PTI Journal *Case Study*

TENDON IMPREGNATION TECHNOLOGY MITIGATES CORROSION AND PROTECTS POST-TENSIONED TENDONS

By

DAVID WHITMORE, GARTH FALLIS, HAIXUE LIAO,
STIG STROMBECK, AND IVAN LASA

POST-TENSIONING INSTITUTE ®

Authorized reprint from: August 2014 issue of the PTI Journal

TENDON IMPREGNATION TECHNOLOGY MITIGATES CORROSION AND PROTECTS POST-TENSIONED TENDONS

BY DAVID WHITMORE, GARTH FALLIS, HAIXUE LIAO, STIG STROMBECK, AND IVAN LASA

THE PROBLEM

Bonded post-tensioned tendons are grouted to provide corrosion protection to the embedded steel strands. These steel strands are at an increased risk of corrosion and failure when there are defects in the installed grout. The most common grout problems (defects) include:

1. Voids: Voids may be present as a result of incomplete filling of the ducts or grout leakage which may occur prior to hardening of the grout. More commonly, voids are a result of grout bleed, where excess water in the grout floats to the top of the grout, resulting in a pocket of water or a void if the water later evaporates. Grout bleed was a common occurrence and typically ranged between 3 and 5% of total grout volume when standard cement/water grout was used.

2. Variations in grout properties: Grout is intended to provide a uniform, protective environment around post-tensioned strands. Variations in grout properties create variations in corrosion potentials, which can initiate and sustain corrosion. A variation in properties such as pH, density, porosity, and chemical composition (for example, chlorides and sulfates) can result in corrosion. Excess water used with prepackaged grouts can result in segregation and the creation of a layer of porous and/or soft grout with a different chemical composition compared to good-quality grout. Excess water in cement/water grouts can result in the presence of a soft, chalky, porous upper layer of grout in addition to the voids caused by bleed, as mentioned previously. It has been verified that variations in grout properties can hasten corrosion initiation without the need for other environmental contaminants.

3. Chloride-contaminated grout: The detrimental effect of chlorides and their ability to initiate corrosion is well known. Despite this knowledge and the desire of owners, engineers, and suppliers to avoid chlorides, chloride contamination may still occur. Chloride contamination can occur in a number of ways, including:

- Exposure to chlorides in the environment:
  - Seawater or salt spray may come in contact with the steel strands or may accumulate in the ducts during construction.
  - Chlorides may accumulate over time if the structure is exposed to seawater or deicing salt. Susceptible areas include grout voids and tendons near joints or cracks in the structure.
- Chloride contamination of the grout:
  - Grout can be contaminated through the use of mix water containing chloride.
  - In some cases, the grout itself may contain chlorides.

THE SOLUTION

The Post-Tech Tendon Impregnation system has been developed to mitigate corrosion caused by these problems.

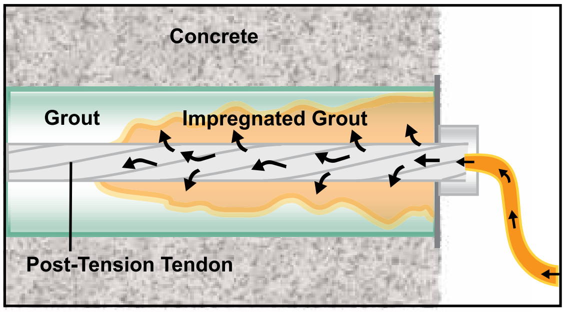

Fig. 1—Impregnation from end of tendon.

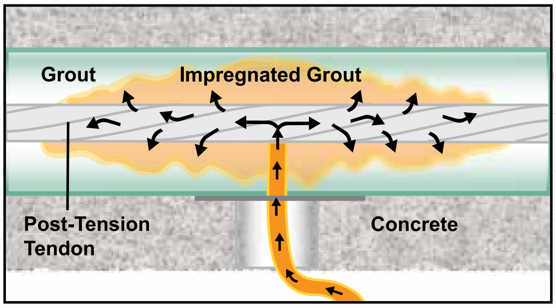

Fig. 2—Impregnation from a midpoint location on a tendon.

