



SUMIDEN WIRE
— PRODUCTS CORPORATION —

Epoxy Coated and Filled Strand Questions & Answers

August 2015

Preface

With rising requirements for durability in prestressed concrete structures, many people have been interested in anticorrosive, coated PC steel products. Of course cement grouting systems are the most popular method for corrosion protection because of its high anticorrosive potential and economic efficiency. As customers' needs have grown for both long life concrete structures and short construction times, global interest has focused on anticorrosive coated PC steel. In light of this growing market demand, Sumiden Wire has promoted the use of Epoxy Coated and Filled Strand (ECS) for PC structures to meet their customers' needs.

Now in Japan, the use of ECS has spread. ECS has enabled the construction of advanced permanent structures in that market. ECS is expected to be used not only for improving the durability of the structure but also shortening the construction time. For example, ECS is the first choice for external tendons inside box girders in Japan.

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

We hope this document helps the reader understand more about our ECS.



Japan Highway Corp. Ibi-gawa bridge (2002)

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Q-1

What kind of standard / recommendation is applied for Epoxy Coated Strand?

Epoxy Coated & Filled Strand (ECS) is known as an anti-corrosion seven-wire PC Strand used for permanent structures. Standards and recommendations are as follows.

[Standard & Code]

General

ISO 14655-1999 <Epoxy-coated strand for the prestressing of concrete>

USA

ASTM A 882-A882M <Standard Specification for Filled Epoxy-Coated Seven-Wire Prestressing Steel Strand>

Korea

KS D ISO 14655 -2002 <Epoxy-coated strand for the prestressing of concrete>

China

GB/T 21073-2007 <Epoxy-coated seven-wire prestressing steel strand>

Code for Construction Project of Shanghai <Design code for prestressed concrete structures>

[Recommendation & Guideline]

Post-Tensioning Institute < Recommendations for Stay Cable Design, Testing and Installation>

Post-Tensioning Institute < Recommendations for Prestressed Rock and Soil Anchors>

Precast/Prestressed Concrete Institute < Guidelines for the Use of Epoxy-Coated Strand>

Q-2

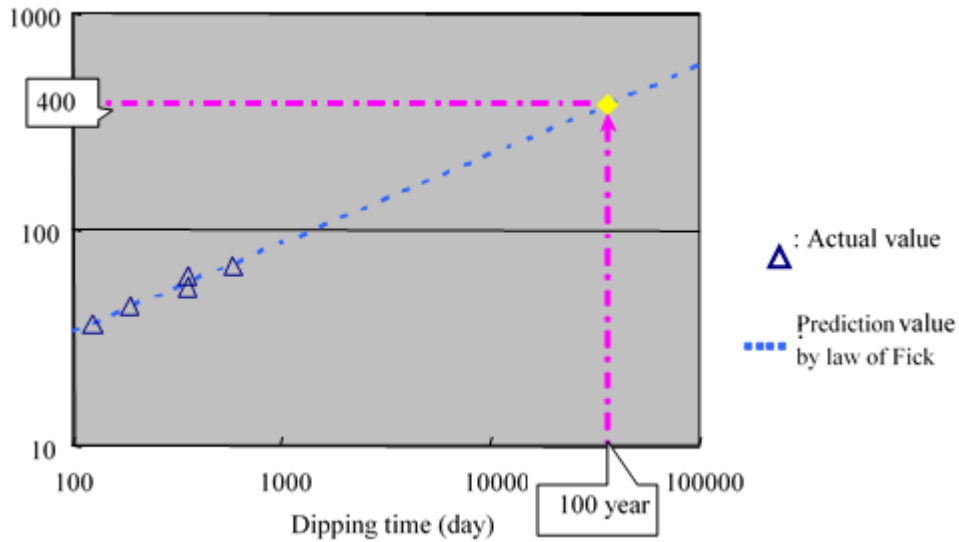
How long can Epoxy resin be expected to last as an anti-corrosion coating?

Epoxy resin has been introduced in the industrial world since at least the 1940's. The following description is a simulation of the durability of Epoxy resin when used for over 100 years.

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 the 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 several kinds of coating membrane soaked into simulated sea water. In these experiments, the length of time for the chloride ions to hit the surface of inner steel coincides with the length of time until blister appearance.

The following graph (next page) 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 the 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 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.



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

The temporal change of chloride ion penetration depth under sea water dipping

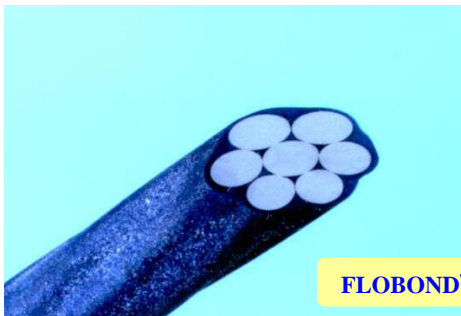
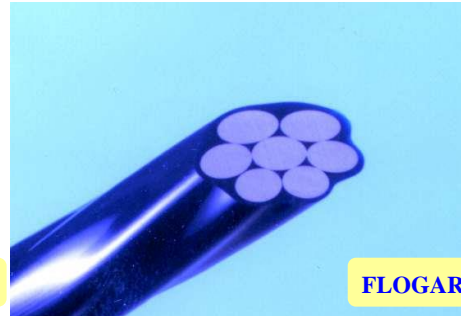
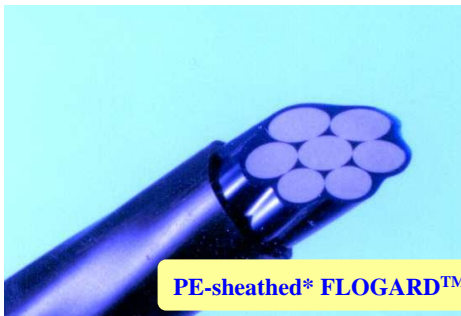
It is important to recognize this plot is based on coatings dipped directly into seawater. Although predicting the lifespan of ECS in an actual structure is hard to perfectly judge, considering the environment inside a box girder is much more moderate than continuous, direct exposure to sea water in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

Q-3
How many types of ECS are available?

* 4 types of ECS are available. FLOGARD™, FLOBOND™ (high bonding), PE sheathed FLOGARD™ and PE sheathed FLOBOND™, in each sizes are available now.

