Steel Reinforcement Bar (Rebar) – A Tensile Testing Guide

Introduction

Steel reinforcing bar, or rebar, is embedded in concrete to improve the overall strength of the concrete that surrounds it. Material products standards exist to help ensure that rebar produced throughout the world exhibits the same physical, chemical, and mechanical properties regardless of the source. Proper mechanical testing is then necessary for determining if the rebar meets its published specifications, ensuring the quality of the product.

Mechanical testing requirements for rebar can vary, but typically fall into the following basic test categories:

- Tensile
- Bend
- Compression
- Fatigue

Other related product testing, such as slip testing of mechanical splices (couplers), may also be required. This document will focus primarily on the very common, yet sometimes challenging, tensile test.

Tensile Testing and Standards

At a global level, technical committees governed by the International Organization for Standardization (ISO) develop product and testing standards for reinforcement bar products. In addition to specifying properties, such as the minimum upper yield strength (Reh), Rm/Reh ratio, and elongation values for ribbed steel bar products, ISO product standards, such as ISO 6935-2, also specify how the tensile properties are to be measured. Unique testing requirements for the product are included directly in the standard and additional reference is made to ISO 15630-1, which focuses specifically on test methods for similar products. ISO 15630-1 provides further references to the more general metals tensile testing standard, ISO 6892-1, where applicable.

	ISO	ASTM
Rebar Product Standard	6935-2	A615
Rebar Testing Standard	15630-1	A370
Metals Tensile Test Standard	6892-1	E8

Table 1 – Examples of common rebar product and testing standards

On a regional level, many countries also have local standards organizations that may have existed even before the global ISO committees were formed. They often maintain their own product and testing standards or can elect to adopt the global ISO standards where appropriate. For example, in the US ASTM has long-developed product and testing standards for reinforcement bar. Product standards, such as ASTM A615, A706, A955, and A996, provide minimum product specifications and also include unique testing details for determining the tensile properties. Reference may also be made to additional testing requirements found in ASTM A370. This steel testing standard covers the mechanical testing of steel products. It then includes further reference to the primary metals tensile testing standard, ASTM E8.

Regardless of the governing body, the information provided in most global and local standards is quite detailed and intended to help the user understand the following basic testing requirements:

- Equipment required
- Associated terminology and symbols
- Specimen preparation
- Testing procedures or methods
- Calculations or results to be determined

Even though standards provide these thorough details, some aspects may still be left to the user's interpretation, which can often lead to variations in how the testing is performed. Additionally, if a lab is testing product to a variety of global or local standards, it can be challenging to fully understand and capture the subtle differences in terminology and methodologies found in the different standards.

This document is meant to act as a supplement to rebar product and testing standards and will attempt to provide further explanation in areas that are commonly misinterpreted or misunderstood by users. The content is intended to be general and summary in nature so it can be applied regardless of what test standard is being followed.

Equipment Considerations

Accommodating Bent Specimens

As the standards indicate, it is necessary to straighten rebar specimens prior to tensile testing. As a result, many test pieces may still have a slight bend or non-linearity over their length. Therefore, it is best if the load frame and grips are able to accommodate slightly bent specimens.

Fig. 2 - Uncoiled rebar exhibiting slight bends over length

Grips that mechanically clamp on center are recommended in order to maintain axial alignment of the specimen. Hydraulic, side-acting grips, such as the Instron® DuraSync™ design are best for addressing bent specimens because the mechanical balancing (synchronizing) between the 2 sides allows them to always clamp on center even when side loads from bent specimens are acting against the jaws closing. This helps improve alignment and eliminates the need to "reset" the grips between tests.

"Resetting" is typically associated with hydraulically synchronized grip designs that cannot clamp on center when specimen side loads exist. Failure to reset these types of grips between tests can allow for misalignment between the upper and lower grips.

