SUMIDEN WIRE
PRODUCTS CORPORATION

Sumiden Wire Products Corporation

Epoxy-Coated and Filled Strand
Questions & Answers

December 2023

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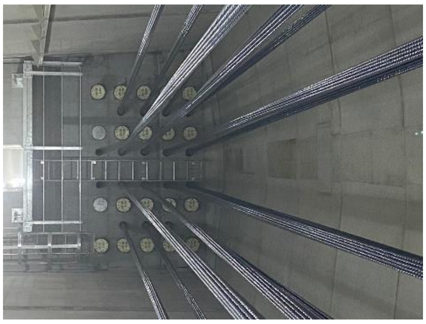
Preface

With rising requirements for durability in prestressed concrete structures, many people have been interested in anti-corrosive coated PC steel products. Cement grouting systems have been the most popular method for corrosion protection. As customers' needs have grown for both long-life concrete structures and short construction time, global interest has focused on anti-corrosive coated PC steel. In light of this growing market demand, Sumiden Wire Products Corporation has promoted applications of Epoxy-Coated and Filled Strand (ECS) for PC structures to meet customers' needs.

The applications of ECS have been spreading. ECS has enabled constructions of advanced permanent structures in the market. ECS is expected not only to improve the durability of the structures but also to shorten the construction time. For example, ECS is now the primary option for external ductless tendons inside girders in Japan.

The following are answers to frequently asked questions about ECS. We also summarized the main features and construction precautions for ECS from the aspect of material, design and construction.

We sincerely hope this document will help you have better understanding about ECS.

Yoshinogawa Sunrise Bridge (2022, Japan)


Himiyume Bridge (2019, Japan)

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Q1-1

What are the special features of ECS?

ECS has 3 advantages compared to other anti-corrosive coated strand alternatives.

(1) High corrosion protection
(2) Construction durability
(3) Excellent resistance against fretting fatigue

(1) High corrosion protection

ECS's excellent anti-corrosive ability is caused by the high adhesiveness and durability of the epoxy resin. Its anti-corrosive ability is also achieved because the voids between the wires are fully filled with the epoxy resin. In Japan there are many construction sites with severe environments, like oversea bridges, because many customers recognize the excellent performance and reliability of ECS.

(2) Construction durability

The quality of coated steel after construction installation is just as important as after production. To keep high quality even after installation is completed, the coating must retain enough thickness for anticorrosion. Coating thickness may be reduced in highly pressurized situations, like inside a deviator region. Especially, in the most severe applications such as high-capacity ductless external cables with a small bending radius, the quality of the coating is very important. Epoxy resins are one of the most suitable coating materials in this important area because of its excellent mechanical properties and high compressive strength, high tensile strength and high elastic coefficient. These tough properties are the result of the 3-dimensional chemical cross linking inside the epoxy resin.

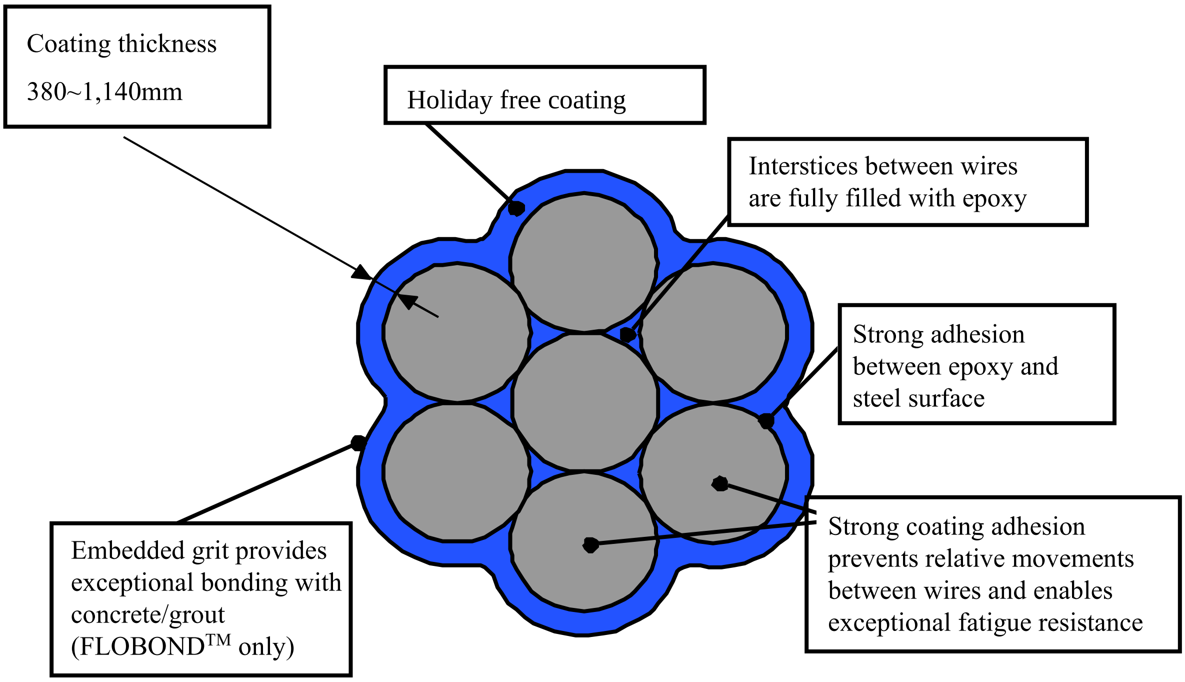
These tough and durable properties of epoxy coatings also make it easy to handle ECS with a pushing machine.