Types of ECS

	1 st anticorrosive layer		2 nd anticorrosive layer	Application
	Material	Surface Aspect of 1 st layer	Material	
FLOGARD™	Epoxy resin	Smooth	None	*External tendon for box girder *Stay cable
FLOBOND™	Epoxy resin	Embedded sand for good adhesion with concrete	None	*Inner tendon *Pre-tensioning system *Stay cable
PE-sheathed FLOGARD™	Epoxy resin	Smooth	Polyethylene coating with close contact to 1 st layer	*Outer tendon for box girder (ex, for severe chloride polluted area) *Stay cable
PE-sheathed FLOBOND™	Epoxy resin	Embedded sand for good adhesion with concrete	Polyethylene sheath (no adhesion with 1 st layer)	*Ground anchor


FLOBOND™

FLOGARD™

PE-sheathed* FLOGARD™

PE-sheathed* FLOBOND™
*** PE-sheathed**

PE Sheathing is not applied by Sumiden Wire. A third-party extruder would need to be hired by the customer.

Q-4

What are the special features of using ECS?

The 3 features mentioned below are the strongest advantages of ECS compare to other anticorrosive coated strands.

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

(1) High corrosion protection

ECS's excellent anticorrosive ability is caused by the high adhesiveness and durability of the epoxy resin. Its anticorrosive ability is also achieved because the voids between the wires are fully filled with the epoxy resin. In Japan there are many construction results with severe environments, like oversea bridges, because many customers recognize this excellent ability 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 external tendons 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 invulnerable properties of epoxy coatings also make it easy to handle ECS with a pushing machine.

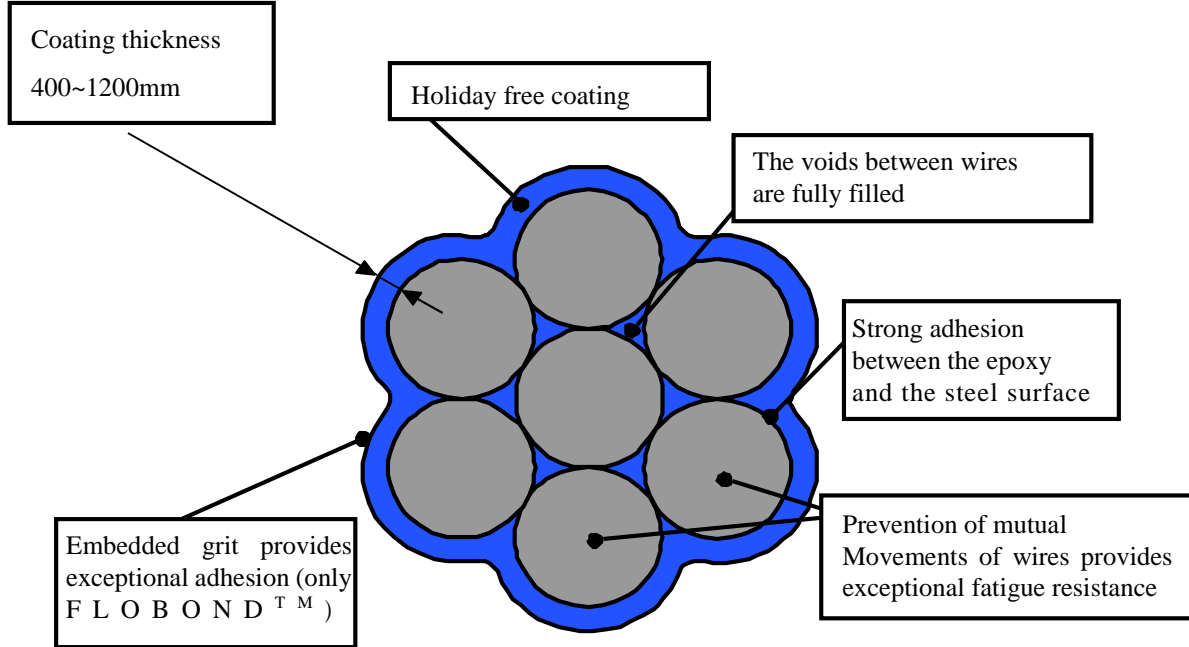
(3) Excellent resistance against fretting fatigue

Epoxy coating prevents mutual movement of wires because the voids between the wires are fully filled by 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 strand. This feature of the epoxy coating as a spacer is particularly effective for the application of a deviator of an external tendon 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.

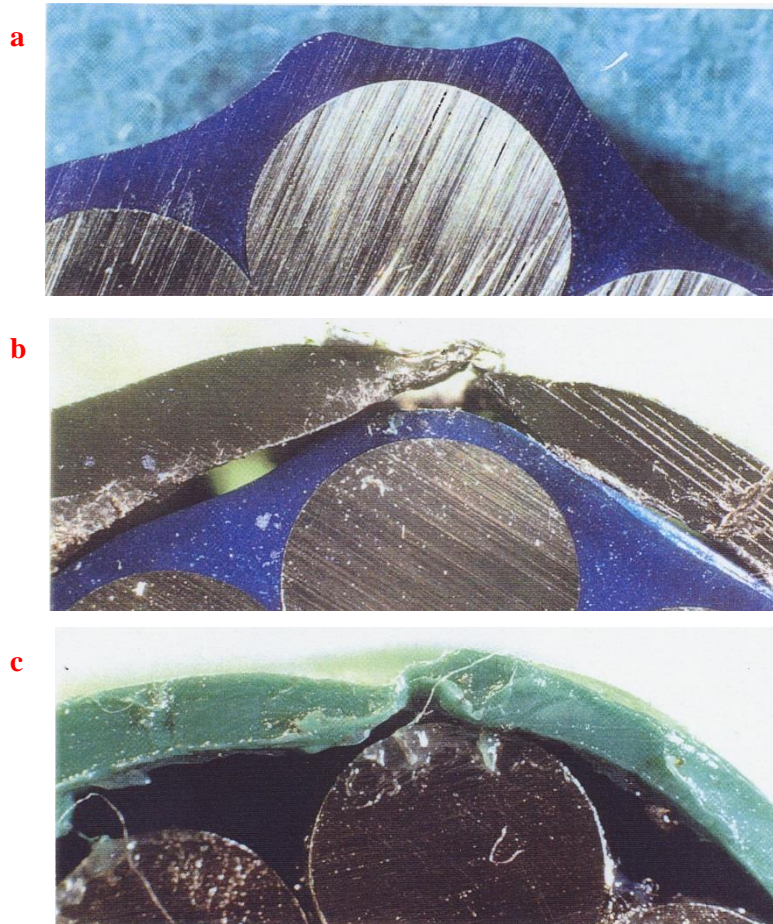


The main feature of ECS



High anticorrosive ability of ECS

(The test result of 1,000 hour salt spraying, 1.bare PC strand, 2.galvanized PC strand, 3.ECS)



Toughness of epoxy coating [The cross section after compression tested]

- a) ECS (Enough anticorrosion coating thickness remained after compression test)
- b) PE-covered ECS (Epoxy coating is protected by the cushioning PE sacrificially crushed)
- c) Greased & Sheathed Monostrand (PE layer crushed and has a hole that grease can escape)

Q-5

Is there any standard for ECS?

