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Effect of plate edge preparation on notch toughness, July 6, 1951

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PRESSURE VESSEL RESEARCH COMMITTEE
Fabrication Division

Lehigh University Project

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Introduction

The program carried out during the fiscal year 1950-1951 at Lehigh University consisted of two phases. The first was a study of the effect of plate edge conditions as produced by machining, flame-cutting, or shearing on the notch toughness of the pedigreed steels A201 and A285 used in previous investigations. The second phase covered the repeated load tests on cold worked and on welded specimens, in which the behavior of the steels was studied under repeated plastic straining.

The results of these investigations are reported in the form of the papers prepared for publication.

Respectfully submitted,

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Part I

Effect of Plate Edge Preparation on Notch Toughness

The Effect of Fabrication Processes

on Steels Used in Pressure Vessels

EFFECT OF PLATE EDGE PREPARATION ON NOTCH TOUGHNESS

By

S.S. Tör, J.M. Ruzek, R.D. Stout

This work has been carried out as a part of an investigation sponsored by The Fabrication Division of the Pressure Vessel Research Committee.

Fritz Engineering Laboratory

Lehigh University

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EFFECT OF PLATE EDGE PREPARATION ON NOTCH TOUGHNESS

By

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INTRODUCTION

This paper is one of a series resulting from a project at Lehigh University sponsored by the Fabrication Division of the Pressure Vessel Research Committee. This project has as its object, the study of the effect of various fabrication operations such as welding, cold forming, and heat treatment on the mechanical properties of pressure vessel steels.

One of the steps in fabrication is the sizing of plates by machining, flame cutting, or shearing. The question arises whether these operations will affect the notch toughness of the steel by introducing notches or metallurgical changes. It may be said that these conditions will later be erased during the joining of the plate edges by welding; but not all of the edges necessarily receive welding, and others may be incompletely joined by skip welds or partial fillet or lap welds.

It was decided to investigate the notch toughness of steel plate which had been prepared by machining, by flame cutting, or by shearing.

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TEST PROCEDURE

Specimen Design

In order to measure the effect of edge preparation on notch toughness, it was necessary to develop a specimen that would incorporate a notch in which the prepared edge would be an integral part. This was to avoid an artificial notch which would mask the effect of the original edge condition. The design which was adopted is shown in Fig. 1. This specimen is tested under slow bending, with the center notch in tension.

It will be noticed that the notch is of large radius to permit its preparation by shearing or flame cutting. The ends of the specimen are undercut to prevent possible tilting during bending. The width of the specimen is equal to the original plate thickness.

The Steels

The steels used for these tests were the two pedigreed steels described fully in previous reports(1). They were ASTM grades A-201 and A-285, 5/8 inches thick and analyzing as follows:

Steel Analysis

	C	Mn	P	S	Si	Cr	Ni	Cu
A-201	0.15	0.53	0.20	0.022	0.20	0.04	0.05	0.07
A-285	0.20	0.35	0.19	0.028	0.02	0.04	0.10	0.14

All specimens were cut from plates in the as-rolled condition.

Specimen Preparation

The significant step in the preparation of the specimens was the production of the notch contour. Three series of specimens were prepared: one by machining, one by flame cutting, and one by shearing.

The machined notches were obtained by drilling and reaming a one-inch diameter hole in the plate and then splitting the plate through the hole on a band-saw. Two specimens could then be produced from the pieces.

The flame-cut notches were made on a special machine which provided a circular motion at the proper speed for a standard cutting torch.

The sheared notches were produced by punching a one-inch diameter hole in the plate on a commercial press and then splitting the plate as was done for the drilled holes.

Enough specimens were prepared to permit postheating to be a part of the study. Postheating was carried out for one hour at 500°F, 1150°F, and 1600°F (the latter on A-201 steel only).

The appearance of the prepared notches is represented in Fig. 2.

Testing

The specimens were in sufficient number to allow tests over a range of temperature. The observations recorded during the tests included the percentage of lateral contraction at the bottom of the notch and the energy absorbed to failure. The transition temperature was defined as that at which the contraction or energy absorption had dropped to half its value in the shear fracture temperature range.

Testing temperatures were obtained by a cooling (or heating) bath from which the specimens were transferred to the testing jig shown in Fig. 3. Note the guide at one side of the jig to prevent tipping of the specimen. The crosshead of the tensile machine provided loading at 2.7 inches per minute.

RESULTS AND DISCUSSION

The results of the investigation are presented as transition temperature curves in Figs. 5 through 11. The transition temperatures have been selected from these curves and plotted in a summary bar graph in Fig. 12 for easier examination. Only the lateral contraction data have been given, because the energy absorption criterion leads to identical conclusions and virtually identical transition temperatures. Typical fractured specimens are shown in Fig. 4. Note the large deformation and shear fractures evident in tests at the higher temperature as compared to the slight deformation and cleavage fractures at the low temperature - except for the machined notch.

Examination of Fig. 12 reveals several points of interest.

In both steels the machined notches were too mild to produce a transition even at -140°F, the lowest temperature tested. The flame cut notches had higher transition temperatures, but they were not nearly so high as those obtained with the sheared notches.

Heat treatment as 500°F had an adverse effect on both flame cut and sheared specimens, whereas treatment at 1150°F improved both types noticeably.

The postheating at 1600°F of the A-201 plates was especially significant. The transition temperatures of both flame cut and sheared specimens were lowered beyond -160°F. This is strong evidence that the harmful effects of these methods of edge preparation are not due to the sharp notches that are introduced by the ripples of the flame cut or the small tears accompanying shearing, but rather that the heat effect or the plastic deformation is responsible. In other words, the adverse effects are not due to geometrical factors such as tiny notches; they are due to metallurgical changes resulting from flame cutting or shearing.

One other factor must not be overlooked with respect to the 1600°F treatment. In the furnace, the atmosphere scales the steel and thus sloughs off a few thousandths of an inch of the metal. This can conceivably contribute to the improvement by its removal of superficial imperfections. It is not believed, however, that this effect was important in these tests.

It can therefore be concluded that flame cutting, and especially shearing, lower the notch toughness of the plate. In flame cutting, the rapid thermal cycle probably produces microstructures of reduced ductility. In shearing the cut edge of the plate is so severely deformed plastically that it retains little ductility when further deformation is imposed. Since heat treatment at 1150°F relieves these conditions somewhat, it is measurably beneficial. Normalizing at 1600°F restores the as-rolled properties of the plate. Thus local flame-normalizing of either of these edge conditions might be of definite benefit in actual fabrication.

SUMMARY

1. A specimen has been developed to allow study of the effect of plate edge preparation on notch toughness.

2. Flame cutting and especially shearing lower the notch toughness.

3. Postheating at 500°F raises further the transition temperature of flame cut and sheared specimens. Postheating at 1150°F is noticeably beneficial to the steels.