(3) Excellent resistance against fretting fatigue

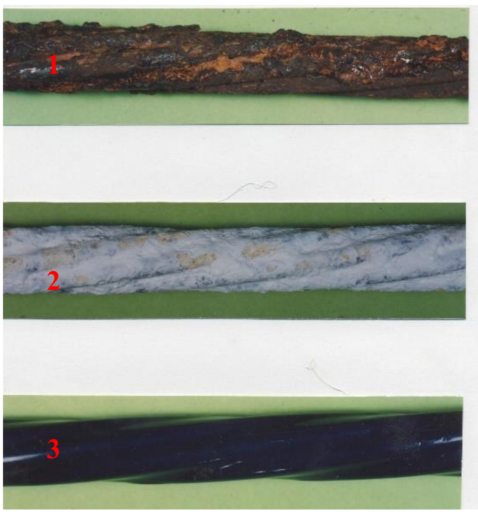
Epoxy coating prevents mutual movement of wires because the voids between the wires are fully filled by the tough and adhesive epoxy resin. Therefore, fretting wear is reduced and resistance against fretting corrosion is much better compared to bare strand.

When using several strands bundled in a multi-cable, the epoxy coating works as a spacer or cushioning material preventing direct metal-to-metal surface contact among each neighboring strands. This feature of the epoxy coating as a spacer is particularly effective for the application of a deviator of a ductless external cable or the anchorage and saddle zone of stay cables.

If you would like more knowledge about this feature, we could provide you many of our test results about fatigue test not only by single strand but also with multi-strand cables. Please request the test report.

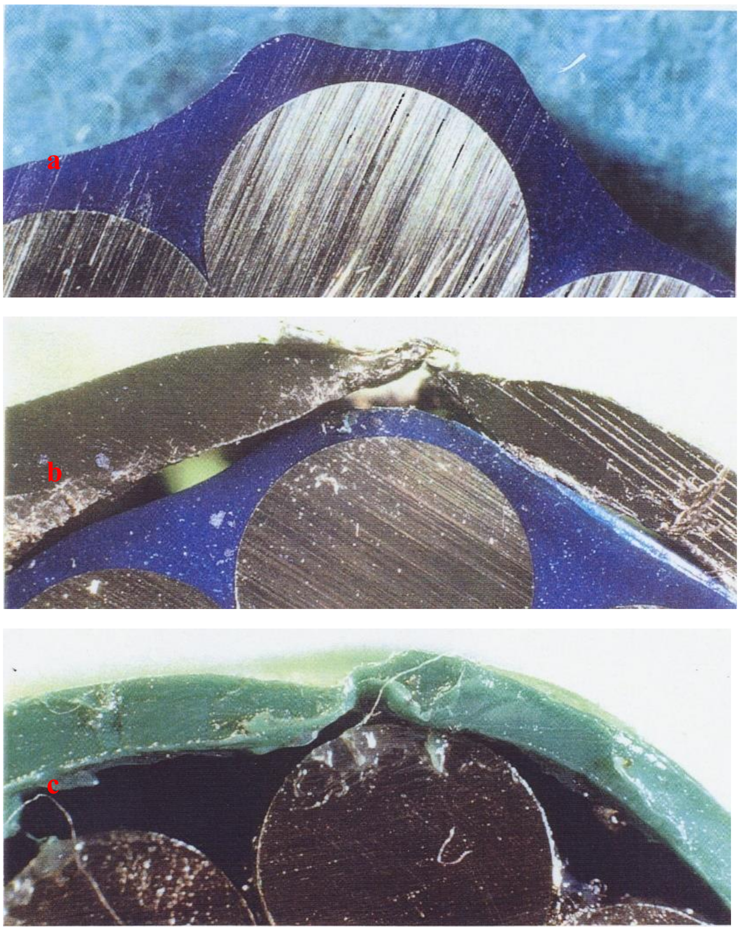


Main features of ECS



High anti-corrosion ability of ECS

(1,000 hour salt spray test, 1: bare PC strand, 2: galvanized PC strand, 3: ECS)



Enough toughness of epoxy coating [The cross section after compression tested]

a) ECS (enough anti-corrosion coating thickness remains after compression test)

b) PE-coated ECS (epoxy coating is protected by the cushioning PE sacrificially crushed)

c) Monostrand (PE layer crushed and has a hole that grease would flow out)

Q1-2

What kind of standards are there for ECS?

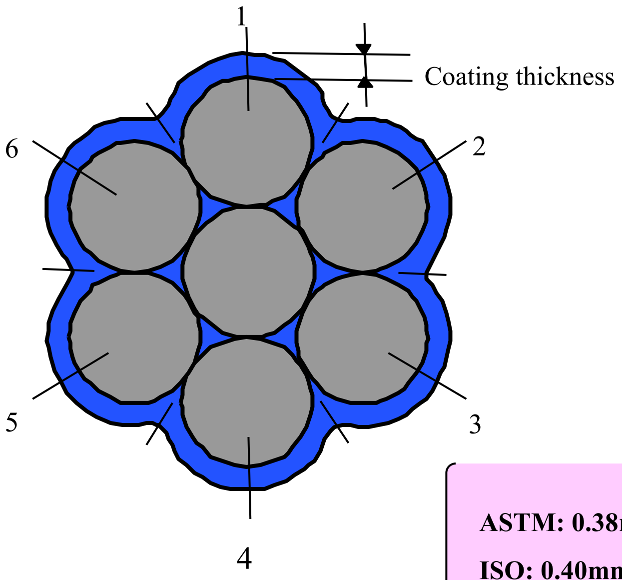
ECS is defined by ASTM A882 and ISO 14655.

In the United States, ECS is defined by ASTM A882. In the first version of ASTM A882, it included both ECS types of filled and non-filled. However, in recent versions, only filled ECS type is allowed due to unreliable anti-corrosion potential with non-filled ECS. ASTM requires several severe environment tests such as salt spray test and chloride ion penetration test. Sumiden Wire's ECS passes all tests.

Also, ASTM requires the test for adhesion between strand and concrete. FLOBOND™, high adhesive type of ECS, has equal or higher adhesiveness to that of bare strand and concrete.

On the other hand, in ISO (ISO14655-1999), both non-filled type ECS and filled type ECS are standardized.

As for the range of standard coating thickness is from 0.38mm to 1.14mm for each crown region in ASTM. And in ISO, the standard coating thickness is from 0.4mm to 0.9mm for all crown regions of filled ECS. Sumiden Wire's ECS is compliant with these international standards.