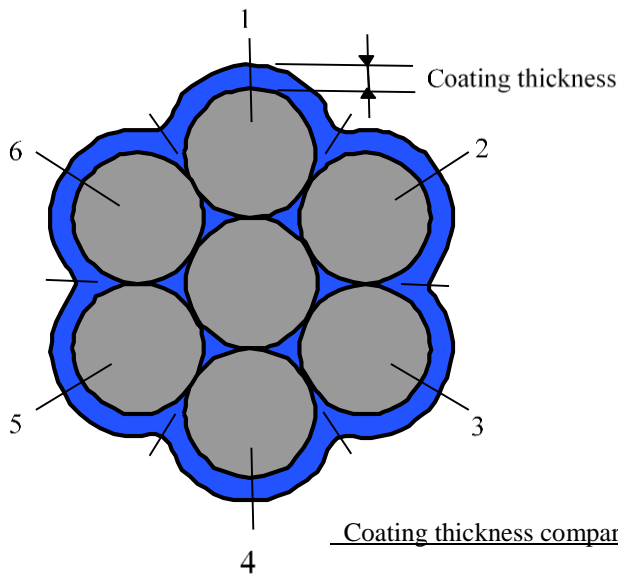
Yes. ECS is specified in ASTM A882 and ISO 14655.

In the United States, ECS (Epoxy Coated Seven-Wire Prestressing Steel Strand) is defined by ASTM A882. In the first version of ASTM A882, it included both non-filled ECS type and filled ECS type. However, in recent versions, only filled ECS type is allowed because the anticorrosion potential of non-filled ECS is unreliable. ASTM requires several severe environment tests such as salt spraying test and chloride ion penetration test. Sumiden Wire's ECS passed each of these strict tests.

ASTM also 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.

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

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



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

Q-6

How do you control the coating thickness of ECS?

We control coating thickness by measuring it at the crowns of each wire every 2,000 linear feet or less during production. The thickness is checked using a magnetic thickness gauge.

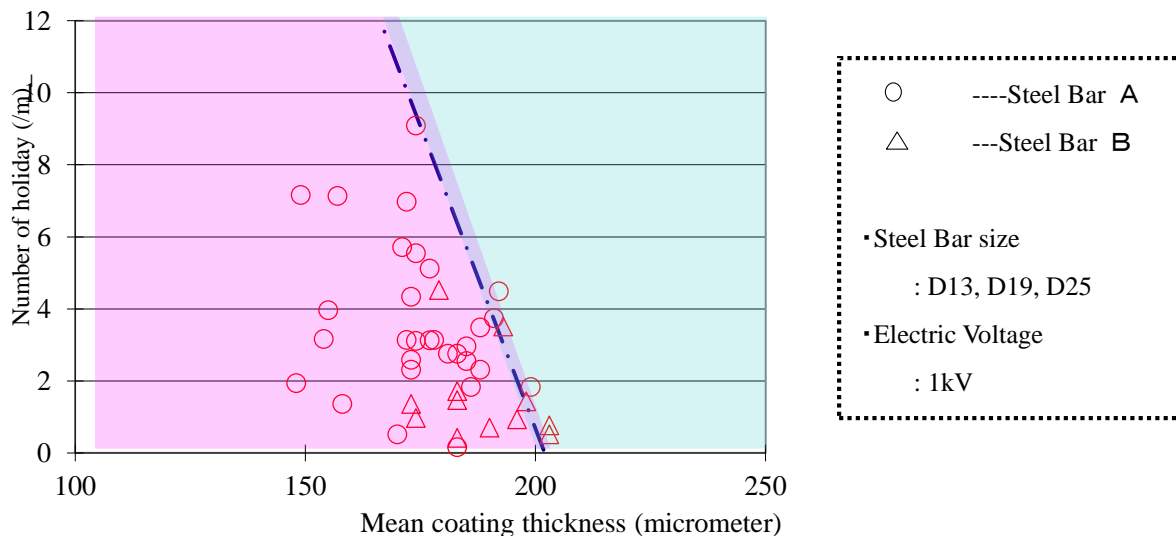
Q-7

How do you control holidays in the epoxy coating?

We take two strategies below for eliminating the holiday in the epoxy coating.

1. Keeping minimum coating thickness over 400 micrometer, twice of theoretical minimum holiday-free coating thickness.
2. Checking the entire length of ECS by aqueous electrolyte inline holiday detector charged 67.5V DC.
3. Checking the entire length of ECS by inline holiday detector charged 3000V DC.

It is well recognized the more coating thickness increases, the frequency of holiday occurrence decreases. As a typical example, we take a chart of the relationship between an epoxy coating thickness and the frequency of holiday occurrence reported by Japan Society of Civil Engineers. You can see the relationship between them in the graphic below. Over ~200 micrometers, the frequency of holiday occurrence drops to near 0; therefore, the minimum coating thickness range of ECS @ 400 micrometer contains a 2x safety margin. We can guarantee a holiday-free condition for our ECS based on this safety margin.



Interrelation between coating thickness and number of holiday

Furthermore, to prevent an unexpected failure, all of our ECS is checked inline with a 3,000V holiday detector. Commonly, an electric leak detector charged to 2000V is used for holiday detection for other coated steels. However, we standardized 3,000V for holiday detection of ECS because we found technically it was possible for a 2000V detector to overlook a holiday under 20 micrometer diameter.

Q-9

Is Epoxy resin durable against moderate UV light exposure?

Yes, but the epoxy resin is not suitable for use in strong, prolonged UV light radiation environments. Prolonged exposure in direct sunshine has enough energy to degrade the epoxy coating, but the exposure in a short period, like a few months of construction time, does not have any negative effect on ECS's anticorrosion or ductility performance.

