Current mechanical fastener specifications and test procedure

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CURRENT MECHANICAL FASTENER SPECIFICATIONS
AND TEST PROCEDURE

First Progress Report
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DEVELOPMENT OF COMPREHENSIVE TEST
PROCEDURES FOR CONNECTIONS IN COLD-FORMED
STEEL AND APPROPRIATE EVALUATION METHODS

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1. INTRODUCTION

There already exists an incredibly large inventory of mechanical fasteners of various types, sizes and mechanical properties, with hundreds of additions or modifications being added each year. In the aerospace industry alone, for example, the introduction of the Boeing 747 brought an additional 150 nuts, 800 bolts and 250 washers into the field, to say nothing of other types of fasteners such as screws and rivets. Most fastener manufacturers also willingly produce "specials", or fasteners considered as non-standard whose specifications are established by the customer. Thus, there is virtually an infinite number of possibilities in the design and performance of mechanical fasteners.

In an effort to standardize some of these fasteners, many organizations have established specifications on dimensions and materials, and some of them have also established minimum specifications on mechanical performance. These specifications, however, were often determined to fulfill the requirements of the particular industry involved, and are not always consistent with the specifications of other industries. In addition, some manufacturers have established their own specifications for their products. The result is a large number of specifications without the desirable universality.

But specifications are not so great a problem as the lack of standardized test procedures to determine fastener properties and their performance in joints. Many users have been compelled to perform their own tests on products and assemblies they intend to use, and then prove the adequacy of their connection
designs to various authorities to obtain approval for their use. This is a costly and time-consuming process. The need for recognized and accepted standardized test procedures is clear.

Many benefits may be realized by establishing unified standard tests for fasteners. The following is a list of some of the advantages that can be attained with standardized test procedures:

1. Testing techniques and criteria required for the design and development of superior fasteners will be available, eliminating the need for developing new test procedures.
2. Fastener specifications may be easily produced and checked with a series of standard tests.
3. Duplication of tests by producers, users and authorities will be eliminated.
4. New fasteners can be readily evaluated.
5. The degree of interchangeability, substitutability and replaceability of fasteners can be determined by comparing standard test results.

2. PURPOSE AND SCOPE

2.1 General

The purpose of this report is to review the present test procedures on mechanical fasteners, as the initial step in establishing standard test procedures and performance criteria for fasteners used by the cold-formed steel industry. Tests of properties of slight importance to this industry, such as fatigue and high temperature characteristics, have been omitted. Data for this report were obtained from the open literature, design
specifications, and in two instances from manufacturers. It is by no means all inclusive, yet it should give the reader a firm idea of the major test procedures employed today, as well as some possible future test procedures.

It is not the intent of this report to compare the various specifications in existence, but merely to give the reader an appreciation for the number available. Anyone with a further interest in these specifications may readily obtain them from the organizations involved.

The nearly infinite variety of mechanical fasteners on the market today prohibits a thorough discussion of each type. Consequently they are classified here in the broad categories of bolts and screws, tapping screws and cold rivets. The cold rivet category includes all types of cold rivets, including split, tubular and blind rivets. Special fasteners which incorporate back-up devices, such as Molly bolts, are not included if they are other than blind rivets. Such devices as studs, eyebolts, cap screws and drive screws are also excluded, as is the technique of metal stitching. They are further restricted to standard-type devices employed in the cold-formed steel industry, so various specialty devices, such as spring locking devices, are omitted.

The discussion on test procedures is divided into tests applicable to all fasteners and those applicable only, or primarily, to bolts and screws, tapping screws or rivets. It is subdivided into tests of the fastener itself and tests of the connection.
2.2 Definitions

The following terms used herein shall be defined as follows:

Bolts and Screws: Externally threaded fasteners designed for assembly with either a special nut or a tapped hole in the part to be fastened.

Tapping Screws: Hardened screws that either cut or form their own mating threads in an untapped hole. Self-drilling tapping screws drill their own hole.

