

# STEEL REINFORCEMENT BAR: A TENSILE TESTING GUIDE

Steel rebar is commonly used around the world to reinforce concrete. Understanding the basics of rebar tensile testing is critical to ensuring product quality.

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Steel reinforcing bar, or rebar, is embedded in concrete to improve the overall strength of the surrounding concrete. Material product standards help guarantee that rebar produced throughout the world exhibits the same physical, chemical, and mechanical properties regardless of the source. Proper mechanical testing is necessary to determine if the rebar meets its published specifications, ensuring product quality. Mechanical testing requirements for rebar can vary, but typically fall into these main categories:

- Tensile
- Bend
- Compression
- Fatigue

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

## TENSILE TESTING AND STANDARDS

At the 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 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 to measure tensile properties. Unique testing requirements 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.

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 global ISO standards where appropriate. For example, in the U.S., ASTM has established product and testing standards for rebar. Product standards such as ASTM A615, A706, A955, and A996, provide minimum product specifications and also include unique testing

**TABLE 1—COMMON REBAR PRODUCT AND TESTING STANDARDS**

	ISO	ASTM
Rebar product standard	6935-2	A615
Rebar testing standard	15630-1	A370
Metals tensile test standard	6892-1	E8

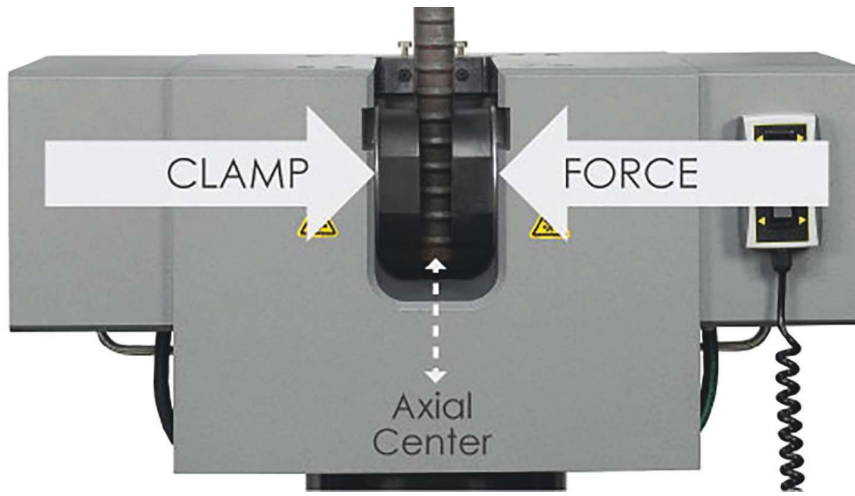
details for determining tensile properties. Reference may also be made to additional testing requirements found in ASTM A370. This steel testing standard covers mechanical testing of steel products. It then includes further reference to the primary metals tensile testing standard, ASTM E8.

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

- Required equipment
- Associated terminology and symbols
- Specimen preparation



Uncoiled rebar with slight bends over length.



Instron DuraSync side-acting grips clamping rebar specimen on center.

- Testing procedures or methods
- Calculations or results to be determined

Even though standards provide these details, some aspects may still be left to interpretation, which can often lead to variations in testing performance. Additionally, if a lab is testing products to a variety of global or local standards, it can be challenging to fully understand and capture subtle differences in terminology and methodologies.

This article attempts to clarify areas commonly misinterpreted or misunderstood by users. The content is intended to be general and summary in nature so it can be applied regardless of which test standard is followed.

## EQUIPMENT CONSIDERATIONS

**Accommodating bent specimens:** As standards indicate, rebar specimens must be straightened prior to tensile testing. As a result, many test pieces may still have a slight bend or nonlinearity over their length. Therefore, load frame and grips that are able to accommodate slightly bent specimens are best.

Grips that mechanically clamp on center are recommended in order to maintain axial alignment. Hydraulic side-acting grips are best for addressing bent specimens because the mechanical balancing (synchronizing) between the two sides allows them to always clamp on center even when side loads from bent specimens act against the

jaws closing. This helps improve alignment and eliminates resetting of 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 misalignment between upper and lower grips.

**Specimen deformations and scaling:** Grip jaws (faces) must accommodate deformations and scale common on rebar specimen surfaces. Scale build-up 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 failures potentially caused by grips. If the broken specimen halves remain stuck in the jaw faces, operators must dislodge them through use of a hammer or other means, which can reduce efficiency and add to operator fatigue and frustration.

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



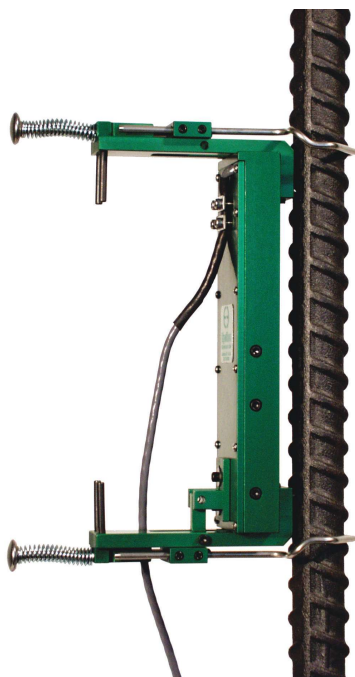
Abundant scale accumulation on lower grip after one test.



Number 18 (57 mm) bar separation (recoil) after failure.

**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 specimen recoil. Grips are most impacted 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 can also damage equipment. For these reasons, hydraulically actuated grips (wedge or side-acting) are recommended.

