Painting Bolted Connections for Bridges

KTA-Tator, Inc., 14 June 2016
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High-strength bolts have been used to assemble steel structures for over 60 years, supported by research conducted by the Research Council on Riveted and Bolted Structural Joints (RCRBSJ). RCRBSJ was founded in 1947 but is now known as the Research Council on Structural Connections (RCSC). Despite the long history of use, there is still confusion when it comes to painting faying surfaces, bolt holes and fasteners. This article will attempt to clear up some of the confusion and provide items to consider when designing and painting bolted connections.

Fig. 1: Test plates for slip coefficient testing with test coating already applied. Figures courtesy of the authors unless otherwise noted.
TESTING OF COATINGS FOR SLIP-CRITICAL JOINTS

Before discussing the interpretation of test results for coatings used in slip-critical joints, it is helpful to understand the testing procedures. Testing and certification of the coatings is addressed in RCSC’s “Specification for Structural Joints Using High-Strength Bolts.” The revision in effect at the time of this writing is August 1, 2014 (with April 2015 errata), although proposed changes are currently under discussion. Certification requires that criteria be met for both slip coefficient testing and tension creep testing, as outlined in Appendix A of the specification.

The specimens must first pass the slip coefficient testing before being subjected to tension creep. A minimum slip coefficient of 0.30 is required for Class A certification and a minimum slip coefficient of 0.50 is required for Class B certification. Although not discussed in this article, there is also a Class C certification, which requires a minimum slip coefficient of 0.35. Class C is for roughened hot-dip galvanized surfaces.

Fig. 2: Slip coefficient test apparatus with testing underway. A vertical load is applied to the center of the three plates to induce slip.

COEFFICIENT OF FRICTION (COF) TESTING

The slip coefficient test is used to determine the mean slip coefficient of a coating under short-term static loading. The test plates for slip coefficient testing are fabricated from 5/8-inch-thick, flat carbon steel (no raised edges, protruding defects or warp) with a minimum yield strength of between 36-and-50 ksi. The plates measure 5/8-inches-by-4-inches-by-4 inches with a 1-inch hole drilled 1 ½-inches from one edge and one of the sides (5/8-inches-by-4 inches) is machined smooth. While the specification does not explicitly indicate whether hot-rolled or cold-rolled steel is to be used, the surfaces must be as flat as possible. The surfaces of cold-rolled steel are typically flatter than those of hot-rolled steel and offer greater planarity, so cold-rolled steel is typically used.

The plates are abrasive blast-cleaned and coated with the material being evaluated — for example, inorganic zinc, organic zinc or thermal spray coatings (TSC). The standard requires the test coating to be applied to both sides of each plate at a thickness 2 mils greater than the maximum that will be applied to the structure (typically 2 mils greater than the manufacturer’s recommended maximum thickness), but the thickness reported on the certification does not include the extra 2 mils.
Each test specimen is composed of three coated plates. Figure 1 shows two of the plates used for slip coefficient testing.

The mean slip coefficient of the coating is determined by testing five replicate specimens (three test plates per specimen). The test setup has two major loading components, one to apply a clamping force to the specimen plates and another to apply a compressive load to the center plate so that the load is transferred across the faying surfaces by friction (Fig. 2). A threaded rod is inserted through the holes of the three plates, rather than a bolt. A nut on the end of the rod secures the plates and a clamping force is applied and maintained throughout the test using a hydraulic cylinder at 49 ± 0.5 kips to represent the minimum clamping force of an A490 bolt. A vertical load is subsequently applied to the center plate at a rate not exceeding 25 kips/min until slip occurs between the plates. Testing of each replicate specimen requires approximately seven minutes to complete.

Fig. 3: Test plates for tension creep testing with the test coating applied to the top halves. The blast-cleaned and uncoated bottom halves are for assembling the plates into a chain. The uncoated portions are only connected using loose pin bolts and are not part of the test.

**TENSION CREEP TESTING**

Tension creep is the tendency of a coating to undergo deformation under sustained service loading and includes the effect of a loss in clamping force due to significant compression or creep deformation of the coating. The test plates for tension creep are composed of 5/8-inch-thick, flat carbon steel (again with no raised edges, protruding defects or warp) measuring 4-by-7 inches with two 1-inch holes drilled 1 ½ inches from each end. Surface preparation and application of the test materials is identical to the plates prepared for slip coefficient testing. Each test specimen consists of three plates with the test coating applied to the top halves. Figure 3 shows two of the plates used for tension creep testing.

