1950

Room temperature tensile tests as an index of transition temperature of steel plates, Welding Journal, Vol. 29, p. 477-s, 1950, Reprint No. 71 (50-3)

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Recommended Citation

Tor, S. S.; Stout, R. D.; and Johnston, B. G., "Room temperature tensile tests as an index of transition temperature of steel plates, Welding Journal, Vol. 29, p. 477-s, 1950, Reprint No. 71 (50-3)" (1950). *Fritz Laboratory Reports.* Paper 1447.
http://preserve.lehigh.edu/engr-civil-environmental-fritz-lab-reports/1447

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July 7, 1950

File No. 208

To

Executive Committee and Fabrication
Division, Pressure Vessel Research Committee,
Welding Research Council

Gentlemen:

The attached report under the revised title "Room Temperature Tensile Tests as an Index of Transition Temperatures" by Sadun S. Tör, Robert D. Stout, and Bruce G. Johnston - Fifth Progress Report of this investigation - is transmitted to you for your comment and criticism.

This report is scheduled for presentation at the annual meeting of the Welding Society and presumably will be published in the September Welding Journal as we will have it on Mr. Spraragen's desk by July 10.

It is my opinion that this report may represent the most practical contribution that we have yet made to your committee and may point the way to a de-emphasis of transition temperature tests.

Very sincerely yours,

Bruce G. Johnston
Director

BGJ:fs

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ROOM TEMPERATURE TENSILE TESTS AS AN INDEX OF TRANSITION TEMPERATURE OF STEEL PLATE

Progress Report No.5 on the Effect of Fabrication Processes on Steels Used in Pressure Vessels

by

Sadun S. Tör[*], Robert D. Stout[o] and Bruce G. Johnston[#]

INTRODUCTION

When the Pressure Vessel Research Project at Lehigh University was started four years ago it was with the purpose of studying and determining the effects of various fabrication processes on the steels used in pressure vessels. Ultimately, it was hoped that through this extensive study, not only would the general knowledge in this field be enlarged, but also data would result which the design engineer could make use of in pressure vessel design. Two steels were selected and major parts of heats purchased. Four progress reports have already been published as a result of this program[1,2,3,4] in which studies of various notch-bend tests, the effects of plastic strain and post heat treatments, and the effects of welding on these steels were reported. In this paper further analysis of the data as reported in one of the earlier papers, namely Progress Report No.3 by Osborn, Scotchbrook, Stout and Johnston[3], is presented, and it is

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(1,2,3,4,5) Numbers pertaining to references listed at the end of the article

indicated that deformations in the standard tensile test at room temperature are significantly related to the transition temperature of these and other steels.

A relationship between tensile test results and transition temperatures has been sought previously. Recently, Dr. C. F. Tipper[5] in her paper "Correlation of Test Results", said, "... some relation between tensile test results and notch-bend and notch-tensile results is to be expected whenever plastic deformation occurs." However, her data fail to substantiate this statement and she is forced to state in her conclusion, "the transition temperatures cannot be predicted from the tensile test results, although low transition temperatures are associated with high values of reduction in area."

In this paper data are presented in a different manner and it is shown that, allowing for a rather uniform zone of scatter, a straight line relation does exist between tensile test results and transition temperatures.

MATERIAL

Steel Plate: Steel used in this investigation was aluminum-killed ASTM A-201 Grade A and Rimmed ASTM A-70 (now A-285) in $1\frac{1}{4}$" and 5/8" thickness. Steel A-201 had 0.15 carbon and 0.53 manganese and Steel A-70 had 0.20 carbon and 0.35 manganese. (See reference 2 for further details.)

Plastic Straining: The $1\frac{1}{4}$" material in both steels was tested after the following permanent straining operations:

1 - None
2 - 1% tension
3 - 5% tension
4 - 10% tension
5 - 1% compression

The 5/8" material was tested only after operation 3.

Heat Treatment after Plastic Deformation: Material in each of the above strained conditions was tested after the following heat treatments:

1 - Room temperature
2 - 600°F
3 - 800°F
4 - 1150°F
5 - 1600°F

PROCEDURE

The materials used and testing procedures were described fully in references 1, 2 and 3; however, it may be pertinent to give a brief description of the Lehigh slow-notch-bend, Charpy, and tensile specimens, their treatments and the testing methods, as adapted to the present program.

The Lehigh Slow-Notch-Bend Test:

In Fig. 1 can be seen the specimen and the testing jig used to determine transition temperatures by the slow-bend method. The notches were machined in two cuts after the straining and heat treating operations. The direction of plastic strain was in the direction of the long axis of the specimen. Transition curves were established by testing twelve double notch specimens at various temperatures and observing the following criteria:

1. total energy absorbed in breaking specimen
2. percent cleavage in the fracture surface
3. percent lateral contraction 1/32 in. below the notch after fracture.

To obtain a transition curve and thus determine the transition temperature, each of the above given criteria was plotted against the temperature of the test, and the average of the points at each temperature were joined by straight lines. The temperature corresponding to the point on the curve at 50% of the maximum value was defined as the transition temperature and was indicated by T_E for energy criterion, T_B for percent cleavage fracture criterion and T_N for percent lateral contraction under the notch criterion.

The Charpy Test:

Standard V-notch Charpy specimens with a 0.08 in. deep notch and with the direction of plastic strain parallel to the long axis of the specimen were used. The notch direction was normal to the surface of the plate. Twenty-four specimens tested at six temperatures were used to plot the transition curve. Transition temperatures were determined in the same manner as in the Lehigh Slow-Notch-Bend-Test.

Tensile Test:

Standard 0.505 in. diameter tensile specimens machined subsequent to the same plastic strain and heat treatment sequences were tested in duplicate and all the pertinent data were recorded.

Explanation of the Graphs:

The relationship between the tensile specimens and the Lehigh slow-notch-bend or Charpy specimens was obtained by plotting the percent reduction in area as obtained from the standard room temperature tensile tests against transition temperatures in degrees Fahrenheit as obtained from slow-notch-bend specimens or standard V-notch Charpy impact specimens. In addition "T_N" transition temperatures are plotted against:

$$\epsilon_b \text{ (total ductility)} = \ln \frac{A_o}{A_b}$$

$$\epsilon_u \text{ (uniform ductility)} = \ln \frac{A_o}{A_m}$$

$$\epsilon_n \text{ (necking ductility)} = \ln \frac{A_m}{A_b}$$

where: A_o = initial cross-sectional area

A_b = cross-section area at breaking

A_m = cross-section area at maximum load

It should be borne in mind that the points on these graphs represent two different steels and 30 different treatments prior to tensile or transition temperature tests. Hence a large variation in the resultant properties is represented.

Discussion of the Graphs:

In Fig.3 "T_n" lateral contraction transition temperature as obtained by the Lehigh slow-notch-bend specimen is plotted against the reduction in area. The reduction in area values cover a range of 20% (from 50% to 70%) and the transition temperature covers a range of 200°F (from -120°F to +80°F). The relationship is a straight line with some scatter. The scatter is of the magnitude to be expected from this type of data. In Fig.4 "T_N" transition temperature as obtained from V-notch Charpy specimen are plotted against % reduction in area. The curve from Fig.3 is superimposed here to afford a better comparison between the two tests. The Charpy transition temperatures are roughly 90°F higher than those obtained for similarly treated steel by the Lehigh slow-notch-bend test. Fig.5 shows the relation between Lehigh slow-notch-bend and V-notch Charpy transition temperatures where % contraction under the notch is used as criterion.

It can be seen that in spite of the scatter there is a definite correlation between the two test methods. In Fig.6, percent reduction in area values are plotted against the energy transition temperature as obtained from V-notch Charpy specimens with the energy absorbed during test used as criterion. The resulting straight line is practically the same as in Fig.4. However, the points are bunched together indicating that the energy criterion for use in transition temperature determination with the Charpy specimen is not as sensitive to changes in strain or heat treatment as percent contraction uder the notch measurements.

In Fig.7 ϵ_b (total ductility) has been plotted against Lehigh slow-notch-bend transition temperature T_N. Here again the straight line relationship is in evidence. However, when ϵ_u and ϵ_n, uniform ductility and necking ductility, respectively, are plotted against transition temperatures T_N- Fig.8 and 9, the relation is obscured by excessive scatter.

Fracture appearance used as a criterion for transition temperature determination is not as sensitive as either the energy criterion or % contraction criterion in the Charpy or Lehigh slow-notch-bend tests. In Fig.10 transition temperatures as determined by fracture appearance defined as percent cleavage has been plotted against percent reduction in area values obtained from tensile tests. The relationship is not of the straight line type but rather curvilinear.

Up to this point all of the data presented have been confined to the results of the research performed at Lehigh University. However, it was considered desirable to to survey the transition temperature literature to uncover some substantiating data suitable for plotting percent reduction in area against transition temperature. Such data were found in the ASM Campbell Memorial Lecture of 1947[6] delivered by Dr. A. B. Kinzel. The Kinzel slow-notch-bend specimen, Fig.11, and testing jig, Fig.12, are very similar to those used in the Lehigh slow-notch-bend method. The main differences in the test specimens are in the plate thickness and the V-notch depth; the Kinzel specimen was ½ inch thick and the V-notch was 0.05 inches deep; whereas the Lehigh specimen as used in the Pressure Vessel Research Program was 5/8" thick with 0.08" deep V-notch. The differences in the testing jig are the specimen support span which is 4½ inches in the Kinzel jig and 7 in. in the Lehigh jig and the ram tip which in the Kinzel jig has a radius of ¼" and in the Lehigh jig has ½" radius.

It is noteworthy, however, that contraction under the notch was used as a criterion for transition temperature determination and also both tensile and slow-notch-bend tests were performed on a great variety of steels ranging from plain carbon to alloy, Moreover, the fact that both of these investigations were performed on steels similarly treated enables one to make a correlation study similar to that carried out for the Lehigh data.