Rivets: "Headed fasteners of malleable material used to join parts by inserting the shank through aligned holes in each piece and forming a head on the headless end by upsetting." 4

3. FASTENER SPECIFICATIONS AND STANDARDS

"Over a period of years a great number of material specifications and dimensional standards covering headed and threaded fasteners of all types have been developed through the co-ordinated efforts of manufacturers, consumers, engineering societies and trade associations." 5 A partial listing of specifications in use follows:

ANSI STANDARDS (American National Standards Institute, Inc.)
ISO RECOMMENDATIONS (International Organization for Standardization)
ASTM SPECIFICATIONS (American Society for Testing and Materials)
SAE SPECIFICATIONS (Society of Automotive Engineers, Inc.)
AAR SPECIFICATIONS (Association of American Railroads)
API SPECIFICATIONS (American Petroleum Institute)
IFI DOCUMENTS (Industrial Fasteners Institute)
EEI SPECIFICATIONS (Edison Electric Institute)
FEDERAL SPECIFICATIONS

MILITARY SPECIFICATIONS

RCRBSJ SPECIFICATIONS (Research Council on Riveted and Bolted Structural Joints, AISC)

U.S. DEPARTMENT OF COMMERCE, NATIONAL BUREAU OF STANDARDS

AMERICAN BUREAU OF SHIPPING

LLOYD'S REGISTER OF SHIPPING

AIR FORCE-NAVY AERONAUTICAL STANDARD DRAWINGS
(Aeronautical Standards Group)

NAS DRAWINGS AND SPECIFICATIONS (National Aerospace Standards Committee)

MS STANDARDS (Military Standard)

(a) Details of these standards, including standard number, title, and name and address of the distributor, are found in "Fastener Standards", published by the Industrial Fasteners Institute.

(b) The standards pertinent to this project are listed in detail in the Bibliography of this paper.

In addition to these and other national specifications, some manufacturers have developed their own special products and provide their own specifications. Some specifications, although providing for minimum mechanical properties, do not state in detail how these properties are to be determined. Most of the literature provided by fastener manufacturers simply gives data pertaining to the configurations of their standard products, without mention of mechanical properties.

4. TEST PROCEDURES APPLICABLE TO ALL FASTENERS

4.1 Tests of fastener

Standard test procedures to determine the mechanical
properties of the fastener itself, applicable to any fastener, are scarce. ASTM Standard A370, Section III, is entitled "Steel Fasteners", but applies only to bolts. MIL-HDBK-5A\textsuperscript{7}, issued to provide uniform data for the aerospace industry, cites ARDC Report No. 33 of the Aerospace Industries Association (AIA) as the recommended procedure for testing fasteners and joints. This is the only standard test procedure found applicable to all fasteners, and has been adopted as a Military Standard.\textsuperscript{29}

4.1.1 Tension test procedure

The AIA tension test procedure is intended "to provide a standardized method for testing fasteners in tension at room temperature."\textsuperscript{8}

The scope of this procedure is as follows: "This procedure applies to all types of structural fasteners, single piece and multiple piece, blind and inspectable, threaded and non-threaded, including all types of driving and locking devices. This procedure is intended to define the test required to determine the tension strength of the fastener itself, not the strength of the fastener in any particular sheet combination."

Test equipment is a test machine capable of applying the load smoothly at a controllable rate, with a load indicating device accurate within one percent of the load. An averaging microformer type extensometer or equivalent, with an accuracy of 0.5\% of the indicating strain is to be used, with the scale arranged such that the load-deflection curve has a slope of 60\textdegree{} or less.

The recommended test fixture is the NAS 1069 fixture, shown in Figure 1, or for short grip fasteners the tension plate type
fixtures shown in Figure 2. Fasteners having a specific grip range, such as rivets, are to be tested in maximum grip, minimum grip, and at least one intermediate grip. This is accomplished by using various orientations of Plates A and B, as shown in Figure 3. Threaded fasteners having no specified grip range are to be tested at the grip length where two or three bolt threads extend below the face of the nut. Installation preload is provided by shims located between the test fixtures, and the use of washers under fastener heads, nuts, or collars is prohibited.

The assembled test jig, Figure 4, is placed between the compression heads of the machine and loaded at a specified rate to failure. The NAS 1069 fixture, if used, is placed between self-aligning bolts attached to the machine tension heads. A minimum of five specimens are to be tested for each fastener diameter and test condition.

It should be noted that the dimension tolerances for these fixtures are very tight, and that a separate AIA fixture or NAS 1069 adaptor is required for each fastener size to be tested, making these fixtures inappropriate for fasteners used by the cold-formed steel industry.

4.1.2 Double shear test procedure

The AIA double shear test is a standard procedure and method for double shear testing, recommended whenever the fastener to be tested is of sufficient length. The test equipment is the same as that for the tension test, save that the extensometer is not used. Figures 5A and 5B show a sketch of the preferred double shear test fixture, but a full
circle compression or tension type double shear test fixture may be used provided that certain dimensions and tolerances specified for the preferred fixture are met.

