The Nuts & Bolts of a Building—Literally

BY THOMAS J. SCHLAFLY, MONICA STOCKMANN, AND GEOFF WEISENBERGER

Photos: Geoff Weisenberger

Shot-blasted nuts.

Steel arrives in bar form directly from the mills.

The ends of the bars are color-coded by grade.

WHEN IT COMES TO STEEL-FRAMED buildings the beams and columns, due to their high visibility, get all the glory. But a building is certainly more than what meets the eye. In particular, bolts are a very necessary but often unnoticed component in many buildings. Although bolts are typically unseen in the finished building, bolt quality is of utmost importance to the building's safety.

Questioning Quality

On the subject of bolts and safety, last year AISC received several questions regarding defective bolts. A few disturbing pictures were circulating around the steel construction industry, showing structural bolts that appeared to be bleeding; seams on the bolts were highlighted with dye penetrant.

Many people expressed concern about these bolts and asked if there was a problem with the bolt manufacturing process as a whole. AISC looked into the matter and concluded that the pictured bolts did not indicate a systemic problem in the manufacturing process, and responded that the ASTM bolt standards define defects, acceptance criteria, and sampling plans. These ASTM quality elements,

Nuts, still orange-hot, after being formed.

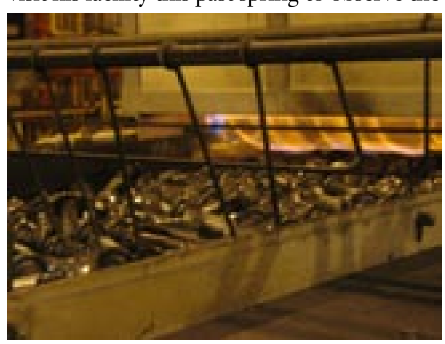
Punch-outs (left, in photo) are recycled.

along with reliance on a fastener manufacturer that is quality certified as required by the Fastener Quality Act, result in reliable fasteners in which a project team can have confidence. That does not mean that there will never be defects, but it does mean that they will not be frequent, systemic, or in quantities that would compromise typical structures.

Here at AISC, we found one of the ASTM quality elements especially intriguing: The quality sampling plan looks for defects on a statistical basis. (This is sufficient if the producer's manufacturing processes result in consistent quality.) This inspired us to learn more about the fastener manufacturing process, the typical quality-related issues encountered, and the quality controls a good manufacturer uses to provide the consistent level of quality the industry relies on.

Trekking to Peru (Illinois)

Fortunately, Unytite, a large bolt and nut manufacturer, is located just 120 miles south of the AISC offices in Peru, Ill. Chuck Hundley, the company's operations manager and a member of the Research Council on Structural Connections, invited a few AISC staff to visit his facility this past spring to observe the



Hardening involves temps of up to 1,570 °F.

bolt and nut manufacturing process and to discuss the quality checks that occur to make bolts safe products for use in structures.

Unytite may not be well known to fabricators and engineers because they sell fasteners through distributors rather than directly to fabricators. But this allows them to focus their resources on manufacturing while the distributors provide customer service to the end users. Unytit, a family-owned company, was established in Kobe, Japan, and its Peru plant has been in operation since 1990. Roughly 43% of the facility's output is structural bolts, 21% is structural nuts, and the remaining 36% is for automotive and OEM applications.

In the structural market, Unytite has the capacity to manufacture both tension-control (TC) and standard bolts, ranging from ⅝ in. to 1¼ in. diameter in size; and nuts ranging from ⅝ in. to 1⅝ in. diameter. Its structural fastener offerings include ASTM A325TC (F1852) and A490TC (F2280) structural bolt/nut/washer assemblies; ASTM A325 and A490 hex head structural bolts; ASTM A194 Grade 2H heavy hex nuts; and ASTM A563 Grade DH and DH3 heavy hex nuts. Their Japan plant

Bolt-threading equipment.

Threaded bolts on the move.

can provide fasteners up to 48 mm (1⅞ in.) in diameter, 1,000 mm (40 in.) long.

On the shop tour, we observed the manufacturing of nuts, structural bolts, and other fasteners. We started with the raw materials. The pictures that we saw last year were of bolts manufactured outside the U.S. and not by Unytite in Illinois or in Japan. We could see a manufacturer's mark on the bolt heads but could not find that mark in the register of known manufacturers. Wherever they were made, it is very likely those seams were a result of a flaw in the raw material.

