Guidelines for the Use of Epoxy-Coated Strand

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This report presents guidelines to design engineers, plant personnel and specifiers for using epoxy-coated strand in prestressed concrete and cable stay applications. These guidelines cover the properties of the product, design considerations, handling, installing and stressing of strands, including permissible concrete curing temperatures. Procedures for patching and protection of the ends of strands are given. This document is not intended as a guide for the selection of corrosion protection systems (of which epoxy-coated strand is one option), nor should it be construed as an endorsement of any product by the Precast/Prestressed Concrete Institute.

PREFACE

The PCI Ad Hoc Committee on Epoxy-Coated Strand was first constituted in early 1988 and, later that year, published a report, "Industry Information on Epoxy-Coated Strand for Prestressed Concrete." This report was distributed to all Producer and Associate Members of the Institute. The committee was subsequently deactivated.

In 1990, the committee was reactivated in response to a request by the Federal Highway Administration (FHWA) for more information on the use of epoxy-coated strand, primarily for its use in bridge structures.

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1.0 INTRODUCTION

The current code requirements for the design of prestressed concrete structures provide a high degree of corrosion resistance and result in economical and durable systems. Since 1958, when the American Concrete Institute (ACI) first published "Tentative Recommendations for Prestressed Concrete,"[1] design requirements for prestressed concrete have included special provisions for "elements exposed to weather or corrosive atmosphere." Initially, the design requirements focused on limiting concrete tensile stresses under service loads to enhance durability. In the 1970s, increased concrete cover requirements were introduced. As a result of continued improvements in design and fabrication techniques, prestressed concrete is widely recognized as a durable structural system with low maintenance costs.[2]

More recently, the effect of exposure of prestressed concrete elements to particularly harsh environments has been given further attention and appropriate measures have been identified.[3,4] While the use of additional corrosion protection systems is not necessarily appropriate for all prestressed concrete construction, it may be justified in situations where severe exposure conditions are anticipated. In 1982, for example, the Federal Highway Administration (FHWA) issued a memorandum requiring the use of corrosion protected reinforcing steel and tendons in bridge decks. The consequences of corrosion to the reinforcing steel in concrete structures under these harsh exposure conditions may be significant in terms of both structural safety and economic impact. For harsh environments, the use of epoxy-coated prestressing strand can provide the extra measure of corrosion resistance needed.

At elevated temperatures, there is a reduction in the bonding ability of the coating as well as a reduction in its shear modulus, which results in a loss of prestress. Parameters related to elevated temperatures which affect design and fabrication are presented.

2.0 SCOPE

The intent of these guidelines is to provide information and procedures that are different from or in addition to those required for uncoated strand. These guidelines address cable stays and the design, fabrication, handling, stressing and accelerated curing of concrete components in which epoxy-coated strand is used.

This document should be used in conjunction with the following publications:

- *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products*, MNL-116, Precast/Prestressed Concrete Institute, Chicago, Illinois, 1985.
- *Post-Tensioning Manual*, Fifth Edition, Post-Tensioning Institute, Phoenix, Arizona, 1990.
- *Recommendations for Stay Cable Design, Testing and Installation*, Committee on Cable Stayed Bridges, Post-Tensioning Institute, Phoenix, Arizona, 1990.

3.0 MATERIALS

Epoxy-coated strand should comply with ASTM A882-92 (inch-pound units) or A882M-92 (SI units), "Standard Specification for Epoxy-Coated Seven-Wire Prestressing Steel Strand."

Epoxy-coated strand is usually fabricated with low-relaxation strand.

4.0 PRODUCT DESCRIPTION

Epoxy-coated strand is seven-wire prestressing strand with an organic coating, the thickness of which can vary from 25 to 45 mils (0.64 to 1.14 mm). Two types of coating are available, namely, a smooth type and one with particles of grit embedded in the surface. The smooth type has low bond characteristics and is intended for use in unbonded post-tensioned systems, external post-tensioned systems and cable stays. The grit-impregnated type is for use in bonded pretensioned and post-tensioned systems.

