# THROUGH-THICKNESS TENSION TESTING OF STEEL

A symposium
sponsored by ASTM
Committee A-1 on
Steel, Stainless Steel,
and Related Alloys
St. Louis, Mo., 17–18 Nov. 1981

ASTM SPECIAL TECHNICAL PUBLICATION 794
R. J. Glodowski, Armco Inc., editor

ASTM Publication Code Number (PCN)
04-794000-02

1916 Race Street, Philadelphia, Pa. 19103

Library of Congress Catalog Card Number: 82-72887

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Printed in Baltimore, Md. (b)
February 1983

# Foreword

The Symposium on Through-Thickness Tension Testing of Steel was held in St. Louis, Missouri, on 17–18 November 1981. ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys was sponsor. R. J. Glodowski served as symposium chairman and has edited this publication. G. J. Roe, Bethlehem Steel Corporation, and Michael Wheatcroft, American Bureau of Shipping, served as session chairmen.

# Related ASTM Publications

Rolling Contact Fatigue Testing of Bearing Steels, STP 771 (1982), 04-771000-02

Stainless Steel Castings, STP 756 (1982), 04-756000-01

Application of 2¼Cr-1Mo Steel for Thick-Wall Pressure Vessels, STP 755 (1982), 04-755000-02

Toughness of Ferritic Stainless Steels, STP 706 (1980), 04-706000-02

Properties of Austenitic Stainless Steels and Their Weld Metals (Influence of Slight Chemistry Variations), STP 679 (1979), 04-679000-02

Intergranular Corrosion of Stainless Alloys, STP 656 (1978), 04-656000-27

Rail Steels—Developments, Processing, and Use, STP 644 (1978), 04-644000-01

Structures, Constitution, and General Characteristics of Wrought Ferritic Stainless Steels, STP 619 (1976), 04-619000-02

# A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

*ASTM Committee on Publications*

# ASTM Editorial Staff

# Contents

# Introduction

Through-thickness tension testing of steel is concerned with the evaluation of tensile properties in the direction perpendicular to the rolled surface of a steel plate. This through-thickness orientation has also been referred to as the short transverse or "Z" direction.

It has long been recognized that the mechanical properties of commercially available steels are anisotropic. However, the significance of mechanical properties in the through-thickness direction only became of engineering importance when a particular type of weldment cracking known as lamellar tearing became a serious problem. The susceptibility of a given welded joint of lamellar tearing depends on many factors including design details, restraint levels, welding conditions, and material ductility. The most widely accepted method of relating the material ductility factor to lamellar tearing has been the reduction of area of a round tension test specimen, oriented perpendicular to the planes along which much of a lamellar tear propagates. Since lamellar tearing occurs in planes roughly parallel to the plate surface, the test specimen orientation of concern was in the direction perpendicular to that plane, namely, the through-thickness direction.

About five years ago ASTM recognized the need to address the subject of through-thickness tension testing. A task group was formed to write a specification for testing procedures and acceptance standards for the determination of through-thickness reduction of area values in plates over 25.4 mm (1 in.) thick. The principle purpose of the testing was to provide a steel plate with increased resistance to lamellar tearing. This work resulted in ASTM Specification for Through-Thickness Tension Testing of Steel Plate for Special Applications (A 770), approved by the Society on 28 March 1980.

In the process of writing ASTM A 770 it became clear to those involved that through-thickness tension testing had a set of characteristics quite different from those normally associated with in-plane testing (longitudinal or transverse to the rolling direction). Some of the factors considered were the effects of specimen design, preparation, and location in the plate, and the inherent variability of the test results. Because it was felt that knowledge of these factors could be very useful to users of the specification, a symposium was organized in which different investigators shared their experience and knowledge of through-thickness testing. The symposium was held in St. Louis, Missouri, on 17–18 November 1981. It is hoped that the symposium and this resulting volume provide workers involved in through-thickness tension testing with some insights they might not otherwise obtain.

The contents of this publication are divided into two sections, similar to the arrangement of the two symposium sessions. The first group of papers is primarily concerned with test methods and, in particular, the design and preparation of the test specimen. The second group of papers emphasizes relations between the through-thickness tension test results and metallurgical factors such as the role of inclusion types and distribution, strength levels, plate thickness and location effects. This division of papers is not rigorous, however, since several papers deal with test methods and metallurgical factors.

This publication is a contribution of the Joint Task Group on Through-Thickness Tension Testing of Subcommittee A01.02 on Structural Steel for Bridges, Buildings, Rolling Stock, and Ships, and Subcommittee A01.11 on Steel Plates for Boilers and Pressure Vessels, both Subcommittees of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys. As Chairman of the Joint Task Group, I would like to acknowledge the contributions of all the members of the Task Group in assisting with the organization of the symposium and serving as reviewers of the papers. In particular, Michael Wheatcroft and Gerald Roe deserve recognition for their review efforts and for serving as session chairmen.