Solid shank fasteners to be tested in double shear are to have an uninterrupted, straight cylindrical portion of the shank at least two diameters long. Fasteners in which the shear load is carried through more than one piece, e.g. blind rivets, are to be tested with all fastener parts in the installed condition, but without preload. This condition is attained by first installing the fastener in a split block of specified dimensions, and then removing the block and testing the fastener in the test fixture.

The test is conducted by firmly attaching the lower die in a precision die set, closely aligning the upper and lower dies in all directions with a sample specimen in place between the dies, and firmly attaching the upper die to the die set. The die set and fixtures are then placed between the compression heads of the test machine.

Load is applied smoothly at a specified rate until ultimate load is reached and then falls off to 90% of this load or less. The test is considered satisfactory if the specimen has been partially or fully sheared.

This fixture has the same disadvantages as the tension fixture, namely close tolerances and the need for a separate fixture for each size tested.

4.1.3 Interaction test procedure

The "Fastening and Joining" issue of Machine Design cites a test procedure for the interaction of tension and shear on a
fastener. \(^4\)

"Generally, a special test fixture is used which subjects the test fastener first to straight tensile load to failure. A second fastener is installed, and the fixture reoriented \(15^\circ\) and tested. The procedure continues at \(15^\circ\) increments until the fastener is tested in pure shear. The data is plotted on a graph ..." Details of this procedure are found in MIL-STD-1312.\(^{29}\)

4.2 Tests of joint

Test procedures for joints formed with any fastener again are provided only by AIA. MIL-HDBK-5A contains the results of shear and bearing tests conducted on fasteners and fastener and sheet material combinations common in the aerospace industry. The tests were generally conventional single and double shear lap joint tests, and the allowables given apply only to a narrow range of parameters, with values for parameters outside this range requiring substantiation by test.\(^7\) Various aerospace companies, however, still conduct their own tests, typically single shear, single fastener lap joint tests.\(^9\)

4.2.1 Tension test procedure

AIA provides for the testing of joints in tension by using the same procedure and fixture design as for the tension test of the fastener itself. In this case the actual sheet material and thickness to be used in the joint is used for the fixture, and the counterbore is omitted.

4.2.2 Lap joint test procedure

This procedure is intended by AIA to provide a standard method for determining the room temperature strength of mechanically fastened sheet metal lap joints loaded to produce shear
on the fasteners, and has been adopted as a Military Standard.\textsuperscript{29} This is essentially the conventional single shear lap joint test, with two bolts in line with the direction of load. The procedure calls for the fasteners to be tightened to the torque specified for use, washers to be used under the nut in bolt connections, and both straps of the specimen to be of the same gage and material. Figure 6 shows the standard test specimen.

5. TEST PROCEDURES APPLICABLE TO BOLTS AND SCREWS

5.1 Tests of fastener

There are at least three sets of national standards that apply to bolts and screws. The American Standards Association (now the United States of American Standards Institute) publishes dimensional requirements for products recognized as "American Standard," but fails to specify mechanical requirements.\textsuperscript{10-12} ASTM Standard A370 and IFI Specification 104 are essentially identical in test procedure, the former applying to steel products and the latter governing stainless steel and nonferrous products. In addition to the standard hardness tests on the bolt and nut, these specifications apply only to tensile tests, and are described below.\textsuperscript{13,14}

5.1.1 Tension test procedure

It is preferred that bolts be tested full size. If the size of the bolt prohibits full size testing or the individual product specifications permit the use of a machined specimen, it is to be machined from the shank to the standard test size given by ASTM Standard A370 for steel or Method 211, Federal Test Method Standard No. 151 for stainless or nonferrous material.\textsuperscript{15}
The bolt or screw is assembled in the fixture of a tensile testing machine, such as shown in Figure 7, leaving six complete threads unengaged between the self-aligning grips. The load is applied axially. Bolt elongation is measured to determine yield strength, either by the offset method with the offset specified (often 0.2) or by the load at a total elongation of 0.5%, as specified. A gage length of 2 inches or 4 diameters of the test specimen is used. Failure must occur in the body or threaded section, with no failure at the junction of the body and the head.

5.1.2 Wedge tension test procedure

This test is identical to the tension test procedure outlined in Section 5.1.1, save that a circular or square wedge of specified dimensions and material hardness is placed under the head of the bolt being tested. Failure must not occur at the junction of the body and the head.

5.1.3 Proof load test procedure

The overall length of the bolt is measured prior to its being placed in the testing machine and loaded to the proof load specified in the product specification. The proof load is maintained for a period of ten seconds before release. The specimen is to show no permanent deformation on removal and re-measurement.