Every plastic resin which is exposed to direct sunshine without any kinds of UV resistant additive, such as carbon or UV absorbent, will degrade when exposed to UV light for a long period of time. Our ECS's epoxy coating contains a small amount of UV resistant additives for achieving excellent mechanical properties. Furthermore our epoxy resin has UV absorbent features inside of its structure, and this absorbent feature could be damaged by prolonged UV exposure.

Therefore, we do not recommend the use of ECS in applications where direct exposure to sunshine over long periods of time would occur such. In such a case, we recommend the use of PE sheathed ECS.

Although theoretically epoxy resin is degradable by UV exposure, our ECS does not degrade over a short period of time. We have test results of our ECS with UV exposure as mentioned below.

1. No sign of corrosion of bare strand underneath coating layer could be found on ECS after 720 cycles of multiple cycle corrosion resistant tests. This test is standardized on Japan Highway Standard 403-199(2). This test would be the equivalent UV exposure of a few years UV exposure in Tokyo, Japan.
2. A set of epoxy coated strand samples have been tensioned and exposed to direct sunshine in Okinawa prefecture for over 15 years (since 2000), near the same latitude as Florida, with no sign of corrosion to the bare strand underneath the coating layer and no blistering caused by degradation of the coating layer. This test is still being performed.

[The amplitude of UV light in Okinawa prefecture is about 8W/m^2 (average value from 1973 to 1982: reported by Local Meteorological Observatory of Japan). And the amplitude of UV light in the box girder, about 0.015W/m^2 (typical value of fluorescent bulb, the only expectable source for UV light), is about 1/500 of direct sunshine in Okinawa. Therefore, it can be said 7 years durability in Okinawa is equivalent to approximately 3500 years durability in the box girder.



- **ECS after 7.5 years exposure @ 0.7P_u tensioning in Okinawa**
- **No corrosion or blister occurring**

Q-10

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

No.

With the ECS, it is often observed that all wires break at the same time like a PC bar. However, such a failure mode occurs only with a tensile strength test when the first wire breaks at its breaking strength. The impact of the first break transferred through the epoxy film to the other wires that are also reaching to their breaking strength. Therefore, the ECS has more chance to break simultaneously comparing a bare strand at a tensile strength test.

However, in case one wire accidentally breaks at an actual tensioning strength such as 70% of its breaking strength, other wires at the 70% of the breaking strength cannot be broken by the impact of the first wire failure.

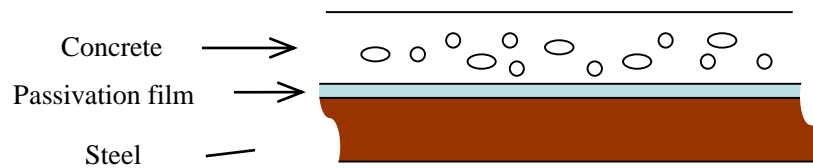
Also, because of the cushioning effect of the ECS, the stress concentrations in the gripping region that are typical when testing bare strand are significantly reduced when testing epoxy coated strand. This cushioning effect in the gripping region typically allows for virtually simultaneous rupture of all 7 wires in the free length of the test span.

Q-11

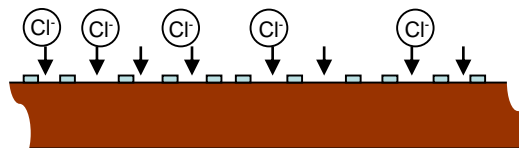
From an electrochemical point of view, does the ECS with a holiday or coating damage tend to generate corrosion more aggressively comparing to Bare Strand?

No. Assuming the corrosion is generated by natural penetration of chlorine ion from concrete surface, the mechanism of the extension of corrosion, for example bare strand, is as follows:

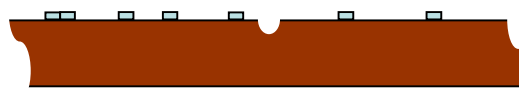
- 1 Creation of Passivation films by alkaline environment (Stable condition)



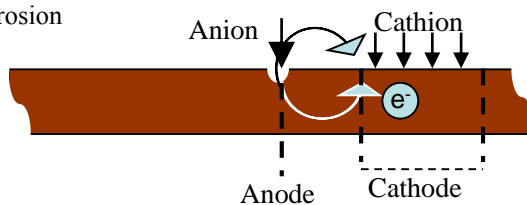
- 2. Rupture of Passivation films by penetrated chlorine ion



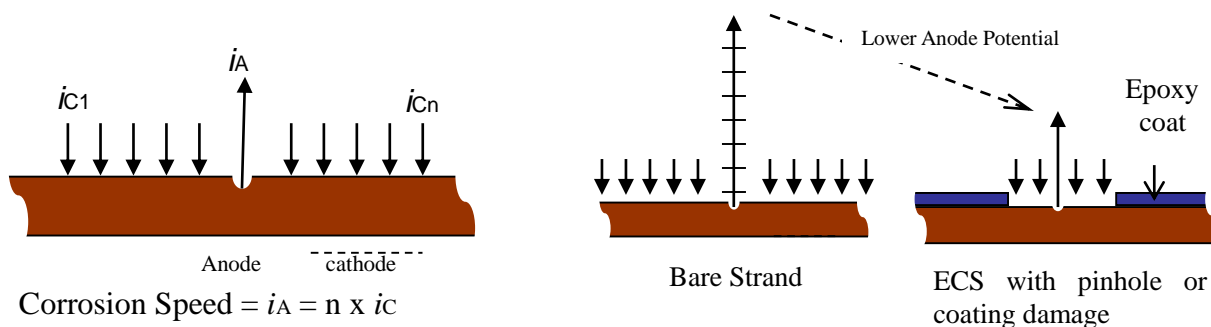
- 3. Generation of un-uniform corrosion



- 4. Creation of “Micro Closed Circuit” and extension of corrosion



Electrochemical reaction speed (corrosion speed = i_A) depends on the area of cathode as shown below. A bare strand can have unlimited cathode area, where the ECS has non-conductive epoxy cover around the damaged area. Therefore, ECS, even when damaged, shall has less risk to propagate corrosion when compared to bare strand.



Q-12

What are the advantages of ECS compared to galvanized PC strand?

There are five advantages for ECS mentioned 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-4 (Page9), ECS can endure salt spraying test for 1,000 hours, although galvanized PC strand would be degraded in its surface by the same test. This shows that our ECS's anticorrosive resistance is superior to galvanized PC strand. Furthermore the internal wire in ECS, which are composed between center wire and outer wires, are filled with non-corrosive material; unlike galvanized PC strand. The feature makes ECS even more superior.

