The Truth about Corrosion in Self-Drilling/Self-Tapping Screws

By Dana Benton, P.E.

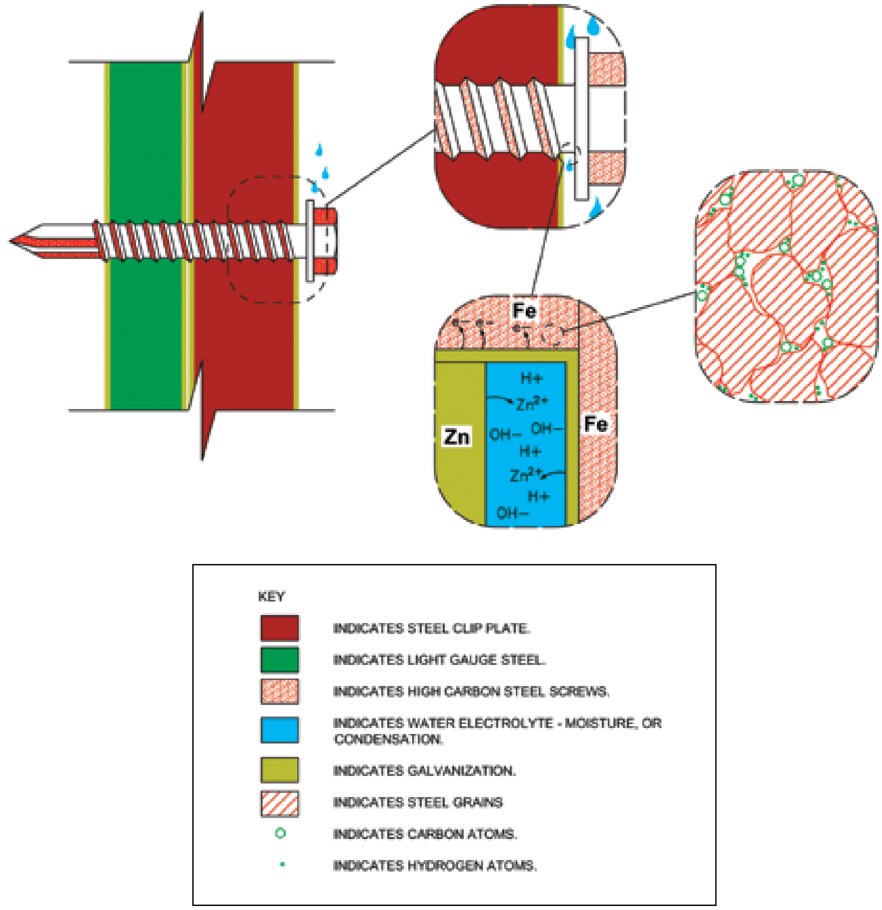
Insidious corrosion that affects self-drilling screws for exterior cladding support has become a major source of confusion in the building profession. Most contractors and architects are surprisingly unaware of this issue, even though corrosion has resulted in many fastener failures and, in some cases, litigation. This lack of understanding has been very apparent on recent projects where contractors mix and match various screw types with little or no corrosion protection. Even when specific corrosion resistant screws are specified, inferior screws are found on job sites. Despite the fact that the engineer of record specifically identifies the proper screws, corners are often cut and inferior screws show up on jobs. In some cases, the engineer is forced to tell the contractor to remove and replace a large percentage of critical screws to safeguard the integrity of façade element connections. This is not always done in blatant disregard for the contract documents, but rather due to a misunderstanding of how corrosion protection works and how the mechanical properties of screws are affected by moisture.

The two types of corrosion that affect hardened steel screws are hydrogen embrittlement (HE) and hydrogen assisted stress corrosion cracking (HASCC). Although HE and HASCC are little known and even less understood, they can lead to catastrophic failure and millions of dollars in repair costs. These types of corrosion are undetectable until after the failure occurs. Failure can happen at any time during the life of a building.

Currently, only one manufacturer provides a screw specially designed to prevent both HE and HASCC. However, this particular screw costs about seven times more than comparable screws. In an effort to save costs, contractors will often use other screws without prior approval from the engineer.

The Pitfalls of Electroplating

HE is caused by the zinc electroplating process that nearly all screw manufacturers use in order to prevent general corrosion. Typically, the first step in zinc electroplating is an acid bath and an alkaline bath to ensure that the zinc adheres uniformly and well. Next, the screws are electroplated.



Hydrogen embrittlement in self-drilling self-tapping screws.

For HE to occur, the steel screws must come into contact with hydrogen ions. As the smallest atom, hydrogen is capable of diffusing through hardened steel. The hydrogen atoms may lodge in the inter-granular boundaries of the steel if the screws remain in the acid or alkaline bath for too long, or if the acid concentration is too high.