5.2 Test of joint

A large number of bolted joint tests have been conducted, primarily single bolt, single and double shear lap joint tests. Empirical formulas have been derived from the results of these tests and are available in various handbooks and specifications.
Formulas, curves and tables have been developed for single and double shear and bearing, as well as the interaction of shear and bearing.\textsuperscript{7,9,16,28}

A great number of experiments on bolted connections has been performed at Cornell University under the sponsorship of the American Iron and Steel Institute.\textsuperscript{17-21} These have been single and multiple bolt, single and double shear tests on material of different strength, thickness and ductility, using bolts of various material, strength and preload. In general the bolt diameters were greater than or equal to 1/2 inch. Shims were sometimes used to reduce eccentricity in single shear test.

Use of single and double shear lap joint tests of bolted connections is so common that it might be considered standard.

6. TEST PROCEDURES APPLICABLE TO TAPPING SCREWS

6.1 Tests of fastener

USA Standard B18.6.4 and IFI Standards IFI-112 and IFI-113 provide for the mechanical testing of tapping screws.\textsuperscript{22-24} As the USA Standard only specifies a drive and torsional strength test, similar to tests included in the IFI Standards, only the IFI test procedures are presented here, with the exception of the standard hardness test.

Sections 6.1.1-6.1.5 refer to tests applicable to all tapping screws, while Section 6.1.6 outlines tests on self-drilling tapping screws only.

6.1.1 Tensile strength test

The screw is assembled in a tensile testing machine with a minimum of six threads exposed, and an axial load is applied
against the under head bearing surface until screw failure occurs. The test machine is to have self-aligning grips. The tensile strength of the screw is the maximum load in pounds occurring at or prior to screw fracture.

6.1.2 Torsional strength test

The screw is securely clamped such that the threads in the clamped length are not damaged, with a minimum of two full threads extending above the clamping device and a minimum of two full threads exclusive of the point held within the device. A suitable clamping device is a split threaded block held together by the application of external pressure. A blind hole may be used in place of the device, provided the hole depth will insure breakage occurring beyond the point. Torque is then applied to the screw, with the torsional strength torque defined as the torque required to produce failure.

6.1.3 Drive test

The screw is driven into the hole in a test plate of specified thickness and hardness until an internal thread of full major diameter is formed completely through the plate or until the screw head comes in contact with the plate, whichever occurs first. Drive speed shall not exceed 30 RPM. The drive torque is defined as the maximum torque occurring during the test.

6.1.4 Clamp load and proof torque test

A measuring device capable of measuring the actual tension in the screw during tightening is employed while the screw is driven to the specified clamp load in a test plate. The torque required to develop the clamp load is the clamp load torque. Tightening is continued until a torque equal to the proof torque
is applied to the screw. The assembly remains in this state for ten seconds after which the screw is removed by application of removal torque.

6.1.5 Ductility test

The screw is inserted into a drilled hole in a hardened wedge block and an axial compressive load is applied against the top of the screw head. Loading is continued until the plane of the under head bearing surface is permanently deformed through 5 degrees with respect to a plane normal to the axis of the screw.

6.1.6 Tests applicable to steel self-drilling tapping screws only

6.1.6.1 Drill hole size test

The screw is inserted through a sleeve or collar with an inside diameter approximately 0.010 inches greater than the major diameter of the screw. The sleeve or collar is to be of such length that sufficient unthreaded point length extends to drill a hole through 0.035 inch thick material without thread engagement. After the hole is drilled the screw is removed and the diameter of the hole gaged.

6.1.6.2 Drive to strip test

A hole is drilled in a specified test plate in a manner specified in the Drill Hole Size test. The sleeve is then removed and replaced with a spacer which allows full thread development through the plate thickness. The screw is then driven to strip, and the drive and strip torques recorded.

6.2 Tests of joints

Although there exist no standard test procedures for joints formed with tapping screws, a number of tests have been performed
on these joints. A sample of the types of tests conducted is presented here.

6.2.1 Buildex Division, Illinois Tool Works, tests

Four different tests were run: shear tests of sheet to sheet and sheet to structural, pull-out from sheet and pull-over of sheet, using #1 and #4 Teks on 26-18 gage sheet. The pull-over tests were performed by fastening the sheet to a rigid fixture, using eight equally spaced screws on a 4-3/4 inch square. The test screw was put through the center of the square and tightened against a flat surface. Information on the other tests was not available, but it is assumed the shear tests were single fastener, single shear lap joint tests.

A simulated uplift test was also conducted to obtain local building code approval. In this case the deck to be approved was inverted with the joists exposed upward and concrete blocks were stacked on the deck.