From the view of the amount of zinc coating, galvanized PC strand does not have enough anticorrosion ability. The mechanism of anticorrosion system of galvanized iron is based on sacrificial anticorrosion. Therefore, the amount of galvanizing zinc is the important factor for its anti-corrosion ability. The amount of zinc for galvanized PC strand is limited to lower than 200g/m² that is 1/2.5 of the standard value of galvanized anticorrosion steel plate. Therefore, it cannot be expected to have the same anticorrosion ability as a galvanized anticorrosion steel plate.

(2) Strength of strand

During the galvanizing process of PC strand, it needs to be heated up to ~450 degree Celsius, which causes the strand strength to decrease to about 90% of the original bare strand's value. On the other hand, ECS is only heated to ~200 degree Celsius, which is less than half of galvanized PC strand. This makes ECS maintain almost all of its original strength.

(3) Reactivity with cement grout

Epoxy resin has no reactivity with cement grout and fresh concrete. Therefore, ECS can save the construction charge and reduce the construction time because cement grout or concrete can be available for anticorrosive protection for the area surrounding the anchorage region. On the contrary for galvanized PC strand, cement grout cannot be available for anchorage region protection, and it needs to be coated with expensive and time consuming liquid Epoxy resin or Polyurethane resin. Zinc can react with strong alkaline chemicals like fresh cement or grout. And it is believed the hydrogen gas occurred by this reaction could attack the strained bare strand underneath the coating. Although there is no

evidence and the commonly established theory is that hydrogen molecules will not harm strained steel, we think galvanized PC strand should not be used when in direct contact with cement grout or concrete.

(4) Fretting corrosion resistance

Our ECS has a high level of fretting corrosion resistance because our ECS has the tough epoxy coating layer on the surface of each individual wire thereby preventing direct surface contact of metal to metal.

As we well know, bare PC strand easily corrodes by fretting corrosion in the situation that strands are directly contacted with 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 of metal to metal. To prevent direct contact by each galvanized strand, covering PC strand by polyethylene is effective. However, indeed this method could not solve this problem completely because polyethylene can be crushed easily in the region where strand compression exists from the side by high pressure like in a deviator region. Furthermore HDPE covered galvanized PC strand can be more expensive than ECS.



(Bare)



(ECS)



Fretting corrosion test in practical scale.

19S15.2 and Appearances of (a) bare PC strand and (b) ECS after 2 million cycles.

(5) Good environmental acceptability

In Europe, zinc is identified as a kind of endocrine-disrupting chemical. Epoxy coating used on our ECS contains no harmful material which is able to elute off into environment.

Q-13

What are the advantages in prefabricated multi ECS cable against other prefabricated multi cable?

Of course all of benefits of a single ECS against another single PC strand remains even in the form of a multi cable. The additional benefits of an ECS multi cable are outlined below.

First, the ECS advantages compared to a prefabricated multi monostrand cable are:

- (1) Smaller diameter of cable
- (2) Smaller bending radius of cable
- (3) Easier to anchor

- (1) Smaller diameter of cable

HDPE, the main anticorrosive layer of a monostrand, is weaker than Epoxy resin. The thickness of HDPE of each single tendon is also thicker than the Epoxy coating on ECS. So the diameter of multi tendons comprised of bundled monostrands are larger than that of ECS. For example in the case of a 19S multi cable, the diameter of multi ECS cable is about 20 mm smaller than that of monostrand multi-cable. This smaller diameter which can reduce the wind resistance in a stay cable application.

- (2) Tough anticorrosive layer

Epoxy resin has a three-dimensional crosslink in its micro structure. These structures substantially reduce the thickness reduction cause by the creep phenomenon when exposed to high side pressure. On the contrary, HDPE has less resistance against creep. Therefore, in the use of monostrand for prefabricated multi PC cable, some measures for reducing thickness reduction of HDPE should be incorporated. For example, the bending radius for prefabricated multi monostrand cable must be larger than that of an ECS multi cable to reduce the side pressure.

- (3) Ease of anchoring

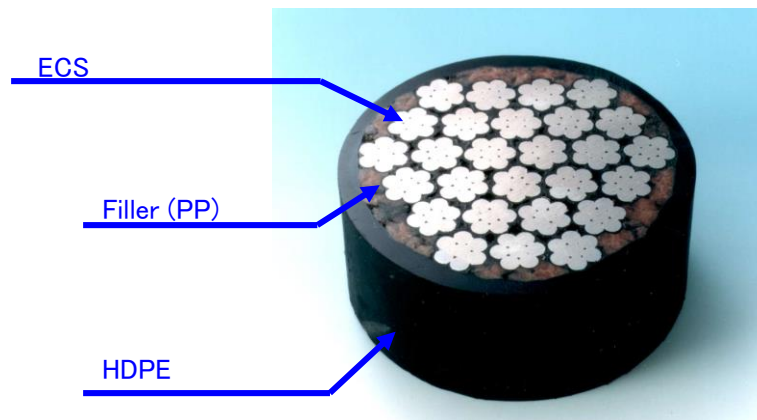
ECS does not need to be stripped off before the anchoring process. This feature makes not only construction time shorter but also the reliability of the anticorrosion layer in the anchorage area is enhanced.

Other advantages compared to a prefabricated multi galvanized cable are mentioned below.

- (1) Small diameter of cable
- (2) Strong strength of cable

(1) As mentioned at Q-12, ECS has high resistance for fretting corrosion. Galvanized PC strand is often applied for stay cable as an element of the multi cable with an additional outer sheath for preventing fretting corrosion. This makes the total diameter of a multi galvanized cable larger than that of a multi ECS cable.

(2) As mentioned at Q-12, during the galvanizing process, the heat treatment decreases the strength of the galvanized PC strand. On the other hand, the strength is not decreased during the process of applying the epoxy coating. This allows ECS to retain almost of its original strength compared to the original bare strand in a multi cable as well.



Prefabricated Multi ECS cable (27S)



Samonoe-Bokyo-Onashi Bridge (Aomori, Japan) :

Applying prefabricated multi ECS cable for stay cable

Q-14
What capacity of cable is available by using ECS?

Any capacity of cable can be manufactured by using 12.7 mm, 15.2 mm or 15.7 mm diameter ECS. The cable type regularly prepared is listed below.

Capacity of ECS Cable

For Outer Cable	For Inner Cable	For Stay Cable
7S	3S	9S
9S	4S	12S
12S*	5S	19S
19S	9S	27S
27S	12S	37S
	19S	48S
		61S
		91S
		108S

In case of requiring other type of cable, please contact us.

