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High corrosion resistance of ACFR conductor

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SUMMARY

Regarding new overhead conductor cable technology called as "Carbon Fiber Composite Core conductor", the technology shows great interest in its superior characteristics increasing the capacity, low sagging and low losses without doing any changes in existing tower structure modifications.
But the product life time with respect to corrosion aspect is also an important factor to be considered. This paper brief about the corrosion aspect of ACFR (Aluminum Conductor Fiber Reinforced) conductor which use Carbon Fiber Composite Cable (hereinafter, called CFCC) as core.
Tokyo Rope International Inc. (TRI) performed a salt spray test for evaluating the corrosion resistance of the ACFR compare to the ACSR. As a result, almost no corrosion occurred in the ACFR with compare to ACSR in which the steel core and the aluminum conductor caused corrosion. It was confirmed that the ACFR has better corrosion resistance compare to the ACSR.

KEYWORDS

HTLS Conductor, Carbon fiber composite core, ACFR, Reconductoring transmission line, Carbon composite core conductor, Corrosion, dissimilar metal, Galvanic corrosion, Bimetal corrosion

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1. Introduction

In recent years, due to its excellent properties, using carbon fiber as a core material is more popular and it is preferable choice for global power transmission utility. There are several overhead conductor cable manufacturers who use different types of carbon fiber composite as a core of conductor cable. Especially, these are being introduced to the market where power demand is vigorous.

Product service life of conductor cable may exceed 40 years. One of important factor that determines the product life of conductor cable is "corrosion". ACSR consists of steel core and aluminum where both materials are not having same potential differences. Corrosion often becomes a serious problem depending on the use environment. It is very important to evaluate that conductor cable using carbon fiber core has sufficient corrosion resistance performance even when compared with ACSR.

2. Characteristics of ACFR

Aluminum Conductor Fiber Reinforced (hereinafter, this is called "ACFR") conductor construction is as simple as ACSR conductor where the stranded steel core is replaced with stranded carbon fiber composite core. The trapezoidal wire shaped construction of ACFR conductor is shown in Figure-1.

The raw material carbon fiber and epoxy resin matrix are bunched together to form a composite wire and are coated with protection layer. And thus formed single carbon fiber composite wires are stranded together to form a stranded Carbon Fiber Composite Cable (hereinafter, this is called "CFCC"). CFCC has the same advantage as that of the single carbon fiber composite core like higher strength, lower weight, lower thermal expansion and higher corrosion resistance.

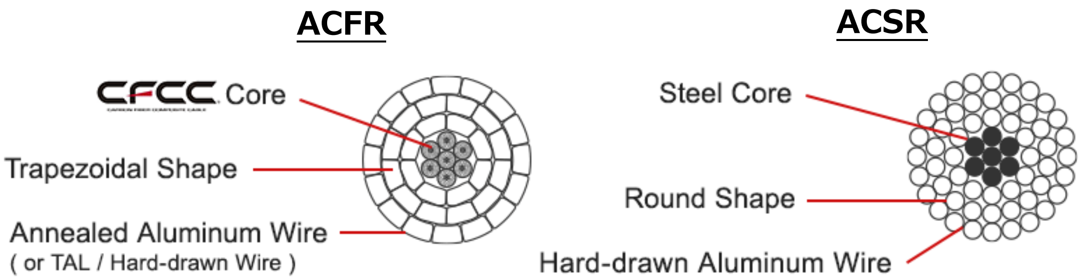


Figure-1 The trapezoidal wire shaped construction of ACFR and ACSR

3. Mechanism of corrosion

There are several mechanisms of corrosion. Here lists the major ones.

(1) Galvanic corrosion (Figure-2, aka. Bimetallic corrosion)

When two metals with different electrode potentials (ex. aluminum and steel) contacts each other in the presence of an electrolytic solution (ex. salt water), the less noble metal corrodes faster.

This corrosion shall occur when both of the following two conditions are met.:

(i) the dissimilar metals come in contact with each other electrically,

(ii) both metals are immersed in one electrolytic solution.