ASTM: 0.38mm~1.14mm (fill) **(All of each crown)**
ISO: 0.40mm~0.90mm (fill) **(Mean of all crowns)**

Coating thickness comparison ASTM with ISO

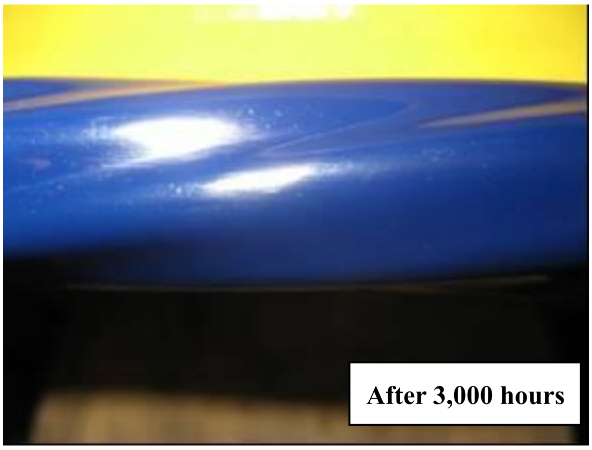
Q1-3

What kind of test data is available about the durability of ECS?

Some third-party tests complying with ASTM A882 are shown below:

1. Salt spray test (ASTM B117, under 70% GUTS for 3,000 hours)

➡ Result : No evidence of rust on strand or coating deteriorations after the test



Salt spray (fog) test under 70% GUTS, 3000 hours

1.2 Chemical resistant test (ASTM G20, immersing ECS in solutions for 45 days)

- Distilled water
- 3M $CaCl_2$
- 3M NaOH
- Saturated $Ca(OH)_2$

➡ Result : No coating deteriorations such as blister, softening, disbonding, holiday development during the test

After 45 days (3M $CaCl_2$)

Chemical resistance test

Q1-4

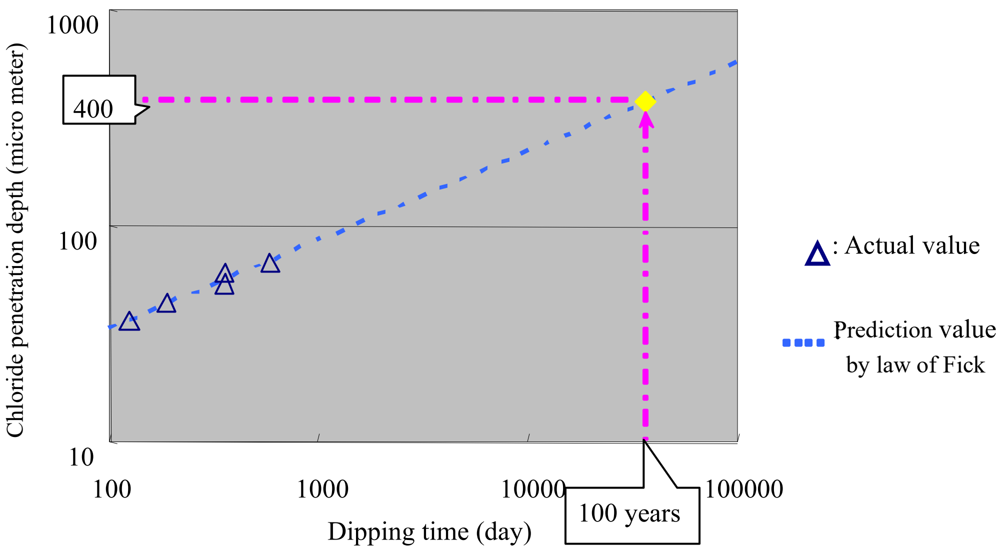
How long can epoxy resin be expected to last as anti-corrosion coating?

Epoxy resin has been used in the industrial world for approximately 60 years. The following description is a simulation of the durability of epoxy resin.

There are many prediction methods for plastic coatings. One of the most severe conditions for aging coatings is dipping in sea water. The lifespan of an anticorrosion coating under sea water is best predicted by the penetration time of chlorides. Chlorides are one of the strongest corrosion-accelerating factors from the outer surface of coating to the interface between the coating and the steel. This means corrosion starts once the chloride ions penetrate through the coating layer. This fact was verified by experiments on the several kinds of coating membrane soaked into simulated sea water. In these experiments, the duration of the chloride ions to hit the surface of inner steel coincides with the duration before blister appearance.

The following graph shows the result of an extrapolation of the relationship between coating thickness and lifespan of the anti-corrosion property of an epoxy coating with direct contact to seawater based on Fick's law[*1]. It shows 400 micrometers thickness of epoxy coating is enough for 100 years durability, even in seawater.

*1-----the Law of Fick: The most fundamental law for describing material transfer by diffusion. It is well known that actual diffusion phenomena; such as diffusion of chlorides into a coating layer; obey the second law of Fick. According to this law diffusion distance is proportional to the square root of diffusion time. There is a linear relationship between diffusion distance and time in the double logarithmic plot.



<u>The temporal change of chloride ion penetration depth under sea water dipping</u>

(Yoshitaka Ishihara: The 12th Steel coating technical meeting P.41)

It is important to recognize this plot is based on coatings dipped directly into seawater. Although predicting the lifespan of ECS in an actual structure is hard to perfectly judge, considering the environment inside a box girder is much more moderate than continuous, direct exposure to sea water in corrosiveness, this data suggests ECS is capable enough to endure over 100 years when used as a ductless exposed external tendon inside a concrete box girder.

Q1-5

Is ECS suitable for anti-corrosion against chloride?

Yes.