Three replicate specimens (of three plates each) are linked together in a single chain-like arrangement (Figs. 4 and 5). The clamping force is achieved by connecting the painted portions of the plates with 7/8-inch diameter A490 bolts that are secured with corresponding nuts. The unpainted portions are only connected using loose pin bolts and are not part of the test. A load is applied to the chain in tension and held for 1,000 hours (approximately 42 days). At the end of 1,000 hours, the tension is increased over the course of a few minutes to a final load. Both the locked tension for 1,000 hours and the final tension to be placed on the specimens are derived from a formula that is based on the slip coefficient classification of the samples and the average clamping force. While the actual clamping force depends on the bolt type or installation method, for Class B it is a minimum of 32.7 kips for the locked tension and a minimum of 49 kips for the final tension. Because bolts are used to secure the samples, the results could be impacted if there is significant compression of any material — for example, the paint, TSC or galvanizing on the
faying surfaces or beneath the bolt head or washer/nut and the steel plates, which could affect the clamping force.

Fig.4: Slip coefficient test apparatus with testing underway. A vertical load is applied to the center of the three plates to induce slip.
INTERPRETATION OF SLIP COEFFICIENT AND TENSION CREEP RESULTS

According to the RCSC specification, the mean slip coefficient of coatings can be categorized as Class A or B, and as indicated previously, a Class A slip coefficient rating is a minimum of 0.30 and Class B is a minimum of 0.50.

Bare abrasive blast-cleaned steel and most inorganic zinc primers meet Class B. Some organic zinc primers meet Class B, but others only meet Class A. Clean mill scale meets Class A. For TSC, an FHWA study (Slip and Creep of Thermal Spray Coatings, Publication No. FHWA-HRT-14-083) tested both sealed and unsealed 100-percent zinc and 85/15 (zinc/aluminum). The slip coefficient of both unsealed
systems was > 0.75, easily exceeding the Class B requirement. The slip coefficient for the sealed systems was 0.414 for 100-percent zinc and 0.439 for 85/15, which only meet the Class A requirement. For tension creep, both of the unsealed systems met the Class B criteria. When sealed, both systems failed, even though the tension creep parameters were based on the less rigorous Class A requirements. When used in joints, TSC should not be sealed.

There are a few factors to be cautious of when applying the slip coefficient and tension creep test results to shop and field work.

Recognize that the tests are performed with the same material on the mating faces. For example, the same Brand X primer is applied to all faces of the test plates and the certification is then issued for the specific product that was tested. Though applying Brand X inorganic zinc to one face of a joint and Brand Y inorganic zinc to the other face may perform, the certification does not address the use of two different brands in a single joint unless it is specifically tested that way. Likewise, the certification does not address the use of Brand X inorganic zinc on one face and Brand Z organic zinc on the other, even if both products are produced by the same manufacturer, unless it is specifically tested that way.

The minimum primer curing time used during the qualifying tests before assembling the joints must be strictly adhered to; otherwise, the uncured paint in the joint could behave as a lubricant. The RCSC specification states that research indicated “that all curing effectively ceased at the time the joint was assembled and paint that was not fully cured at that time acted as a lubricant. The slip resistance of a joint that was assembled after a time less than the curing time used in the qualifying tests was severely reduced. Thus, the curing time prior to mating the faying surfaces is an essential parameter to be specified and controlled during construction.” The qualification tests establish the minimum time required to achieve adequate curing of the product so that the slip resistance is not impacted.

The maximum thickness and thinner type shown on the certification must not be violated for the certification to be valid. This is why the thickness of the primer specified for connections is often different (lower) than the thickness specified for the rest of the steel.

The test plates are typically coated with the same material at the same thickness on the backsides (beneath the bolt, washer and nut) and the faying surfaces. That is, if a single coat of inorganic zinc primer is applied to the faying surfaces at 7 mils, the same inorganic zinc primer is applied to the backside of the plates at 7 mils. The presence of paint on the backsides of the specimens has no effect on the slip coefficient test results since the clamping force is maintained continuously throughout the test. However, paint on the backsides of the samples for the tension creep test could influence the results because the clamping force is accomplished using 7/8-inch A490 bolts, and a loss of clamping force could result from compression of the coating (Fig. 6).
Fig. 6: Samples are assembled for tension creep to determine the effect of the full coating system applied to the backside. Note the visible compression of the coating after pre-tensioning the bolt.

Since the primer is applied to the backsides as part of the normal test protocol, any compression of the coating is incorporated into the test results. However, the effect on bolt pretension of any additional coats applied to the backsides of the plates is not incorporated into the normal test regimen. Accordingly, for a given project, if a decision is made to paint the backsides of the splice plates with the full coating system rather than just the primer, the effect of the full paint system on the tension creep performance is not clearly addressed by the certification. It should be noted, however, that professionals closely involved with the RCSC specification have indicated that specimens with 10 mils of coating on the backsides of the plates had been successfully tested in the past; and therefore, it was assumed that up to 15 mils of combined coating thickness/galvanizing thickness (in the case of galvanized fasteners) would not likely affect the results. While this assumption may be valid, because many different coating types and brands are used in the field, it is the author’s opinion that if multiple coats will be applied to the backside of splice plates prior to bolting, consideration should be given to testing the system, at least in those cases where a Class B certification is required.