6.2.2 One steel producer's test

This was also a simulated uplift test, using the simple test set-up shown in Figure 8, and tested the connection for pull-out or pull-over.

6.2.3 Cornell University tests

Single shear tests were performed on #14 and #10 tapping screws using a device designed at Cornell for testing shear connections. Because it is felt that this device, or some modification of it, might prove useful in future connector tests, some detail is presented here.

A plan view of the Cornell device is shown in Figure 9. Load is applied by means of a hydraulic jack through bars pin-
connected to the arms, and measured with a load cell. The two parts of the specimen whose connection is to be tested are each clamped between the flat plates constituting the arms with high-strength, high-torque bolts. These bolts provide a friction-type connection, thus eliminating stress concentrations which might be produced by the bolts bearing against the specimen. Dial gages placed at the end of each arm measure the relative movement of the joint.

The geometry of the device is such as to eliminate undesirable eccentricities, and keeps the loads acting co-linearly. Movement is restricted to the plane of the flat plates through the use of guide tracks, with teflon pads used to reduce friction to a minimum. Figure 10 shows an unconnected specimen installed in the test fixture.

Lap joints can be readily tested without eccentricity by using shims of the same thickness as the materials being tested. Figure 11 shows the fixture with a lap joint formed with material of equal thickness, while Figure 12 shows a lap joint with members of unequal thickness.

7. TEST PROCEDURES APPLICABLE TO COLD RIVETS

The great number of cold rivet types available, with widely varying mechanical properties, has caused probably more tests to be performed on rivets and riveted assemblies than on any other fastener type. The single shear lap joint test is perhaps the most common, although double shear lap joint, tension and bearing tests are also performed. The USA Standard pertaining to rivets specifies only the dimensional requirements.27
Various charts and tables have been prepared for the use of special types of rivets in different materials, but the number and variety of rivets in existence still often necessitate assembly tests under simulated service conditions. In fact, the Technical Committee of the Tubular and Split Rivet Council states: "In the final analysis, the only way to get a realistic picture of design performance is to test the complete assembly under its simulated service conditions."^4

8. SUMMARY

8.1 Tests of fasteners

The only test procedures intended to be standard for all fasteners are the Aerospace Industries Association's tension and double shear tests. The fixtures for these tests, however, are expensive and must be made for each fastener size to be tested. In addition to the standard hardness tests, a standard tension test exists for bolts and screws, and a series of standard mechanical property tests is available for tapping screws.

Non-standard tests are devised and performed to fulfill specific requirements.

8.2 Tests of joints

AIA's single shear lap joint test is intended to be standard for all joints connected with mechanical fasteners. AIA also allows its tension test to be used as a joint test procedure.

Although they are not standardized, the single and double shear lap joint tests are so widely used and accepted that they could probably be considered as standard. In addition, special
tests are commonly devised to test a given application of a particular product.
REFERENCES


ADDITIONAL REFERENCES:


NOTES:
1. Adaptor hole diameter determined by fastener diameter.
2. Cup type adaptor identical save that adaptor screws into base of test fixture.
Dimensions B, C, D, T depend on fastener size.

Chamfer all hole edges to provide head fillet clearance.

Material: 4140 Alloy Steel heat treated to 200,000 p.s.i. or equal.

FIGURE 2: AIA TENSION FIXTURES FOR SHORT GRIP FASTENERS
FIGURE 3: ORIENTATION OF AIA TENSION FIXTURES FOR VARIOUS GRIP LENGTHS

SHORTEST AVAILABLE GRIP

INTERMEDIATE GRIP

LONGEST GRIP AVAILABLE WITHOUT USE OF SHIMS
Figure 4: AIA Tension Fixture Set-Up

Shouldered Stud

Tension Plates

Detail
FIGURE 5A: SKETCH OF AIA DOUBLE SHEAR TEST FIXTURE
FIGURE 5B: SKETCH OF AIA DOUBLE SHEAR TEST FIXTURE
$D =$ Nominal Fastener Diameter.
When edge margin is to be investigated as a variable, it is permissible to change the $3D$ dimension.

$H =$ Hole Diameter.
Use hole size specified in governing specification. For Blind, Taper Shank and other special fasteners use hole sizes required for the product application.
FIGURE 7: TYPICAL BOLT TENSION TEST SET-UP
FIGURE 8: SIMPLE TEST SET-UP FOR SIMULATED UPLIFT
FIGURE 10: SECTION A-A WITH UNCONNECTED SPECIMEN INSTALLED
FIGURE 11: SECTION A-A FOR LAP JOINT WITH EQUAL THICKNESS PARTS