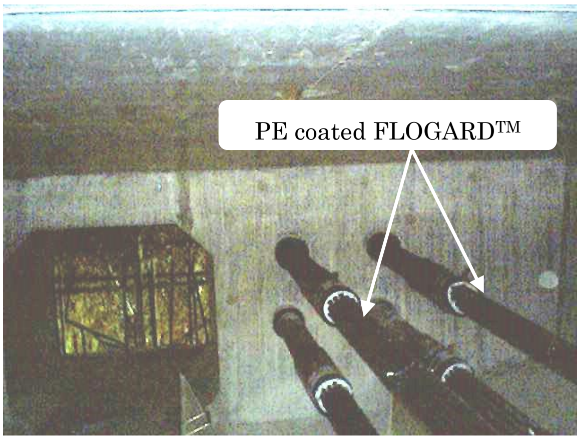
ECS is very suitable for severe chloride corrosive environments. Epoxy coating has been applied for not only PC strand but also for many applications such as coated steel plates for oversea metal bridges or coated body of oceangoing boats. Epoxy resin itself has high chemical resistance and can endure against contacting directly to many chemicals, like acid or alkali, not only chloride.

Furthermore, the minimum epoxy coating thickness of our normal ECS is 15 mils (380 micrometers). This minimum thickness is more than enough compare to general epoxy coated steel with 50 - 150 micrometers of coating thickness. Therefore, it can be said the anti-corrosive ability of ECS, even in severe chloride corrosive environments, is at a very high level.

In some cases, FLOBOND™ (grit-type ECS with grit embedded on the surface for high adhesiveness with concrete) has been applied to internal tendons inside the duct for more anti-corrosive ability. Applying PE coating on FLOBOND™ is also effective for higher durability against chloride attack to the prestressing steel.

Now, ECS is the first option for anti-corrosive PC strand for chloride corrosive environments. For instance, in the coastal area in Okinawa, Japan where it is a severe salt-corrosive region, many bridges are using ECS because of its high reliability and anti-corrosive ability. Also, ECS is an effective option for anti-corrosion against chloride attack in cold areas where deicing salt needs to be used.

Kouri Bridge (Okinawa, Japan)



In the box girder of Kouri Bridge:
PE coating applied on FLOGARD™

Q1-6

At a tensile strength test of the ECS, it is often observed that all wires break simultaneously. Does it indicate a poor ductility of the ECS?

No.

At tensile tests, all wires of ECS typically break at the same time due to the strong adhesion between epoxy coating and each wire. Also, as is often the case with ECS, all broken wires show ductile fracture with necking which indicates entire strand breaks at its ultimate tensile strength.

However, in case single wire accidentally fractures at actual tensioning work at site (e.g. up to 70% GUTS of strand), other wires typically do not fracture by the impact of the first wire break.

Coating adhesion kept after the break

Ductile wire breaks

Q1-7

Is epoxy resin affected by UV light exposure?

Yes. Epoxy resin is not suitable for use under strong UV light radiation. However, the dose of UV radiation inside of box girder is not harmful. Although the direct sunshine has enough energy to degrade the epoxy coating, exposure in a short period, like a few months of construction time, does not have any effects on ECS's anti-corrosion ability.

In general, long-term direct sunshine exposure degrades plastic materials without any kinds of UV resistant additives such as carbon or UV absorbent. Our ECS's epoxy coating contains a small amount of UV resistant additives for excellent mechanical properties. Furthermore, epoxy resin has UV absorbable functional group inside its structure, and this group could be damaged by UV exposure for long period of time.
Therefore, long-term ECS exposure to direct sunshine is not recommended. If ECS needs to be exposed to direct sunshine for long time, utilizing HDPE coating on ECS is recommended.

Although theoretically epoxy resin is degradable by UV exposure, ECS would not be degraded in short period of time. We have practical test results of ECS with UV exposure as mentioned below.

1. No sign of bare strand corrosion underneath coating layer was found on ECS after 720 cycles of multiple cycle corrosion resistant tests. This test is standardized in Japan Highway Standard 403-199(2). This test would be the equivalent UV exposure treatment test to a few years UV exposure in Tokyo.
2. After over 7 years exposure in Okinawa prefecture where it is at nearly the same latitude as Florida, no sign of bare strand corrosion underneath the coating layer or no blister caused by coating degradation was found on ECS. The UV light intensity in Okinawa prefecture is about 8 W/m2 (averaged value from 1973 to 1982 : reported by Local Meteorological Observatory of Japan), while that in the box girder is about 0.015 W/m2 (typical value of fluorescent bulb, the only expectable source for UV light), which is about 1/500 of direct sunshine in Okinawa. Therefore, 7 years durability in Okinawa is equivalent to approximately 3500 years durability in the box girder.

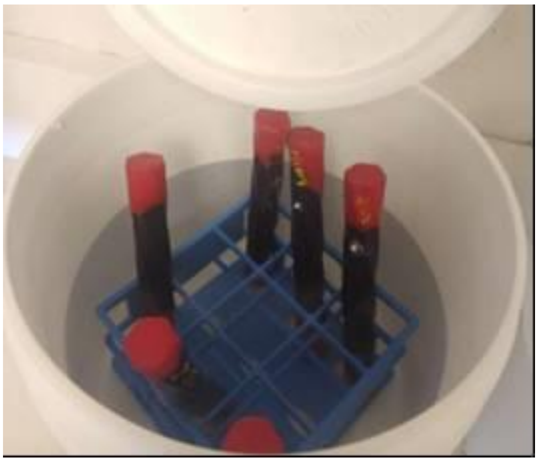

ECS after 7.5 years outdoor exposure under 70% GUTS tension in Okinawa

Q1-8

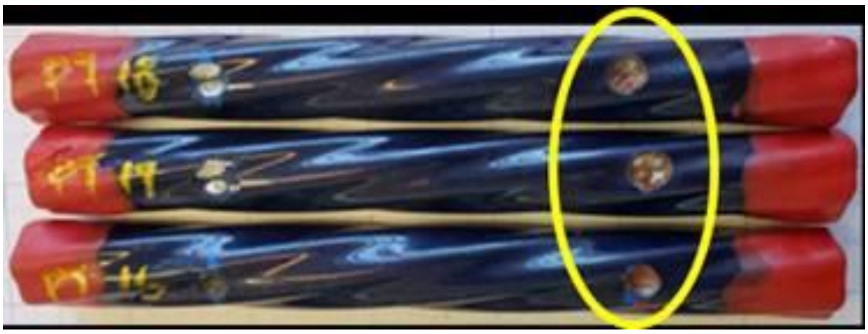
Does a holiday or a coating damage on ECS cause more aggressive corrosion migrating into steel wires inside epoxy coating?