And please make sure that ECS have to be applied with HDPE sheath in case of applying ECS for inner cable.

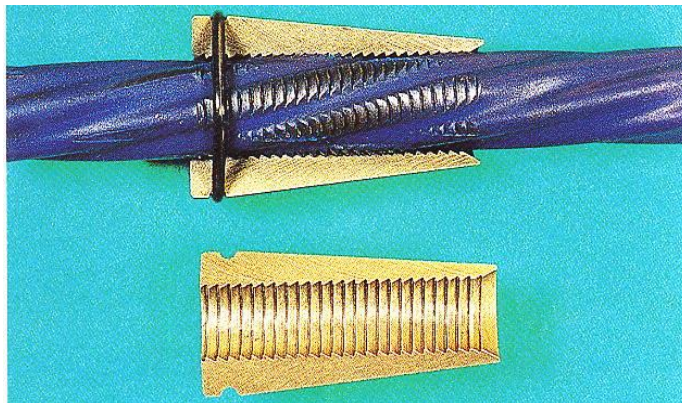
Q-15

What kinds of anchorage parts are used for ECS?

ECS has to be anchored using specially designed anchorage parts and wedges.

ECS has a relatively thick coating for good anticorrosion. Wide and deep wedge teeth are needed for good anchorage of the strand. The teeth have to be designed to penetrate through the coating layer and directly bite the steel surface to prevent slipping through.

Do not use wedges designed for bare strand for ECS anchorage. Ignoring this caution may cause severe accident involving human lives.



Good fitting of ECS and special wedge

Specially designed epoxy coated strand bite-through wedges are available from a US manufacturing company. Contact your Sumiden Wire sales representative for more information.

Q-16

What applications are suitable for PE sheathed ECS?

We recommend applying PE sheathed ECS for the following applications.

- (1) For external tendons directly exposed to sunshine like external tendons located outside of girder or stay cable
- (2) For external tendons requiring long term reliability in severe chloride polluted regions

(1) HDPE containing carbon filler has a high resistance for UV induced degradation. In general, epoxy resin does not have high resistance for UV attack. However, PE sheathed ECS achieves high durability against direct UV light exposure without losing any special features of ECS.

(2) HDPE is a relatively soft material compared to epoxy resin. At the deviator region, tensioned strand gets high side pressure and it compresses the coating layer of the strand. In such situations of high side pressure, HDPE behaves as a cushioning layer and this reduces the epoxy coating thickness reduction cause by side pressure. Of course without PE sheathed epoxy coating enough thickness remains even after the compression at the deviator region, but in the cases where double or triple durability is required, such as a severe chloride polluted region, we recommend using PE sheathed ECS to further protect the epoxy coating from thickness reduction by compression. HDPE also works as a protector for epoxy coating by preventing thickness reduction due to abrasion with rough handling.



Example of installation of PE sheathed FLOGARD™

Q-17

What is the precaution in design when using ECS?

- (1) Setting loss has to be 9mm
- (2) Making choices from Normal relaxation and low relaxation strand.

* We can produce both normal relaxation ECS and low relaxation ECS. If you are interested in using low relaxation ECS, please contact us.

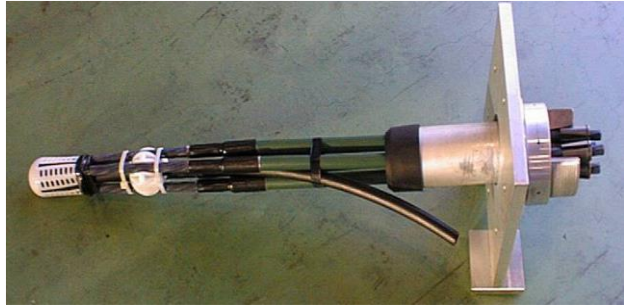
Q-18

What kinds of applications are there for ECS?

The most typical applications are mentioned below.

< For bridge construction >

- # External tendon inside girder
- # External tendon outside girder
- # Stay cable
- # Inner cable for chloride polluted region
- # Connecting cable for precast slabs



< Ground anchor >

- # Permanent anchorage system
(**FLOTECH™ anchorage system**)



< Temporary tendon >

- # Temporary circumferential tendon for tank

FLOTECH™ system and its example of construction

If you are interested in these applications, please contact us.

Q-19

Is ECS suitable for chloride attack region?

Yes. ECS is very suitable even for severe chloride polluted region. ECS anticorrosive coating was applied for not only PC strand but also for many applications, such as coated steel plate for oversea metal bridge or coated body of oceangoing boats. The epoxy resin itself has a very high chemical resistance ability and can endure against direct contact with many chemicals, like acid or alkali, not only chloride.

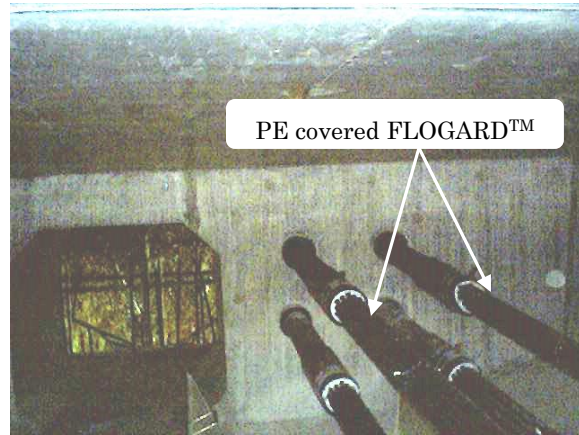
Furthermore, the minimum thickness of the epoxy coating of our normal ECS is over ~400 micrometers. This coating thickness is more than enough compared to that of generally used epoxy coatings in other steel products where thickness is typically from 50 to 150 micrometers. Therefore, the anticorrosive ability of ECS, even in severe chloride polluted region, is at a very high level.

In some cases FLOBOND™, with quartz sand embedded on its surface to allow high bonding performance with concrete, is available with embedding into grout inside of sheath, as more anticorrosive ability for coated tendon. PE sheathed FLOBOND™ is also available to allow even higher durability against chloride attack.

Now in Japan, ECS became the first choice for anticorrosive coated PC strand for chloride polluted regions. Even in the most severe chloride polluted region, the sea side of Okinawa prefecture, ECS has been applied for many numbers of bridges. And that number is steadily increasing because of the high reliability of ECS's anticorrosive ability.