The screws come into contact with hydrogen again when they are plated. During the plating, the screws are subjected to an electrical current while being submerged in an aqueous solution of zinc salts. Positively charged zinc and hydrogen ions in the solution are attracted to the negatively charged screw. The hydrogen ions then migrate into the gaps between the grains of the metal. After electroplating, the hydrogen is sealed inside the screws. The highest accumulation of hydrogen in the inter-granular boundaries occurs at the areas of highest stress, because these areas have the most prominent voids. In order to become more stable, the hydrogen ions bond together to form H_2. The H_2 molecules are greater in size than the individual hydrogen ions and act as a prying force against the grains of the steel, making the voids larger. This causes the steel to lose ductility and become more brittle, with much less tensile capacity.

One way to prevent HE in zinc electroplated screws is by "baking off" the hydrogen after the electroplating process. Studies have shown that the screws must be baked for a minimum of four hours at 400°F within one hour of electroplating. These stringent requirements are likely to drive off most, if not all, of the hydrogen. Still, it is imperative that screws are tested for HE after baking to guarantee that all of the hydrogen is expelled. Joe Greenslade, a private consultant in the field of fasteners who has written several articles on hydrogen embattlement, maintains that the General Motors test is the most rigorous and most similar to real world conditions. Some screw manufacturers claim to bake their screws and test for HE, but most either have no set criteria for baking and testing or else their criteria is less stringent than the recommendations above.

Mechanical Zinc Plating

HE can be avoided altogether if screws are mechanically zinc plated rather than electroplated. With mechanical plating, screws are not washed in acid and alkaline baths and are not positively charged to attract zinc. Instead, the screws are tumbled in a lined barrel with a mixture of glass impact beads, water, chemicals and zinc powder. Through the kinetic energy of the tumbling, the glass beads "cold weld" the zinc powder to the surface of the screw. Water polishing brightens and consolidates the coating. Although not as common as zinc-electroplating, mechanical zinc plating is a far safer choice for prevention of HE.

Reactions in the Field

The primary difference between HE and HASCC is that HE happens during the manufacturing process and HASCC occurs after installation. HASCC can result from hydrogen generated after installation by a galvanic reaction between dissimilar metals. Galvanic reaction occurs when two different metals come into contact with each other in the presence of an electrolyte. Electrolytes are any substances that contain free ions (charged particles) and conduct electricity (e.g. water). All metals have different levels of electronegativity, which is a measure of the ability of molecules to attract and form bonds with outside electrons. The greater the difference in electronegativity between two metals, the greater is the potential for electrons to flow from one metal to the other. The metal with less electronegativity will corrode, because its electrons will flow into the other metal via the electrolyte. The purpose of zinc-electroplating – and likewise galvanizing – is to place a sacrificial metal (i.e. zinc) between the two metals that need to remain intact.

In the case of cladding support framing, a galvanic reaction can occur when hardened steel screws come into contact with dissimilar metals in the presence of an electrolyte. The electrolyte is usually rain during construction, water that leaks into the structure, or even moisture due to condensation. The screws are zinc-electroplated attached to galvanized metal studs and steel clip plates. As the screw is driven through the metal stud or the clip plate, it can come into contact with the non-galvanized steel of the metal stud or clip plate, and a galvanic reaction may occur. Additionally, if the clip plates are not galvanized then a galvanic reaction can occur. The zinc plating on the screw is sacrificed to the steel of the metal stud or the clip plate. Hydrogen is a by-product of the galvanic reaction because as electrons from the zinc pass to the steel, positive zinc ions are released into the water and effectively separate the water molecules into hydrogen and hydroxide by bonding with the hydroxide. Similar to HE corrosion due to manufacturing processes, the hydrogen produced by the galvanic reaction can migrate into the intergranular cracks in the steel screw through any scratches in the zinc plating and cause brittleness and cracking. With HASCC, the crack is most likely to occur at the interface between the shaft and the head of the screw, because this is the location of the highest stress and therefore the location with the highest concentration of hydrogen. If screws have been corroded by HE or HASCC, their tension capacity is greatly reduced and their heads may pop off when placed in direct tension.

Damaging Effects

Brittle cracking is a structural engineer's worst nightmare because it happens suddenly and without warning. For example, imagine a cladding support connection that requires 3.2 screws, and 4 are used; if one screw suddenly gives way (due to HASCC), the load to that connection may be redistributed to nearby stud connections, which are then overloaded, and progressive failure, also known as a "zipper effect", could be initiated. Corrosion of this type is not visible and impossible to detect until after the damage has occurred and the screw fracture can be observed. Even more alarming is the fact that this failure can occur at anytime during the life of the building, because there is no guarantee that water won't come into contact with the screws due to storm damage or even condensation. The only recourse is to make sure that the screws used during construction are invulnerable to HE and HASCC.