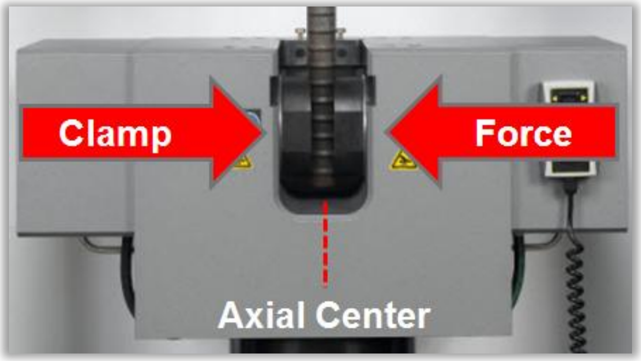

Fig. 3 - DuraSync side-acting grips clamping rebar specimen on center

Specimen Deformations and Scaling

Grip jaws (faces) must accommodate the deformations and scale that is common on the surface of rebar specimens. Buildup of scale in the teeth of the jaws can lead to specimen slippage. Tooth patterns that are too aggressive can cause premature specimen failures and may also prevent the specimen halves from being easily removed after the test. Therefore, tooth profiles should allow scale to fall away naturally or be easily brushed away between tests. They should also alleviate the chance of failures that are caused by the grips. If the broken specimen halves remain stuck in the jaw faces, the operator must dislodge them through use of a hammer or other means. This can reduce efficiency and add to operator fatigue and frustration.

The mechanical functions of the grips should also be protected against the falling scale. If scale is allowed to get between moving parts, critical surfaces can be galled and lead to poor performance or grip failure. It is important to regularly remove scale from the testing equipment to help prevent unnecessary wear and tear.

Fig. 4 - Abundant scale accumulation on lower grip after one test

Violent Specimen Failures

Because rebar specimens release a lot of stored energy during tensile failure, the testing system must be able to withstand the shock that results from the specimen recoil. The grips are impacted the most and must be robust enough to absorb the energy and still hold the broken specimen halves so they do not eject from the testing frame. Flying specimen pieces could become a safety hazard to the operator and result in damage to the equipment. For all of these reasons, hydraulically actuated grips (wedge or side-acting) are recommended.

Fig. 5 - #18 (57 mm) bar separation (recoil) after failure

Extensometers

Extensometers are not always required when testing rebar. If a distinct Yield Point (Upper Yield - Reh) is visible, the yield strength can be determined without an extensometer by reporting the Stress value at this point. Elongation after Fracture (ASTM and ISO) and the Total Elongation at Maximum Force (ISO) can both be determined manually after the test from marks placed on the specimen surface.

However, there are many times when an extensometer must be used in order to calculate results such as Offset Yield (Rp 0.2) or when determining elongation values automatically from an extensometer instead of manually from specimen marks. In these cases, extensometers used typically have large gauge lengths compared to those used on machined metals specimens. They must also be robust enough to withstand scale falling on them during testing and be able to attach to the uneven surface of deformed bars. Depending on the deformations, they can be attached to the flat surfaces in between deformations or on a longitudinal rib if one exists.

The most common extensometers used in rebar testing are manual clip-on style instruments that are attached directly to the rebar by the operator prior to running the test. If the instrument is not designed to remain on through failure, it must be manually removed by the operator after yielding occurs, but before the specimen fails. Manual instruments that are designed to withstand specimen failure offer advantages, but will likely experience faster wear of the knife edges if frequently used through failure.

Fig. 6 - Manual, clip-on style rebar extensometer

Most manual instruments are also designed to have a fixed gauge length. When testing many sizes of rebar with varying gauge lengths, it is necessary to have several extensometers that have unique gauge lengths. There are some manual instruments on the market that can be configured for several different gauge lengths, allowing a single instrument to cover most common requirements. Such devices will require the operator to manually configure the instrument properly between tests requiring a different gauge length.

Automatic contacting instruments, such as the Instron® AutoX750 offer several advantages over manual devices. Automatic removal and attachment allow the operator to stay out of the test space, eliminating any risks associated with specimen failures. The gauge length is set automatically from software inputs and is infinitely adjustable over the entire travel of the instrument, allowing a single instrument to cover all specimen requirements. It can also be left on through failure if desired. Automatic instruments are likely the best solution if automatic recording of elongation measurements is required. This will be addressed further in the results section.