Fig. 3—End view of a single strand from a tendon showing the interstitial spaces between the wires.

Fig. 4—Concrete surrounding a single seven-wire strand shows a radial pattern of impregnation.

The system uses the interstitial spaces between the wires of each strand to deliver (transfer) a unique corrosion-inhibiting tendon impregnation material along the length of the cable. The tendon impregnation material is then able to seep between the wires of the strands, to impregnate the surrounding grout or concrete. In doing so, corrosion activity is reduced or prevented (Fig. 1 through 4).

The tendon impregnation material is designed to form a film on exposed steel surfaces such as steel strands, which are exposed in grout voids. The impregnated grout has improved corrosion and moisture resistance, which provides improved corrosion protection to steel surfaces that are in contact with grout.

FLORIDA DEPARTMENT OF TRANSPORTATION (FDOT)

FDOT has a number of post-tensioned bridges which have experienced corrosion of the post-tensioned tendons as a result of grout issues as described previously or that have been identified with such conditions that make the tendons susceptible to corrosion.

To investigate the capabilities of the Post-Tech Tendon Impregnation technique, FDOT proposed a two-stage evaluation process:

1. Laboratory confirmation, followed by a
2. Field demonstration.

Laboratory Confirmation

The laboratory confirmation was completed on actual bridge tendon specimens provided by FDOT (Fig. 5). The tendon specimens provided to Vector Corrosion Technologies were sections of external tendons which had been removed from a bridge in Florida. Each specimen was 4.5 in. (114 mm) in diameter and contained nineteen 0.5 in. (13 mm) diameter strands. The specimens were well grouted and between 3 and 4 ft (0.9 and 1.2 m) in length.

The specimens were prepared and impregnated in the lab. Impregnation was completed from the cut end of a tendon specimen, as illustrated in Fig. 6, as well as from the midpoint along the length of a tendon specimen, as illustrated in Fig. 7.

Laboratory testing confirmed the ability of the impregnation material to travel along the length of the specimen, soak into the grout surrounding a strand, and pass from strand to strand across the section.

Fig. 5—End view of one FDOT tendon specimen, as received.

Fig. 6—Impregnation being completed from end of prepared specimen.

Fig. 7—Impregnation being completed from midpoint of specimen.

Field Demonstration

Based on the success of the work in the laboratory, a field demonstration project was scheduled and completed.

The demonstration project was completed on external tendons in a box girder bridge in Florida (Fig. 8 and 9). This structure was chosen for a number of reasons, including:

1. All work could be completed from inside the box girder without interfering with traffic.

2. This structure contained external tendons which would facilitate inspection and evaluation of the effectiveness of impregnation after the work was completed. Removal and replacement of sections of the plastic duct and grout on external tendons would make inspection and evaluation of performance much easier compared to internal tendons.

Fig. 8—FDOT cable impregnation trial bridge: street view.

Fig. 9—FDOT cable impregnation trial bridge interior view. External tendons visible along bottom of box section.

3. Recent inspection revealed the presence of soft grout in some tendons, making the tendons susceptible to corrosion development.

Impregnation of the post-tensioned tendons was completed during the week of September 16-20, 2013. Vector Corrosion Technologies' technical crew performed the work. Inspection services and logistical support were provided by Concorr Florida, Inc., under contract with FDOT.

The objective of the field demonstration was to evaluate the ability of the tendon impregnation system to penetrate the bonded post-tensioned tendons in field structures. Some of the questions to be answered included:

- Can a tendon be impregnated from an end anchorage location?
- Can a tendon be impregnated from a midpoint location?
- How far can the material flow down the length of a tendon?
- How long will it take?
- Will the material impregnate the grout surrounding the strands?
- Will the material provide corrosion protection to the post-tensioned strands?

In most locations, impregnation was completed from the anchorage end and the impregnation material was pushed through the interstitial spaces until the material reached the opposite end of the tendon (Fig. 10 and 11). Tendons on this bridge varied in length from 235 to 255 ft (72 to 78 m). In one location, impregnation was completed from the midpoint of a tendon.

After impregnation was complete, the duct was opened and grout was removed to confirm the impregnation material had traveled along the length of the strands and had penetrated the grout directly surrounding the strands (Fig. 12 through 16).