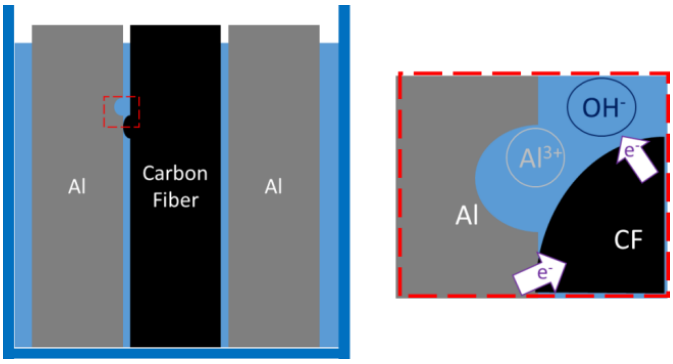


Figure-2 Galvanic corrosion

(2) Pitting corrosion (Figure-3)
Normally aluminum exposed to the atmosphere has a thin oxide skin on its surface, which protects the metal from further oxidation. When the skin is destroyed by attacks of chloride ions (Cl^-), corrosion starts at that specific point. Theoretically this type of corrosion has nothing to do with other materials, and sometimes results in pits extending from the surface into the metal.

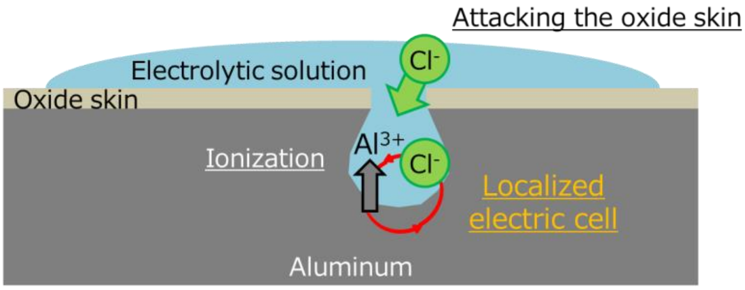


Figure-3 Pitting corrosion

(3) Crevice corrosion (Figure-4)
When aluminum has some deposits on its surface, then the deposits makes a narrow spaces (this is called "crevice") which the access of the working fluid from the environment is limited. When the inside and outside of that crevice have different oxygen concentrations, aluminum inside the crevice corrodes faster due to the formation of an oxygen concentration cell.

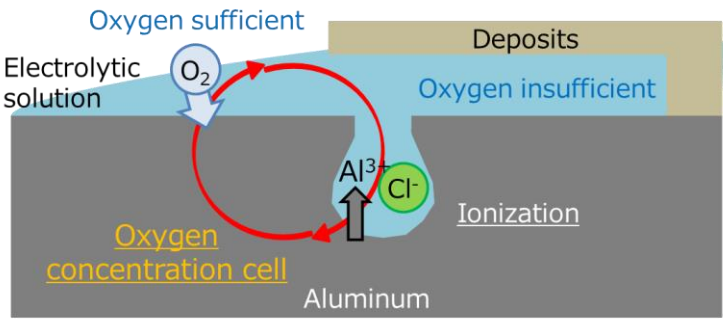


Figure-4 Crevice corrosion

4. Progressive behavior of corrosion

The environmental factors related to corrosion of overhead transmission lines are almost caused by sea salt. In the survey results in Japan, data showing that sea salt corrosion has occurred is 74%. [1]

Sea salt corrosion mechanism is based on galvanic type corrosion and this is characterized mainly in inner aluminum wire layer of overhead conductor.

, based on galvanic corrosion, is characterized by corrosion progress of aluminum conductor mainly inside the electric wire (shown in Figure-5 [2]).

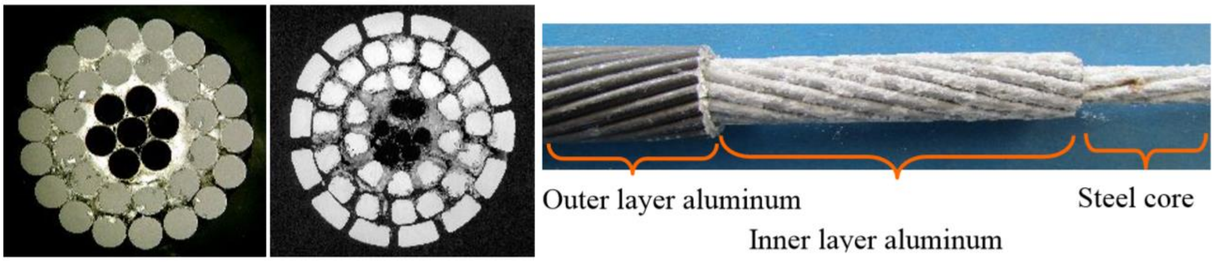


Figure-5 ACSR sample from coastal area of Japan [2]