Fig. 7 - AutoX750 testing #11 (36mm) Rebar on a 1500KPX

Testing Speeds and Control

One of the more challenging aspects of complying with test standards is determining how to properly and efficiently execute the tensile test. Despite standards providing specific details for allowable test speeds and control modes for the different stages of the test, it can still be difficult to perform the test properly. This may relate to both standard interpretation challenges and the limitations of the test equipment.

Details that influence test control and speeds can be found scattered throughout various sections of test standards. It may also be necessary to reference more than one standard in order to have all the required test setup information. This can make it very difficult to fully understand all aspects of the test sequence and how to make it work on a given testing system.

For rebar tensile testing, it is helpful to break down the tensile test into the separate stages of the test. This applies regardless of which test standard is being followed.
The **5 basic regions** are:

- Pretest
- Preload
- Elastic Region
- Yielding
- Plastic Region

Pretest

During the pretest stage, the machine is made ready for testing. The proper grips are installed and test opening adjustments are made. Prior to installing the specimen, the force (load) measurement should be set to zero. Once the specimen is loaded into the system, the force should NOT undergo any further "zeroing" as this will affect the test results. If using a manual extensometer for measuring strain, it should be attached to the specimen making sure to properly set the knife edges at the instrument's gauge length. The strain measurement should then be set to zero prior to loading the specimen.

Preloading

The preloading stage is used to apply a minimal preload (<5% of expected yield strength) to the specimen in order to properly seat it in the grips and to also aid in pulling the specimen straight prior to testing. A plot of stress or force versus crosshead or actuator displacement will typically show significant displacement for a minimal increase in load due to the grips and load string pulling tight (taking up system compliance). If a preload is not applied and an extensometer is being used, many rebar specimens will show negative strain at the beginning of the test as the specimen straightens. Because of this and/or system compliance, the data during the preloading portion of the test is often ignored or not recorded on the Stress-Strain graph.

On servo-controlled systems, preloading is usually done slowly using crosshead or actuator displacement feedback for controlling the test speed. Controlling preloading from load, stress, or strain feedback is not recommended as it could lead to undesirable and rapid acceleration until the specimen is pulled tight in the grips.

Depending on the amount of system compliance or slack that was taken up (reduced) during the preload, it may be necessary or desirable to zero the strain measurement at the end of preloading. However, caution must be taken so as to not adversely affect the overall strain measurement. In either case, test results that rely on strain from the extensometer should be adjusted so any non-linear behavior at the very beginning of the test curve does not adversely affect any test results. This is addressed under the Linear Slope section of results later in this document.

Elastic Region (before Yielding)

The elastic region or straight line portion of the test as seen on the Stress-Strain plot can often exhibit some non-linear behavior initially due to further straightening of the rebar specimen. If using an extensometer, this may show up as slightly negative strain at the beginning of the test and is generally considered normal for rebar.

Depending on the standard being followed, a variety of test control and target speeds are allowed during the elastic region and until the onset of yielding. The control and associated rate used may depend on the equipment limitations or specific product being tested.

When running the tests on servo-controlled systems, it is important to keep the following scenarios in mind. If using crosshead or actuator displacement control it is generally acceptable to use the same control and speed through both the elastic and yielding portions of the test. However, if stress or strain feedback control is used, the test must switch to crosshead or actuator displacement control just prior to or at the onset of yielding.

Yielding

Once yielding begins, many rebar grades exhibit a defined yield point that is seen as an abrupt bend in the Stress-Strain test curve. It is then followed by a period of specimen elongation with little to no increase in force. Because of this, servo-controlled systems must be controlled using crosshead or actuator displacement feedback in order to maintain a constant rate of travel throughout yielding. It is very important to note that using stress control during yielding will cause the test to accelerate excessively, which is in direct violation of the standards. This can also cause the yield point (upper yield) to be masked or smoothed and cause yield strength results to be higher than expected. Likewise, strain control from an extensometer can also become erratic during yielding and, is therefore, not recommended when testing rebar.