No.

Chemical resistance test specified in ASTM A882 (test method in ASTM G20) specifies immersing ECS specimens with a man-made hole into chemical solutions (distilled water, 3M $CaCl_2$, 3M NaOH, saturated $Ca(OH)_2$) for 45 days. ECS samples with a hole shows rust only at the exposed steel surface and do not show any evidences of coating deteriorations, undercutting of steel wire, or further corrosion migration other than exposed spot in the hole.



Immersing ECS samples into solution



ECS samples with a hole after immersing into 3M $CaCl_2$ for 45days

Q1-9

What are the advantages in ECS against galvanized PC strand?

There are five advantages over galvanized PC strand with ECS as below:

(1) Anti-corrosion ability

(2) Strength of strand

(3) Reactivity with cement grout

(4) Fretting corrosion resistance

(5) Good environmental acceptability

(1) Anticorrosion ability

As you can see in the picture of Q-2, ECS can endure salt spraying test for 1,000 hours, while galvanized PC strand is degraded. This shows that our ECS's anti-corrosive resistibility is superior to galvanized PC strand. Furthermore, unlike galvanized PC strand, the interstices of ECS between center wire and outer wires are completely filled with epoxy which enables superior anti-corrosion property with ECS.

From the view of zinc coating amount, galvanized PC strand does not have enough anti-corrosion ability. The mechanism of anti-corrosion system of galvanized steel is based on sacrificial anti-corrosion. Therefore, the zinc amount is the important factor for its anti-corrosion ability. The zinc amount for galvanized PC strand is limited to maximum 200 g/m^2 that is 40% of standard value of galvanized anti-corrosion steel plate. Therefore, galvanized strand should not have the same anti-corrosion ability as galvanized steel plate does.

(2) Strength of strand

During the galvanizing process of PC strand, the bare strand needs to be heated up to 450 degree Celsius, and the strand tensile strength decreases to about 90% of the initial bare strand value. On the other hand, ECS is heated up to approximately 200 degree Celsius which is much lower than for galvanized PC strand. This temperature level does not affect the tensile strength of the strand.

(3) Non-reactivity of coating with cement grout

Epoxy resin has no reactivity with cement grout and fresh concrete. Therefore, you can save the construction cost and time by utilizing ECS because cement grout or concrete can be applicable as anti-corrosive protection. On the contrary for galvanized PC strand, cement grout is not suitable for anchorage section due to the reaction with zinc coating which generates hydrogen. Some researchers report hydrogen causes stress corrosion on steel. Therefore, for the protection of galvanized strand, alternative materials as liquid epoxy resin or polyurethane resin are required, which is more time-consuming and less cost-effective.

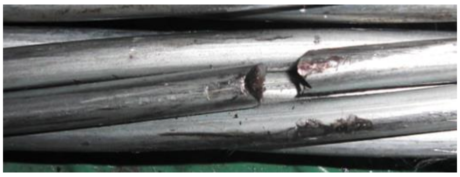
(4) Fretting corrosion resistance

ECS has high level fretting corrosion resistance because of the epoxy coating layer which prevents direct contact or relative movement between wires.

As is well known, bare PC strand easily corrodes by fretting corrosion in the situation that strands directly contact each other and they are given a friction of micro-motion. Galvanized PC strand is almost the same as bare strand and fretting corrosion is caused by direct surface contact between strands or wires. PE coating on galvanized or bare strand cannot be a solution for this problem because PE can be crushed easily in the section where strand gets compressed from the side like a deviator section.

(a) Bare strand

(b) Galvanized strand



(c) ECS

Full-scale fretting fatigue test (19S15.2mm, 2 million loading cycles), appearances of (a) bare strand, (b) galvanized strand, and (c) ECS after the test

(5) Good environmental acceptability

Recently, in Europe, zinc is focused as a kind of endocrine-disrupting chemical. Epoxy resin for ECS does not contain any harmful materials which can elute off into environment.

Q2-1

What kind of applications can ECS be applied to?

Typical applications are as below:

< For bridge construction >

- **# External ductless cables inside of girder**
- **# External ductless cables outside of girder**
- **# Stay cables**
- **# Internal cables in corrosive environment**
- **# Bridge and pavement decks**

< Ground/dam anchor >

- **# Permanent anchorage system**

< Tanks >

- **# Permanent tendons**

If you are interested, please contact us for details.

External ductless cables inside girder

Stay cables

Dam anchors

Internal cables in corrosive environment

Ground anchors

Q2-2

What are the advantages of external ductless ECS cables?

In many cases, ECS has been applied for external ductless cables because of the special features of ECS mentioned below.

