282.0	1.3 1.6	1.5	1.29
	T	161.5 152.0	156.5	0.6 1.0	0.8	0.73
1000	L	272.0 280.0	276.0	4.7 4.3	4.5	1.55
	T	211.5 202.5	207.0	1.0 1.6	1.3	1.19
1000 (0.5 in. dia.)	L	269.0 270.5	269.7	6.8 5.6	6.2	1.51
	T	242.0 --	242.0	2.2 --	2.2	1.39
1000 (0.3 in. dia.)	L	264.4 270.0	267.2	9.3 10.1	9.7	1.50
	T	265.0 275.0	270.0	4.8 5.7	5.3	1.55

TABLE X

Results of Notch Tension Tests (K = 10) on 0.9 in. dia.
V-Mod. 4330 Steel Specimens (1600°F/oil)

Tempering Temp. -°F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
250	L	212.0 226.0	219.0	1.0 0.9	1.0	0.83
	T	158.5 181.0	169.7	1.0 0.9	1.0	0.66
500	L	258.5 252.5	255.5	0.9 0.6	0.8	1.08
	T	157.0 145.0	151.0	0.6 0.6	0.6	0.64
750	L	267.0 277.0	272.0	2.3 2.8	2.6	1.25
	T	147.5 155.0	151.0	0.9 0.6	0.8	0.70
1000	L	282.0 275.0	278.5	3.2 1.9	2.6	1.56
	T	190.0 198.0	194.0	1.3 1.9	1.6	1.11
1000 (0.5 in. dia.)	L	268.0 266.4	267.2	2.9 4.5	3.7	1.50
	T	221.0 225.0	223.0	4.5 2.3	3.4	1.28
1000 (0.5 in. dia.)	L	268.0 272.2	270.1	4.5 10.3	7.4	1.51
	T	247.5 256.5	252.0	14.3 9.4	11.9	1.45

TABLE XI

Results of Notch Tension Tests (K = 3) on 0.9 in. dia. 98B40 Steel Specimens (1550°F/oil)

Tempering Temp. -°F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
400	L	332.0 334.0	333.0	1.3 3.5	2.4	1.10
	T	249.5 262.5	256.0	1.6 2.2	1.9	0.87
575	L	313.0 319.5	316.5	2.8 3.5	3.2	1.17
	T	241.5 231.0	236.5	1.9 2.2	2.1	0.89
700	L	290.0 293.0	291.5	2.5 2.2	2.4	1.25
	T	252.0 213.0	232.5	2.5 0.3	1.4	1.01
800	L	294.0 283.0	288.5	2.5 2.8	2.7	1.41
	T	221.0 226.5	224.0	1.3 2.5	1.9	1.10
900	L	272.0 269.0	270.5	5.0 3.2	4.1	1.39
	T	222.0 234.0	228.0	1.9 2.5	2.2	1.17
900* (0.5 in. dia.)	L	305.0 310.0	375.0	3.9 4.8	4.4	1.59
	T	291.0 278.0	284.5	3.0 2.2	2.6	1.46
900 (0.3 in. dia.)	L	272.0 288.0	280.0	11.6 --	11.6	1.45
	T	270.0 249.0	259.5	2.1 4.3	3.2	1.33

* Results not used in evaluation presented in this report because they are doubtful.

TABLE XII

Results of Notch Tension Tests (K = 5) on 0.9 in. dia. 98B40 Steel Specimens (1550°F/oil)

Tempering Temp.- °F	Type of Specimen	Notch Strength 1000 psi		% Reduction of area		Notch Strength Ratio
			average		average	
400	L	-- 238.0	238.0	-- 2.2	2.2	0.79
	T	193.0 177.5	185.5	0.6 1.3	1.0	0.63
575	L	246.0 249.0	247.5	1.6 0.3	0.9	0.92
	T	177.0 184.0	180.5	1.3 1.3	1.3	0.68
700	L	240.0 260.0	250.0	1.9 2.5	2.2	1.07
	T	155.0 170.0	162.5	0.6 1.0	0.8	0.70
800	L	252.0 249.0	250.5	2.2 2.5	2.4	1.22
	T	168.5 174.5	171.5	0.7 1.3	1.0	0.84
900	L	249.0 242.5	246.0	3.1 2.9	3.0	1.27
	T	193.0 203.0	198.0	1.6 1.6	1.6	1.02
900* (0.5 in. dia.)	L	285.0 278.0	281.5	3.2 4.4	3.8	1.45
	T	254.0 272.0	263.0	1.8 2.5	2.2	1.35
900 (0.3 in. dia.)	L	271.0 269.0	270.0	3.7 0.3	2.0	1.39
	T	248.0 244.0	246.0	2.3 2.7	2.5	1.26

* Results not used in evaluation presented in this report because they are doubtful.

TABLE XIII

Results of Notch Tension Tests (K = 10) on 0.9 in. dia. 98B40 Steel Specimens (1550°F/oil)

Tempering Temp. -°F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
400	L	191.5 179.0	185.5	0.3 3.8	2.1	0.61
	T	162.0 172.0	167.0	0.7 0.6	0.7	0.57
575	L	219.0 169.0	194.0	1.0 0.7	0.8	0.72
	T	154.0 147.5	151.0	0.6 0.3	0.5	0.57
700	L	210.5 195.5	203.0	1.0 0.3	0.7	0.87
	T	152.0 124.5	138.5	1.0 0.6	0.8	0.60
800	L	224.0 241.0	232.5	1.6 1.3	1.5	1.14
	T	152.0 148.5	150.5	1.0 0.7	0.8	0.74
900	L	224.0 234.0	229.0	1.6 1.9	1.8	1.18
	T	145.0 171.5	158.5	0.6 0.6	0.6	0.81
900* (0.5 in. dia.)	L	272.0 278.0	276.0	3.1 2.6	2.9	1.42
	T	222.0 225.0	223.5	0.9 0.9	0.9	1.15
900 (0.3 in. dia.)	L	262.0 262.0	262.0	4.9 5.2	5.1	1.35
	T	237.0 231.0	234.0	4.0 3.9	4.0	1.20

* Results not used in evaluation presented in this report because they are doubtful.