The goal of this publication is to provide information to metallurgists who are concerned with providing steel plates with improved through-thickness properties, and particularly to design engineers who may be interested in what is involved in testing the through-thickness properties of steels. The results of these tests need to be viewed somewhat differently than normal mechanical property data. The information in this publication should provide some insight for these evaluations.

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# Test Methods

*J. M. Holt*[1]

# Effect of Specimen Type on Reduction-of-Area Measurements

**REFERENCE:** Holt, J. M., "**Effect of Specimen Type on Reduction-of-Area Measurements,**" *Through-Thickness Tension Testing of Steel, ASTM STP 794,* R. J. Glodowski, Ed., American Society for Testing and Materials, 1983, pp. 5–24.

**ABSTRACT:** Because the susceptibility of plate material to lamellar tearing is believed to be related to the amount of reduction of area measured by a tension test specimen oriented in the through-thickness (*Z*) direction, tests were conducted to determine the influence of specimen dimensions on the tensile properties of ASTM A36, A588, and A514 Grade F steels for the two types of specimens commonly used for testing in the *Z*-direction. The first is the standard specimen with the length of the reduced section shortened so that the overall length of the specimen is equal to the thickness of the plate (stub specimen). The second is the standard specimen machined from a blank that has been prepared by welding prolongations to the plate surfaces so that the plate forms a full-plate-thickness insert at the midlength of the specimen (tab specimen). Because the intent was to compare only the trends in the changes of the tensile strength values and the reduction-of-area values for the different specimens, and because variability obtained in the longitudinal direction is less than that obtained in the through-thickness direction, the specimens were oriented in the longitudinal direction of the plate.

The results indicated a significant decrease in the reduction of area and a significant increase in the tensile strength of both types of specimens as the thickness of the insert or the length of the reduced section is decreased to less than two specimen diameters. These trends are due to constraint in plastic flow caused by the higher strength of the weld area of the tab specimens or by the shoulders of the stub specimens.

**KEY WORDS:** lamellar tearing, materials testing, reduction-of-area measurements, steel plates, tensile strength, tension test, test methods

Susceptibility of plate material to lamellar tearing appears to be related to the amount of reduction of area (RA) determined with a tension test specimen oriented in the thickness (*Z*) direction [*1,2*].[2] Consequently, specifications are being written that require through-thickness (*Z*-direction) tension tests [*3*]. An ASTM standard 12.7-mm (0.50-in.)-diameter tension test specimen (A370) can be obtained in the *Z*-direction for plates having a thickness of about 114 mm (4½ in.) or greater. To test lighter-gage plate, some investi-

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[2] The italic numbers in brackets refer to the list of references appended to this paper.

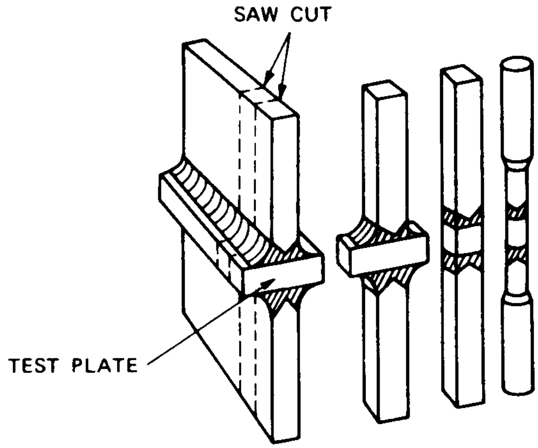
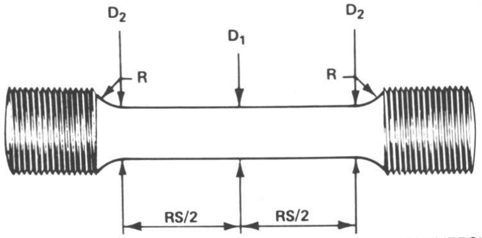



FIG. 1—*Tension test specimen with welded extensions for through-thickness tensile strength and ductility measurements.*

gators have used small-size specimens with dimensions that are proportional to those of the standard specimen. Other investigators have designed specimens (often called stub specimens) in which the length of the reduced section of the standard specimen is made shorter, while the other dimensions remain unchanged, so that the overall length of the specimen does not exceed the plate thickness. Still other investigators have welded extension prolongations (tabs) to the plate surfaces (Fig. 1) to obtain sufficient length for the standard-size specimen; these specimens are often called tab specimens.