**PAINTING OF BOLT HOLES**

Painting of bolt holes does not affect the life of the steel because once the bolts and plates are in place, the weather is sealed out, preventing corrosion. When bolt holes are specified to be painted, it is typically done to prevent the formation of rust stain from the holes between the time of painting and assembly. A good source of information regarding the painting of bolt holes is found in AASHTO/NSBA “Steel Bridge Collaboration S 8.1-2014,” which is also published as SSPC-PA Guide 13, “Guide Specification for Application of Coating Systems with Zinc-Rich Primers to Steel Bridges.”

SSPC-PA Guide 13 states the following in paragraph 3.4:

“Miscellaneous Surfaces to be painted and the coating system to be used shall be as indicated on plans and/or contract documents. Unless otherwise noted, paint is not required on flange surfaces that will be embedded in concrete, or inside bolt holes, although overspray is permitted on flange surfaces and inside bolt holes.”
Another document, SSPC-PA 1, “Shop, Field, and Maintenance Painting of Steel,” has been revised and is undergoing final review. While the following has not been officially approved by SSPC at the time of this writing, it establishes the position of the committee responsible for drafting the revisions. Note the last sentence.

“7.8.1 Contact surfaces of members to be joined by high strength bolts in a friction connection (faying surfaces) shall provide the required slip coefficient based on the specified class of slip resistance based on the design criteria. Uncoated faying surfaces shall meet the surface preparation and cleanliness requirements for the specified class and shall be free of oil and grease. If coated faying surfaces are required or permitted, the coating used shall be tested and certified to the required class (see Note 15.13) and shall not exceed the thickness tested. The application to, or removal of, coating from bolt hole interiors is not required unless specified in procurement documents, although overspray coating is frequently present.”

It is common to see holes only incidentally coated with overspray, rather than purposely painted (Fig. 7).

**CLEANING AND PAINTING OF FASTENERS**

A number of fastener types are used in bolted connections, but the following discussion is limited to black bolts and galvanized bolts (hot dip galvanized and mechanically galvanized). SSPC-PA Guide 13 also addresses the painting of fasteners in Sections 5.4 and 5.5.

**BLACK BOLTS**

According to SSPC-PA Guide 13, when black bolts are installed prior to cleaning and painting, the fasteners are blast-cleaned together with the steel to achieve the specified surface cleanliness and profile and primed with the same inorganic or organic zinc specified for the structure. (Note that this Guide is specifically for the use of zinc primers. If a non-zinc primer is being applied to the structure, the same primer would be applied to the fasteners.)
When black bolts are installed after painting has been completed, the Guide recommends that the fasteners be blast-cleaned prior to painting. While blast-cleaning the bolts installed after painting results in an excellent surface for the application of the coatings, there are significant drawbacks to this approach during implementation. In order to properly prepare the fasteners, the blast nozzle must be held at many different angles to the surface and pointed in many directions. The result is the potential for extensive over-blast damage to sound, intact coating located in proximity to the fasteners.

If the shop coating involves zinc primer without the intermediate and finish coats, the entire area within the potential damage zone should receive an additional coat of primer. Note that “potential damage zone” is used because the specific pinpoints of damage will not always be readily apparent. If the shop primer is an inorganic zinc, then organic zinc (rather than inorganic) should be applied to the damaged area. If the primer is organic zinc, organic zinc would typically be reapplied. In the case of the organic zinc, the specification or manufacturer’s recommendations will likely require SSPC-SP 7/NACE No. 4, “Brush-Off Blast Cleaning” of the entire area of potential damage to prepare the primer to receive another coat.

If the shop coating involves a primer and epoxy intermediate coat, the intermediate coat specified for touching up the structure should be applied to the potential damage zone. Preparation of the intermediate coat in the damaged area should be the same as is required by the specification for preparing the intermediate coat to receive the field finish. If the damage exposes the substrate, the primer should be spot-applied to those locations before application of the intermediate coat.

If all coats have been shop-applied, the extent of the damage must be assessed to determine whether the finish coat alone is adequate, or if spot application of primer and intermediate coat is required. When applying the finish, it is likely that the existing finish will need to be brush-blasted first to achieve good adhesion. It should also be recognized that the areas repaired with the new finish will be readily visible so it is important to square up the application, but if a patchwork appearance is not acceptable the finish will have to be applied to logical break points.

In order to avoid the need to blast-clean the bolts after assembly and deal with the repairs, when feasible, specifiers use galvanized bolts or treated bolts (with proprietary inorganic coatings, for example) that can be field painted after solvent cleaning and/or pressure washing and limited hand/power tool cleaning.

