

# **pti** *Technical Notes*

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## **Selection of Filler Material for Multistrand PT Tendons**

### **INTRODUCTION**

Ducts are used in bonded and external post-tensioning to provide a void that permits the installation and stressing of strands after the concrete has been placed and hardened. Typically, ducts are filled with protective material after stressing to ensure that water and contaminants do not collect in the duct. In the case of bonded tendons, cementitious grout is always used. In the case of external tendons (unbonded), cementitious grout is most often used but other materials, such as petroleum waxes or grease, have been used as well.

The proper selection of filling material for post-tensioning tendons is critical to the performance and durability of the system. This Technical Note describes the merits and limitations of the potential filler materials, and is intended to provide guidance to owners and designers in making the appropriate choice for a given structural application.

In selecting a filler material for a post-tensioned (PT) tendon, a designer should consider a number of key factors. Generally, these considerations should include:

- Design needs: bonded or unbonded tendons;
- Material properties, including compatibility with system components and concrete, permeability, and long-term stability;
- Constructibility, including ease and speed of installation, availability of qualified workers, and safety;
- Structural effects, including strength capacity and serviceability;
- Corrosion protection/durability;
- Quality assurance with respect to available specifications and inspection;
- Maintenance, repair, and rehabilitation; and
- Cost in terms of material, labor, and equipment.

The relative significance of each factor may vary depending on the structural application and the environmental exposure. The following information compares the available filler materials.

### **CEMENTITIOUS GROUT**

#### **Use**

Cementitious grouts have been used for over 50 years for tendon protection and durability and have been the filler material of choice on multistrand tendons constructed worldwide.

Cementitious grout serves several important functions. First, the grout fills the duct and provides a cementitious barrier against the ingress of water, chlorides, and other corrosion-causing contaminants. Second, the alkalinity of the grout creates a passive environment providing corrosion protection to the steel. Third, in bonded PT, the grout bonds the strand to the duct and hence to the surrounding concrete, facilitating the transfer of force between the tendon and the concrete.

Cementitious grout for post-tensioning applications is usually a combination of cement and water, along with admixtures necessary to obtain required properties such as fluidity, low permeability, bleed resistance, and stability.

#### **Material properties**

Extensive experience with cementitious grouts has shown that they are extremely compatible with both concrete and PT system components. Grout admixtures must be tested for compatibility with other grout constituents.

Prior to 2001, most PT grouts were site mixtures of cement, water, and admixtures. Research and experience has shown that these mixtures, while generally performing well, were prone to bleeding. Since 2001, bleed-resistant, thixotropic grouts have predominantly been used in the United States (Thixotropic grouts tend to be fluid when agitated but revert to gel-like consistency when at rest.) Standard grout specifications such as PTI M55-1.12<sup>1</sup> require the use of high-performance, non-bleed grouts for all but noncorrosive exposures.

#### **Constructibility**

Current PT systems and components, including ducts and anchorages, have been designed to work with cementitious grouts. The accessories have been continuously improved and today's systems work well. Required equipment for installation is readily available. Pumps and colloidal mixers routinely used for grouting of tendons have a long and reliable track record.

Likewise, experienced grouting personnel are readily available. Today's construction crews are familiar with and understand how cementitious grouts behave; they know what to expect.

However, quality of installation is important to the performance of cementitious grouts. While the vast majority of

grouted PT structures have performed well, a number of grout-related problems have been observed. In many of these, improper workmanship and inadequate inspection were major contributors.

PTI has a certification program to train and certify crews on the proper and safe techniques to install, stress, and grout multistrand tendons using cementitious grouts. The American Segmental Bridge Institute (ASBI) has a training program in which it certifies over 100 grouting technicians per year. In addition, PTI certifies over 300 new workers each year through its program and renews certification for hundreds more.

To address construction issues, studies have been performed on the use of emulsifiable oils, which can be used for temporary corrosion protection of the stressed tendons. This can extend the period of time between tendon stressing and injecting the tendon with grout.

### **Structural effects**

The structural interaction of grouted tendons and concrete is well-documented, has been thoroughly researched, is recognized by design codes, and is well understood by designers.