4. Postheating at 1600°F lowers the transition temperature below -160°F. This behavior is strong evidence that the adverse effects of flame cutting or shearing are not due to the formation of notches at the surface but rather are due to metallurgical changes in the metal at the prepared edge by heating or plastic deformation.

ACKNOWLEDGMENTS

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.

REFERENCE

"Composition and Property Variation of Two Steels" by C.J. Osborn, A.F. Scotchbrook, R.D. Stout and B.G. Johnston; Welding Journal Research Supplement vol. 28, No. 5, pp. 227-235 (1949).

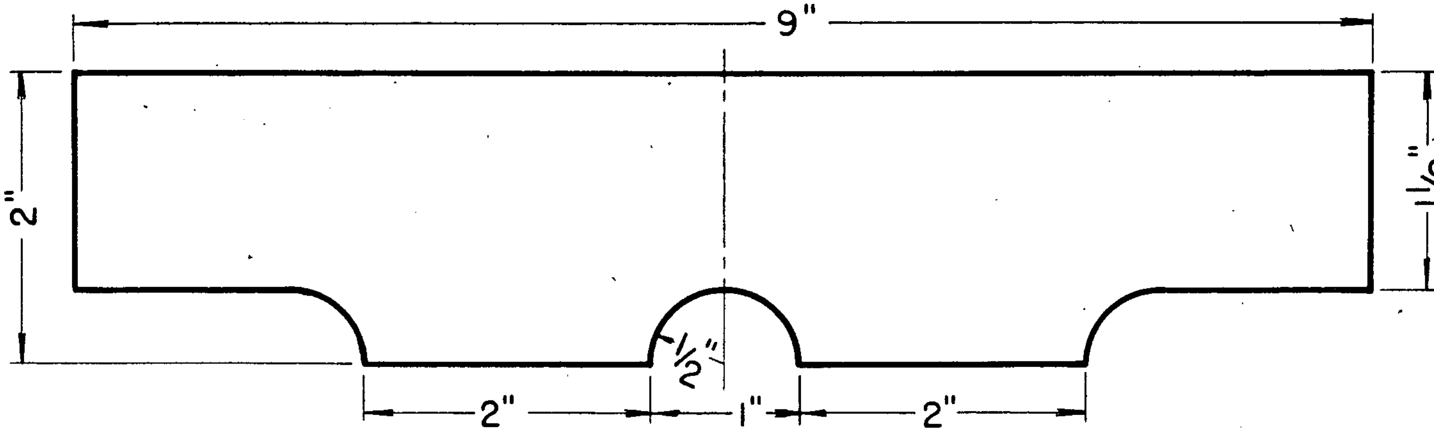


FIG. 1. PLATE EDGE EFFECT TEST SPECIMEN

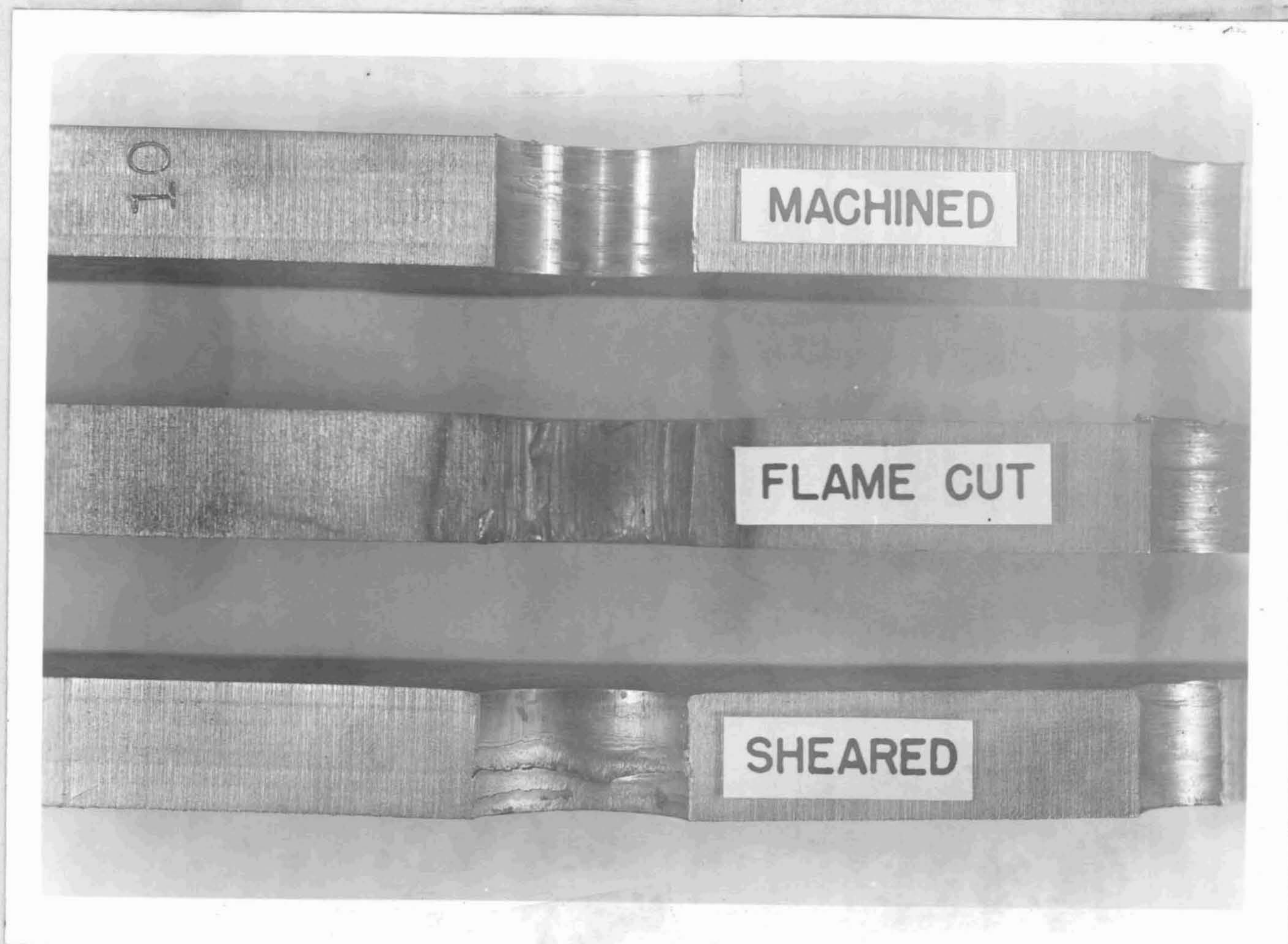
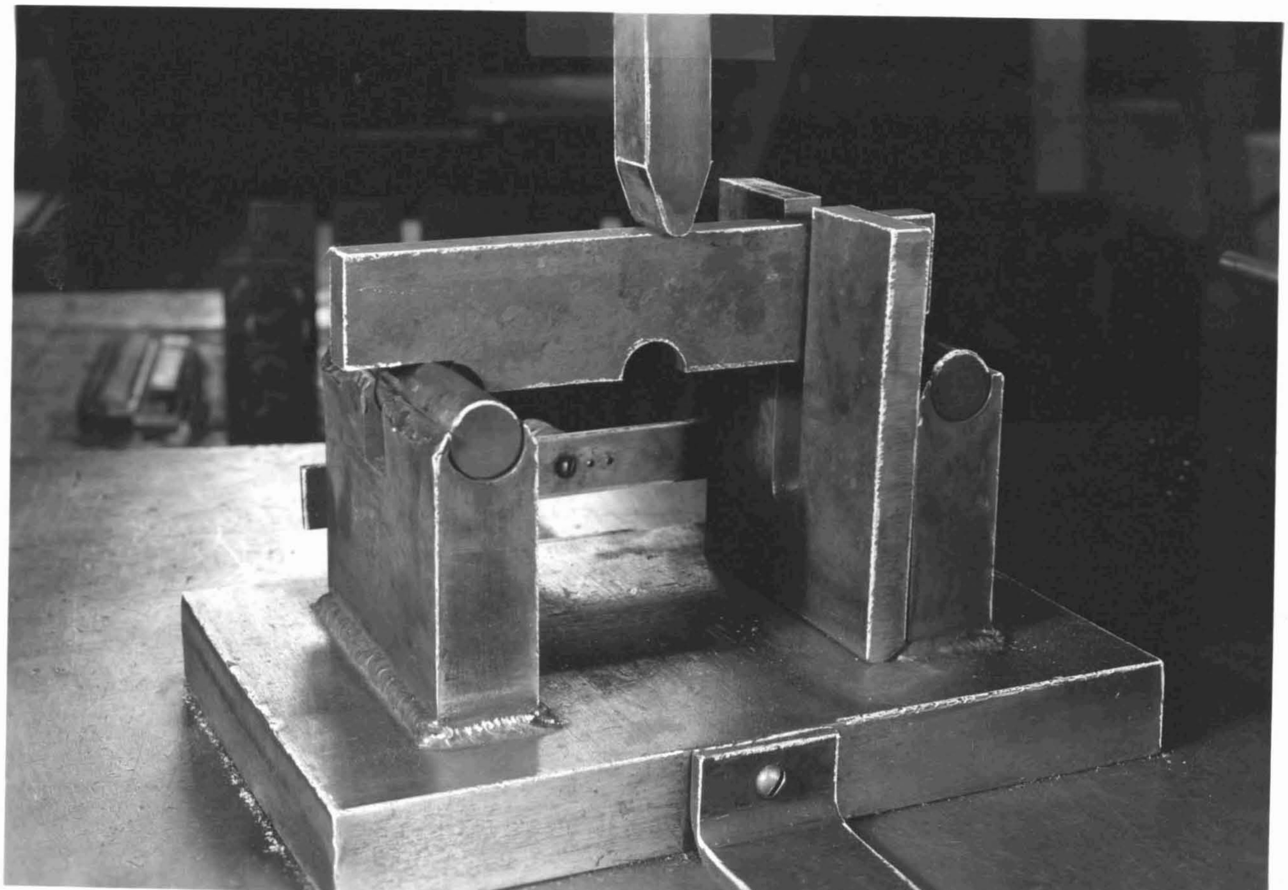