Soft Solution

High carbon (hard) steel is more susceptible to HE or HASCC than low carbon (soft) steel, because carbon atoms provide "traps" for hydrogen to accumulate and propagate cracks. The hydrogen interacts with, and is retained by, the carbon atoms. According to Greenslade, HE and HASCC are avoided in screws with core hardness of Rockwell C 36 or less, i.e. when carbon content (hardness) is kept below a certain limit (RC 36), hydrogen trapping is diminished and crack initiation will not occur. Additionally, hardened steel is inherently more brittle than low carbon steel because the carbon impurities and hydrogen impurities decrease ductility even further. One manufacturer has taken advantage of the HE/HASCC invulnerability of low-carbon steel by making a screw with a dual-hardness. The screw tip is hard enough to penetrate and cut threads in the base metal, yet the shaft (the load bearing portion with the highest stress concentrations) is soft enough to provide ductility and strength without brittleness. The shaft hardness is RC 28-34. This technique is fairly new. The manufacturer asserts that the screw also has a proprietary coating that provides substantial resistance to other types of corrosion. Unfortunately the higher price tag is inevitably a bone of contention between engineers and contractors.

Organic Offerings

Many of the available self-drilling/self-tapping screw manufacturers claim that their proprietary organic coatings provide "superior corrosion resistance." Climaseal®, Grabbergard, Kwik-Cote, and Quik Guard are examples of such proprietary coatings. Relative to other comparable high-carbon screws, this may be true. These coatings insulate the screw from the base metal that they are screwed into, and in the absence of metal to metal contact, there is no galvanic reaction and therefore no HASCC. Typically, screws that are mechanically zinc plated and treated with an organic proprietary coating are substantially less expensive than the screw with dual-hardness. However, it is highly unlikely that screw manufacturers will guarantee that their organic coating will not wear off when the screw is driven into the base material. Unfortunately, there is currently no ASTM corrosion resistance test for organic coatings that mimics the wear and tear on screw coatings during construction. Salt spray testing is the ASTM approved method for testing general corrosion resistance in fasteners. ICC reports give information on salt spray testing for various fasteners with proprietary coatings, but salt spray testing does not relate directly to HE or HASCC.

Code Confusion

Current code requirements for self-drilling/self-tapping fasteners are very vague about corrosion treatment and make no mention whatsoever about HASCC. Self-drilling/self-tapping screws can easily meet all code requirements and still be at risk for both HE and HASCC. There is some discrepancy in code requirements, e.g. SAE J933 recommends that the core hardness of tapping screws be kept below RC 36 to avoid brittle failure; while SAE J78 specifies a core hardness upper limit of RC 40. Even if hardened screws meet the recommendations mentioned above for baking and HE testing, they are still susceptible to HASCC in the field.

Rules of Thumb

The following are recommendations for engineers, screw manufacturers, and changes to code requirements:

- Screws should either have dual hardness with a screw shaft hardness of less than RC 36, or they should either be mechanically plated or electroplated and baked at 400°F for four hours and then tested for HE per GM testing requirements. ASTM standards need to be set for post-plating baking of screws and testing for HE.
- ASTM 1940 provides guidance for HE monitoring during the plating process and should be adopted by all screw manufacturers that make self-drilling/self-tapping screws.
- If screws do not have dual hardness, they should be coated with an organic coating that is proven to withstand typical construction wear and tear. ASTM standards need to be set and adopted by screw manufacturers for organic coating application methods and testing.
- ICC reports for self-drilling/self-tapping screws should be thoroughly reviewed for resistance to HE/HASCC before approval.
- Self-drilling/self-tapping screws must be clearly specified by the engineer by brand, plating type, size, and organic coating (where applicable). This information should be very clear in both the structural drawings and specifications, and should be verified during the submittal process. Given the lack of HE/HASCC awareness amongst contractors and their eagerness to save money on this seemingly insignificant part, it is smart to double check the screws at the jobsite – even requesting to see the boxes that the screws came in.

HE and HASCC are issues that must be addressed by structural engineers, contractors, and testing institutions. The recommendations above can help to greatly reduce the likelihood of HE/HASCC occurrence. A relatively small amount of up-front expense can prevent a significant damage and expense later on.▪

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References

"Elco® Technical Bulletin – Understanding and Assessing the Potential for Structural Failure of Hardened Fasteners. Acument Intellectual Properties, LLC 2008

Greenslade, Joe, "Electro-plated Tapping Screws Should Be Tested for Hydrogen Embrittlement", **http://www.greensladeandcompany.com/** pg 182-183, Mar./Apr. 2004

ER-4780, pg 1, ICC Evaluation Service, Inc. 2004.