Kouri Bridge (Okinawa., Japan)



In the box girder of Kouri Bridge :
Applying PE covered FLOGARD™

Q-20

Is there any case that ECS has been applied for external tendons?

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

- (1) Easy to check
- (2) Easy to install
- (3) Easy to repair (Possibility of exchange to suitable design)

(1) ECS without PE covering or sheathing can be used for external tendons inside a girder. In this application, the epoxy coating is visible in the structure after installation, so it is very easy to check the appearance of the coating. In fact, we have the experience of checking the inside of a box girder on the BY433 bridge owned by the Metropolitan Expressway Public Corporation in Japan (over 100 meters of girder with approximately ten cables, each containing 19 strands of ECS.) All of the external tendons could be checked by several people in just a few days. After 10 years of service, no abnormality was found. This level of inspect ability is not possible with a grouted sheath bare strand installation. The ease of checking ECS is one of its remarkable features.



In the girder of BY433 Bridge, checking appearance of ECS with flash light and bare eye

(After 10 years of service, no abnormality was found)

(2) The installation of ECS for external tendons in a girder is much easier than installing a grouted bare strand tendon. The ECS does not need a grouting sheath in the free length; therefore the tasks of installing the sheath and filling it with grout are avoided.

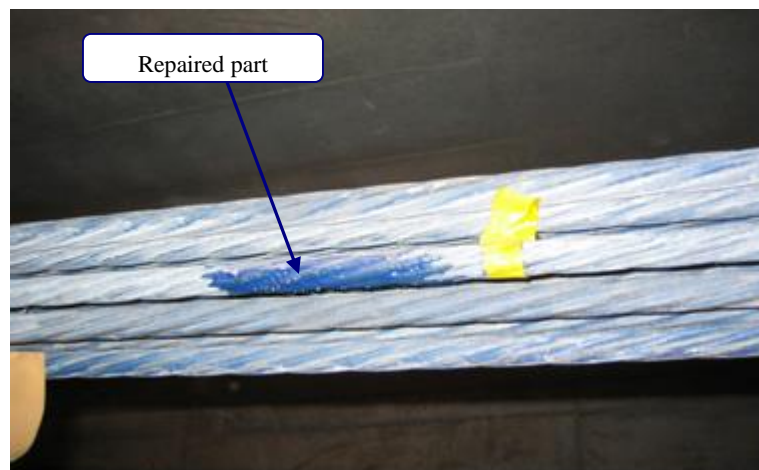
Furthermore, misalignment, like abnormal crossing or twisting of strands, can be easily recognized by monitoring throughout the installation process. Therefore, if such an abnormality is observed, it can be corrected before the tensioning process.



Installed ECS as external tendon inside of girder (Ibi Bridge : FLOGARD™)

(3) When and if a defect or malfunction is found, repair and/or replacement of a cable can be performed. This is an excellent feature of ECS external tendons. If only a repair is needed, the coating of the ECS can be repaired with a 2-part epoxy patch kit system. This repair will restore the corrosion resistance back to its original state.

In case of a malfunction when exchanging the tendon is required, ECS cables can be exchanged. However, please design the structure to make exchanging ECS feasible by taking care in the structure dimensions and the accessibility of the anchorages.



Repaired ECS (BY433 Bridge : FLOBOND™)

Typical case of ECS external tendons

Ikeda-Hesokko Bridge (Tokushima, Japan)	27S15.2mm	Akabuchi-gawa Bridge (Shizuoka, Japan)	12S15.2mm
Kiso and Ibi Bridge(Twinkle) (Mie, Japan)	19S15.2mm 27S15.2mm	Miyakoda-gawa Bridge (Shizuoka, Japan)	19S15.2mm
Ritto Bridge (Shiga, Japan)	19S15.2mm	The number of previous results are over 130 bridges.	

Q-21
Is there any case where ECS has been applied for an inner cable?

Yes. In many cases, ECS has been applied for inner cables in chloride polluted region of Japan because of the recognition of the high anticorrosive ability of ECS.

In most cases ECS, FLOBOND™, was placed in the sheath filled by cement grout for achieving much further anticorrosive ability.

We recommend to apply ECS especially for inner cable as a connecting tendon for precast segments or slabs.

Typical case of ECS inner cable

Shiosai Bridge (Hanging slab : Shizuoka, Japan)	4S 15.2mm 5S 15.2mm	Kouri-Ohashi Bridge (Okinawa, Japan)	12S 15.2mm
Kuretsubo Bridge (Pushing : Ministry of construction)	3S 15.2mm 9S 15.2mm	Futami-Ohashi Bridge (Okinawa, Japan)	12S 12.7mm 4S 12.7mm
Noho-Ohashi Bridge (Okinawa, Japan)	12S 12.7 mm 4S 15.2 mm	Other 11 bridges in Japan (As of Nov, 2007)	



Shiosai Bridge (Shizuoka, Japan) : applying ECS, FLOBOND™, for inner cable

Q-22
Is there any case that ECS has been applied for stay cable?

Yes. Many customer esteem ECS as a suitable tendon for stay cable because of its high anticorrosive ability that is kept even during construction.

The 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	Shuzuoka, Japan	385	130	37	2002	Extra dosed
Sannohe bridge	Aomori, Japan	400	200	19, 27	2004	Extra dosed
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
Yang Yang bridge	Korea	350	100	22	(2008)	Extra dosed
Moo Young bridge	Korea	860	165	27	(2008)	Extra dosed
38 Grand bridge	Korea	770	140	27	(2008)	Extra dosed
Guemodo And bridge	Korea	300	140	37	(2008)	Extra dosed
Penobscot Narrows bridge	U.S.A.	646	354	41-73	2006	Stay cable
Veterans Glass City Skyway	U.S.A.	374	187	82-156	2007	Stay cable
Ohnogawa bridge	Kumamoto, Japan	285	113	27	(2008)	Extra dosed