Fig. 2



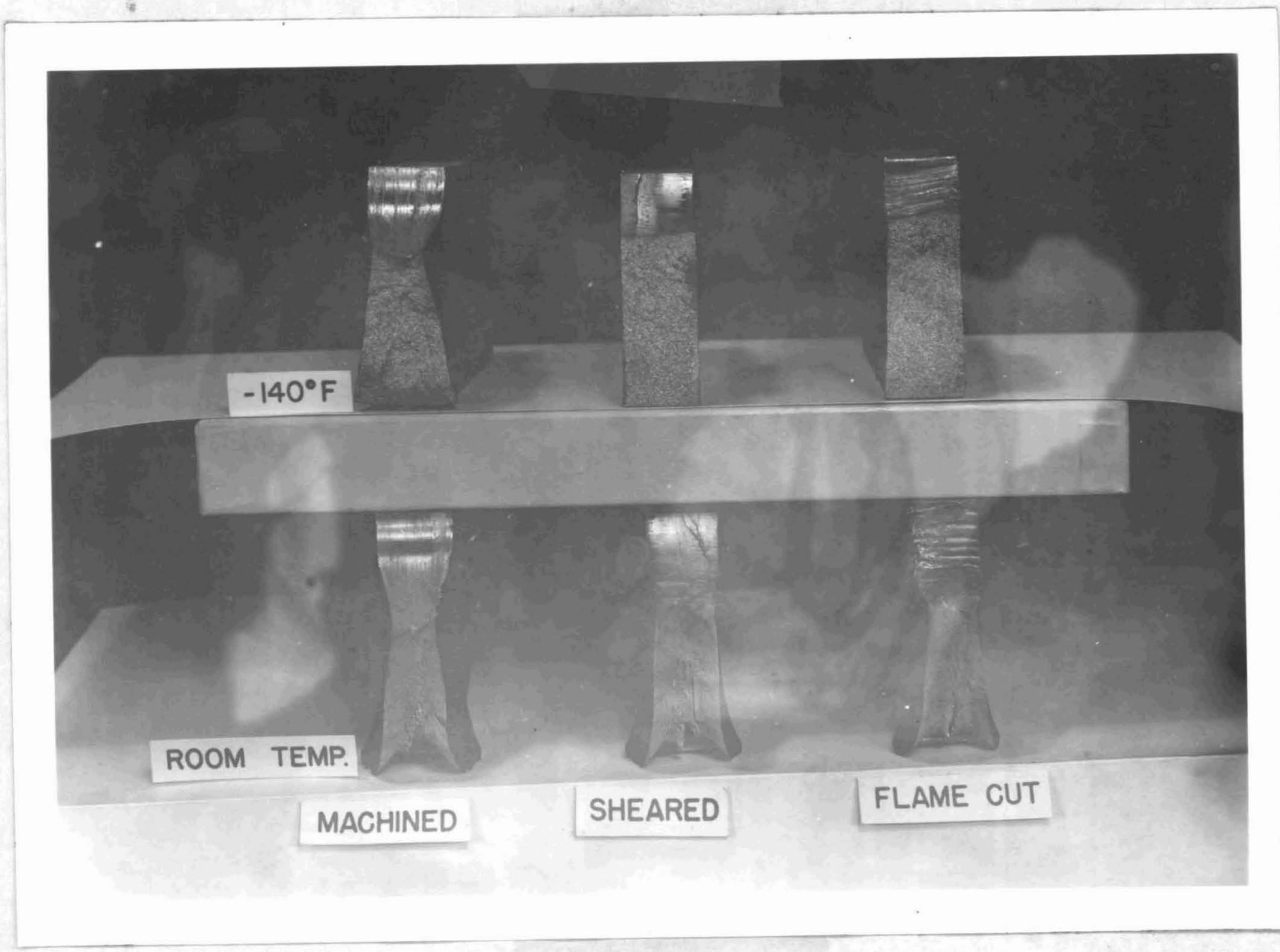


Fig. 4

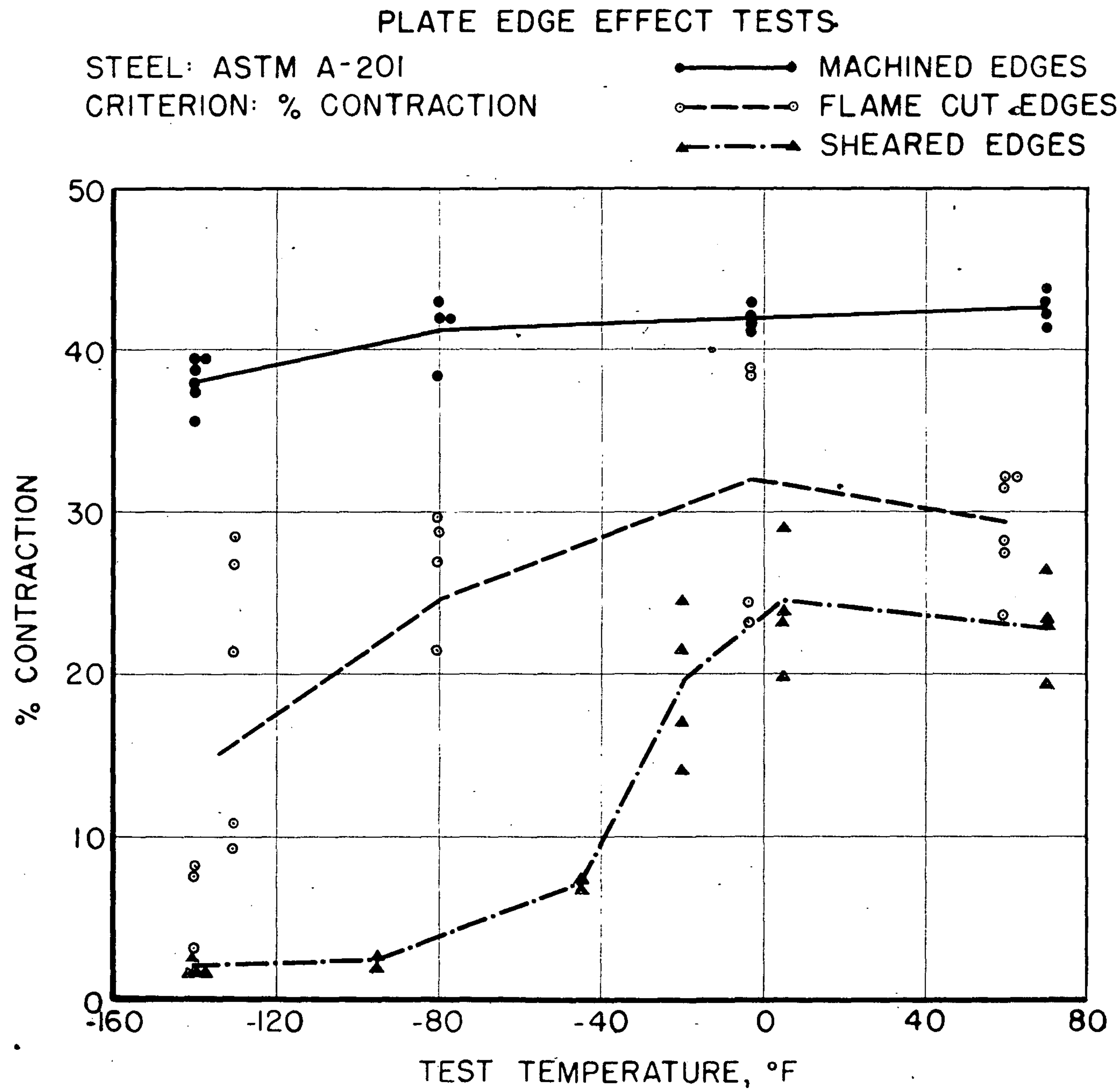


FIG. 5. TRANSITION CURVES OF A-201 STEEL 5/8" THICK, SHOWING THE EFFECT OF MACHINED, FLAME CUT AND SHEARED EDGES WITHOUT HEAT-TREATMENT.