Notwithstanding the coating thickness tolerance specified in ASTM A882, epoxy-coated strand is available with a less variable coating thickness. Reduced coating thickness variability may need to be specified to ensure compatibility with certain stressing hardware. Manufacturers of epoxy-coated strand should be consulted.

Note: Epoxy coating is not a replacement for the sheathing used in unbonded post-tensioned systems. In internal post-tensioned applications, epoxy-coated strand must be encased in a duct.

In addition to the strand having an external coating, it is also available with the interstices between the individual wires filled with epoxy; this is to prevent the migration of corrosive chemicals, either by capillary action or by other hydrostatic forces. This type of strand should be specified when there is risk of contaminants or moisture entering the ends. Specifications for this type of "filled" epoxy-coated strand are presented in ASTM A882, Supplement No. 1.

5.0 DESIGN CONSIDERATIONS

5.1 Properties

The development and initial testing of epoxy-coated strand is described in the literature.[5,6] The stress-strain behavior of coated strand is similar to that of uncoated strand. Wire fracture occurs prior to rupture of the coating, which is indicative of adequate coating ductility.

The production procedure of the "filled" strand requires unstranding, coating and re-stranding. It does not appear that this coating process has any effect on the strength of the epoxy-filled strand.

5.2 Elongation

Elongations for coated strand may be calculated in the same manner as for uncoated strand using the load-elongation data supplied by the strand manufacturer. The value of elastic modulus of coated strand is based on the load-elongation tests after coating.

5.3 Relaxation

Tests of coated low-relaxation strand have shown the relaxation to be significantly higher than that of uncoated strand. Epoxy-coated strand manufacturers presently recommend that the stress-relaxation component of the losses be calculated by doubling the relaxation loss calculated for uncoated strand. The manufacturer of the epoxy-coated strand should be consulted for suitable relaxation loss values, which may vary depending on the nominal diameter of the strand.

5.4 Bond

In bonded prestressed concrete applications, the prestressing force is transferred to the surrounding concrete through the grit in the epoxy coating. ASTM A882 requires that grit impregnated epoxy-coated strand shall be capable of withstanding a temperature of 150°F (65°C) without reduction in the bond properties. Details of the test procedure for verifying this property will be given in the next revision of ASTM A882.

Tests on samples of epoxy-coated strand supplied by Florida Wire and Cable, Inc., have been conducted[7,8,9] and the results can be summarized as follows:

(a) Based on the research performed at the University of Wisconsin at Milwaukee,[8] detensioning of epoxy-coated strands should not be performed at internal concrete temperatures of higher than 160°F (71°C).

(b) Based on the tests performed at the University of Florida at Gainesville,[7,9] bond could be lost at temperatures of greater than 165°F (74°C). A bond loss was defined as an end slip greater than 0.01 in. (0.25 mm).

It is important for the designer to consider the following temperature effects:

1. For pretensioned applications where accelerated curing techniques are employed, the temperature of the concrete surrounding the strand at the time of prestress transfer should be limited to a maximum of 150°F (65°C) and the concrete temperature should be falling. The epoxy coating will not be impaired if this recommended temperature is exceeded during the curing cycle.

2. Concrete temperatures under sustained fire conditions will most likely be considerably higher than the limits that the epoxy can withstand, which could result in a complete loss of bond between the tendon and the concrete. In pretensioned concrete applications, the fire endurance of a member with epoxy-coated strands will be negligible unless additional bonded reinforcement (prestressed or non-prestressed) is provided.[10] Unlike most building structures, bridge structures may not require a specific fire resistance rating, but the likelihood of vehicle fires and subsequent effects of elevated temperatures should be evaluated.