In ACSR, it is known that galvanic corrosion occurs at the interface between steel core and Aluminum layers/strands during its service life. Similarly, galvanic corrosion occurs between carbon fiber and aluminum layers/strands if carbon fiber and aluminum are contacted directly in the presence of an electrolytic solution.

In ACFR, a protection layer impregnated with epoxy resin is wrapped around the each strand of the carbon fiber composite material (Figure-6). The protection layer prevents direct contact between carbon fiber and aluminum layer of ACFR.

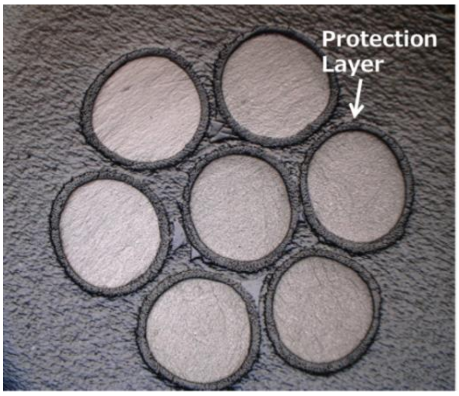


Figure-6 Protection layer of CFCC

Among these corrosion mechanisms, it is difficult to estimate which mechanism will be dominant for overall corrosion. For this reason, a salt spray test, which is expected to reproduce the actual corrosive conditions in practical use, was conducted to compare the corrosion characteristics of ACFR and ACSR.

5. Appearance evaluation in salt spray test

In order to accelerate evaluation of the occurrence of corrosion, salt spray test was applied. The testing conditions are as shown in Table-1.

Due to period of time duration, 1,000 hours is the longest “recommended periods of exposure” in ISO 9227:2012. 2,000 hours in which salt spray test was carried out was twice the longest time 1,000 hours in ISO, and this was used as a breakpoint for our evaluation.

Conductor specimens were shown in Table-2. All the conductors were subjected to a salt spray test with the outer layer of the aluminum conductor stripped in order to make significant difference in a short testing time.

Table-1 Testing condition of salt spray test

Description	Value
Testing standard	ISO 9227:2012 (This is equivalent to ASTM B117-16 and JIS Z 2371.)
Test solution	50 g/L sodium chloride (pH 7.0)
Period of time duration	1,000hr, 2,000hr
Testing apparatus	Salt splay testing machine at Tokyo Rope laboratory (Picture shown in Figure-7)

(i) ACFR and (ii) ACSR are simple relative comparisons.
(iii) The study was also carried out with two conditions of ACFR that is one sample "with" protection layer CFCC core and the other "without" protection layer CFCC core.

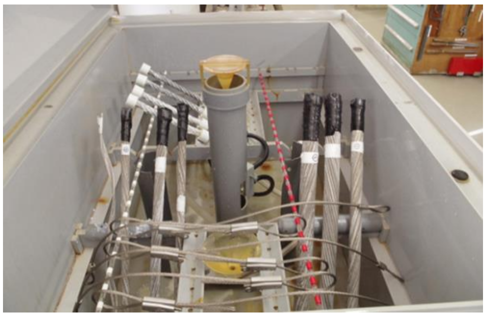
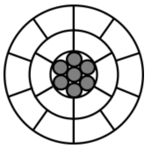
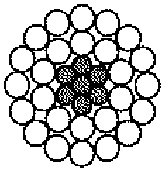
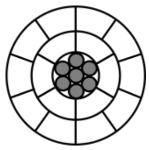
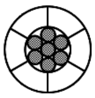
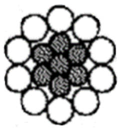
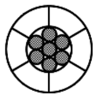