The data from the Kinzel[6] paper are plotted in Fig.13. The percent reduction in area values are obtained from room temperature tensile tests and the transition temperature values are obtained from the Kinzel slow-notch-bend specimen using the under-notch contraction as criterion. It should be noted that Kinzel used the temperature corresponding to 1 percent contraction in the transition curve as his transition temperature. Therefore, his temperature values appear lower then the Lehigh values. To permit a comparison of this straight line, Lehigh transition temperatures were redetermined from the original transition curves, at 1 percent contraction. When the Lehigh percent reduction in area values are replotted against these transition temperatures in Fig.14, it becomes obvious that they lie practically on the same line as the Kinzel data, Fig.15. It should be noted that three groups of steels are represented in the Kinzel data and therefore, a wide range of reduction in area and transition temperature values are present. It is interesting that the Lehigh values which represent two plain low carbon steels should fall on the same curve as the carbon and alloy steels of the Kinzel data.

When % elongation data are substituted for reduction in area, as in Fig.16 and 17, the transition temperatures (% contraction criterion) no longer fall into a satisfactory correlation with the tensile results of either Lehigh or Kinzel.

CONCLUSION

The curves presented in this paper show that, allowing for a band of scatter, there is definitely a straight line relationship between tensile test results, and Charpy or slow-notch-bend transition temperatures. Particularly, this is true of the correlation between percent reduction of area values obtained from the standard tensile test specimens and the transition temperatures as obtained using lateral contraction as criterion. Moreover, this relationship is substantiated by an analysis of results from similar tests conducted by Kinzel[6] at an earlier date.

These curves, therefore, lead one to the conclusion that reduction in area as determined by a tensile test may have more significance than is generally realized. If interpreted in this manner it has the advantage of requiring only a few tensile tests as compared to 24 notch bend tests needed for transition temperature determination. The ultimate aim in this type of correlation would be to substitute the standard tensile test where the many limitations of the V-notch-bend specimens such as the severity of the notch, the condition of the notch bottom, the speed of bending, etc. are absent. Moreover, the tensile test is relatively easy to perform and is universally accepted.

William and Ellinger[7] have shown that plates from Liberty ships in which fractures occurred possess an average of from 6 to 12 ft. lbs. V-notch Charpy values when tested at the temperature of the ship failure. If such a criterion of energy level can be applied to pressure vessels, then it would mean that a steel which has a V-notch Charpy value lower than some specified value at temperatures at which the finished pressure vessel will operate, would be unsatisfactory. Using this specified energy level criterion, V-notch Charpy transition temperatures could be determined on a number of steels and treatments and plotted against percent reduction in area (obtained from room temperate tensile tests) on the same steels. A direct correlation between the operating temperature of the pressure vessel and the percent reduction of area required in the steel would thereby be established. In the fabrication of pressure vessels, the steel is subjected to certain bending, pressing or welding or combination of these operations with the accompanying lowering of the ductility. This loss in ductility could be determined by the design engineer, and before the tensile tests are made, the material could be strained by this amount. Alternatively, the reduction in area after such a prestrain might be predicted by reference to a complete true stress-strain curve of the material. In this way the percent reduction in area determined by the tensile test would more or less represent those portions of the pressure vessel that were strained and therefore retain less available ductility. The transition temperature corresponding to the reduction in area as determined by the above method would then indicate the suitability of that particular steel for use in a pressure vessel at that temperature.

It would be of major interest to determine if the same type of relationship would hold true if flat bar tensile specimens were used instead of round bar.

It is hoped that other investigators will determine the relationships reported herein and that future work be guided along these lines. It would be desirable to obtain tensile and transition temperature data from pressure vessels that have failed.

SUMMARY

Straight line relationships have been shown to exist between room temperature round bar tensile test results and transition temperatures as determined by Lehigh slow-notch-bend, Kinzel slow-notch-bend and V-notch Charpy methods. The possibility of using room temperature tensile tests to predict transition temperatures of pressure vessel steels has been indicated.

ACKNOWLEDGEMENTS

This work was sponsored by the Pressure Vessel Research Committee of the Welding Research Council, which is directed by William Spraragen. P. R. Cassidy is chairman of the Pressure Vessel Research Committee and Boniface E. Rossi is executive secretary. F. L. Plummer is chairman of the Fabrication Division of the Pressure Vessel Research Committee, which guided the project staff in this work.

The project was carried on jointly by the Fritz Engineering Laboratory of the Civil Engineering Department, and the Metallurgy Department of Lehigh University.

The execution of work was made possible by the cooperation of Kenneth R. Harpel, laboratory foreman, and the entire laboratory staff.

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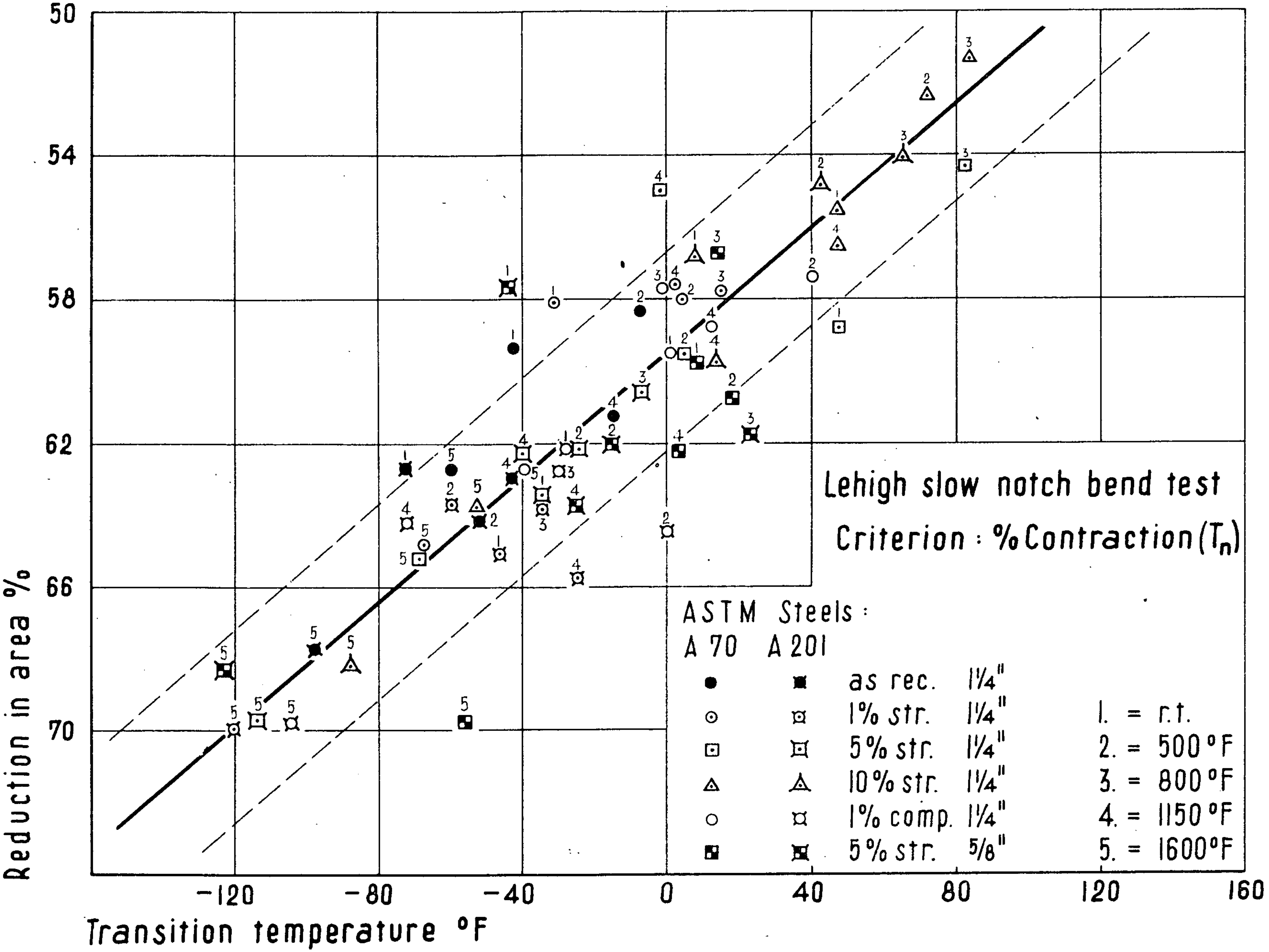


Fig. 3. A70 and A201 steels after various plastic strains and heat treatment. Relation between reduction in area and transition temperature.