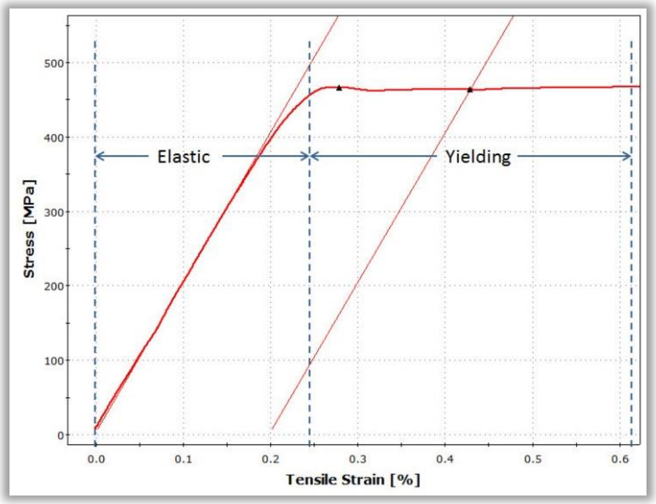

Fig. 8 – Elastic and Yielding regions of a rebar Stress-Strain curve

Plastic Region (after Yielding)

As the standards clearly define, it is acceptable for the test speed to be increased after yielding has completed. For servo-controlled machines, the best way to control the test during this final region is from crosshead or actuator displacement feedback (same as yielding). However, the speed used can be increased according to the standard being followed. This allows for the test to complete in a shorter period of time while still producing acceptable and repeatable results.

	ISO 6892-1:2009	ASTM A370-14
ELASTIC REGION (crosshead separation rate)	0.00025/sec * Lc	0.0625 in/min * GL
ELASTIC REGION (strain rate)	0.00025/sec	Not Specified
ELASTIC REGION (stress rate)	6 – 60 MPa/sec	10-100 ksi/min
YIELDING (crosshead separation rate)	0.00025/sec * Lc	0.0625 in/min * GL
PLASTIC REGION (crosshead separation rate)	0.0067/sec * Lc	0.5 in/min * GL

Table 2 – Target test rates for rebar test regions

Results Nomenclature

Test standards incorporate terms, result names, and symbols to properly identify critical information sought during testing. It is very important to fully understand this information in order to ensure standards compliance and proper results reporting. If testing to multiple standards, it is also necessary to understand the similarities and differences between these items. In some cases, standards organizations can use different terms or result names to refer to the same property. The following table shows a few common examples of results that are found in ISO and ASTM standards. You can see from the table where there are similarities and also differences.

	ISO	ASTM
Yield Point (distinct)	Upper Yield Strength (ReH)	Yield Point (Drop of Beam or Halt of Pointer)
Yield Strength (Offset Method)	0.2% Proof Strength, non-proportional elongation (Rp 0.2)	Yield Strength (0.2% Offset)
Maximum Stress	Tensile Strength (Rm)	Tensile Strength
Ratio of Tensile Strength/Yield Strength	Rm/ReH	Not Required
Strain at Maximum Force	% Total Elongation at Maximum Force (Agt)	Not Required
Elongation after Fracture	% Elongation After Fracture (A or A_5)	Percent Elongation

Table 3 - Common rebar tensile results for ISO and ASTM

Results – No Extensometer

For lower grade bars that exhibit a distinct **yield point**, it is possible to perform the entire test without the use of an extensometer. The yield point can be determined from the stress-extension test curve by locating the first point at which stress drops while extension continues to increase. On older testing systems, the yield point can be determined manually from witnessing the momentary drop of the load pointer and calculating the stress from this load value and the nominal cross sectional area of the bar.