To evaluate the corrosion-protection properties of the tendon impregnation material in a worst-case scenario,

Fig. 10—Impregnation being completed from end of tendon.

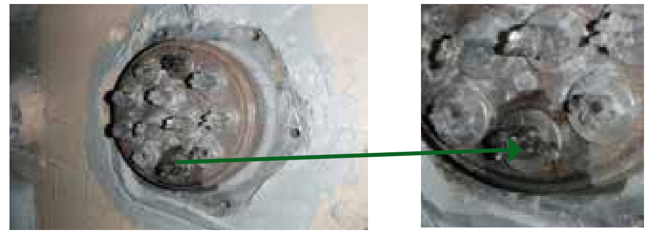

Fig. 11—Impregnation material beginning to seep out far end of tendon (outlet end), 255 ft (78 m) from point of impregnation.

Fig. 12—Removal of plastic duct after cutting.

Fig. 13—Exposed grout condition after removal of duct. Impregnation material visible.

Fig. 14—Chipping grout to expose strands and observe level of saturation with corrosion-inhibiting impregnation material.

Fig. 15—Impregnation material present on outside surface of strands.

Fig. 16—Impregnation material present within and outside strands.

two laboratory tests were conducted using treated and untreated bare steel samples. The samples were exposed to a periodic salt-spray. Figure 17 shows treated and untreated

Fig. 17—Steel plate after exposure to salt-spray test Top left—untreated control; top right and bottom—section treated with impregnation material.

Fig. 18—Post-tensioned strand after exposure to salt-spray test. Left—untreated control; right—treated with impregnation material.

sections of a steel plate after salt-spray exposure. The treated portion of the steel surface was very well protected compared to the untreated portion.

After successful completion of the tests on the steel plate samples, a similar test was completed using treated and untreated sections of post-tensioned strand. Figure 18 shows the results; this second test showed the treated strand to be much more resistant to corrosion.

CONCLUSIONS

The field demonstration and lab testing verified the following:

- The Post-Tech Tendon Impregnation system is capable of impregnating the full length of 235 and 255 ft (72 and 78 m) grouted tendons when completed from an end anchorage location.
- The Post-Tech Tendon Impregnation system is capable of impregnating up to 100 ft (30 m) in each direction when completed from a midpoint location along the tendon.
- The Post-Tech Tendon Impregnation material present in an impregnated strand is capable of penetrating grout adjacent to the strand.
- The Post-Tech Tendon Impregnation material provides greatly improved corrosion protection of steel surfaces.

David Whitmore *is President of Vector Corrosion Technologies, Tampa, FL, a company which specializes in the corrosion protection of steel in reinforced concrete structures. Whitmore has been involved with the Federal Highway Administration on the SHRP and SHRP 2 projects with regard to corrosion protection of concrete bridge structures.*

Garth Fallis, P. Eng. *is Chair of PTI DC-80 Repair, Rehabilitation, and Strengthening Committee and a member of PTI Committee CRT-60 Repair, Rehabilitation, and Strengthening Field Personnel Certification. He is a member of ACI 562 Concrete Repair Code Committee, ACI 423, ACI 440, and ACI 549. He is Vice President of Vector, a professional engineer and an active member and a Past President of the International Concrete Repair Institute.*

Haixue Liao *is Post-Tensioning Segment Manager for Vector Corrosion Technologies. He has over 20 years of experience in post-tensioning design, installation, evaluation, and corrosion repair. He is a member of PTI Committees CRT-60, Repair, Rehabilitation and Strengthening Field Personnel Certification; DC-80, Repair, Rehabilitation & Strengthening; and M-55, Grouting.*

Stig Strombeck *is a Business Development Associate for Vector Corrosion Technologies. He is a recent graduate of the Concrete Industry Management Program at California State University, Chico, Chico, CA.*

Ivan Lasa *is a Corrosion Engineering Specialist with the Florida Department of Transportation and holds degrees in civil engineering and surveying. He has over 25 years of experience in the field of corrosion, specializing in corrosion control of reinforcing steel in concrete and rehabilitation of marine structures.*