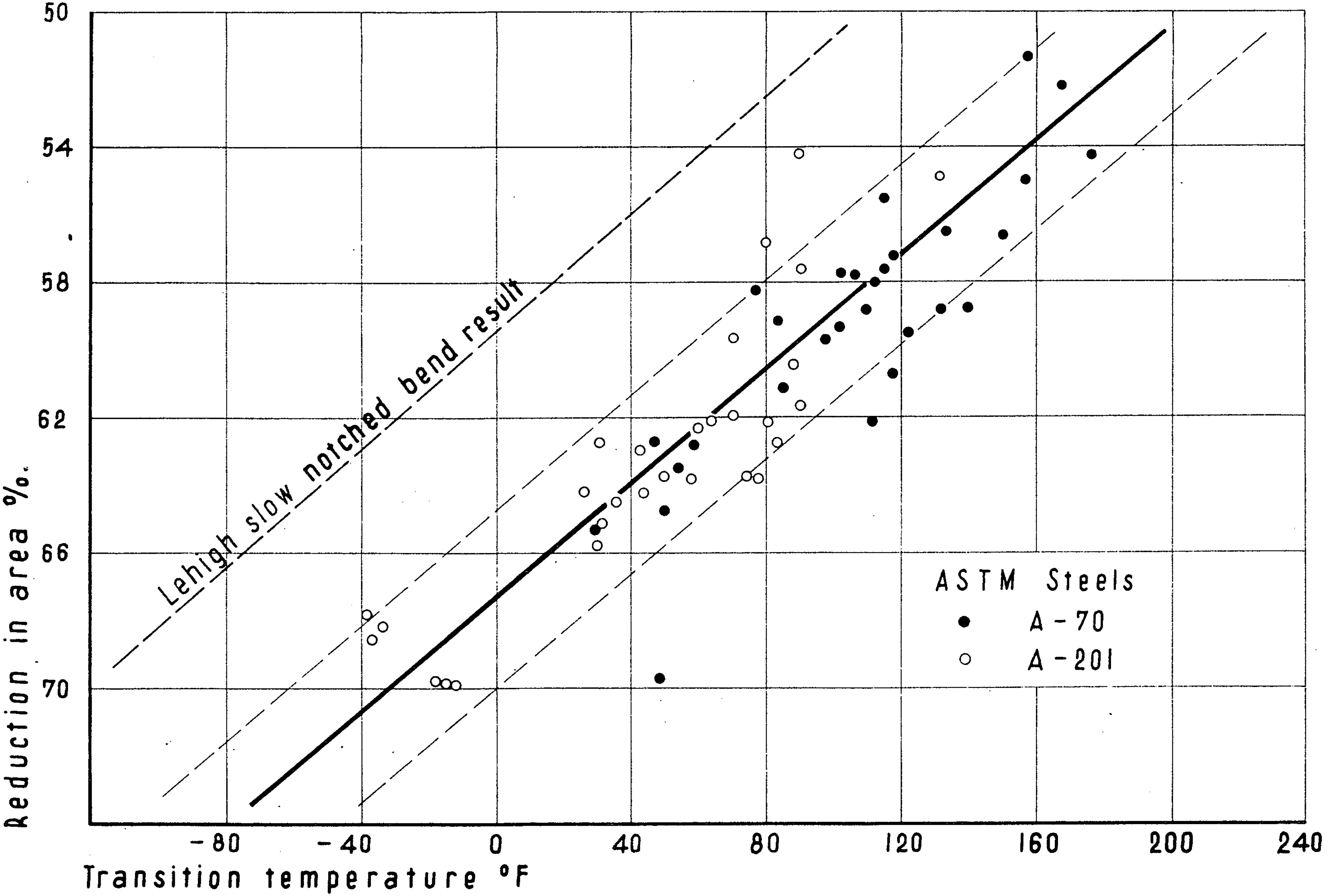


Fig. 4. Relation between transition temperature and reduction in area. V-notch Charpy test criterion: % contraction. A-70 and A-201 steels after various plastic strains and heat treatment.

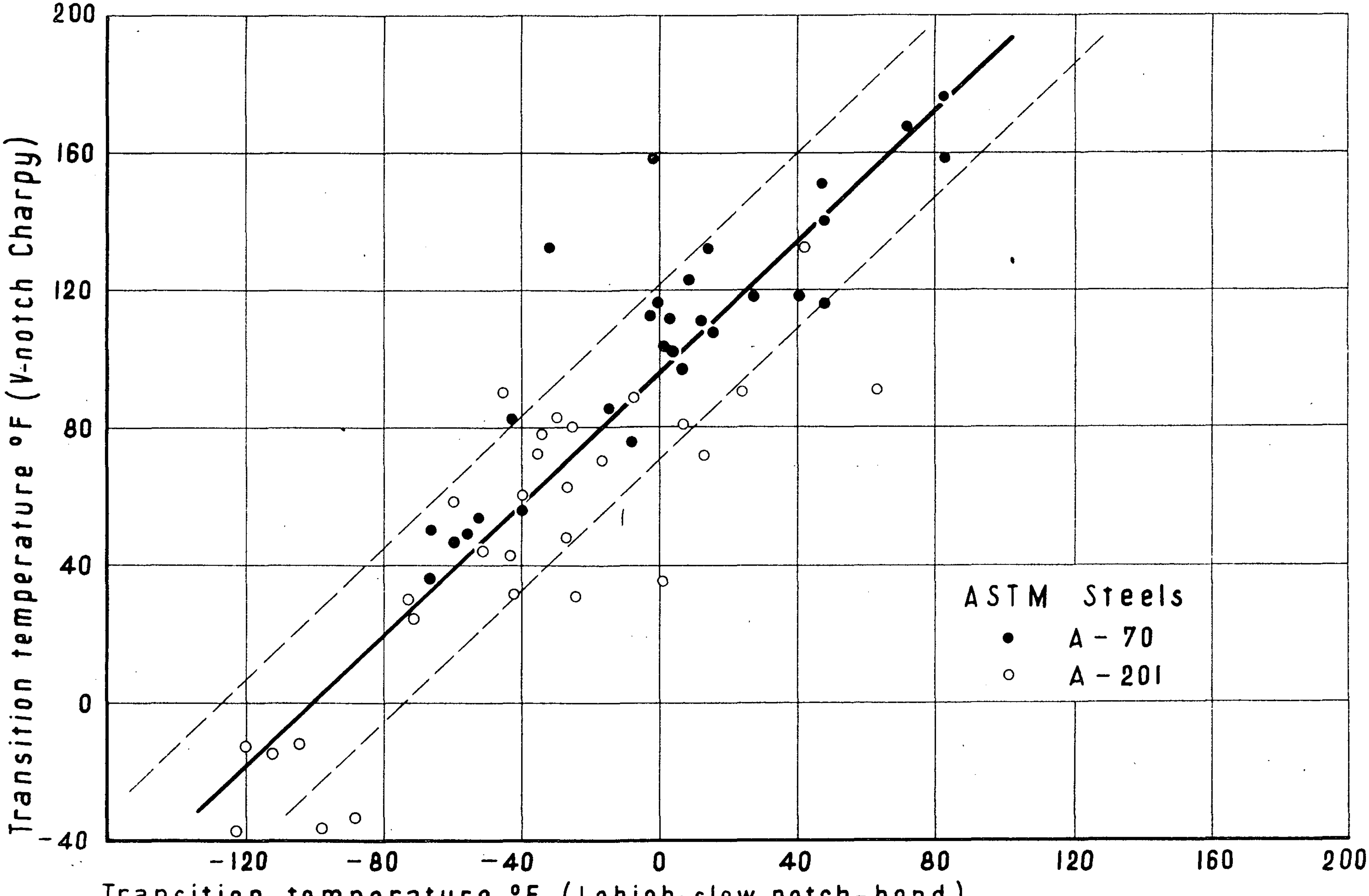


Fig.5. Relation between V-notch Charpy and Lehigh slow notch bend transition temperature. Criterion: % contraction. A-70 and A-201 steels after various plastic strains and heat treatment.

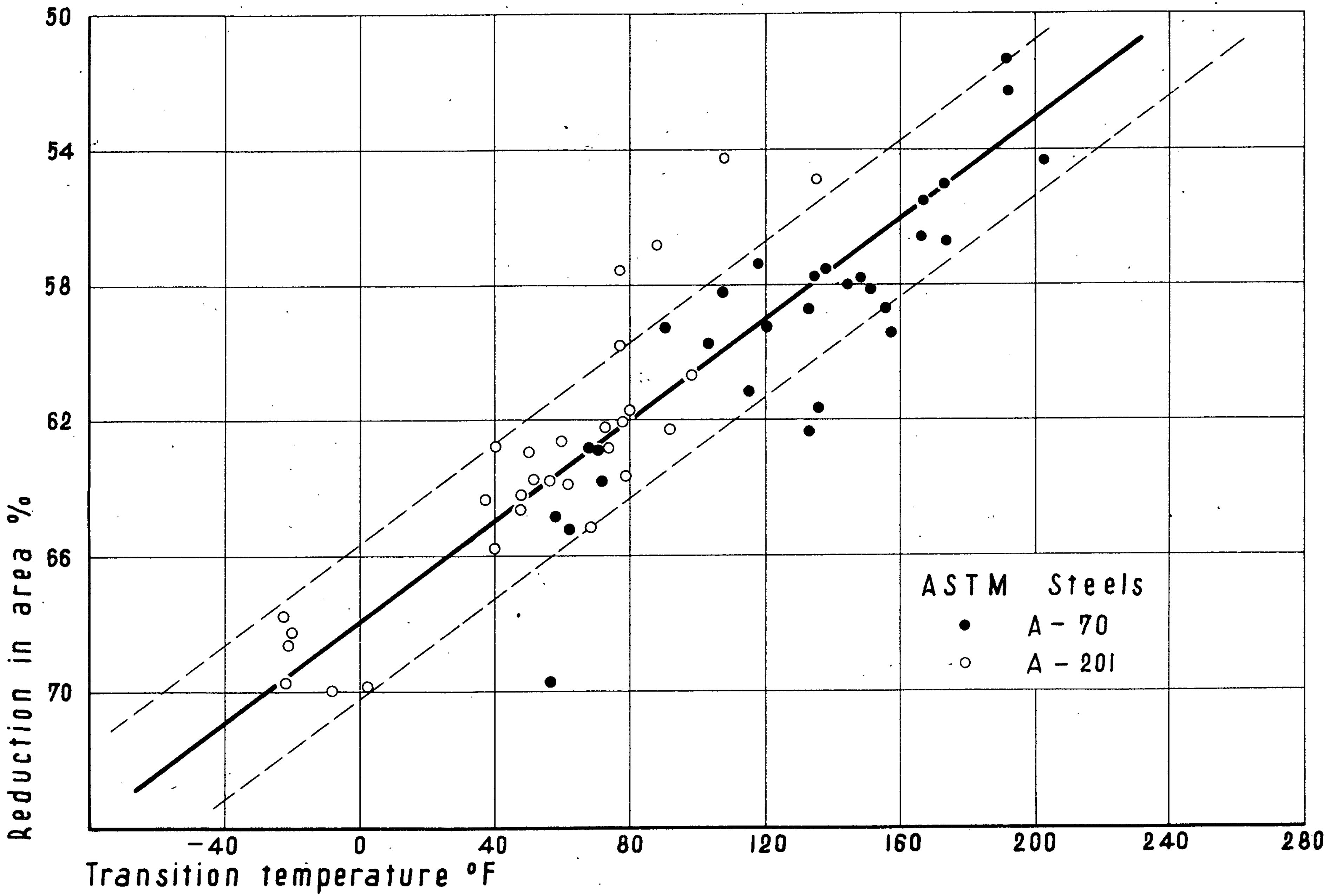


Fig. 6. Relation between reduction in area and transition temperature. V-notch Charpy test. Criterion: Energy absorbed. A-70 and A-201 steels after various plastic strains and heat treatment.