### **Corrosion protection/durability**

As previously noted, the high-alkaline environment of a cementitious grout creates a tightly adhering film that passivates the steel and protects it from corrosion. This protective layer can be compromised by the presence of contaminants such as chloride, or by carbonation.

The durability of grouted tendons has been documented in numerous studies<sup>2-4</sup> and has generally been very good; however, isolated grout-related problems have been reported. The most common grout-related corrosion problems are attributed to incomplete grouting due to improper construction practices and/or to excessive bleeding due to poor mixture design.<sup>5</sup> Recent reports by the Florida Department of Transportation (FDOT) have identified segregation as another potential cause of corrosion in PT tendons. Segregation, while similar to bleeding, is characterized by separation and stratification of the grout constituents, which leaves part of the grout material in a wet plastic state.<sup>6</sup>

Recent specification changes for high-performance grouts have been developed to significantly reduce the potential for bleeding and segregation through the use of admixtures and performance testing. These advances greatly reduce the potential for corrosion problems in grouted tendons.

### **Quality assurance**

Standard specifications are readily available for cementitious PT grouts. As noted previously, these standards have been developed to ensure that grout does not bleed or segregate. These standards also set forth requirements to make certain that grout is properly installed.

Verification of grouting operations is also important. Poor grouting execution is often accompanied by inadequate inspection. Post-grouting inspection techniques are available and are done on a routine basis to detect voids in susceptible ar-

eas such as high points and anchorages. In rare cases where a void is discovered, reliable techniques such as vacuum grouting have been implemented. PTI's Bonded PT Installer certification program provides training for inspectors and construction management personnel.

One disadvantage of cementitious grout is in the assessment of existing grouted tendons. Because the steel is encased in grout, it can be difficult to detect early stages of corrosion in the tendon. Numerous nondestructive test methods are available, but none are totally satisfactory in all situations. Research is underway by the Federal Highway Administration (FHWA), the National Cooperative Highway Research Program, and others to advance nondestructive testing and improve the inspectability of grouted PT.

### **Maintenance, repair, and rehabilitation**

Should the need arise, the replacement of a grouted tendon can be difficult and costly in the case of an external tendon, or practically impossible for an internal tendon.

### **Cost**

The use of cementitious grout is generally the most economical way to fill a PT tendon. A simple cement-water grout is the most inexpensive initially, however, the small additional cost of using a high-performance engineered grout with high bleed and segregation resistance is generally offset by savings in post-grouting corrective actions (for example, vacuum grouting) and future repairs due to improved durability.

### **Performance**

While there have been isolated quality issues in the past, the industry and PTI have responded to the root causes of these issues through improved specifications addressing the grout materials and testing, equipment, installation methods, and personnel training.

The product development and knowledge gained through this process in grouts for post-tensioning has led to advancements in materials, equipment, detailing, and training, which all result in higher quality and workmanship.

### **Future developments**

Despite the long history with cementitious grouts, there are ongoing improvements in the technology. For example, FHWA has a major study (FHWA DTFH6114D00048-Task 5009) to find ways to improve the inspectability and replaceability of grouted tendons. The study will focus on the following areas:

- Replaceable tendons: This technology involves external tendons with tendons passing uninterrupted through diabolos at deviation points and through guide pipes at anchorage locations, thus allowing the replacement of the entire tendon if needed at any point in the life of the structure.
- Assessable tendons: This effort includes the collection and analysis of existing data, material testing and improvements, and post-grouting inspections, besides nondestructive testing.

- Monitorable tendons: The electrically isolated tendon (EIT) technology already exists and is used in Europe and Asia. It provides a means to determine initial construction quality and to monitor tendon condition throughout the life of the structure.

## **FLEXIBLE FILLERS (PETROLEUM WAX AND GREASE)**

### **Use**

Flexible filler materials provide an alternative to cementitious grout in unbonded tendons. (Flexible fillers are incapable of transferring the force through bond from the tendon to the surrounding concrete, and consequently cannot be used on a bonded tendon.) Various flexible materials have been considered, but most common are grease and petroleum-based waxes.