In Unytite's plant we saw several coils (called wire for cold forming and bars for hot forming) of steel; coils range from ½ in. to 1¼ in. and bars range from ⅞ in. to 2 in. in diameter. Hundley explained the lengths to which Unytite goes to qualify suppliers. They order material that is similar to ASTM standards but modified to meet their needs, and the steel is straightened and eddy current tested for surface discontinuities (seams) under very strict tolerances. Different grades of steel in the stock piles are indicated by different colors at the ends of the bar.

Nuts

Nuts are produced via hot-forming. A bundle of steel is loaded on a bar rack system that automatically feeds the steel into the induction system. The steel is heated to a bright orange color (around 2,300°F) in an inductance heating coil, cut to short lengths, and forced into a hex die, and then a plain unthreaded hole is punched. Depending on the size and complexity of the product, this operation occurs at a rate of about 90 to 175 nuts per hour. The nuts are marked in the forming process, where the punch has the manufacturer's mark and identifying grade. The punch-outs are diverted away from the nuts and are eventually recycled.

The next process is to clean the scale off of the nut. The nuts are tumbled in a rotary drum with steel shot (roughly the size of sand), and the shot effectively removes scale from the nuts. The nuts are then heat-treated (and cooled with water) to obtain the specified hardness.

The nuts are then threaded or "tapped" on a bent shank-style tap that is about a foot long. One nut pushes the next over the teeth of the die, and the nuts at the end fall off of the die as the next nut is pushed on. Unytite has 96 spindles to perform tapping. Automated equipment feeds the nuts to various machines, and each machine has either two or four taps.

Fit of the thread is an important quality criterion Unytite has to control, and wear of the thread cutting taps is a main concern. Unytite employs pre-set counters that keep track of how many nuts the tap can thread before re-sharpening is required. Additionally, to control this wear and the thread fit, the technicians operating the threading machines routinely test the nut threads with a "go/no-go gauge." Nuts that are hot-dip galvanized are threaded after the galvanizing has been applied, while nuts that are mechanically galvanized are threaded before.

After the tapping, nuts used for TC bolts, as well as galvanized nuts, are lubricated. Lubrication is one of the most important facets of TC bolt performance. Improper lubrication can result in either high pretension and broken bolts, or low pretension. Lubricants are proprietary products and their composition is typically a valued trade secret for a bolt manufacturer. Unytite's lubricant was selected for its slip coefficient, consistency, and ability to remain consistent through reasonable storage and construction conditions.

Lubricants are usually colored (for coated products) so that the manufacturer and user can see that the nuts are lubricated. It was of interest to learn that the surfaces that require lubricant are both the thread and the bearing surface of the nut. The bearing surface often provides more resistance to torque than the thread.

Lubricant application is similar to a plating line for electo-plating. There is a predetermined weight that will be in each basket. The baskets are transferred to heated tanks that have cleaners and chemicals to coat the nuts. Each tank is monitored for the concentration of the chemicals. The tumbling action of the baskets ensures proper cleaning and coating for the entire nut. Coating of the bearing surface and threads is the key to controlling the torque co-efficiency for the assembly.

Tapping machinery threads the nuts.

Assemblies being packaged for shipping.

Bolts

While nuts are hot formed, structural bolts are cold formed using wire that has already been cleaned, coated, drawn to size, and annealed if necessary. The bolt is formed in stages, which all occur in one forge, transferred through a series stations with various punches and dies that form the part into the specified product. Simply put, the punch, which is indented in the shape of the rounded head, strikes the bar and creates the head (and applies manufacturer and grade markings). Then the bolt is sheared to the desired length and the shank and threaded areas are formed. The process happened so fast that we could not even see the bolts move from one stage to the next. Most of the structural bolts Unytite makes have round heads. Hex-head bolts are made by trimming the sides off of round-head bolts, and these trimmings are also collected and recycled. TC bolts undergo an additional process; a 12-point spline/pintail is added to the end opposite the head. Average output for the structural bolt forming is around 100 pieces per minute.