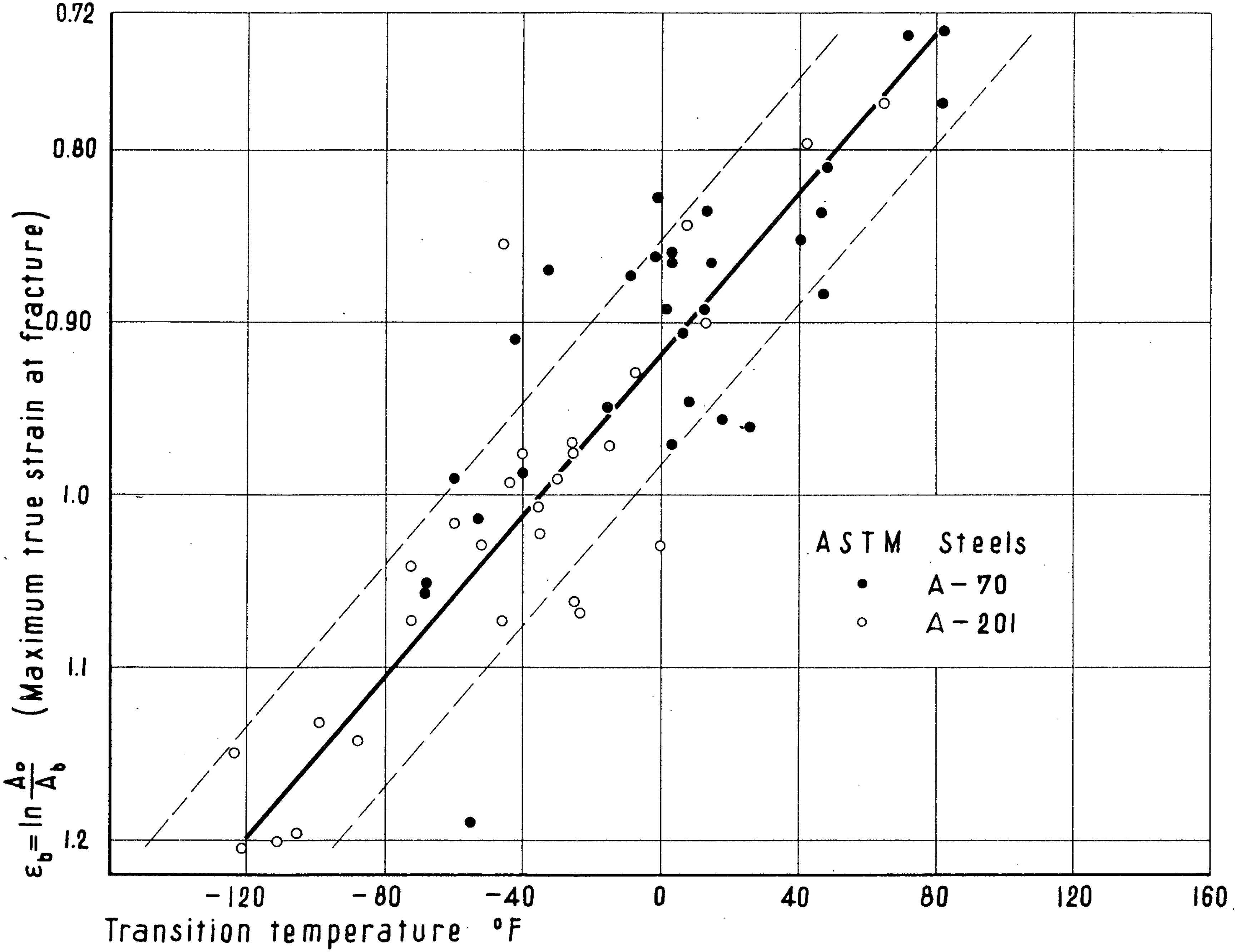


Fig. 7 Relation between ε_b, maximum true strain at fracture and transition temperature. Lehigh slow notch bend test. Criterion: % contraction. A-70 and A-201 steels after various plastic strains and heat treatment.

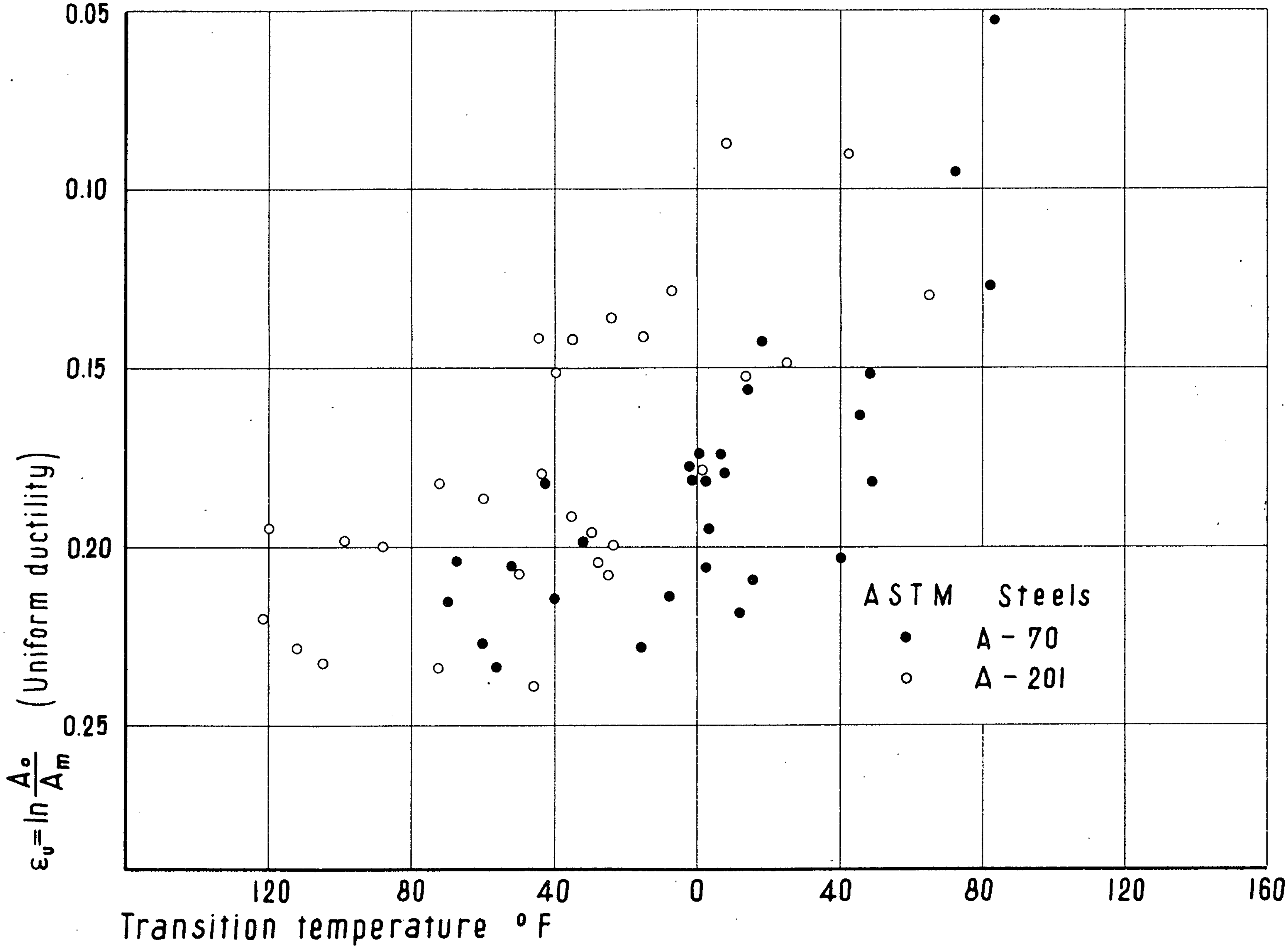


Fig. 8. Relation between ε_u (uniform ductility) and transition temperature. Lehigh slow notch bend test. Criterion: % contraction. A-70 and A-201 steels after various plastic strains and heat treatment.