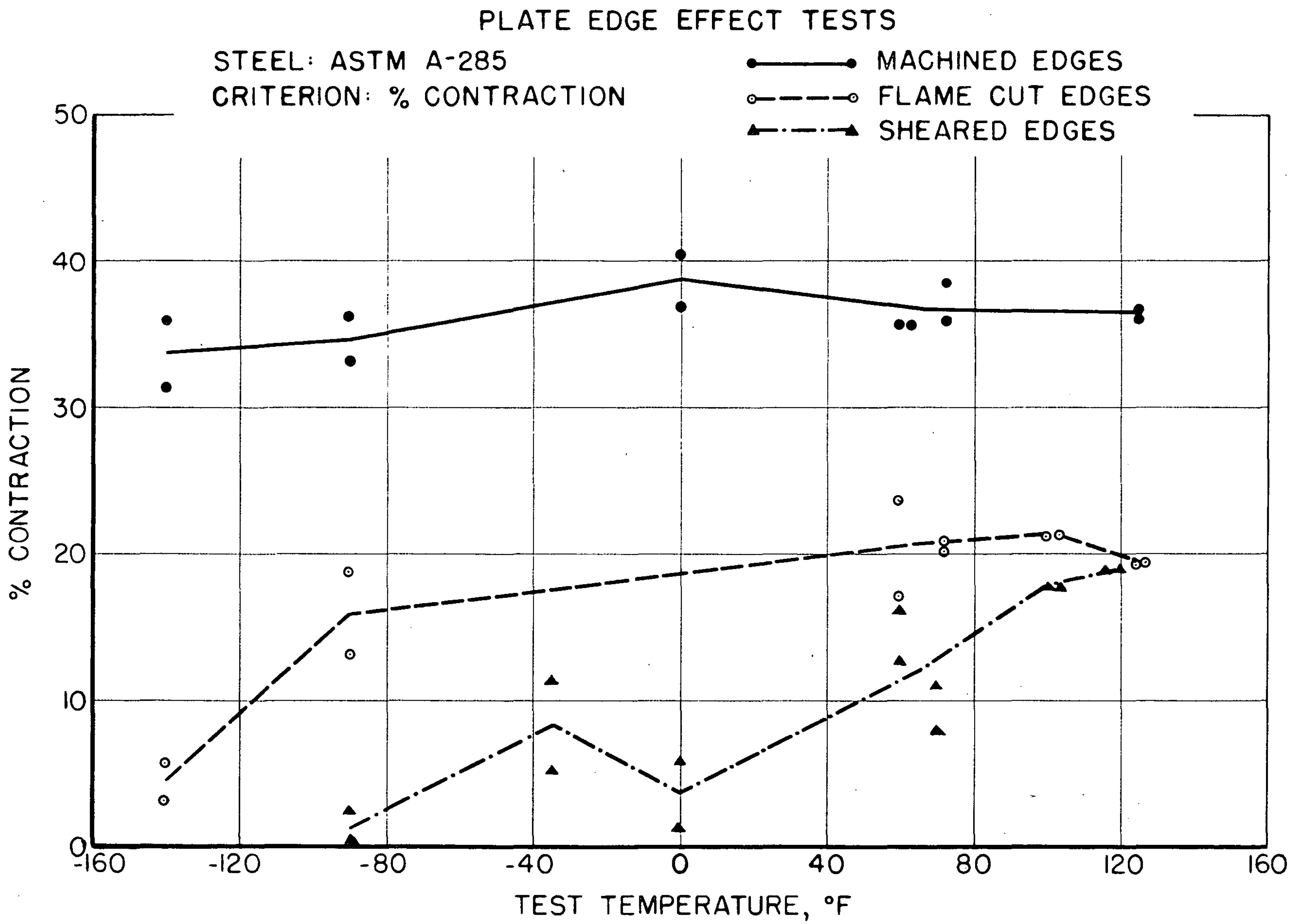


FIG. 6. TRANSITION CURVES OF A-285 STEEL 5/8" THICK, SHOWING THE EFFECT OF MACHINED, FLAME CUT AND SHEARED EDGES WITHOUT HEAT-TREATMENT.

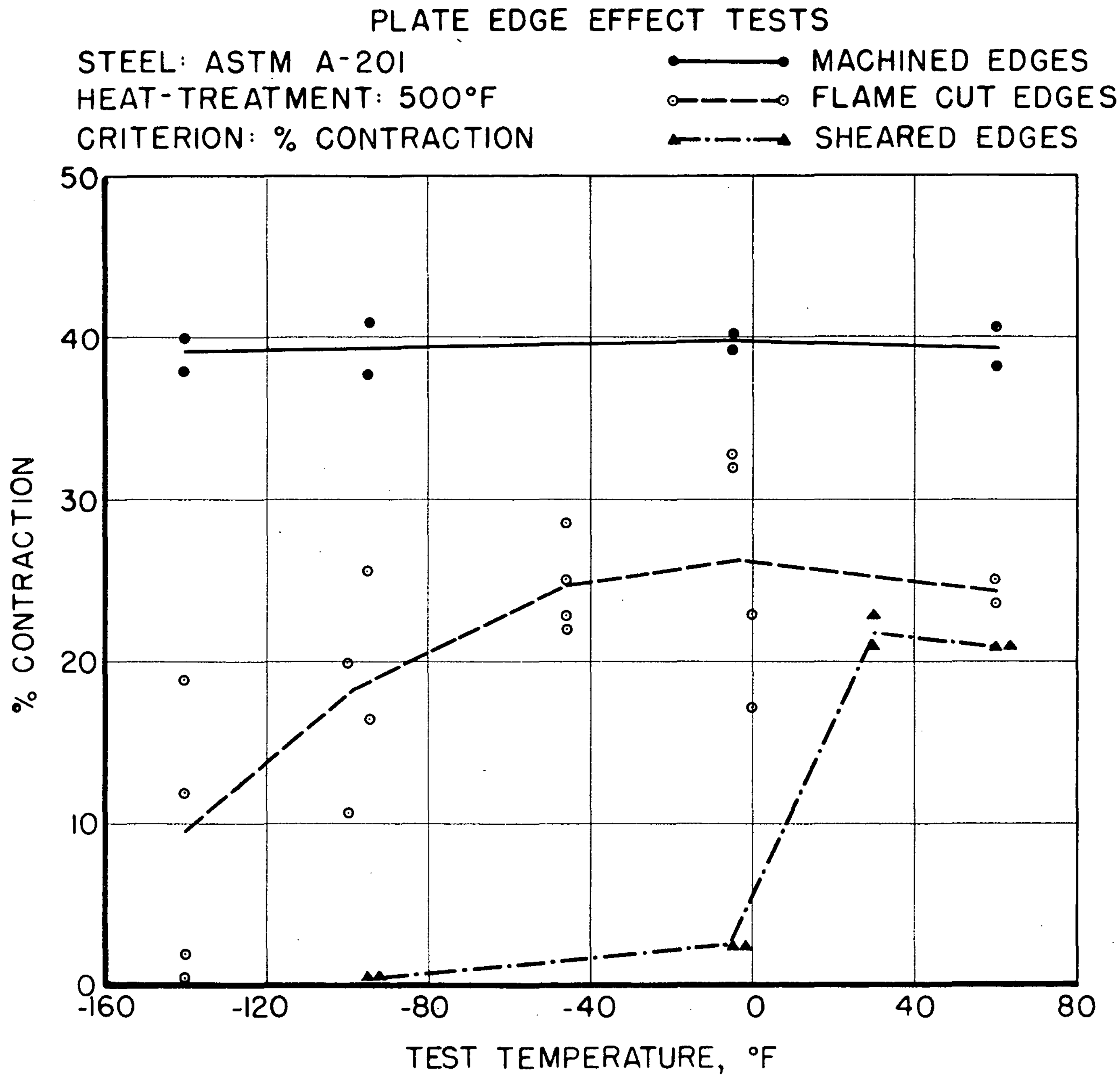


FIG. 7 TRANSITION CURVES OF A-201 STEEL 5/8" THICK, SHOWING THE EFFECT OF MACHINED, FLAME CUT AND SHEARED EDGES AFTER HEAT-TREATMENT AT 500°F.