(1) Easy inspection
(2) No duct or grouting
(3) Easy repair

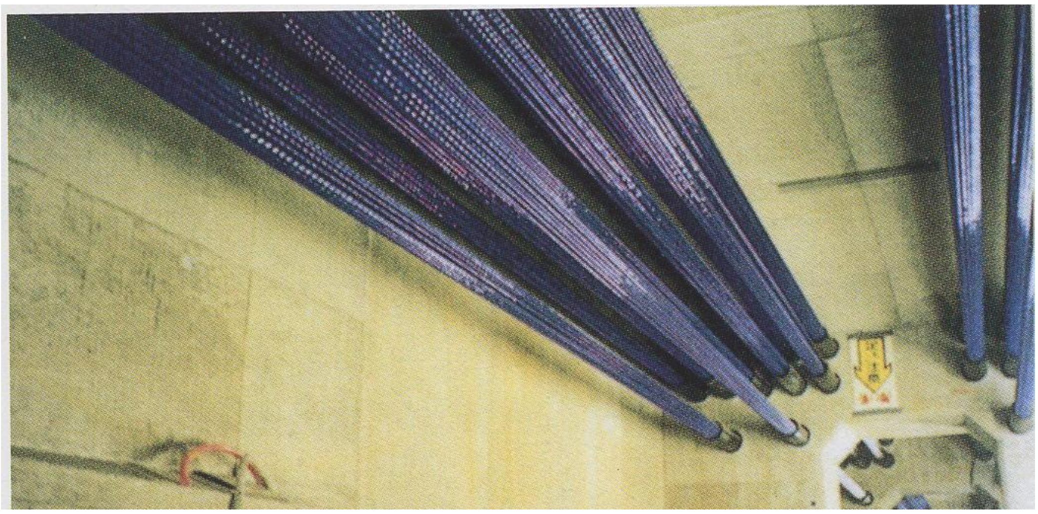
(1) ECS coating surface can be easily inspected anytime. For instance, ECS external cable inspection was performed at BY433 Bridge (Metropolitan Expressway Public Corporation) in Japan. It took only a few days to inspect approximately 10 cables consisting of 19 ECSs per cable in the 100 m-long girder. The inspectability of external ductless ECS cables is one of the remarkable features.

ECS inspection in box girder at BY433 Bridge, Japan after 10 years' service. No abnormality found.

* Courtesy of DYWIDAG-Systems International

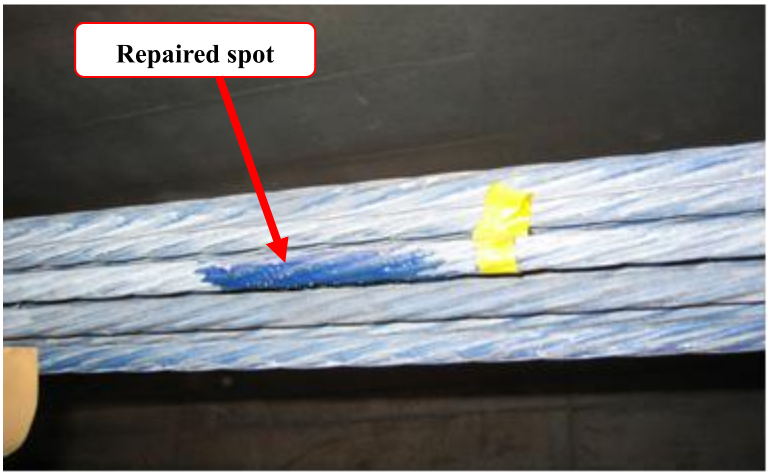
ECS stay cable and anchorage inspection after about 30 years' service. No abnormality found.

(2) The installation work of ECS external ductless cables in a girder is much easier than that of traditional bare strand + grout + duct system. You can eliminate ducts (except deviators) and grout, which enables you to save construction time and cost. Furthermore, abnormal crossing or twisting of strands can be easily detected through the installation process.



External ductless ECS cables inside of girder (Ikeda-hesokko Bridge: FLOGARD™)

(3) If a coating defect or damage is found, coating repair is easy to perform with special epoxy repair paint. Technical data on repair paint is available upon request.



Repaired ECS (BY433 Bridge: FLOBOND™)

Q2-3

Is there any case that ECS has been applied for internal cables?

Yes.

ECS has been applied for inner cables because of its high anti-corrosive ability. In most cases FLOBOND™ (ECS with grit embedded on the coating surface) was placed in the duct filled with cement grout to enforce anti-corrosion. Also, applying FLOBOND™ for internal cables is especially recommended as a connecting tendon for segmental girders or slabs for the risks of water penetration between the segments and inside the ducts.

Shiosai Bridge (Shizuoka, Japan): FLOBOND™ applied to internal cables

Q2-4

Is there any case that ECS has been applied for stay cables?

Yes. Many customers esteem ECS as an ideal tendon for stay cables because of its high anti-corrosive properties, high resistance to fretting and high-fatigue resistance.

Reference list of extra-dosed bridges and stay cable bridges using ECS

Name	Location	Length (m)	Max Span (m)	No. of Strand	The year of completion	Types of bridges
Odawara Bridge	Kanagawa, Japan	268	122	19	1994	Extra dosed
Link Way bridge	Singapore	285	140	1	1997	Stay cable
Second Mandaue-Mactan Bridge	Philippines	410	185	48	1999	Extra dosed
Sashiki Bridge	Kumamoto, Japan	223	105	19	2001	Extra dosed
Fukaura Bridge	Niigata, Japan	140	90	19	2001	Extra dosed
Tobiuo Bridge	Shizuoka, Japan	385	130	37	2002	Extra dosed
Sannohe Bridge	Aomori, Japan	400	200	19, 27	2004	Extra dosed
Penobscot Narrows Bridge	Maine, USA	646	354	41-73	2006	Stay cable
Veterans Glass City Skyway Bridge	Ohio, USA	374	187	82-156	2007	Stay cable
Nanchiku Bridge	Fukuoka, Japan	248	110	37	2007	Extra dosed
Yanagawa Bridge	Iwate, Japan	264	132	27, 37	2007	Extra dosed
Sannaimaruyama Bridge	Aomori, Japan	450	150	27	2008	Extra dosed
Hirano Bridge	Osaka, Japan	132	63	19	2008	Extra dosed
Ohnogawa Bridge	Kumamoto, Japan	285	113	27	2008	Extra dosed
Yangyang Bridge	Korea	350	100	22	2008	Extra dosed
Inje 38 Grand Bridge	Korea	770	140	27	2009	Extra dosed
Geumodo Ando Bridge	Korea	300	140	37	2010	Extra dosed
Muyeong Bridge	Korea	860	165	27	2011	Extra dosed
Corpus Christi Harbor Bridge	Texas, USA	10,400	506	71-121	(2023)*1	Stay cable
Houston Ship Channel Bridge	Texas, USA	6,600	402	55-73	(2023)*1	Stay cable
Twin Bridge over Ameca River	Puerto Vallarta, Mexico				(2023)*1	Stay cable

*1 Under construction at the moment.