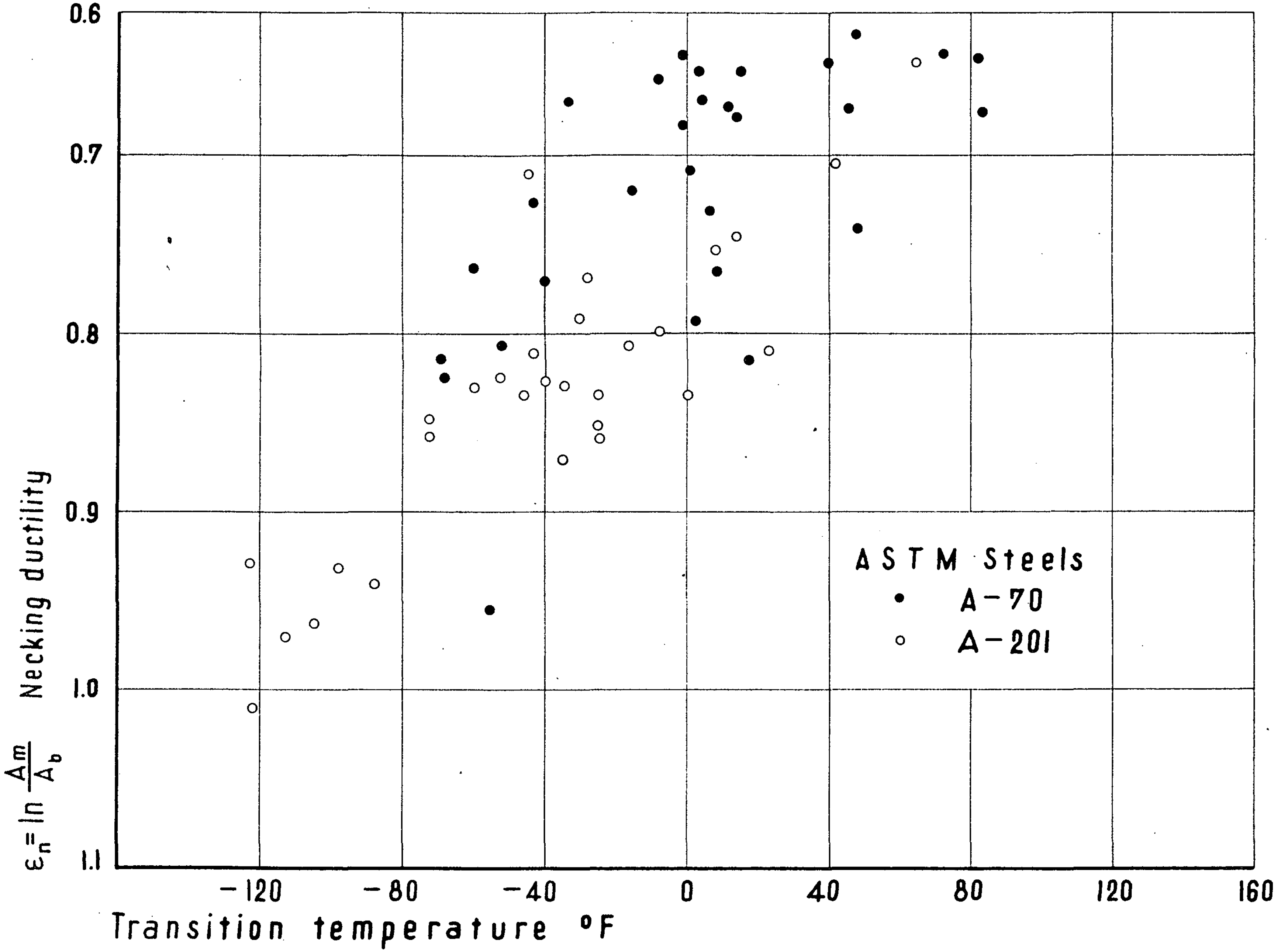


Fig. 9. Relation between ε_n, necking ductility and transition temperature. Lehigh slow notch bend test. Criterion: % contraction. A 70 and A 201 steels after various plastic strains and heat treatment.

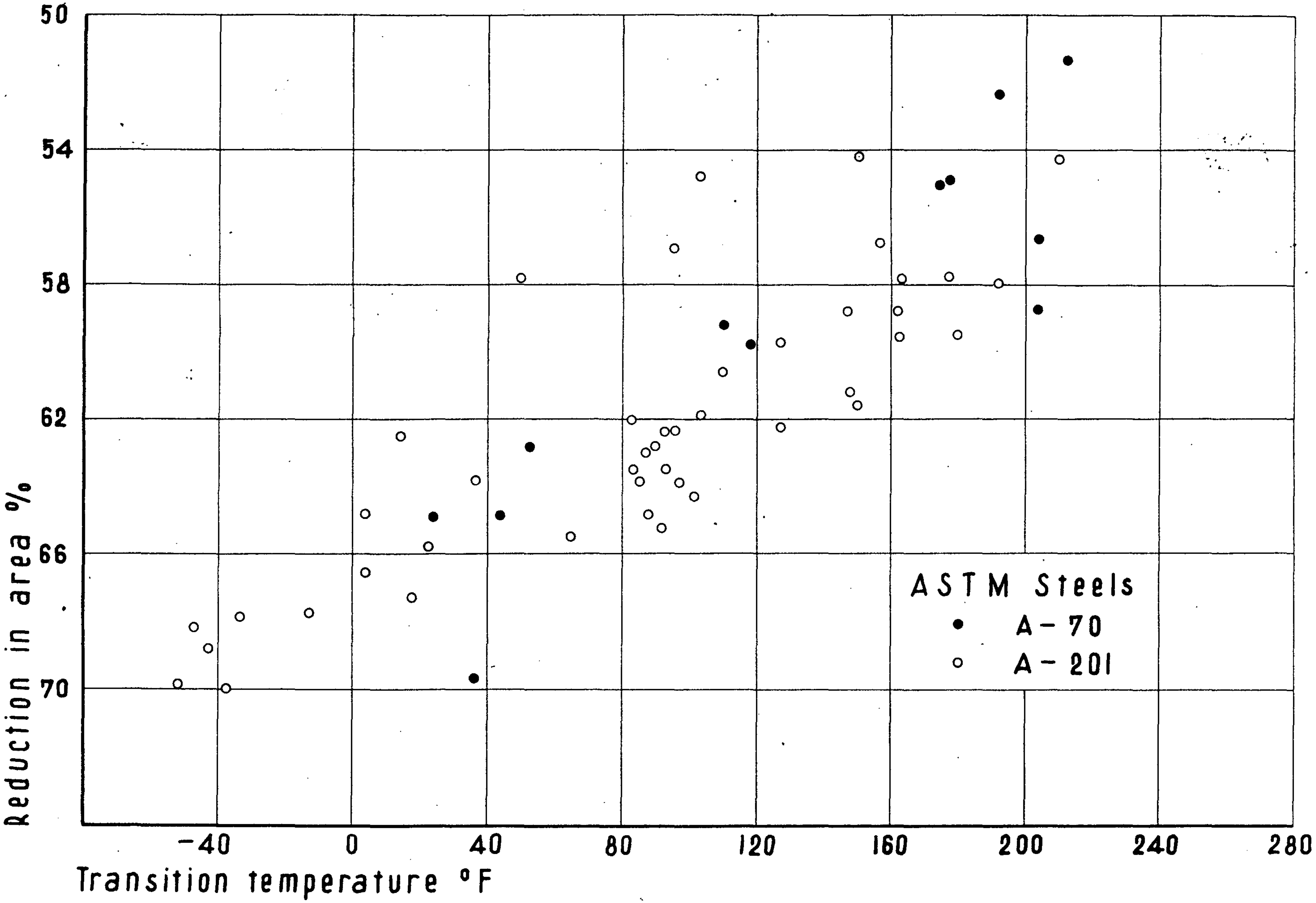


Fig.10. Relation between reduction in area and transition temperature. Lehigh slow notch bend test. Criterion: % cleavage. A 70 and A 201 steels after various plastic strains and heat treatment.

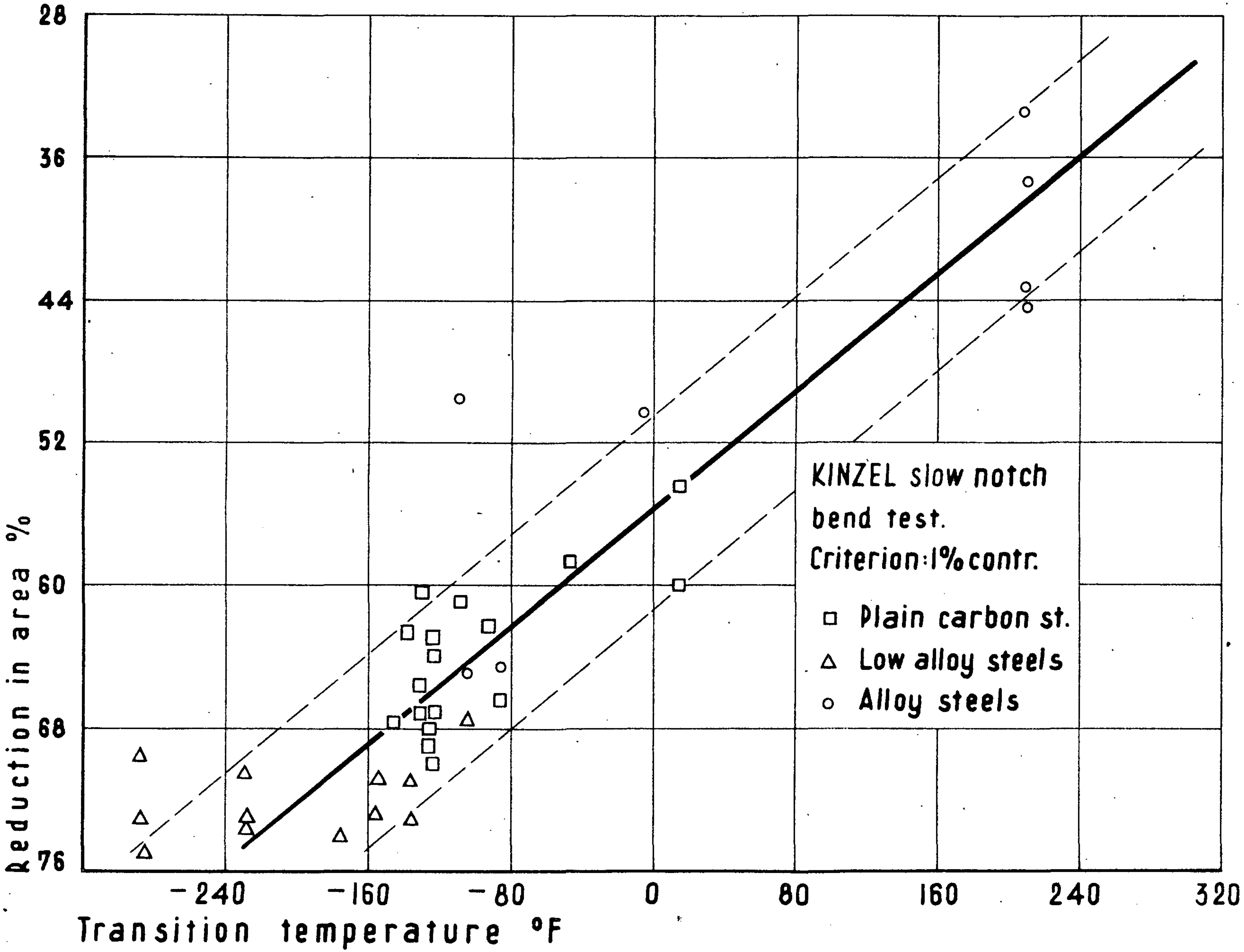


Fig. 13. Relation between transition temperature and reduction in area. KINZEL slow notch bend test. Criterion: 1% contraction. Plain carbon, low alloy and alloy steels as received and as normalized.