The blank unthreaded bolts are then threaded using a rolling process, as opposed to the thread cutting process used for the nuts. Rolled threads are formed by inelastically pushing material from the thread root to the thread tip. Cut threads, as the name implies, are formed by removing material from the unthreaded shank of the bolt. The threading machine is fundamentally a ring, about 15 in. in diameter, and a disk, approximately 13 in. in diameter, positioned such that the space between them becomes slightly narrower as the bolt progresses through the forms. Both the ring and the disk have grooves to form the threads. The disk turns relative to the ring so that the bolt rolls through the space between the thread forms. The notch diameters for TC bolts are also formed during the thread rolling process. As one would expect the tolerances are very tight, and the forms wear so again the thread fit is a quality control point that Unytite watches closely.

Because Unytite's cold-forming processes do not produce scale, shot blasting of the bolts is not required as it is with nuts. Thus, the heat treatment and quench hardening process is the next step for the bolts. Unytite uses a continuous mesh belt with a 2,200 lb/hour capacity, as quality control is easier with smaller batches (if 2,200 lb per hour sounds like a lot for something called a "small batch," know that some furnaces can process twice that much).

Heat treatment is certainly a closely timed, precision process, as raising or lowering the temperature of the bolts too quickly can create significant differences in appearance and quality. The bolts are heated to about 1,570 °F, quenched in oil, and then tempered (around 900 °F) to the specified hardness range. The appropriate temperatures are dependent on the type of material and the specified hardness. Unytite prefers to perform the quench and temper process in-house for cost and quality control reasons. Bolts do not require lubrication, so once the bolts cool, they are ready for assembly and/or packaging.

TC bolts, nuts, and washers are shipped in an assembly to help control thread fit and installation pretension. Unytite buys the washers from an outside supplier, and the nuts are turned onto the bolts automatically. The assembly machines work at around 40 to 45 assemblies per minute, although they are capable of 50. The assemblies are dropped in kegs, which are marked with the specified grade, size, and assembly lot identification and then palletized. And it's fair to say that the majority of the nuts and bolts make it into the kegs. The nut manufacturing process results in about 8% scrap metal (the punch-outs), and less than 1% of finished bolts becomes scrap (the shavings from the trimming and deburring operations).

The Lab

The last stop in our tour was the bolt testing laboratory. Think of a high-tech crime lab with the victim being a bolt or nut and the crime being anything from a crack to unacceptable hardness and tension levels. One machine is a "Super Skidmore" of sorts, a larger version of the Skidmore machine that tests bolt tension. Another machine, which performs magnetic particle testing, uses a black light-sensitive powder, applied to the bolt's surface, to bring cracks "to light."

A hardness testing machine in the testing lab.

Bolts on display in the testing lab.

There's also a hardness testing machine. Other testing devices/procedures for structural nuts and bolts include calipers, micrometers, functional gages (go/no-go), and tensile and proof load testing. The lab performs the tests required by the ASTM standard using the specified sampling plan.

The QA sampling plan provides the certification that the product conforms to the specification. But this only works if production is in control. That in turn is done with many QC tests, vendor controls, and process checkpoints performed on the floor throughout the manufacturing process.

While nuts and bolts are clearly tiny in the scope of the entire framing system, the sheer number of machines and processes—as well as the quality control—that go into manufacturing such small items is large. And this is a testament to the equally large role bolt assemblies play in bringing—and holding—buildings together. **MSC**

*Tom Schlafly (**schlafly@aisc.org**) is AISC's director of research, Monica Stockmann (**stockmann@aisc.org**) is an AISC Steel Solutions Center advisor, and Geoff Weisenberger (**weisenberger@modernsteel.com** is the senior editor of MSC.*

Controlling Tension

Structural bolts became a prevalent method of connecting steel in structural frames in the late 1950s and early 1960s. Tension-control (TC) bolts were introduced in the 1970s and have become the preferred fastener in building construction. TC bolts have a reduced neck or notch between the spline and the end of the bolt. The area of the material at the notch controls the torque and tension of the bolt when the spline shears off during installation. In pretensioned connections, TC bolts provide an indication that the required tension has been reached in the installed bolt. They also permit the use of an electric wrench, because the nut is turned against the bolt shaft, not against the resistance of the person holding the wrench.

TC bolt assemblies, ready to be shipped.