**GALVANIZED BOLTS**

SSPC-PA Guide 13 recommends that galvanized bolts be cleaned by SSPC-SP 1, “Solvent Cleaning,” SSPC-SP 2, “Hand Tool Cleaning,” SSPC-SP 3, “Power Tool Cleaning,” and/or SSPC-SP 12 (Water jetting). Since the publication of SSPC-PA Guide 13, SSPC-SP 12 has been replaced by four individual water jetting standards, SSPC-SP WJ-1 through WJ-4.

The Guide also addresses the removal of lubricant wax/dye applied to the nuts, indicating that it can be accomplished using an alkaline household cleaner such as ammonia with care to make certain that residue from the cleaner is also totally removed. One area of controversy regarding the cleaning of lubricant is whether or not all dye has to be removed. Section 5.4.4 of the Guide requires the removal of “excessive dye,” and in commentary notes to 5.4.4 it states that, “Any dye coloring remaining on galvanized nuts after weathering or the required surface preparation is not believed to be detrimental to subsequent coating performance or appearance. A white cloth wipe test with no color transfer can be used to confirm that all lubricant and non-absorbed dye has been removed, leaving only the residual ‘stain’ on the surface.”
While the Guide indicates that residual staining on the nuts should not be a problem, standards are not available to describe or depict the amount of staining that is acceptable so decisions must be made on a project-specific basis. Figure 8 shows the results of a project-specific examination of cleaning methods. The initial appearance of lubricant/dye and the stains remaining after cleaning are shown. For this project, MEK was found to be a more effective cleaning agent than ammonia. The stains passed the white cloth test and when painted with the system specified for the project, the adhesion was not compromised. When the galvanizing is damaged during tightening and the fasteners are specified to be painted, specifications vary on how to address the damage. But first, the type of damage should be assessed. For example, “smeared” galvanizing is still protective. In areas where the galvanizing is totally removed and the steel exposed, specifications commonly require spot application of organic zinc primer or epoxy mastic (typically aluminum-filled) to the damaged areas followed by the same intermediate and finish being applied to the rest of the structure.

The most important issue with regard to the application of coatings to any type of fastener is to make certain that the coating is completely and thoroughly worked into the crevices and threads, and properly built up on edges, as these areas are the first to corrode.

**SUMMARY**

When bolted connections are slip critical, the certified coating must be applied within the thickness and thinning parameters called for in the certification and the joints not assembled sooner than the cure times used for the qualification testing. When TSC is used on faying surfaces of joints, based on testing conducted by FHWA, it should not be sealed. If the choice is made to apply the full coating system to the backside of splice plates before bolting, consider testing it first to make certain that any loss of pretension that might occur due to the compression of the coating does not adversely affect the tension creep results. For bolt holes, unless some rusting prior to assembly is not acceptable, a common practice is to not require coating the interior surfaces, but allowing the coating to be deposited into the holes as part of the application to the face of the member. When black fasteners are installed after the paint has been applied, abrasive blast-cleaning in preparation for painting can create significant damage to the surrounding coating. Alternative fasteners should be considered if feasible, such as galvanized or treated, in order to
avoid the need for blast-cleaning in the field. Before painting, fasteners must be cleaned of surface contamination, and in the case of galvanized nuts, the lubricant removed to the extent that adhesion of the subsequently applied coating is not compromised. If there are questions regarding the adequacy of the cleaning and the acceptability of remaining stains, the coating system can be applied on a test basis and the adhesion examined. In all cases, when fasteners are painted, it is critical that the specified coatings be thoroughly applied to threads, crevices and edges.

ABOUT THE AUTHOR

Kenneth Trimber is the president of KTA-Tator, Inc. He holds a Bachelor of Science degree from Indiana University of Pennsylvania, is an SSPC Protective Coatings Specialist, is certified at a Level III coating inspection capability in accordance with ANSI N45.2.6, is a NACE-certified Coating Inspector and an SSPC-C3 Competent Person.

Trimber has more than 40 years of experience in the industrial painting field, is a past president of SSPC, chairman of the Committee on Surface Preparation, chairman of the Visual Standards Committee, chairman of the Task Group on Containment and chairman of the SSPC Commercial Coatings Committee. He is also past chairman of the ASTM D1 Committee on Paints and Related Coatings, Materials, and Applications.

Trimber authored The Industrial Lead Paint Removal Handbook and co-authored Volume 2 of the handbook, Project Design. He was the recipient of the John D. Keane Award of Merit at the SSPC National Conference in 1990 and is a former technical editor of JPCL. In 2009 and 2012 he was named by JPCL as one of the 25 Top Thinkers in the coatings and linings industry and in 2015 was the recipient of the SSPC Honorary Life Member Award.