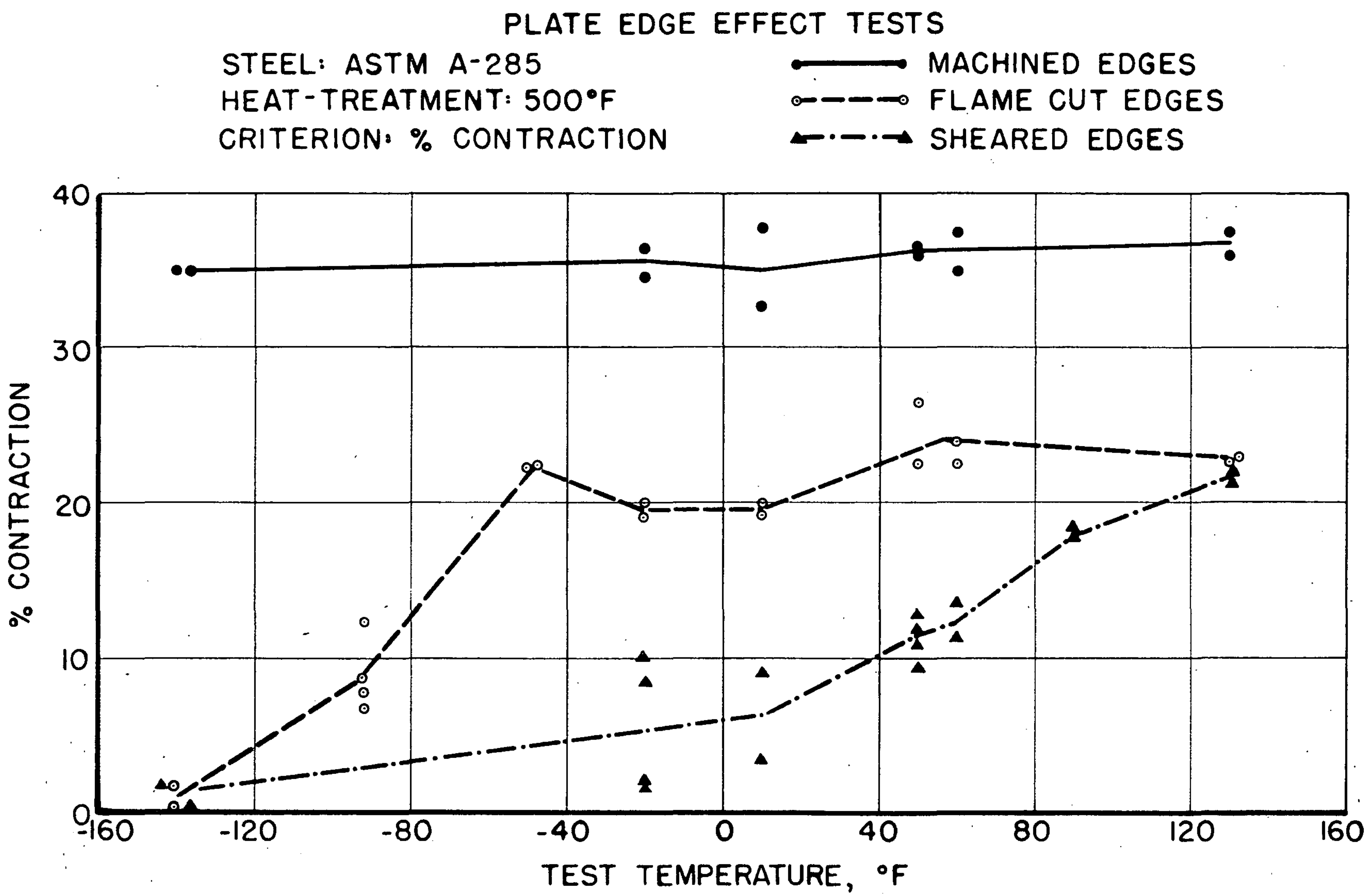


FIG. 8. TRANSITION CURVES OF A-285 STEEL 5/8" THICK, SHOWING THE EFFECT OF MACHINED, FLAME CUT AND SHEARED EDGES AFTER HEAT-TREATMENT AT 500°F.