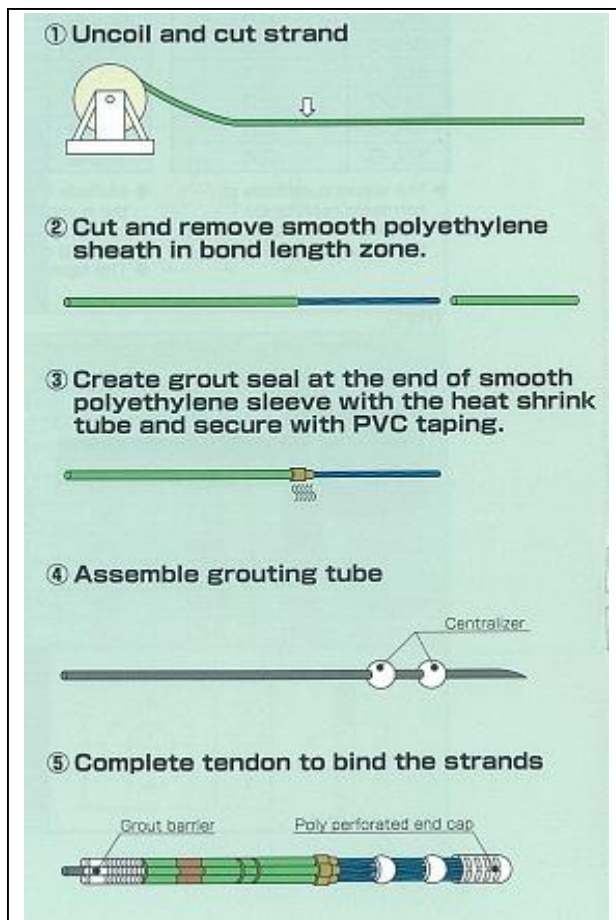
Q-23

Is there any case that ECS has been applied for Ground anchor system?

Yes. PE-sheathed FLOBOND™ has key features of prestressing strand for permanent anchor system.

- * High quality of corrosion resistance.
- * Prefabricated smooth polyethylene protects the epoxy layer from damage.
- * Keep your site clean because there is no grease between ECS and PE-sheath.
- * Easy fabrication because PE-sheathed FLOBOND™ makes anchorage system simple.

An example of processing sequence of fabrication



Q-24

Is ECS available for pre-tensioning system?

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

As a tendon for a pre-tensioning system, one of the most important features is adhesion with concrete. FLOBOND™ is a kind of ECS with embedded quartz sand on its surface for good adhesion with concrete. The adhesion force of FLOBOND™ is equivalent to or superior to that of bare strand measured by transmitted length of adhesion force. In practical use, there is one very important caution. When using FLOBOND™ for a pre-tensioning system, detensioning has to be done below 66 degree Celsius in the temperature of the concrete because the epoxy resin will soften under high temperature. In such situation, adhesion given by surface quartz sand embedded on Epoxy surface will not achieve its full potential. This may cause dangerous accidents like slipping of strand in concrete and/or losing tensioning force.



San Mateo Bridge (California, USA)

Over-sea bridge with its length of 7 mile. All of 2300 tons of ECS are used for pre-tensioning system.

Q-25

Is it possible to install ECS using a pushing machine?

Yes. It is possible to use a specially designed pushing machine for installing ECS. However, using generally used pushing machine with steel capstans will damage the coating surface.

Pushing machines can be used for both FLOBOND™, high adhesion type, and FLOGARD™.



Pushing machine specially designed for ECS

Q-26

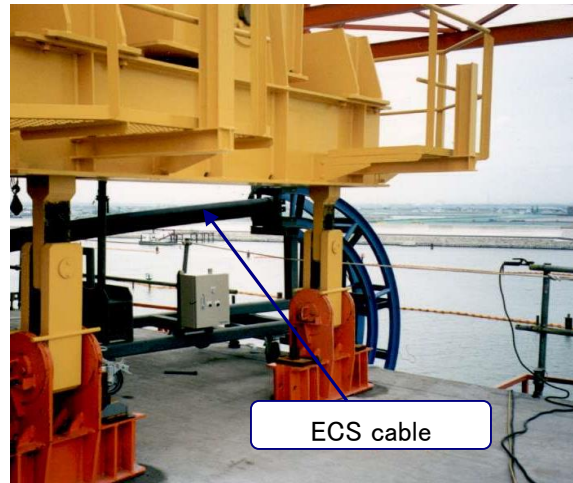
What is the precaution for preventing damage of the coating surface during construction?

The most basic precaution is to prevent ECS from direct contact with something harder than the epoxy resin like metal or concrete. Practically, installation personnel can cover expected contact points with the strand during installation with soft materials like thick fabrics, PVC pipes, wood, etc.

On the surface of bridges, placing plastic pipes and/or wooden plates along the pathline needed for ECS installation is very effective. Inside the girder, putting thin-piled carpet along the passage of ECS is also effective.

We can provide past examples of protection methods with photographs at your request.

In the position where ECS will change direction, specially designed turn rollers are also necessary. The turn-rollers should be equipped with special plastic rollers to prevent surface damage of the ECS. Please contact us for further information.



Specially designed turn roller for ECS

Q-27

What kind of treatment is needed to repair damaged epoxy coating?

Damaged epoxy coating should be touched up using a specially designed touch up patch kit.

These patch kits are designed to have the same anticorrosive ability as the original epoxy coating. This was confirmed by salt spray tests and exposure test in severe salty, corrosive regions.

Please refer to the instruction manual to learn how to use the epoxy patch kits.



Test result of 3,000 hour salt spray test with epoxy patch kit repair on an artificial crack

Q-28

What is the precaution for tensioning and re-tensioning ECS?

It is very important to use specially designed anchoring wedges and tensioning wedges inside the jack used for tensioning ECS.

The main frame of a jack used for ECS looks the same as for bare strand, but the jack for ECS is different in the detail such as the shape of the wedge pocket. Please do not use a jack designed for bare strand tensioning, when tensioning ECS. Ignoring this caution may cause a severe accident involving human lives.

It is important to make a plan to re-strain with the lowest tension on the consideration of maximum stroke of jack for re-tensioning ECS. It is also necessary for re-tensioning to apply specially designed lubricant agent, Moricoat™, on surface of wedges to ease attach and detach of wedges to ECS.

Q-29

Where is ECS manufactured?

We could supply ECS from those factories mentioned below to all over the world.

Please contact us for more information.

Factories in the world

SSW

Sumitomo (SEI) Steel Wire Corp.,
Itami, Hyogo, Japan

JFS

Jiangyin Fasten Sumiden New Material Co.,
Jiangyin, Jiangsu, China

SWPC

Sumiden Wire Products Corp.,
Stockton, California, U.S.A.



The second Mactan Bridge (Philippines) : ECS stay cable

SUMIDEN WIRE PRODUCTS CORPORATION

Contact us at:

Tel: (866) 491-5020 (East), (866) 246-3758 (West)

E-mail: supportpc@sumidenwire.com

URL: <http://www.sumidenwire.com>

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