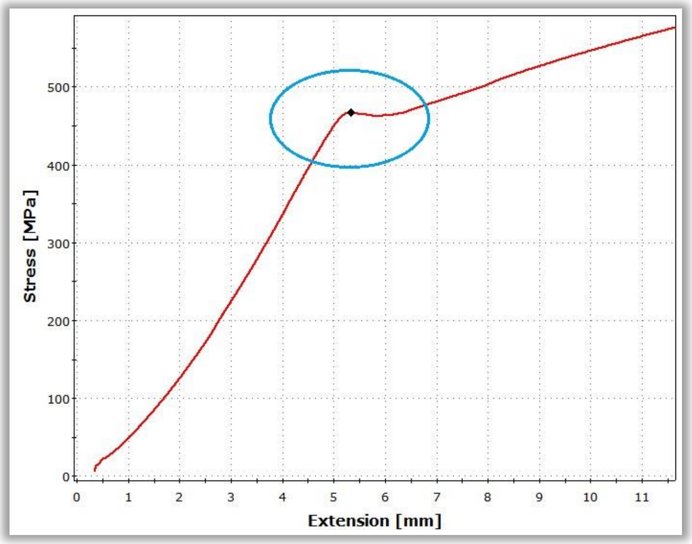

Fig. 9 – Distinct Yield Point on a stress – extension curve

In the previous section that discussed test control, it was pointed out that the machine actuator or crosshead should not accelerate during yielding. This can lead to the yield point being “hidden” on the test curve as the data gets smoothed as a result of the acceleration. If using a servo-controlled system, make sure the test control is from actuator or crosshead extension throughout yielding. If using a manually controlled system, be sure to maintain a constant rate of crosshead separation during yielding. If you are not seeing an expected defined yield point, begin by examining the test control used.

If no extensometer is used, elongation results such as those in the previous table must be determined manually from marks placed on the specimen prior to testing. As the standards describe, the broken specimen halves are placed back together after the test and manual measurements are taken from the marks found on each side of the specimen fracture. If a dispute arises over elongation results, the manual method is typically required for resolving such conflicts.

Overall, the manual method of testing is relatively simple, but relies heavily on the operator to properly record the yield point and manual elongation measurements. Each additional manual step in the process can lead to reduced repeatability and reproducibility of results between operators and systems. This can put results at risk for dispute and may require more frequent retesting.

Results – With Extensometer

Many higher grades of rebar do not exhibit a distinct yield point. In these cases it is usually necessary to determine the yield strength from the offset method. This requires measuring strain with an extensometer and plotting a Stress-Strain curve from which a 0.2% offset yield strength (Rp 0.2) can be determined.

Most modern testing systems are capable of automatically generating the yield strength. However, it is important to verify and validate the test method setup to make sure it is delivering consistent and accurate yield strength results. The following areas should be of particular focus.

Linear Slope

The test standards describe various approaches for fitting a line to the linear portion of the test curve. This line is meant to represent the slope of the elastic region of the curve and can intersect the strain axis somewhere other than the origin due to grips seating and the load string pulling tight as described previously in the Preload section. Since the yield strength is dependent on both the slope of this line and its x-intercept, it is critical that the setup is done properly. The following graph (fig. 10) shows a properly defined linear slope and the corresponding offset yield strength (Rp0.2).

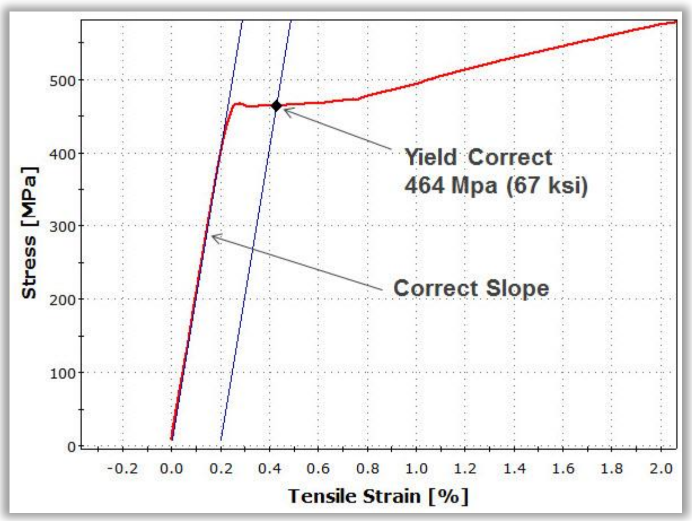

Fig. 10 – Correct Linear Slope line and resulting Offset Yield (Rp0.2)

Improper setup of this slope line could lead to incorrectly failing or passing material due to inaccurate yield strength results! The graph in fig. 11 includes the same test plot as that in fig. 10. However, the line defining the linear slope is not fit properly to the test curve and the corresponding offset yield strength (Rp0.2) is reported higher than it should be.