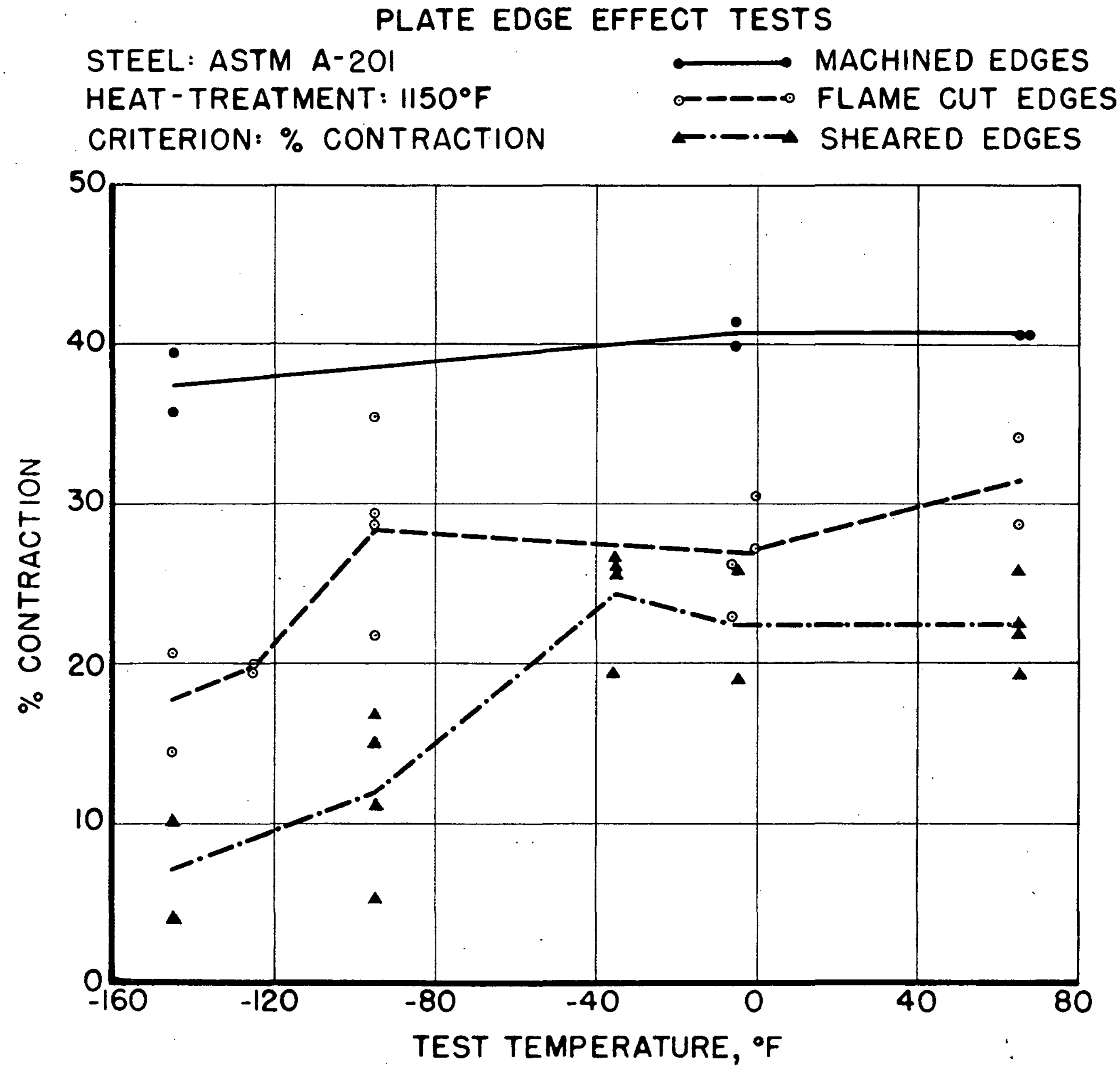


FIG. 9. TRANSITION CURVES OF A-201 STEEL 5/8" THICK, SHOWING THE EFFECT OF MACHINED, FLAME CUT AND SHEARED EDGES AFTER HEAT-TREATMENT AT 1150°F.

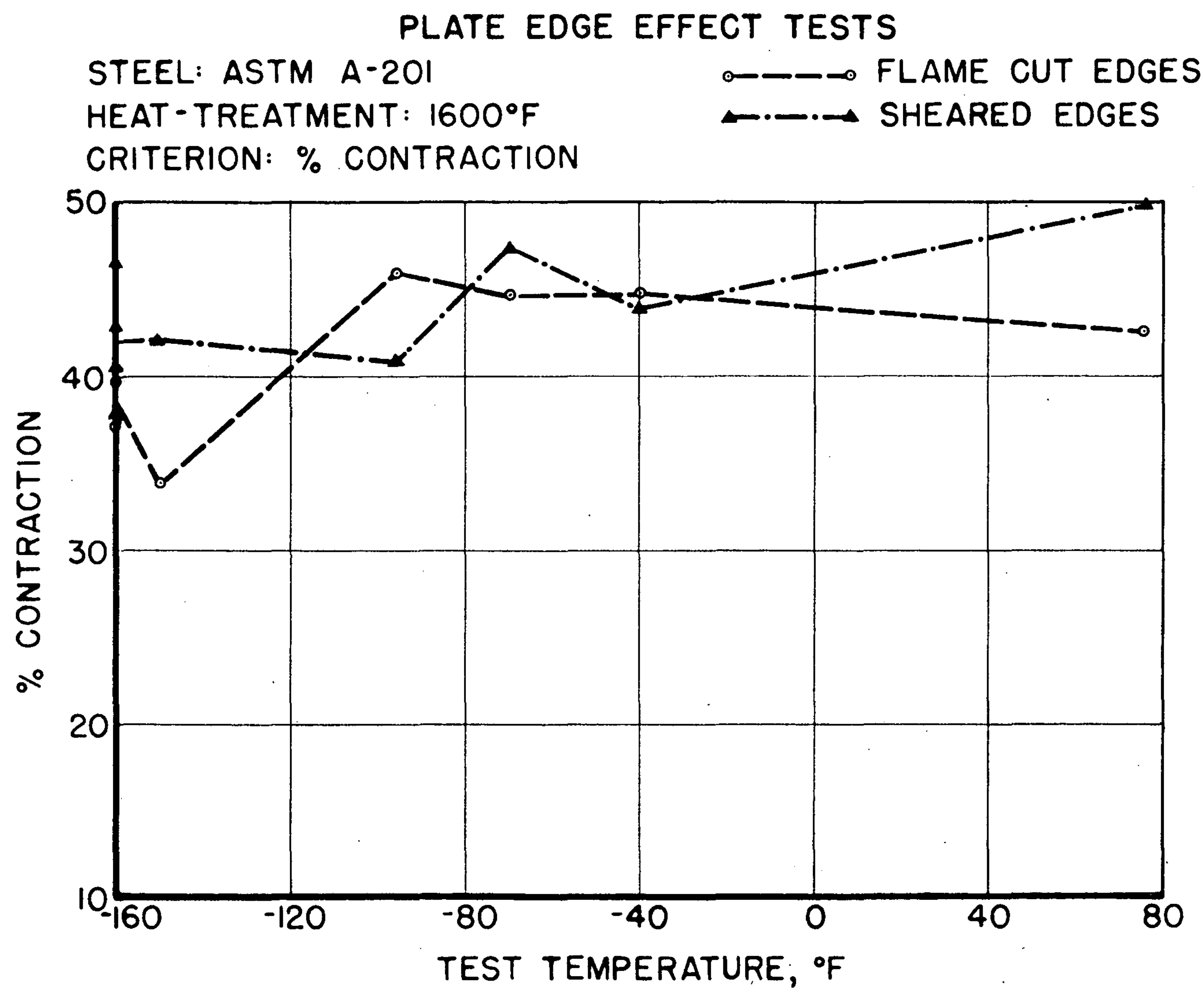


FIG. 11. TRANSITION CURVES OF A-201 STEEL 5/8" THICK, SHOWING THE EFFECT OF FLAME CUT AND SHEARED EDGES AFTER HEAT-TREATMENT AT 1600°F.