Q2-5

Is ECS used for pre-tensioning application?

FLOBOND™, high adhesion type of ECS, is suitable for pre-tensioning system. ECS has been adopted as the tendon for pre-tensioning system. In the United States, bridges commencing with San Mateo Bridge over San Francisco bay, have adopted ECS for pre-tensioning system.

As a tendon for pre-tensioning system, one of the most important features is adhesion with concrete. FLOBOND™ is a type of ECS with embedded grit on its surface which adds good adhesion with concrete. Bond strength is confirmed through the bond test specified in ASTM A882.

San Mateo Bridge (California, USA)

7 mile-long bay bridge where 2,300 metric tons of ECS were used

Q2-6

What are the situations where HDPE coating is recommended on ECS?

Applying HDPE coating over the ECS is recommended in situations mentioned below:

1. External ductless cables installed outside the girder or anywhere exposed to sunshine

   In general, epoxy resin does not have high resistance against UV. HDPE containing carbon filler has high resistance against UV induced deterioration. Therefore, HDPE coating on ECS enables high durability against UV exposure without losing any special features of ECS. Also, HDPE coating works as epoxy coating protection from possible physical or chemical damages when ECS is used outside girder.

2. External ductless cables requiring long-term reliability in severe chloride corrosive environment

   HDPE is a relatively softer material than epoxy. At a deviator section, tensioned strand gets high side pressure and it compress the coating layer of the strand. Under the high side pressure, HDPE behaves as a cushion that eases the epoxy coating thickness reduction. Of course, even without PE coating on ECS, enough epoxy coating thickness remains after the compression at the deviator region. However, utilizing PE coating on ECS is recommended to prevent epoxy coating thickness reduction when multiple anti-corrosion measures are required as in severe chloride corrosive environment. HDPE also works as a protective layer for epoxy coating against abrasion or scratches during transportation or installation processes.


Example case of HDPE coated FLOGARD™ application for external ductless cables

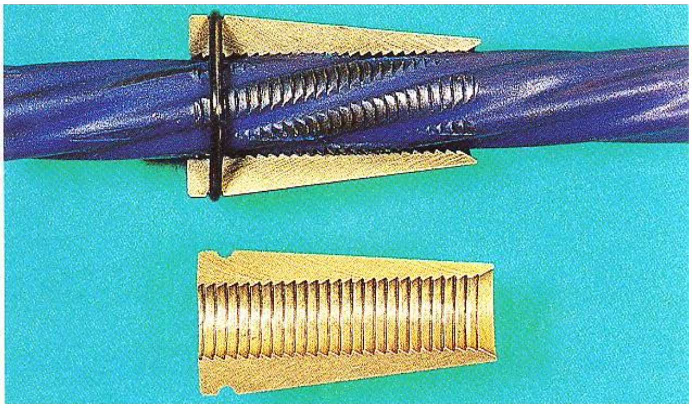
Q3-1

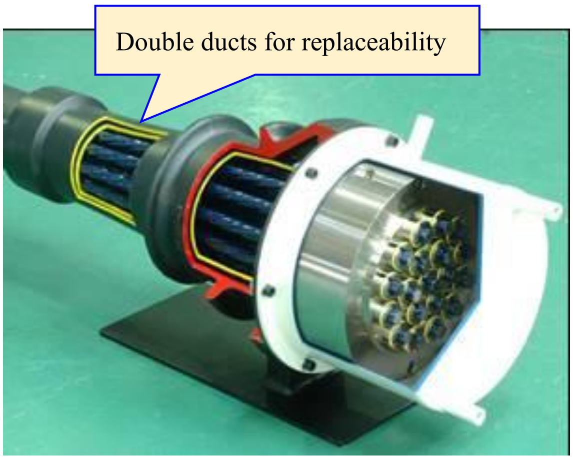
Is the bare strand anchorage applicable for ECS?

No. ECS must be anchored with the special anchorages designed for ECS.

Due to the epoxy coating layer, wedges need bigger teeth for good anchorage of strand. The teeth must be designed to penetrate through the coating layer and directly bite into the prestressing wires inside the coating with enough depth to avoid slippage between the wedge teeth and wires during or after tensioning.
Wedges designed for bare strand with smaller teeth must not be used for ECS. Applying bare strand wedges to ECS may cause strand slippages during or after tensioning and severe accidents or injuries.

Also, due to epoxy coating, you need to note that wedge seating loss with ECS is typically bigger than that for bare strand. Power seating for wedges are recommended before detensioning, or bigger seating loss should be included in the stressing calculation.





(a) For external ductless cable

(b) For internal cable

Anchorage systems for ECS cable

Q3-2

What are the important keys in design with ECS cables?

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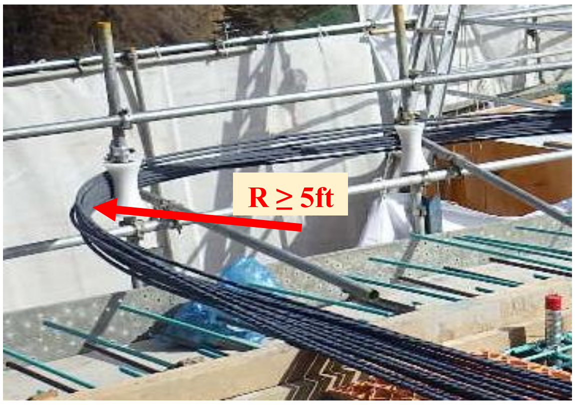
1. Epoxy coating should not be exposed to sunlight regardless of direct or indirect to avoid deterioration due to UV light. HDPE coating should be applied on ECS if the cable is exposed to sun light for a long time.
2. For pre-tensioning applications, concrete temperature should not exceed 150℉ (65℃) to avoid bonding loss between ECS and concrete due to softening on epoxy coating.
3. For post-tensioning applications, PE ducts should be used to avoid high friction between ECS. Utilizing metal ducts may cause high friction between ECS which results in less strand elongation than designed and epoxy coating damages during the stressing process. Also, PE material should be applied wherever ECS may contact with hard surfaces (e.g. wedge plates).
4. All ECS installation path should be properly covered with plastic materials to prevent epoxy coating damages during ECS installation. ECS should not contact with any rigid/stationary harder materials than epoxy such as metal.
5. Special anchorages designed for ECS should be used. Seating loss of wedges at detensioning should be considered. Note that wedge seating loss for ECS is typically bigger than that for bare strand. Specifications issued by anchorage or stressing equipment supplier should be referred.