There are problems with each of these three approaches. The primary drawback to the use of the small-size specimen (with dimensions proportional to those of the standard specimen) is that the cross-sectional area becomes so small that it may not be representative of the bulk material. For example, inhomogeneities (such as inclusions) in the specimen at the point of fracture may be a large fraction of the specimen cross-sectional area, and can therefore result in misleading test data. Conversely, because the cross section is so small, some specimens may contain less than a representative amount of inhomogeneities, again with misleading test results. A large number of specimens can be tested to attempt to obtain a representative average, but the cost of testing becomes prohibitive. Another drawback to the small-size specimen is that many test facilities are not equipped to machine or test such specimens.

The stub specimen usually has the advantage of a larger cross section and "standard" grip ends. Machine-shop automation cannot always be readily utilized with this specimen, however, because of the many different lengths of reduced sections. Also, the specimen cannot be positioned in the desired location within the plate thickness.




CONVERSION FACTOR

1 inch = 25.4 mm

| SPECIMEN GEOMETRY DESIGNATION | NOMINAL SECTION LENGTH, inches | REDUCED-SECTION LENGTH, diameters | SPECIMEN DIMENSIONS, inches | | | | |
|---|---|---|---|---|---|---|---|
| | | | RS/2 | $D_1$ | $D_2$ | R | THREAD |
| 1 | 1/2 | 1 | 0.250 ± 0.005 | 0.505 ± 0.005 | $D_1{}^{+0.001}_{-0.000}$ | $0.50^{+0.06}_{-0.00}$ | 3/4-16 |
| 2 | 1 | 2 | 0.500 ± 0.005 | 0.505 ± 0.005 | $D_1{}^{+0.001}_{-0.000}$ | $0.50^{+0.06}_{-0.00}$ | 3/4-16 |
| 3* | 2-1/4 | 4-1/2 | 1.125 ± 0.06 | 0.505 ± 0.005 | $D_1{}^{+0.003}_{+0.005}$ | $0.50^{+0.06}_{-0.00}$ | 3/4-16 |
| 4 | 4-1/2 | 4-1/2 | $2.250^{+0.06}_{-0.00}$ | 0.900 ± 0.010 | $D_1{}^{+0.005}_{+0.008}$ | $1.00^{+0.06}_{-0.00}$ | 1-1/2-6 |

* STANDARD ASTM SPECIMEN

FIG. 2—*Dimensions of specimens tested.*

The tab specimen offers the convenience of a standard-size specimen for machining and testing and if necessary permits positioning the reduced section at any location within the plate thickness. However, the tab specimen requires equipment and personnel to prepare the tabs and to perform the welding. Furthermore, the heat-affected zone can cause anomalies in testing plate less than 25.4 mm (1 in.) in thickness.[3]

Most plate-producing mills in the United States are tooled to produce and to test the ASTM standard 12.7-mm (0.50-in.)-diameter round tension test specimen with a 51-mm (2-in.) gage length (Geometry 3 of Fig. 2). The overall length of this specimen is approximately 127 mm (5 in.), depending on the type of grip ends required by the test laboratory, and thus tabs must be welded to any plate thinner than 127 mm (5 in.). The object of the present investigation was to determine the effect on reduction-of-area values of (*1*) stub specimens with reduced sections of different lengths and of (*2*) tab specimens with extensions welded to inserts of varying lengths to simulate plates of different thicknesses.

## Materials and Experimental Work

The present investigation was conducted on 25.4-mm (1-in.)-thick plates of ASTM A36, ASTM A588, and ASTM A514 Grade F steels. The chemical

[3] Domis, W. F., this publication, pp. 59–69.

TABLE 1—*Chemical composition of steels investigated.*

| Steel Designation | Chemical Composition, % (Ladle Analysis) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | V | B | $Al_{tot}$ |
| A36 Heat B | 0.20 | 1.11 | 0.007 | 0.023 | 0.029 | [a] | [a] | [a] | [a] | [a] | [a] | [a] |
| A36 Heat A | 0.22 | 1.08 | 0.008 | 0.021 | 0.029 | 0.04 | 0.14 | 0.06 | 0.07 | [a] | [a] | [a] |
| A588 | 0.14 | 1.09 | 0.018 | 0.028 | 0.26 | 0.31 | 0.04 | 0.60 | 0.02 | 0.04 | [a] | 0.04 |
| A514 Grade F | 0.16 | 0.83 | 0.010 | 0.166 | 0.27 | 0.27 | 0.80 | 0.49 | 0.41 | 0.05 | 0.004 | [a] |

[a] Not determined.

composition and room-temperature tensile properties of these plates are given in Tables 1 and 2, respectively. Specimens of ASTM standard geometry were machined from the three steels for use as controls.