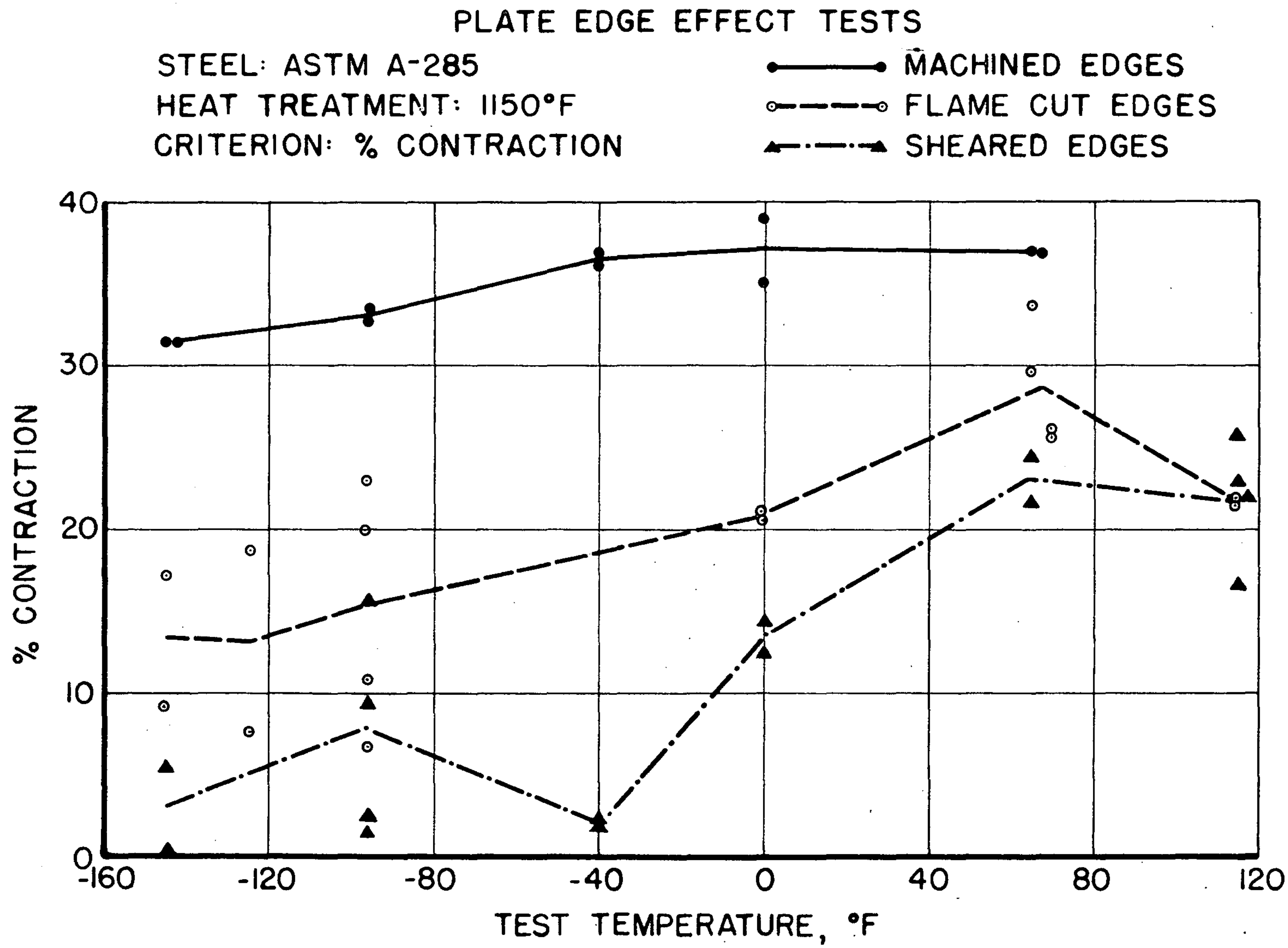


FIG. 10. TRANSITION CURVES OF A-285 STEEL 5/8" THICK, SHOWING THE EFFECT OF MACHINED, FLAME CUT AND SHEARED EDGES AFTER HEAT-TREATMENT AT 1150°F.

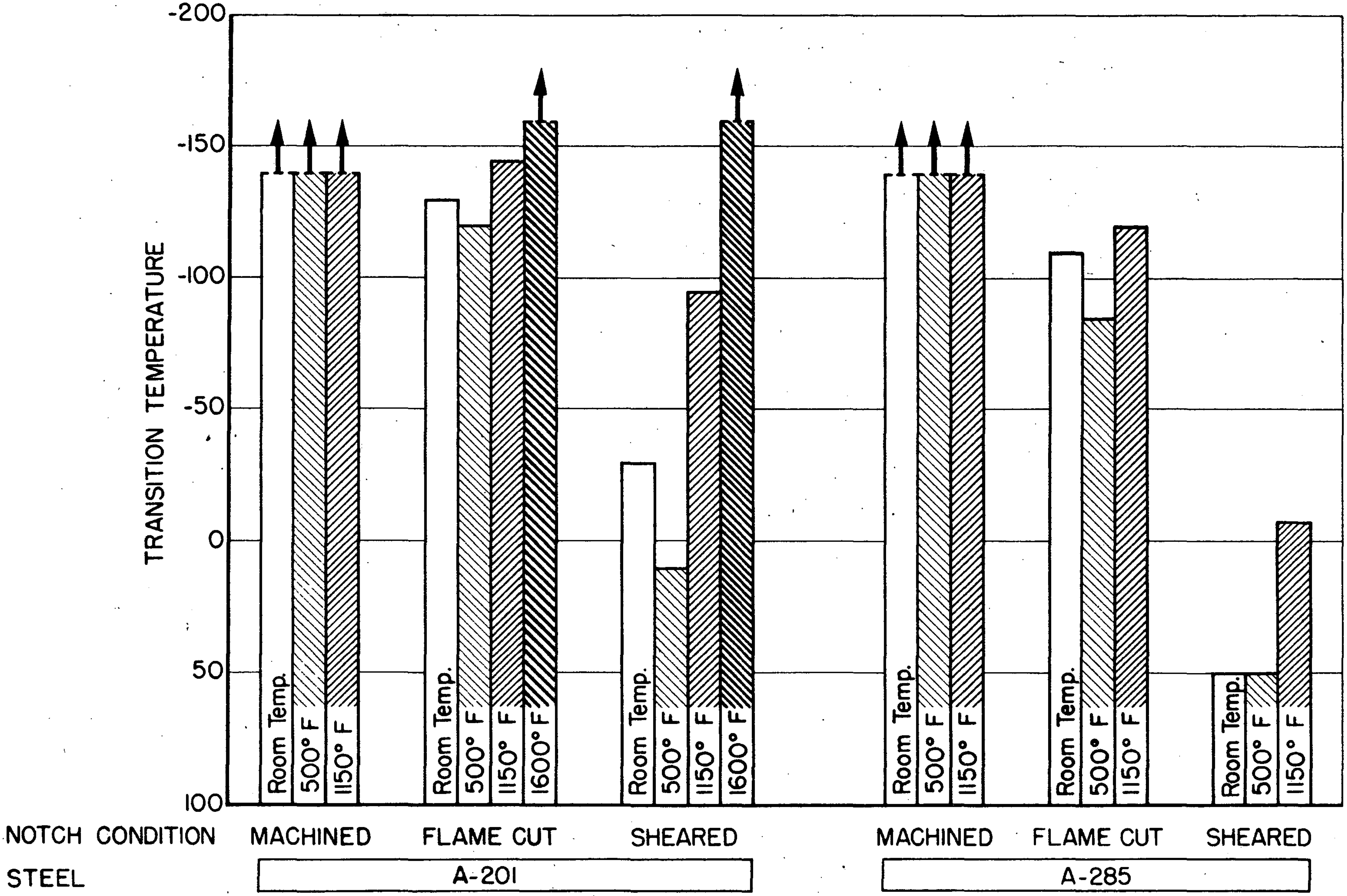


FIG. 12. SUMMARY OF TRANSITION TEMPERATURES AS AFFECTED BY EDGE PREPARATION