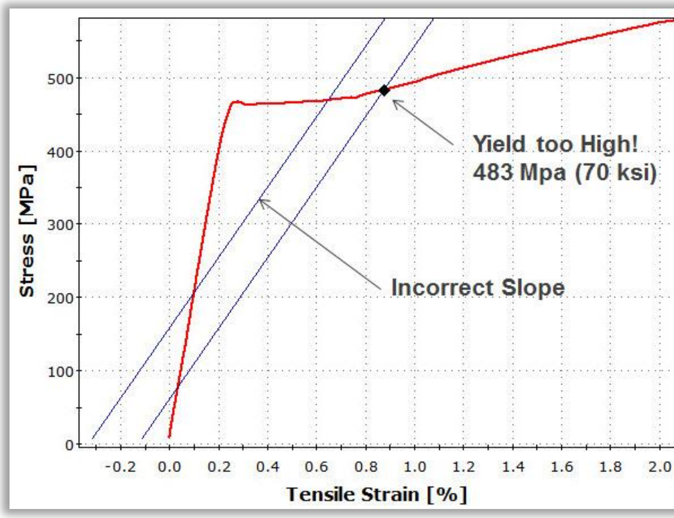

Fig. 11 – Incorrect Linear Slope line and resulting Offset Yield (Rp0.2)

It is also important to calculate (or adjust) all elongation measurements from the x-intercept of the linear slope line and the strain axis and not the origin of the stress-strain curve. This will improve the repeatability of test results and also allows for strain to be zeroed at the end of preloading if desired.

Yield Strength – Offset Method (Rp0.2)

The most common offset used for determining the yield strength of rebar is 0.2%. As the standards clearly describe, the offset line is drawn parallel to the line representing the linear or elastic region of the graph and is offset from the x-intercept of this line. In order to ensure a proper offset, it is necessary to measure strain accurately all the way through yield. Anything that adversely affects the strain reading - such as improper instrument setup or slippage during the test - could directly affect the yield strength result.

Improper test control during yielding can result in yield strengths that are too high. As described previously, acceleration during yielding violates the test standards. More importantly, acceleration or test speeds in excess of those allowed by the standards can lead to elevated yield strength values. This is less obvious on rebar grades that do not normally produce a distinct yield point and can make it easy to incorrectly pass otherwise failing material. Avoid this type of risk by confirming proper test control is established.

Extension Under Load (EUL) Yield

Earlier versions of ASTM rebar standards required an additional yield strength result that reported the stress at 0.35% extension. This was required for all rebar products that do not display a distinct yield point and was done to align ASTM standards with the American Concrete Institute (ACI) building code. Further harmonization was reached between ASTM and ACI regarding this requirement. As of 2014, ASTM rebar standards and the ACI building code no longer require this additional 0.35% Extension Under Load (EUL) yield strength result.

Elongation – Automatic Methods

When using an extensometer, it may be possible to record elongation results, such as Agt or % Elongation after fracture (A_5), directly from the strain measurement. This can help automate the recording of elongation results and eliminate the need for marking the specimen and taking manual measurements after the test.

When determining Agt automatically, the extensometer must remain attached through maximum force. The total strain at the maximum stress point can then be reported automatically by the system testing software. It can also be automatically adjusted to the x-intercept of the linear slope line. However, if the extensometer is a manual type device that needs to be removed before failure, it can be quite dangerous to require the operator to remove it after maximum force occurs. Many grades of rebar will exhibit violent failure shortly after maximum force is achieved. Automatic extensometers provide the added benefit of automatic removal at any point during the test. This protects the operator and possibly the instrument while still allowing for automatic capture of Agt.