5.5 Transfer and Development Length

Several published research reports[11-14] provide information on the transfer and development lengths of grit-impregnated epoxy-coated strand; recommendations in this report are based on these studies. It should be noted that there is a relatively large variation in the available data and thus more research is warranted. An extensive testing program by the FHWA is currently in progress.

5.5.1 Recommended Transfer Length for Single Coated Strands

These recommendations are only applicable to pretensioned concrete members in which a single strand is used (mainly for research purposes) or in which the spacing of multiple strands and the concrete cover are large enough such that the effect of multiple strands can be ignored. For single coated strand, the transfer length is:

$$l_t = 50d_b$$

where

l_t = transfer length
d_b = strand diameter

The test data indicate that the transfer length can be as short as $35d_b$. Thus, for unconfined strands in thin concrete members and where end splitting is a concern, the designer may choose to check concrete stresses at two locations, namely, $50d_b$ and $35d_b$.

5.5.2 Recommended Transfer Length for Groups of Coated Strands

These recommendations cover the majority of practical cases. For multiple coated strand, the transfer length is given by:

$$l_t = 65d_b$$

Where end-zone concrete stresses are a concern, these should be investigated using a transfer length of $50d_b$.

5.5.3 Development Length

For coated strand, the developemnt length is given by:

$$l_d = (f_{su} - 2/3\ f_{se})\ d_b$$

where

f_{se} = effective steel prestress after losses
f_{su} = stress in prestressing steel at ultimate load

This equation and notation are identical to that found in the AASHTO Specifications [Eq. (9-32)]; note that ACI 318-89, Section 12.9, uses f_{ps} in place of f_{su}.

5.6 Creep of Epoxy Coating

Tests[6] have shown that the creep movement (increase in transfer length with time) of the grit-impregnated epoxy-coated strand in concrete members is significantly less than the creep movement of uncoated strand, subject to the temperature limitations given in Section 5.4.

6.0 HANDLING

6.1 General

Epoxy-coated strand requires special handling procedures to avoid damage to the coating and, where the grit-impregnated type is being used, damage to equipment due to the grit's abrasive action. Specific handling instructions are available from the strand suppliers; some important topics are noted in this section.

6.2 Shipping and Storage

Except for short lengths, epoxy-coated strand is shipped on reels. The strand should be covered and stored on the reel to provide maximum protection; the covers should be moisture resistant and capable of shielding the strand from sunlight and the environment. Except for the "filled" type, the ends of the strand should be protected after each partial usage to avoid the ingress of moisture and harmful contaminants.

6.3 Unreeling

All workers should wear protective gloves during the unreeling of grit-impregnated strand.

When unreelingthe strand, the condition of the epoxy coating should be examined for any damage. If any damage is observed, the coating should be repaired in strict accordance with the manufacturer's instructions or the strand should be discarded.

Unlike packs of uncoated strand which dispense strand from the center of the pack, epoxy-coated strand is dispensed from the circumference of a reel. The reel needs to be mounted on a stand such that the reel rotates; the strand can be pulled off the reel and a braking device should be employed to control reel rotation. (Further information on reel stands and brakes can be obtained from the strand manufacturer.)

The strand should not be dragged across surfaces that could (a) damage the coating and, (b) in the case of grit-impregnated epoxy-coated strand, cause unwanted damage to the surface (including steel forms).

6.4 Strand Cutting

The preferred method of cutting epoxy-coated strand is with an abrasive saw. When epoxy is burned in the presence of sufficient oxygen, it results in harmless carbon dioxide and water. Insufficient oxygen may cause harmful carbon monoxide to be given off. If torch cutting must be used, it should be performed in a well ventilated area. Water may be used to extinguish any flames.

7.0 STRAND INSTALLATION AND STRESSING

7.1 Anchors, Chucks and Wedges

Bite-through wedges which are specifically designed and manufactured for use with epoxy-coated strand should be specified. Chucks designed for uncoated strand should not be used. Special anchors and jack grippers are required for coated strand because of the larger diameter and chemical composition of the coating. Conversely, stressing hardware which is designed for coated strand should not be used with uncoated strand.