TABLE XIV

Results of Notch Tension Tests (K = 3) on 0.9 in. dia. Tricent (1600°F/oil), Super Hy-Tuf (1700°F/oil), Hy-Tuf (1575°F/oil) and Super TM-2 (1600°F/oil) Steel Specimens

Steel & Tempering Temp. -°F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
Tricent (Inco) 400	L	350.9 338.6	344.8	2.2 2.5	2.4	1.18
	T	345.0 345.9	345.5	1.6 1.9	1.8	1.17
Tricent (Inco) 550	L	363.6 364.8	364.2	1.6 1.3	1.5	1.31
	T	329.2 297.8	313.5	1.3 2.2	1.8	1.15
Tricent (Inco) 700	L	343.3 336.0	339.7	1.2 0.9	1.1	1.23
	T	290.9 302.5	296.7	0.9 1.6	1.3	1.09
Super Hy-Tuf 550	L	378.0 377.0	377.5	4.4 4.7	4.6	1.30
	T	199.0 207.0	203.0	3.8 1.3	2.6	0.78
Super Hy-Tuf 800	L	300.0 300.0	300.0	2.5 2.5	2.5	1.15
	T	175.5 170.0	172.5	1.2 1.0	1.1	0.72
Hy-Tuf 700	L	222.0 220.5	221.3	4.1 4.4	4.3	0.96
	T	214.0 212.0	213.0	5.6 3.8	4.7	0.94
Super TM-2 500	L	335.0 335.5	335.3	2.2 3.6	2.9	1.24
	T	250.0 171.0	210.5	1.0 1.3	1.2	0.77

TABLE XV

Results of Notch Tension Tests (K = 5) on 0.9 in. dia. Tricent (1600°F/oil), Super Hy-Tuf (1700°F/oil), Hy-Tuf (1575°F/oil) and Super TM-2 (1600°F/oil) Steel Specimens

Steel & Tempering Temp. - °F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
Tricent (Inco) 400	L	277.6 265.7	271.7	0.9 0.9	0.9	0.93
	T	260.3 275.9	268.1	1.3 1.9	1.6	0.91
Tricent (Inco) 550	L	279.0 304.1	291.6	1.6 1.6	1.6	1.05
	T	251.6 221.0	236.3	0.6 0.9	0.9	0.87
Tricent (Inco) 700	L	285.3 283.9	284.6	0.6 0.9	0.9	1.03
	T	266.5 279.0	272.8	0.3 1.2	0.8	1.01
Super Hy-Tuf 550	L	292.0 296.0	294.0	2.2 1.9	2.1	1.01
	T	158.0 143.0	150.5	3.5 1.0	2.3	0.58
Super Hy-Tuf 800	L	240.0 253.0	246.5	0.3 5.5	2.9	0.95
	T	136.0 135.0	135.5	2.2 1.6	1.9	0.50
Hy-Tuf 700	L	205.0 211.0	208.5	0.3 2.4	1.4	0.90
	T	197.0 188.0	192.5	2.5 2.8	2.7	0.85
Super TM-2 500	L	292.0 294.0	293.0	2.9 2.2	2.6	1.07
	T	190.0 176.0	183.0	1.0 1.9	1.5	0.66

TABLE XVI

Results of Notch Tension Tests (K = 10) on 0.9 in. dia. Tricent (1600°F/oil), Super Hy-Tuf (1700°F/oil), Hy-Tuf (1575°F/oil) and Super TM-2 (1600°F/oil) Steel Specimens

Steel & Tempering Temp. -°F	Type of Specimen	Notch Strength 1000 psi		% Reduction of Area		Notch Strength Ratio
			average		average	
Tricent (Inco)	L	203.5 201.3	202.4	0.9 0.6	0.9	0.69
400	T	185.5 190.0	187.8	0.9 0.9	0.9	0.63
Tricent (Inco)	L	211.4 199.7	205.6	0.9 1.3	1.1	0.74
550	T	220.8 209.1	215.0	0.6 0.6	0.6	0.79
Tricent (Inco)	L	244.5 203.5	224.0	1.3 0.9	1.1	0.81
700	T	217.7 213.8	215.8	0.6 0.6	0.6	0.80
Super Hy-Tuf	L	210.0 222.0	216.0	1.3 1.0	1.2	0.74
550	T	119.5 143.0	131.3	-- 0.9	0.9	0.50
Super Hy-Tuf	L	185.0 169.0	167.0	0.9 6.3	3.6	0.65
800	T	121.0 112.0	116.5	3.3 0.6	2.0	0.48
Hy-Tuf	L	192.0 189.0	190.5	1.7 1.7	1.7	0.83
700	T	185.0 174.0	179.5	1.9 0.6	1.3	0.79
Super TM-2	L	210.0 205.0	207.5	1.3 0.9	1.1	0.77
500	T	156.0 167.0	161.5	0.6 1.2	0.9	0.59