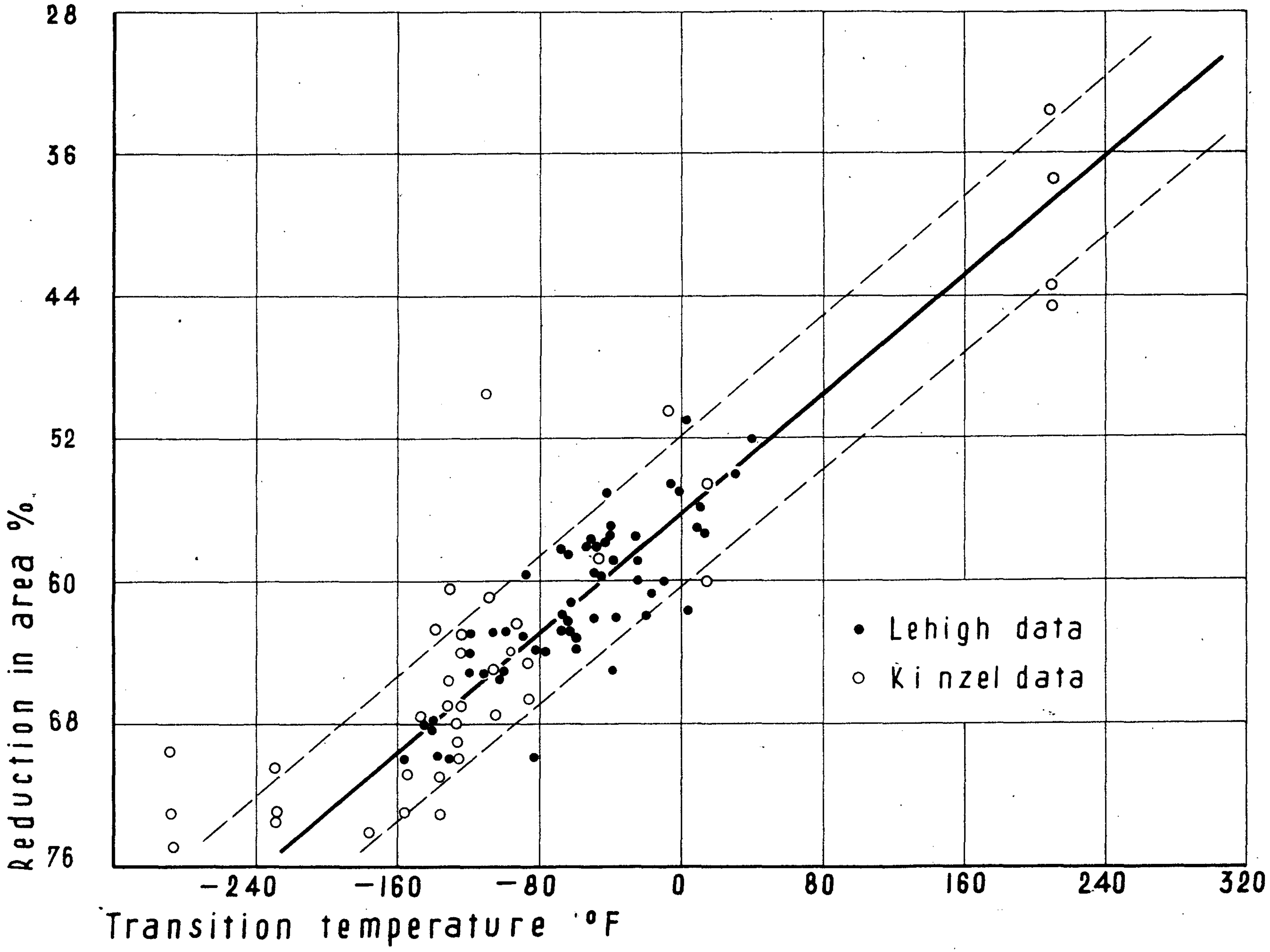


Fig.15. Relation between percent reduction in area and transition temperature from the Lehigh and Kinzel slow notch bend test data. Criterion: 1% contraction.

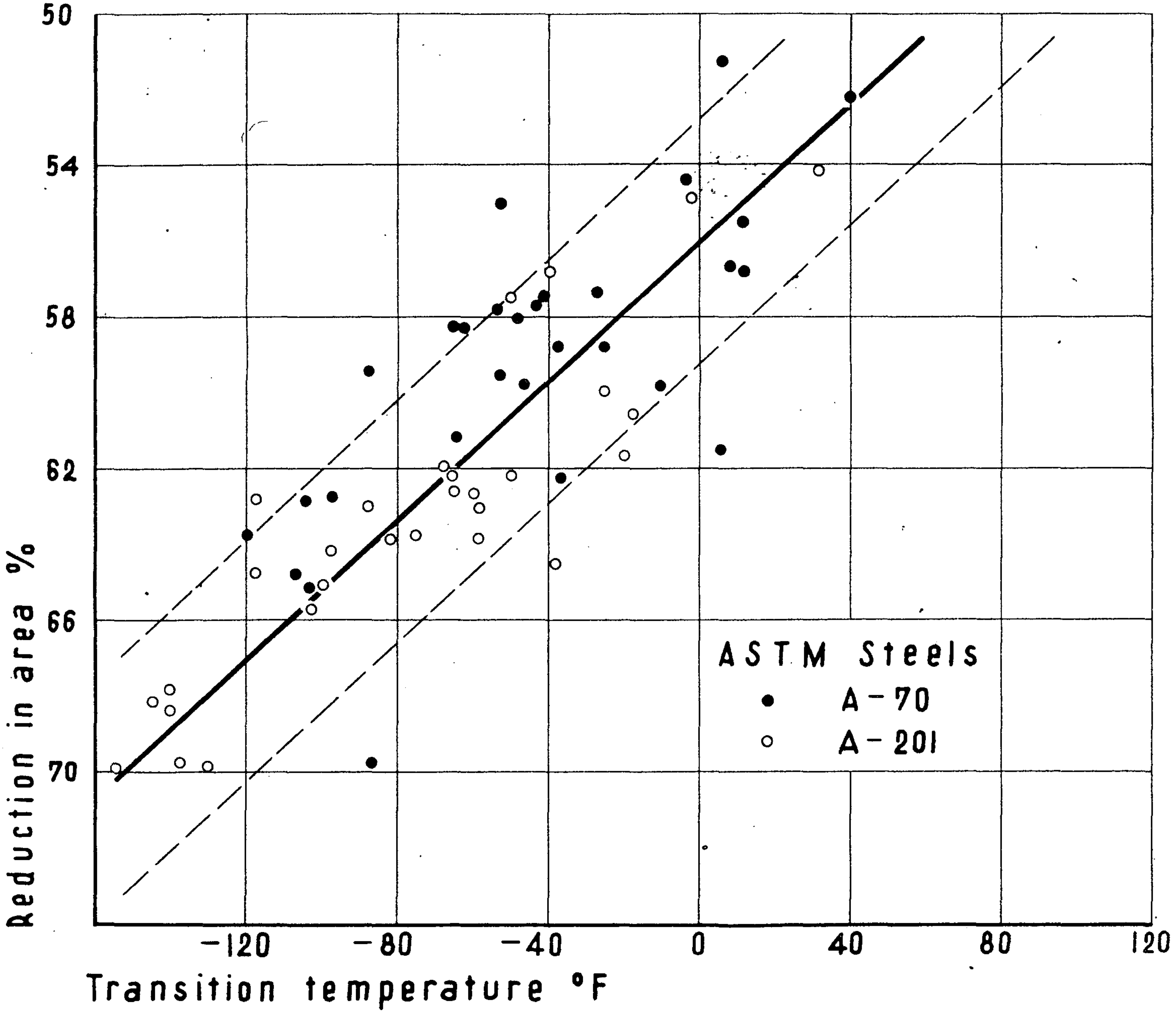


Fig.14. Relation between transition temperature and percent reduction in area. Lehigh slow notch bend test. Criterion: 1% contraction. A-70 and A-201 steels after various plastic strains and heat treatment.