Although the use of specimens with short reduced sections is not an attractive procedure, such specimens were included in this study because stub specimens are used by some investigators and because the shoulders of the specimens restrain the reduced section from contracting (necking) during tensile loading. In a similar manner, the harder heat-affected zone of tab specimens restrains necking. Stub specimens were machined from the three steels with reduced sections 12.7 mm (½ in.) long and 25.4 mm (1 in.) long (Geometries 1 and 2 of Fig. 2). In order to investigate any variability in trends between different heats of the same steel grade, a second set of stub specimens was machined from a 25.4-mm (1-in.)-thick plate from another heat of A36 steel.

The longitudinal axis of the stub specimens was oriented parallel to the rolling direction of the steels, rather than in the *Z*-direction, for the following reasons: (*1*) the tensile data obtained for specimens oriented in this direction show less variability, (*2*) all specimens would have a similar metallurgical structure (that is, there would be less effect of the gradation of properties between surface and midthickness in the rolling direction than in the *Z*-direction), and (*3*) only trends in behavior were of interest in the present investigation, rather than the absolute levels of strength and ductility. It is recognized that the through-thickness reduction-of-area values would be appreciably

TABLE 2—*Tensile properties of steels investigated.*

| Steel Designation | Heat No. | Plate No. | Longitudinal Tensile Properties | | | |
|---|---|---|---|---|---|---|
| | | | Yield Strength, ksi[a] | Tensile Strength, ksi | Elongation, % | Reduction of Area % |
| A36 Heat B | 68E428 | 166 957 | 37.2 | 65.1 | 34.2 | 70.5 |
| A36 Heat A | 70E908 | 347 748 | 36.7 | 65.3 | 34.5 | 70.1 |
| A588 | 71D905 | 464 | 59.5 | 86.5 | 26.7 | 65.6 |
| A514 Grade F | 74A090 | 41 765 | 108.5 | 117.5 | 21.8 | 65.1 |

[a] 1 ksi = 6.895 MPa.

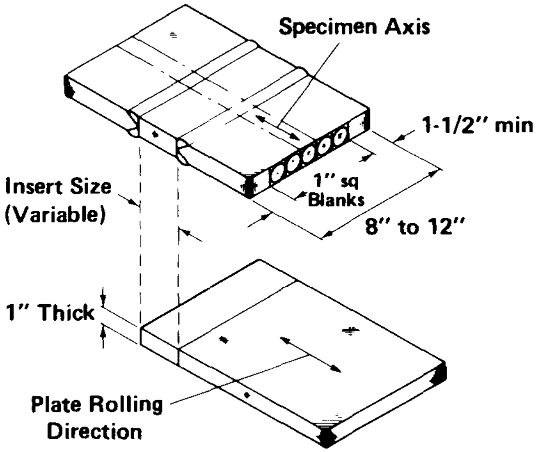



FIG. 3—*Schematic of method of preparing 12.7-mm (0.50)-in.-diameter tab specimens.*

lower and would have greater scatter than the reduction-of-area values determined in the longitudinal direction.

The tab specimen was given the largest emphasis in the investigation because it appeared that specifications for Z-direction testing would require the use of this specimen. [ASTM Specification for Through-Thickness Tension Testing of Steel Plates for Special Applications (A 770) has since been adopted and designates the "tab" specimen as the standard test specimen.] To determine the minimum thickness of plate that can be tested with the tab specimen, inserts with lengths simulating plates with thicknesses of 12.7, 25.4, 38.1, and 63.5 mm (½, 1, 1½, and 2½ in.) were shielded-metal-arc welded to tabs of A514 steel.[4] ASTM standard geometry specimens were then machined from blanks, and the inserts were centered at midlength of the specimens. Figure 3 schematically depicts the method of preparing the tab specimens. The rolling direction of the insert material was parallel to the longitudinal axis of the specimen for the same reasons previously discussed for the stub specimens.

For reasons explained later, 23-mm (0.90-in.)-diameter specimens (Geometry 4 of Fig. 2) were prepared from 12.7- and 25.4-mm (½- and 1-in.)-thick inserts of A36 steel welded to A514 steel tabs. These specimens are geometrically equivalent to 6.4 and 12.7 mm (¼ and ½ in.) inserts in the standard specimen.

The welding procedures are summarized in Table 3. These procedures produced welds with a tensile strength on the order of 895 MPa (130 ksi) (based on conversion of Rockwell A hardness numbers). Macrographs of welded specimen blanks of the steels used are shown in Figs. 4 to 7.

[4] At the time the present investigation was initiated, the stud-welding technique described by Domis (Footnote 3) had not yet been developed at our laboratory.