Anchor wedges and jack jaws should be inspected to ensure that the serrations are intact and completely free of any foreign material. Wedges must be thoroughly cleaned and inspected before each use.

Note: The use of improper or contaminated stressing hardware during pretensioning can result in significant increased risk to worker safety. In external or unbonded post-tensioned systems, the strength of the structure can be compromised.

7.2 Stressing — General

For uncoated strand, it is unusual for the wedges or chucks to slip during the stressing operation. At low stress levels, however, slip may occur on coated strand. This phenomenon is due to a lower radial force at the chuck and the inability of the bite-through jaws to fully penetrate the coating. Using the information presented in these guidelines, each producer should develop specific stressing procedures for epoxy-coated strand.

In the vicinity of the wedges, strand should not have been previously heated, damaged, patched or gripped; anchorage failure may occur. Wedges should be carefully aligned around the strand and seated by light tapping. Hammering wedges or power seating may reduce the anchor set loss, but the procedure should be tested before using it on a regular production basis.

In all methods of pretensioning, the stress or force induced in the tendons should be determined by monitoring the applied force and, independently, by measurement of the tendon elongation from an initial tension to the required tension. This initial tension, usually 1500 to 2500 lbs (7 to 10 kN), is sufficient to remove any slack in the strand. An initial tension of less than $0.06f_{pu}$ causes only minor damage to the coating and the wedge may be relocated and pulled to the final stress without cleaning or replacement. Note that f_{pu} is the ultimate tensile strength of strand.

Final stressing of epoxy-coated strand should be a single stroke operation because after one jacking cycle the jaws of the wedges can become contaminated with particles of epoxy; a second jacking cycle without cleaning the grips may result in a loss of gripping action. If a second jacking cycle is unavoidable, the wedges must be replaced or thoroughly cleaned before reseating.

If, for a special application, a low final stressing force, i.e., less than $0.40f_{pu}$, is required, then the strand supplier should be consulted for special stressing procedures. These procedures should include a maximum temperature which can be permitted in the vicinity of the chuck.

Wedges should not be allowed to unseat during the stressing operation. Epoxy in the wedges will be highly compressed; any movement of the wedges may cause the epoxy to debond from the strand and result in anchorage failure.

Anchorage seating losses for epoxy-coated strand are typically more than that for uncoated strand; the difference is often large enough to be significant. Seating losses will be approximately 1 in. (25 mm) at the live-end anchor and approximately ⅜ in. (10 mm) at the dead end (after initial preload). If information from prior use or from a strand supplier is unavailable, tests should be conducted to confirm seating loss values.

7.3 Pretensioned Applications

Since the overall diameter of epoxy-coated strand is 50 to 90 mils (1.28 to 2.24 mm) larger than that for uncoated strand, it may be necessary to enlarge the holes in the stressing abutment. Holes or slots in the abutment should be chamfered to prevent damage to the coating.

Because strand with the grit-impregnated coating is used in pretensioned applications, abrasion of the stressing abutment and form end plates can occur. Over time, this may result in over-sized holes and possible mislocation of tendons. Each producer should adopt a quality control procedure for checking the strand templates at the abutments and form ends.

In order to cast short members in beds where the stressing abutments may be 100 to 200 ft (30 to 60 m) apart, it is common to use lead strand and splice chucks. Lead strand may be reused for many casting cycles, thus minimizing strand wastage. Splice chucks are designed for use on uncoated strand, which requires that any epoxy coating be stripped from the end of the strand. Specially designed epoxy coating stripping machines are available for this purpose.

Rollers in contact with draped (depressed) strands should be smooth and should allow for the larger strand diameter. If standard rollers are used, the epoxy may be distorted and damaged.