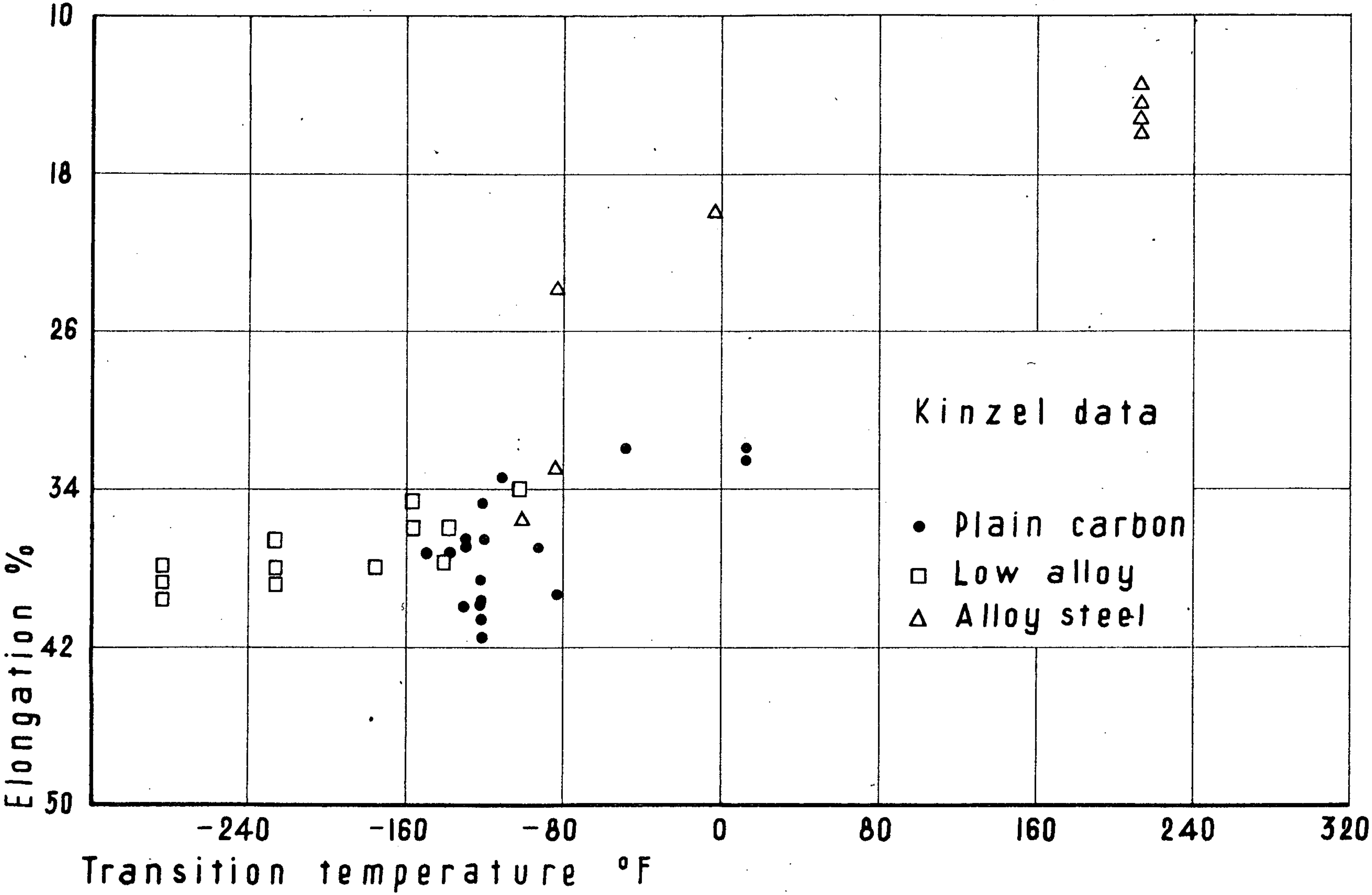


Fig. 17. Relation between elongation and transition temperature. Kinzel-slow-notch-bend test. Criterion: 1% contraction. Plain carbon, low alloy and alloy steels as received and as normalized.

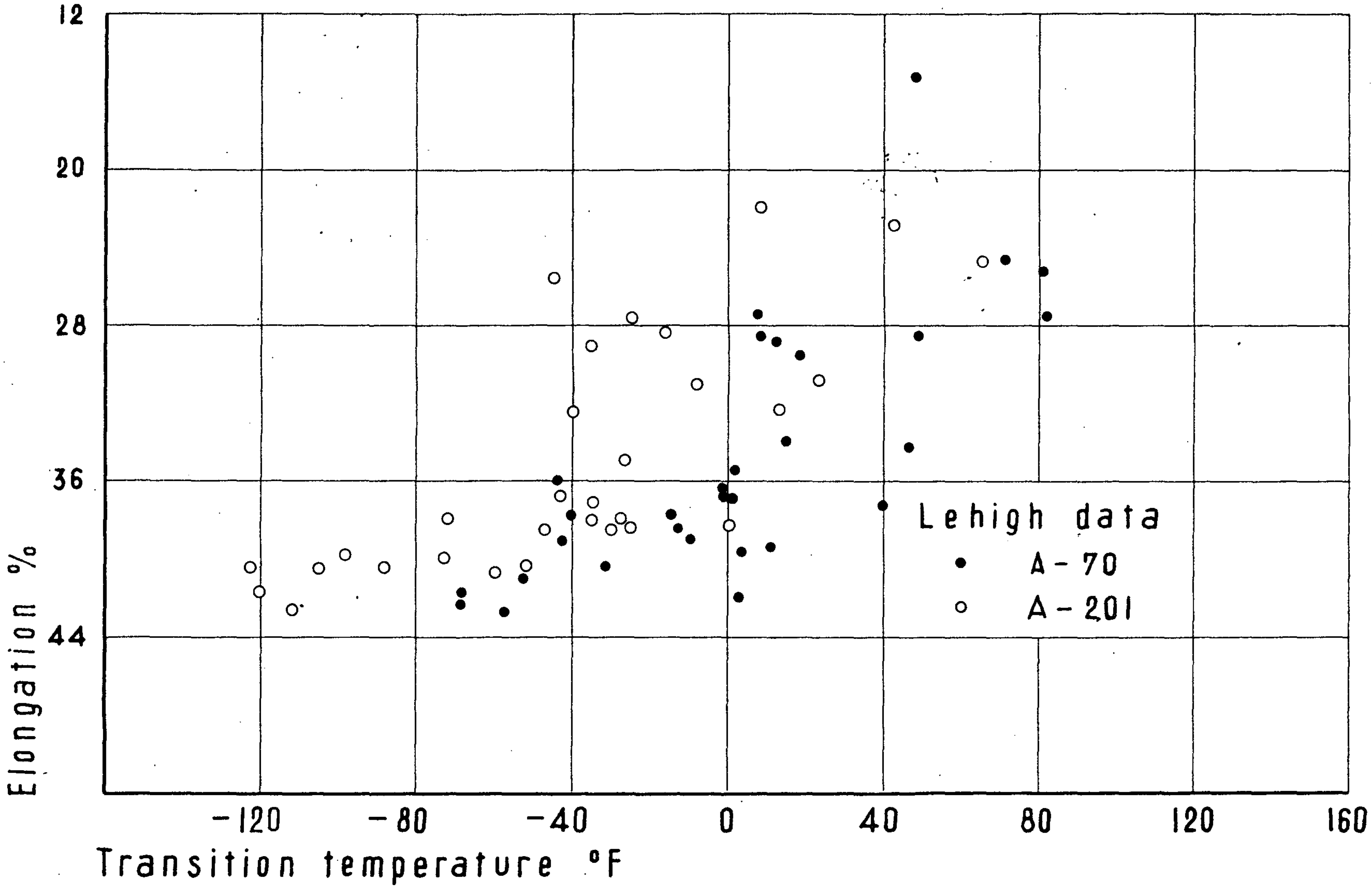
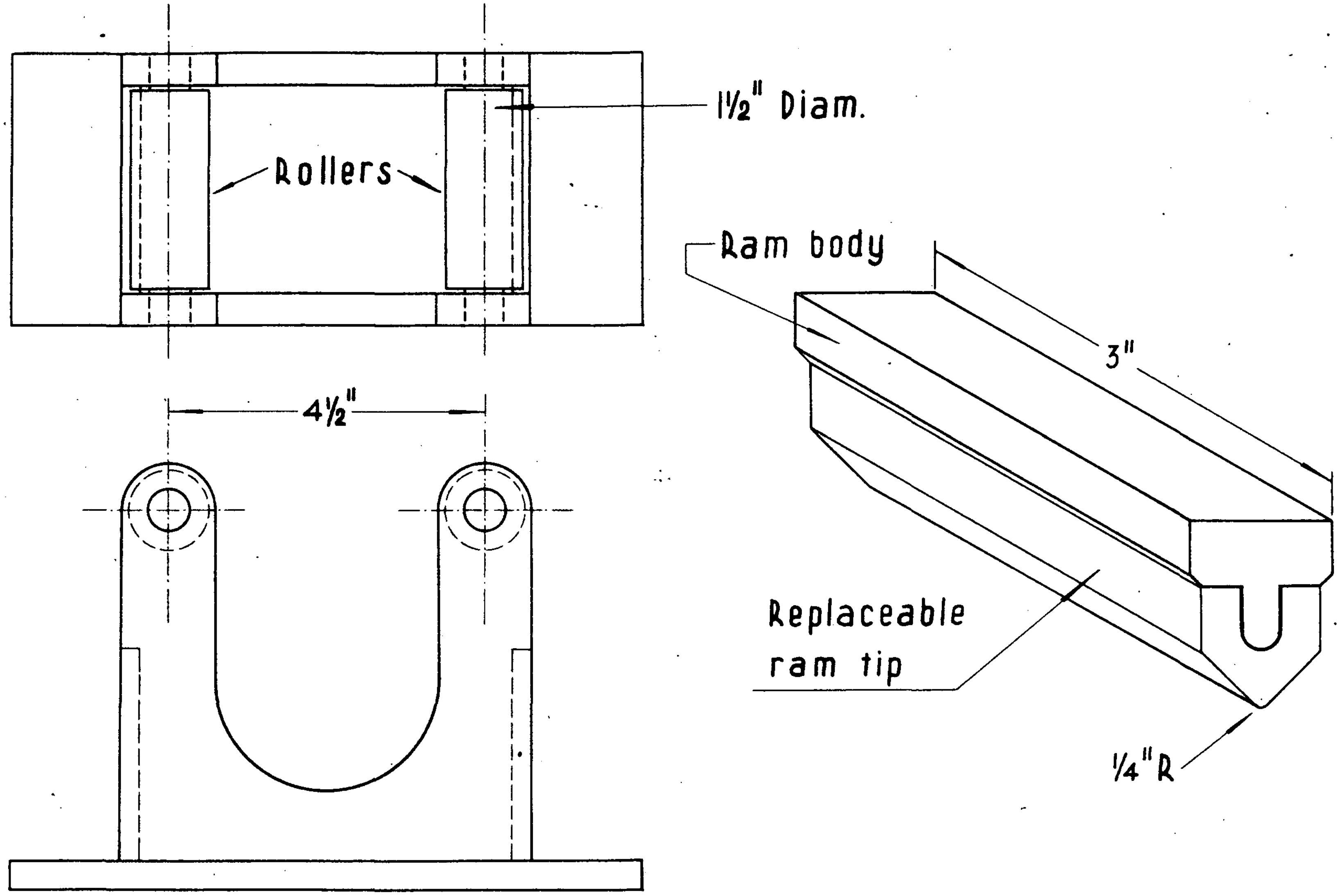


Fig. 16. Relation between elongation and transition temperature. Lehigh slow notch bend test. Criterion: % contraction. A-70 and A-201 steels after various plastic strains and heat treatment.