**Extensometers:** Extensometers are not always required when testing rebar.



Manual, clip-on style rebar extensometer.

If a distinct *yield point* (upper yield strength— $ReH$ ) is visible, yield strength can be determined without an extensometer by reporting the stress value at this point. *Elongation after fracture* (ASTM and ISO) and *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* ( $R_p 0.2$ ) or when determining elongation values automatically from an extensometer instead of manually from specimen marks. In these cases, extensometers typically have large gauge lengths compared to those used on machined metal 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 attached directly to the rebar prior to running the test. If the



AutoX750 testing #11 (36 mm) rebar on an Instron 1500 KPX.

instrument is not designed to remain “on” through failure, it must be manually removed after yielding occurs, but before the specimen fails. Manual instruments designed to withstand specimen failure offer advantages, but will likely experience faster wear of the knife edges if frequently used through failure.

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

Automatic contacting instruments offer several advantages over manual devices. Automatic removal and attachment allow the operator to stay out of the test space, eliminating 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.

## TESTING SPEEDS AND CONTROL

One challenging aspect 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 different stages of the test, performing tests properly can still be difficult. This may be due to both standard interpretation challenges and test equipment limitations. Details that influence test control and speeds can be found scattered throughout various sections of test standards. Referencing more than one standard might be necessary 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, breaking the test into separate stages is helpful. This applies regardless of which test standard is being followed. The five basic regions include:

- Pretest
- Preload
- Elastic region
- Yielding
- Plastic region

*Pretest:* During the pretest stage, the machine is prepared 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 while making sure to properly set the knife edges at the instrument’s gauge length. Strain measurement should then be set to zero prior to loading the specimen.

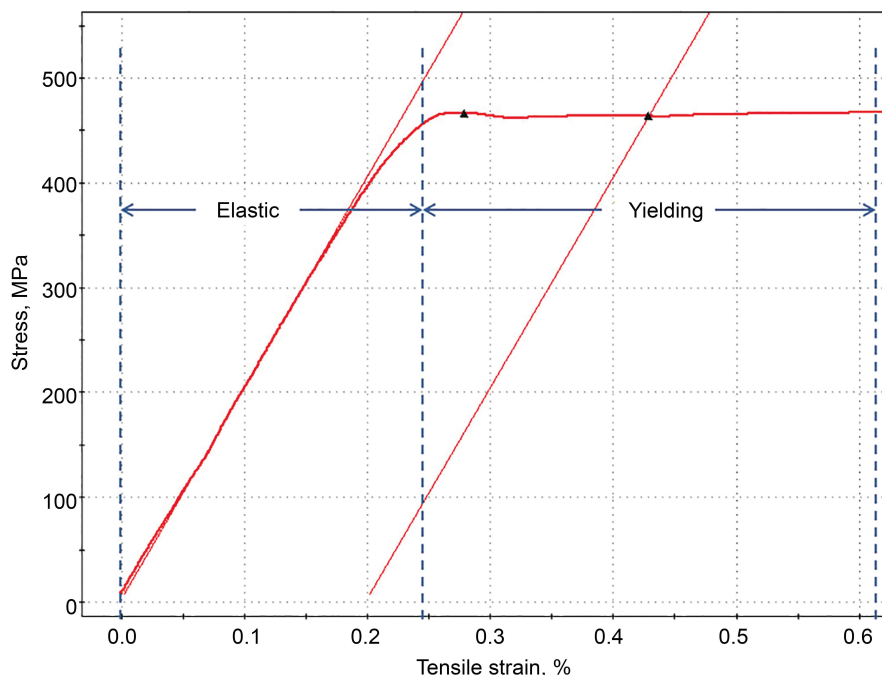
*Preloading:* The preloading stage is used to apply a minimal preload

(<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, data obtained 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 during the preload, it may be necessary or desirable to zero the strain measurement at the end of preloading. However, caution must be taken to not adversely affect overall strain measurement. In either case, test results that rely on strain from the extensometer should be adjusted so any nonlinear behavior at the very beginning of the test curve does not adversely affect test results.

*Elastic region (before yielding):* The elastic region or straight line portion of the test as seen on the stress-strain plot often exhibits some initial nonlinear behavior due to further straightening of the rebar specimen. If using an extensometer, this may appear 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



Elastic and yielding regions of a rebar stress-strain curve.

of yielding. The control and associated rate used may depend on equipment limitations or the specific product being tested.

When running 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 before or at the onset of yielding.

*Yielding:* Once yielding begins, many rebar grades exhibit a defined yield point that appears 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 regulated using crosshead or actuator displacement feedback to maintain a constant rate of travel throughout yielding. It is 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 not recommended when testing rebar.

*Plastic region after yielding:* As standards clearly define, it is acceptable to increase test speed after yielding is complete. 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, speed can be increased according to the standard being followed. This allows the test to be completed in a shorter period of time while still producing acceptable and repeatable results.

## A NOTE ON NOMENCLATURE

Test standards incorporate terms, result names, and symbols to properly identify critical information sought during testing. It is 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

**TABLE 2—COMMON TERMS FOR REBAR TENSILE TESTING RESULTS**

	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 <sub>g</sub> )	% Elongation

differences between these items. In some cases, standards organizations use different terms or result names to refer to the same property. The table above shows a few common examples of result names that are found in ISO and ASTM standards.

## SUMMARY

Global and local rebar product and testing standards define specifications and mechanical testing requirements. These standards help to ensure consistent quality of rebar produced throughout the world. It is critical 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), and graph analysis. ~AM&P

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