The use of flexible fillers worldwide is limited. Grease has been used in nuclear containment structures in the United States to allow force verification and corrosion evaluation to meet the Nuclear Regulatory Commission's surveillance requirements. France appears to be the largest user of wax-filled tendons, specifying it for external PT tendons. (Internal tendons continue to be filled with cementitious grout.) Germany also uses wax, but only for prefabricated tendons. During the period of 1970 to 2000, the United Kingdom built 10 bridges with either grease or wax-filled tendons<sup>7</sup>; however, flexible fillers are no longer specified. Other countries in Europe and Asia do not systematically use flexible fillers in PT construction.

FDOT has recently specified the use of wax to fill all external tendons and selected internal tendons.

### **Material properties**

Grease can bleed and separate over time. Most suppliers now use a microcrystalline wax derived from petroleum rather than grease because of its greater stability. Wax is homogeneous, hydrophobic, and has metal adhesion properties. Based on the experience to date, there do not appear to be any compatibility issues between wax and PT system components. However, due to limited experience with this material, its long-term stability under service conditions is unknown. Experience with other petroleum-based products suggests that some degradation could be expected, particularly over a service life of 75 to 100 years.

### **Constructibility**

There is currently limited experience with flexible fillers in post-tensioning applications in the United States. Quality workmanship will be essential for a successful filling with the added complexity of handling combustible materials at high temperatures. Extensive training will be needed to develop a qualified workforce that is familiar with injection of flexible fillers, and capable of doing a consistent, high-quality job.

For flexible fillers, the injection of filler material at high temperatures will require development of equipment and procedures to assure safe and efficient operations. The need to heat the materials ahead of the filling operation to achieve a uniform temperature of the material will reduce field operation flexibility. (In France, special tanker trucks designed to heat and pump wax have been developed.)

In pumping flexible fillers into PT ducts, it is important that the temperature of the heated material be maintained above its melting point throughout the process. This could be problematic on long tendons in colder climates.

The handling of materials that are heated to over 200°F (93°C) is a potential safety issue for installation crews as well as any people in the vicinity of the operation. Care must be taken to ensure that pumps and hoses are intact and in good working order, connections are tight and secure, and all personnel are wearing the appropriate protective gear in the event of splatters or a blowout.

Clearly, with demand for this approach, the U.S. construction industry will develop these capabilities over time. However, in the short-term, it is important that owners ensure that contractors have the required qualifications and experience.

### **Structural effects**

*Fully unbonded tendons*—All tendons filled with flexible fillers will be fully unbonded, including deviation and anchoring locations. This will have implications on design criteria for shear, ultimate strength, crack, and deflection control.

According to AASHTO LRFD Bridge Design Specifications: capacity decreases for unbonded tendons, with specified factors for flexure and shear reduced compared to fully bonded tendons. Cracking moment also decreases. Fully unbonded tendons will develop lower ultimate tendon stress requiring greater number of strands.<sup>8</sup>

### **Corrosion protection/durability**

Due to its hydrophobic and metal adhering properties, wax filler protects by keeping water away from the prestressing steel. However, its long-term effectiveness—particularly when continually in contact with water—is unknown.

Flexible fillers will likely be subject to the same installation defects as grout—mainly voids or air pockets in the system. Flexible fillers, such as heated waxes, flow as a true liquid and are more likely to trap air, creating voids, if not properly installed.

These materials shrink when they cool and this can cause cracks and voids. This is a particular concern in colder climates, where the temperature differential of the wax between the coldest time of the year and at injection can be over 200°F (93°C). These defects could potentially be areas where water and contaminants can collect if the duct system watertightness is not maintained. As noted previously, there have been no long-term studies conducted to date on the impact that these defects can have on the corrosion protection effectiveness of flexible fillers.

Recent research conducted at the University of Florida to evaluate different injection procedures shows the difficulties associated with achieving void-free tendons and avoiding cracks in the filler material. It was reported that most samples exhibited voids at the high points and some cracking of the filler material.<sup>9</sup>

## Quality assurance

There is not currently a national standard specification for these materials or for their injection, nor are there established quality assurance procedures. Florida DOT has developed its own specification adapted from French specifications.

Construction inspectors in the United States are currently unfamiliar with this technology, and will need to be trained once appropriate QA/QC procedures have been developed.