Holding jig

Fig. 12. Jig for KINZEL-slow-bend test

D , Notch depth = 0.080"

α , Notch angle = 45°

R , Root radius = 0.010"

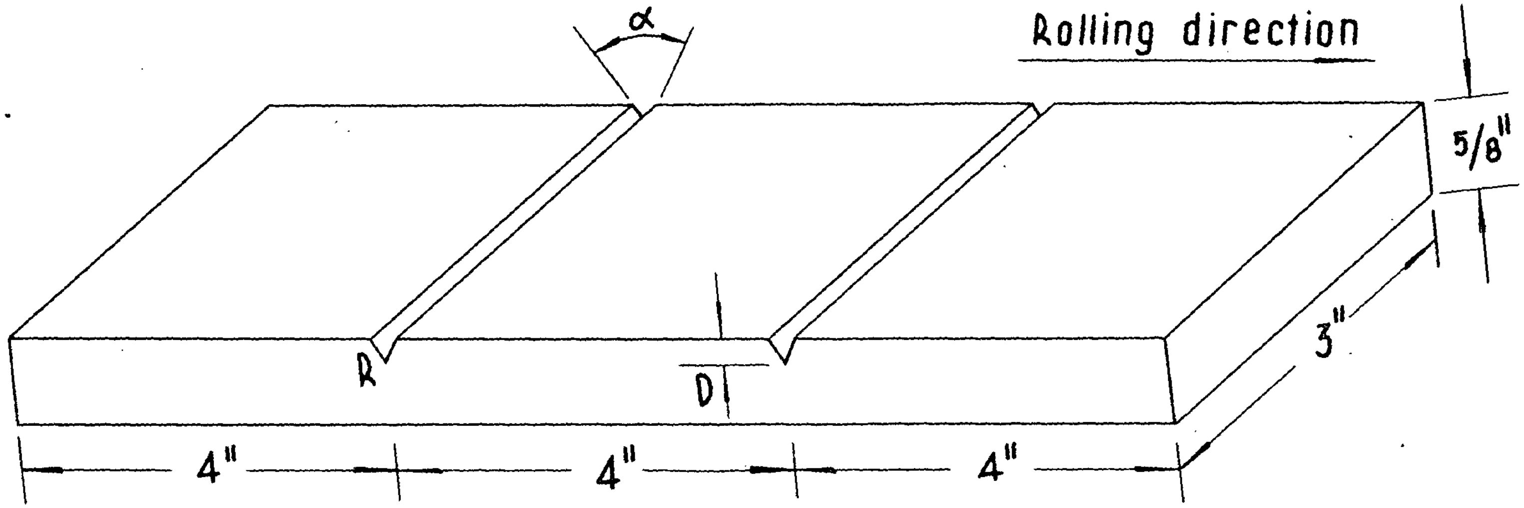


Fig. 1. Lehigh-slow-notched-bend specimen

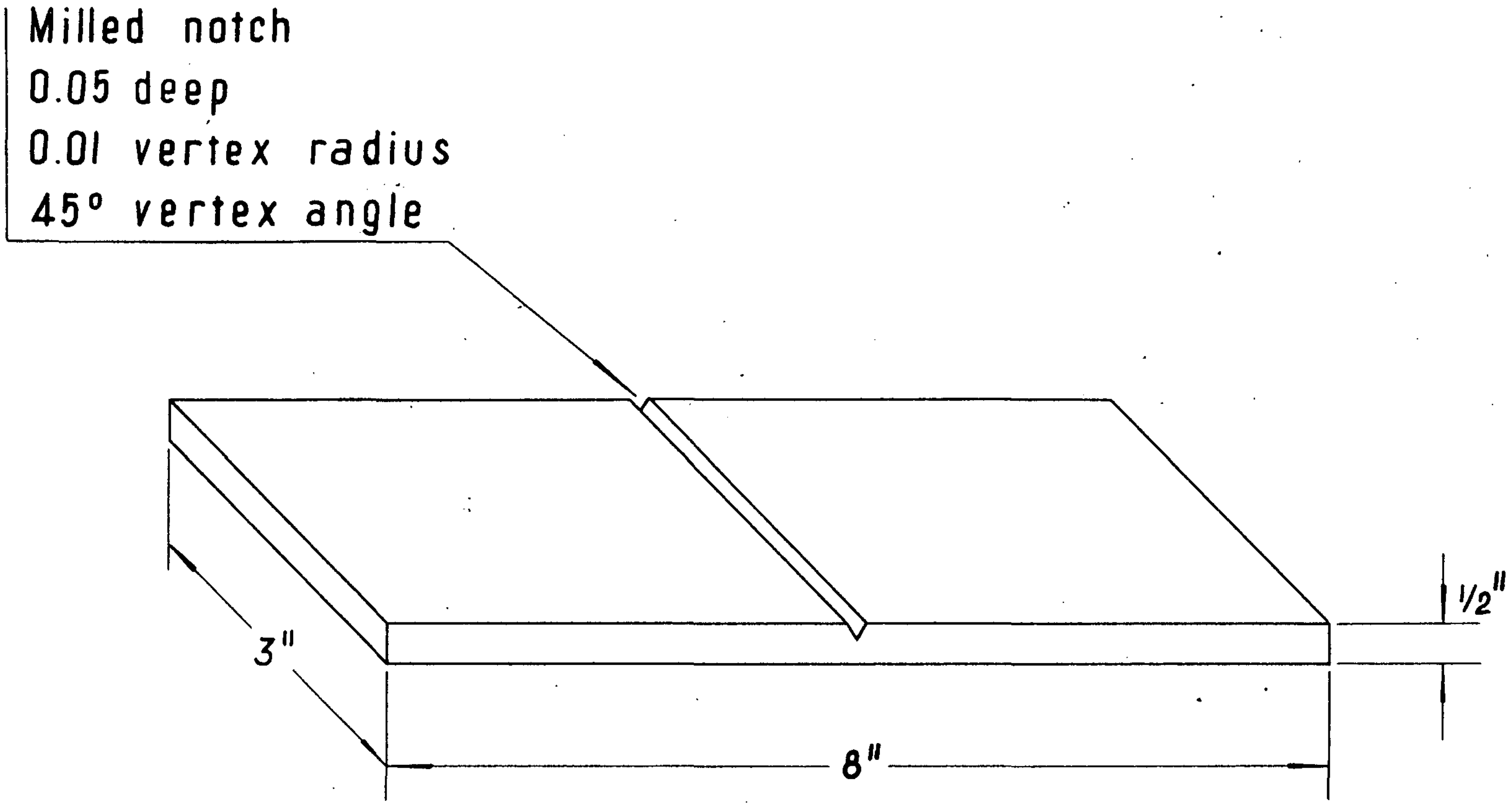


Fig. 11. KINZEL-notched-slow-bend-test specimen

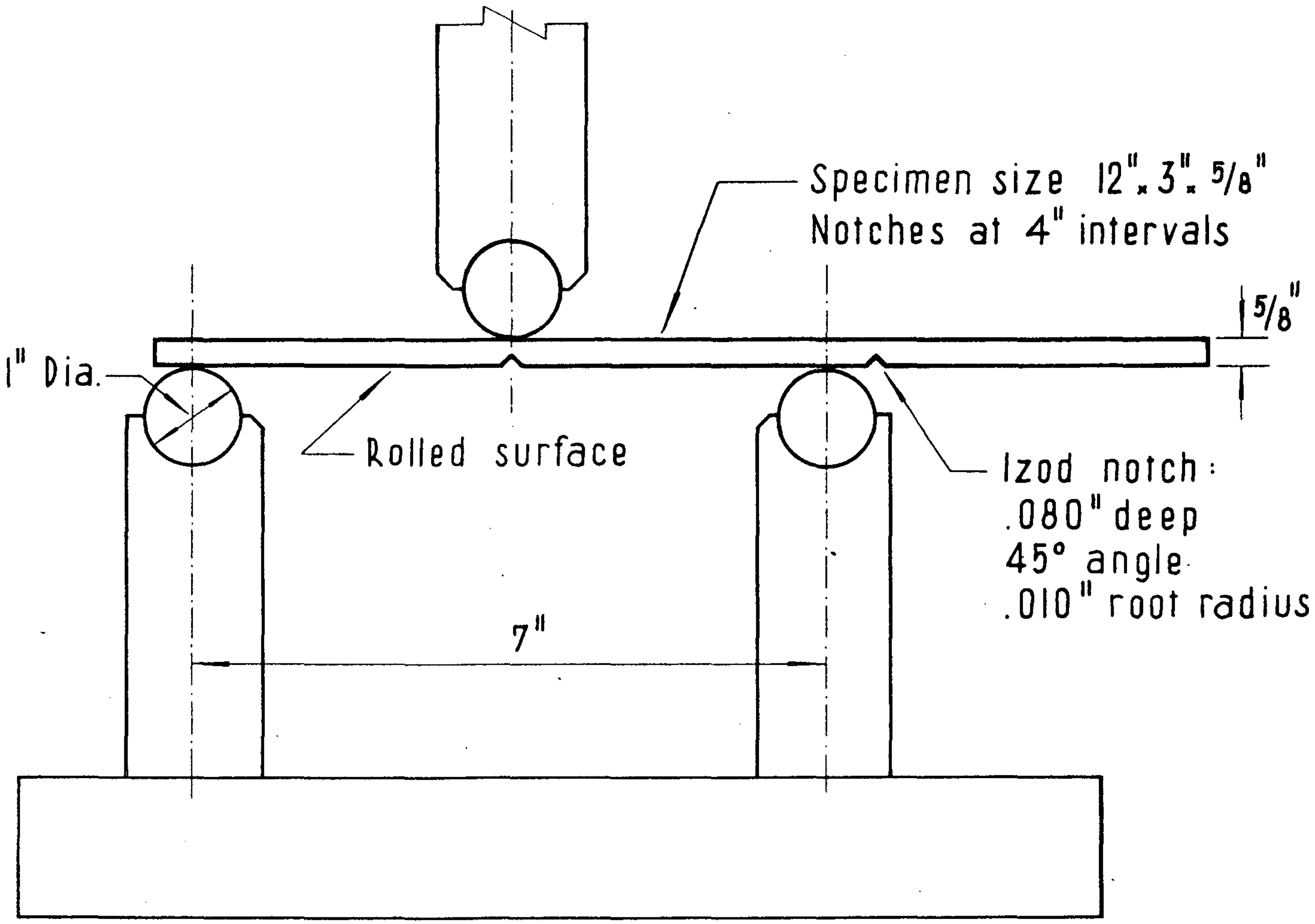


Fig.2. The Lehigh slow notched bend test.