After installation in the casting bed, the condition of the epoxy coating should be re-examined for possible damage. If damage is observed, the coating should be repaired in strict accordance with the manufacturer's instructions or the strand should be discarded.

Detensioning should gradually transfer the force in the strand to the surrounding concrete. If a torch is used, heat should not be applied closer than 6 in. (150 mm) from where a sound epoxy coating is required. (See Section 6.4 for cutting considerations.)

An abrasive saw should be used to trim the ends of the strands. The ends of all strands should be protected in accordance with Section 9.0.

7.4 Post-Tensioned Applications

For external post-tensioning systems, where the tendons are located on the outside of the member, sharp curvatures in the tendon path should be avoided. Where tendons must pass over a deviation point, it may be necessary to provide cushioning material to avoid abrasion of the epoxy coating.

For internal post-tensioning, the use of a galvanized metal duct is not recommended with epoxy-coated strand; severe abrasion of the epoxy will occur during the stressing operation as the strand comes in contact with the spiral duct seams. It is recommended that a polyethylene duct be used.

The coefficient of friction (μ) between grit-impregnated epoxy-coated strand and polyethylene duct has been determined as 0.205 (see Ref. 6). Material specifications and minimum duct radius should comply with the appropriate specifications (e.g., AASHTO[15]).

Anchorages used with epoxy-coated strands should be designed and tested to accommodate the coating. Since wedges used for epoxy-coated strand are larger in diameter than wedges for uncoated strand, anchorage dimensions will increase. As a result, consideration should be given to adequate clearances and edge distances between the anchorage and adjacent concrete surfaces.

Stressing should be undertaken with anchors or chucks designed specifically for use with epoxy-coated strand. Particular attention should be given to the design of pulling (or seating) wedges and wedge seating devices. Multiple gripping for long tendons is possible when equipment specifically designed for the purpose is utilized. Proper lubrication should be used at all times.

Strands should be cut as outlined in Section 6.4. Patching of anchor pockets should be in accordance with Section 9.0.

Grouting should be performed in accordance with the "Recommended Practice for Grouting Post-Tensioned Concrete Structures," published by the Post-Tensioning Institute (PTI).

8.0 CONCRETE CURING TEMPERATURE

See Section 5.4 for recommended maximum concrete curing temperature.

9.0 PATCHING AND PROTECTION FOR ENDS OF STRANDS

The patching and protective compound should be a two-part epoxy system compatible with the fusion-bonded strand coating. The supplier of the epoxy-coated strand should be consulted for further details on materials and methods of application.

All exposed strand ends should be protected after final cutting.

10.0 CABLE STAYS

Cable stays used for bridges and other structures are similar to post-tensioning tendons in that they consist of the following elements:

- Prestressing steel (parallel wires, strands or bars)
- A cementitious grout, or other material, which fills the void between the steel and the encapsulating sheathing
- Anchorages

Epoxy coating of individual strands as described previously provides both the temporary and permanent corrosion protection and obviates the concern for aggressive corrosion agents reaching the strand as a result of cracked grout and potential cracks in the sheathing. So as not to compromise the effectiveness of the system, attention must be paid to anchorage details. Special wedges that bite through the coating and grip the prestressing steel are required. The cut end of the strand must be sealed unless the "filled" type of strand is used.

Since the effective tension in many cable stays, at the time of installation, is not sufficient to seat the wedges all the way to the anchor chuck body, a specific procedure such as the application of an external seating force must be employed. This procedure must be designed so that there is no longitudinal motion of the wedges with respect to the strand after the teeth of the wedges begin to penetrate the surface of the epoxy.

In cases where the load in the cable must be adjusted after installation, such adjustments should be made without unseating the wedges. This is normally accomplished by the use of shims or threaded anchorages with ring nuts.

Where helical spacers are used inside the sheathing, the spacer wire should be epoxy coated to avoid fretting fatigue.

The guidelines found elsewhere in this document are equally applicable to cable stays in so far as they are practical.

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