Unlike grout, where defects usually occur at high points and anchorages, the expansion and contraction of flexible fillers during temperature changes could lead to voids at unpredictable locations in the filler due to the semi-solid nature of the material. This could make detection and inspection more difficult.

## Maintenance, repair, and rehabilitation

One advantage of using flexible fillers is that it makes it easier to replace a tendon in the future if the need arises. To do so will require changed details at anchorages to provide sufficient space for strand removal, replacement, stressing, and injection.

Similarly, with the flexible filler material, it may be possible to restress tendons at a later point during the life of the structure. PT tendons do not normally need to be restressed during the life of a structure, but it can be beneficial in some applications.

## Cost

The cost of using flexible fillers will be higher than traditional cementitious grouts. FDOT has reported that materials costs are approximately seven times higher.<sup>10</sup> It was also estimated that superstructure cost would be 0.5% to 2.4% higher, and total project cost increasing less than 1% increase compared to a grouted system.<sup>11</sup>

As with any new technology, the cost differential on the initial projects where these products may be higher, as contractors cover their risk and investment in training and new equipment. To date, no investment has been made into the development of equipment, methods, details, and training of personnel to ensure quality for the use of flexible filler materials.

Clearly, if demand and experience with these products grows, the relative cost will come down over time. However, based on the experience in France, the cost will remain significantly higher than a grouted system.

## Performance

In France, there have not been any reported corrosion problems associated with wax-filled, external tendons because its use was implemented system-wide in 2001. However, the long-term performance and durability of these systems is unknown at this time.

The biggest problem to date with flexible fillers has been leakage of the filler material out of ducts. A study by the Office of Nuclear Regulatory Research found that during inspections performed at U.S. nuclear power plants several years ago, some of the prestressed concrete containments had experienced leakage of the tendon sheathing filler.<sup>12</sup> Leakage of wax from wax-filled ducts was also reported in the United Kingdom.<sup>7</sup>

## Future developments

For flexible fillers to become a mainstream option in the United States, contractors and suppliers will need to obtain the required equipment and accessories to ensure safe and practical injection. Training will be needed for installers as well as inspectors and other construction management personnel. Finally, standard specifications for flexible materials and related injection operations should be developed to ensure consistent quality and performance across the country.

## Summary

The use of flexible fillers in PT tendons appears to offer owners and designers a useful option where there is a strong need to have tendons which can be replaced and/or restressed in the future, or where prefabrication of tendons is desired. There are still questions about the long-term stability and performance of these products that should be answered. Experience and training will be needed to move this technology from the experimental/ demonstration stage to a mainstream construction operation.

For most standard post-tensioning applications, the use of high-performance, engineered cementitious grout offers the most cost-effective combination of performance and economy. It is important to note that this conclusion is predicated on the right grout (that is, a non-bleed/non-segregating mixture) being properly installed.

A trained workforce is critical to the installation of any system or material, especially in post-tensioning. PTI will continue to expand its training program to include new technologies such as flexible fillers in response to industry needs. Each year, PTI and ASBI certification training are further refined and more effective in educating field personnel and inspectors regarding grouting materials and operations. Similar programs are needed with respect to flexible fillers to give owners confidence that construction personnel are adequately qualified.

Safety of workers is paramount in our industry and there are concerns that the installation methods required by flexible filler material present safety challenges, leaving construction workers exposed to greater risks and hazards than modern grouting methods do. With a very limited level of expertise with flexible fillers, the risk of dangerous field installation mistakes is elevated.

In summary, PTI supports innovation and technology advancement in the post-tensioning industry and flexible fillers are a viable alternative in some cases. Innovation measured by its value and benefit is desirable at all times. Grouted post-tensioning tendons offer proven technology. Owners/specifiers should make a conscious effort to select the right materials and to ensure competent installation and supervision to achieve the full benefit and potential of post-tensioning.

PTI recommends the adoption and implementation of PTI/ASBI M-50,<sup>13</sup> and PTI M55.1-12,<sup>1</sup> as the current consensus standard with wide stakeholder support to ensure the available quality of grouted tendons is achieved.

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