When automatically determining % Elongation after fracture, typically the extensometer must be left on through fracture. Strain is then recorded at the break point determined at the end of the test. The test software must also be able to subtract off the elastic portion of strain to make the result more comparable to the manual method. This is dependent on the standard being followed. If the fracture occurs too close to the knife edge, the elongation results will be lower than expected and may not pass.

Alternatively, if the system is capable of automatically deriving strain from actuator travel (crosshead extension) and the specimen gauge length after the extensometer is removed, it is permissible to remove the instrument after maximum force is achieved. This is because the system compliance (stretch) is no longer resulting in system extension once maximum force has been reached. It is assumed that any actuator or crosshead travel after this point is due only to the specimen elongating. The test software must be able to automatically switch strain sources at the extensometer removal point and normalize the strain measurement in order for this to work effectively. An additional benefit is also realized with respect to the break location. Since the extensometer is removed after maximum force, the elongation measured from actuator or crosshead travel will capture the specimen elongation regardless of where the fracture occurs (assuming it did not fail in the grips). This will result in more consistent elongation results and require less retesting compared to leaving the extensometer on through failure.

It is important to keep in mind that manual elongation methods may still be required in some circumstances and the results are not directly interchangeable with the automatic method. In cases of results dispute, the manual method is typically required.

Summary and Conclusions

Global and local rebar product and testing standards define the rebar specifications and mechanical testing requirements. They strive to ensure consistent quality of rebar produced throughout the world.

It is extremely important for any tensile testing program to make sure there is compliance with required standards and that standards being followed are up to date. To further reduce the risk of incorrectly passing or failing product, it is also essential to regularly evaluate all aspects of the testing process and take corrective actions as necessary. Evaluation should include:

- Equipment (machine, grips, extensometers)
- Specimen Preparation
- Setup (software and hardware)
- Test Control (automatic or manual)
- Calculation of Results (automatic or manual)
- Graph Analysis

Be confident that your testing program is executing efficiently and effectively and only quality product is being supplied or used in field applications.

References

ASTM A370-14: Standard Test Methods and Definitions for Mechanical Testing of Steel Products

ASTM A615/A615M-14: Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

ASTM A706/A706M-14: Standard Specification for Deformed and Plain Low-Alloy Steel Bars for Concrete Reinforcement

ASTM A955/A955M-14: Standard Specification for Deformed and Plain Stainless-Steel Bars for Concrete Reinforcement

ASTM A996/A996M-14a: Standard Specification for Rail-Steel and Axle-Steel Deformed Bars for Concrete Reinforcement

ASTM A1034/A1034M-10a: Standard Test Methods for Testing Mechanical Splices for Steel Reinforcing Bars

ASTM A1035/A1035M-14: Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement

ASTM E8/E8M-13a: Standard Test Methods for Tension Testing of Metallic Materials

ISO 6935-2:2007 Steel for the reinforcement of concrete - Part 2: Ribbed bars

ISO 15630-1:2010 Steel for the reinforcement and prestressing of concrete - Test methods - Part 1: Reinforcing bars, wire rod and wire

ISO 6892-1:2009 Metallic materials - Tensile testing - Part 1: Method of test at room temperature

BS 4449:2005+A2:2009 Steel for the reinforcement of concrete - Weldable reinforcing steel - Bar, coil and decoiled product – Specification

BS EN 10080:2005 Steel for the reinforcement of concrete. Weldable reinforcing steel. General

AC133 - 2010: Acceptance Criteria for Mechanical Connector Systems for Steel Reinforcing Bars

AS/NZS 4671:2001 Steel reinforcing materials

JIS G 3112:2010 Steel bars for concrete reinforcement

GB 1499:1998 Hot rolled ribbed steel bars for the reinforcement of concrete

ACI 318-14 Building Code Requirements for Structural Concrete