Q4-1

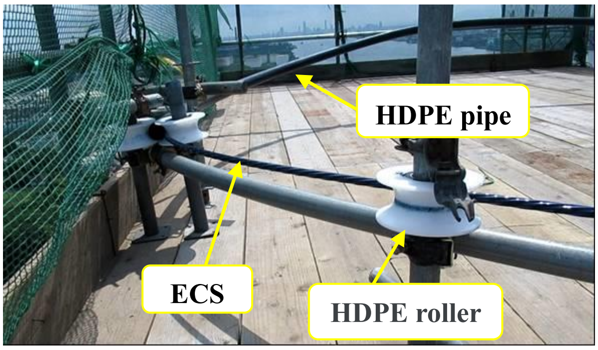
What are the important keys at ECS installation?

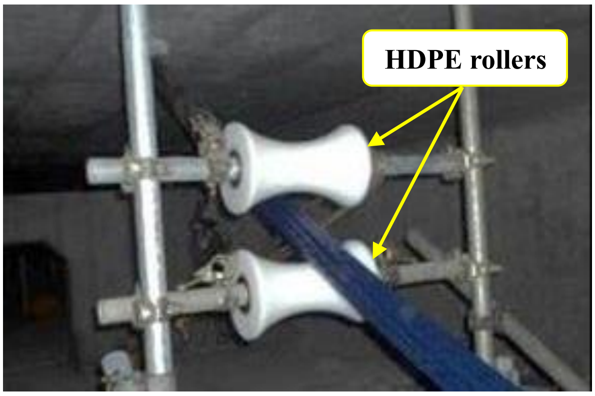
The most basic key is to prevent ECS from direct contact with any materials harder than epoxy such as metal or concrete. It is required to cover anywhere may damage ECS surface along the installation path with softer materials like polyethylene, blanket, or wood. On the bridge surface, placing plastic pipes or wooden plates along the ECS installation path is very effective. In the girder, putting thin-piled carpet is also effective. Please contact us for further details.

If you need to deviate ECS during strand installation, no less than 5ft (1.5m) of deviation radius is recommended to maintain proper coating conditions and properties. Using PE duct guide or plastic roller assembly is effective.



Deviation radius at installation (R≥5ft)





Protection along installation path

Q4-2

What are the important keys for anchorage and tensioning for ECS?

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1. Before stressing
   a. Verify the wedges both for stressing and for anchorage are designed for ECS (bite-through wedges).
      * All post-tensioning systems and stressing equipment for ECS are required to execute verification tests for stressing at its development stage.
   b. Check the teeth at both wedges. You should not use damaged wedges (cracking, flattened teeth, etc.). Also, epoxy residues clogged between the teeth should be removed.
      * Using wrong wedges (e.g. wrong size, bare strand), ones with damages or clogged epoxy residue may cause strand slippages during or after stressing and result in serious incidents.
   c. Check all wedge segments are properly set (there is no missing segments).
      * Missing wedge segments may cause strand slippages or failures during or after stressing.

2. At stressing
   a. Do not stand behind the stressing jack or anchorage.

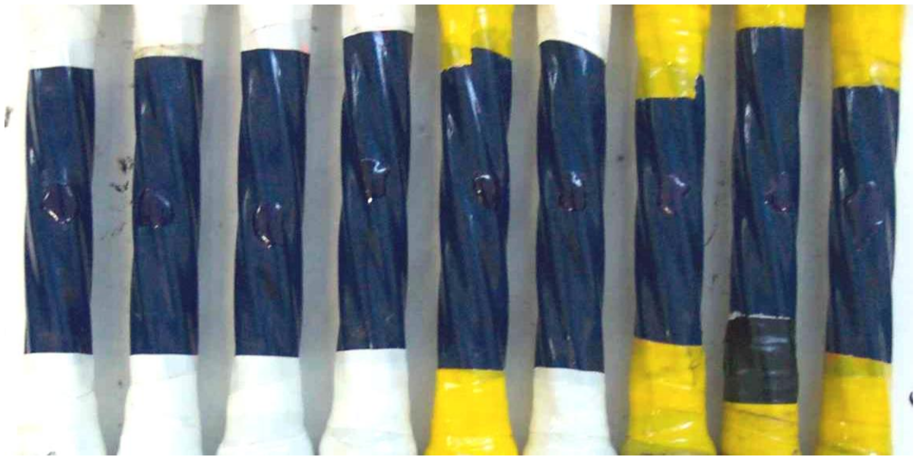
3. At re-stressing (when you need to pull ECSs multiple times to reach to final force)
   a. Verify the stressing wedge segments are properly set (no missing segments) at each time of tensioning.
   b. Do not grip the same location where it is already gripped.
      * It is also helpful to recognize the maximum re-stressing times to safely pull ECS without inspecting wedges prior to stressing work.

4. After tensioning (completion of stressing each cable)
   a. Verify all anchor wedges are properly anchored and no coating damages occur on ECS extra length behind the wedge plate except wedge bites.
   b. Check all stressing wedges. Remove epoxy residues remaining between wedge teeth. Eliminate any damaged wedges (cracking, flattened teeth, etc.).

Q4-3

What is needed for coating damage repair?

Damaged spots of epoxy coating need to be repaired with specially designed touch-up paint. We have investigated that special paint is designed to have the same level of anti-corrosive properties as original epoxy coating. Please refer to instruction manual about proper use of touch-up paint.



3,000 hour salt spray test for repair spots on artificial coating defects

ECS stay cables at Sannaimaruyama Bridge
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