Figure 7 - The overview of apparatus setup

Table 2 - Testing condition of salt spray test

Description	Unit	Value		
		(i) ACFR 315	(ii) ACSR 410	(iii) ACFR 315
Whole conductor	-			
Tested condition	-			
Detail	-	Trapezoidal shaped aluminum wire, CFCC core "with" protection layer	Round shaped aluminum wire, Zinc-coated steel core The amount of Zinc coating: 260 g/m^2 or more (JEC-3404-2010).	Trapezoidal shaped aluminum wire, CFCC core "without" protection layer
Core size	Nos./mm	7 / 2.6	7 / 3.5	7 / 2.6
Aluminum conductor size	Nos./mm	6 / 4.98 (Outer 10 / 4.98)	10 / 4.5 (Outer 16 / 4.5)	6/4.98 (Outer 10 / 4.98)
Outer diameter	mm	22.36	28.5	22.36

6. Result of appearance evaluation in salt spray test

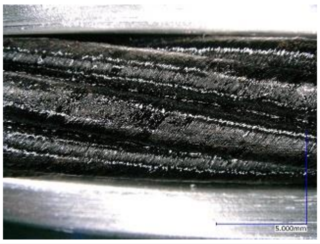
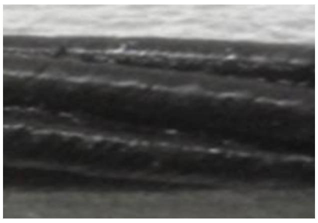
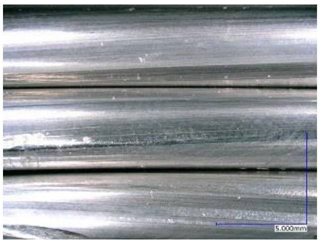
(i)ACFR (core “with” protection layer): After completion of 2,000 hours test, the inner surface of the aluminum conductor was a shiny and with good surface condition by seeing with naked eye. And there was no indication that galvanic corrosion occurred.

(ii) ACSR (Zinc coated steel core): After completion of 2,000 hours test, the inner surface of the aluminum conductor was not shiny when compared with the sample before salt spray test. And Aluminum hydrate adhered on its surface. It was observed that small red rust in the steel core even with the presence of Zinc coating, it was understood that steel and aluminum both were contacted each other and galvanic corrosion has occurred.

From the above, in the ACFR, protection layer hardly prevents progress of galvanic corrosion by avoiding direct contact between CFCC core and aluminum conductor. Moreover, corrosion resistance performance of ACFR is considered that it might be better than ACSR which cannot avoid contact with dissimilar metals corrosion.

(ⅲ) ACFR (core “without” protection layer) : After completion of 2,000 hours test, although the shine on the inner surface of the aluminum conductor is partly lost, the surface condition is good and there are no signs of corrosion due to dissimilar metals is occurring.
The ACFR without protection layer, it was observed that the carbon fiber is exposed on the surface, but its surface area is very smaller than the area of the aluminum conductor. The contact of carbon fiber and aluminum conductor may initiate the galvanic corrosion, but its corrosion rate is slow compared to the corrosion rate of ACSR.

Table-3 Appearance comparison in salt spray test

Specimens		Initial state 0 hour	Salt spray 1,000 hours exposure	Salt spray 2,000 hours exposure
(i) ACFR	Aluminum conductor			
	CFCC core			
(ii) ACSR	Aluminum conductor			
	Steel core			
(iii) ACFR without protection layer	Aluminum conductorr			
	CFCC core			

7. Salt spray test by Kinectrics

The results of salt spray test that was conducted by Kinectrics Canada are shown in this section. The condition was based on ASTM B 117 and test date: June, 2018 – August, 2018. 550 mm^2 ACFR / TW (Core designation: 7 / 3.2, 9.6 mm CFCC) was used for evaluation.

The objective of the salt spray test is to investigate the effects of a controlled salt spray exposure on samples of 550 mm² ACFR/TW conductor for 1,000 hours. After completion of 1,000 hours of test, tensile strength test for Aluminum wire and CFCC core was performed. All three (3) samples were simultaneously subjected to salt spray exposure in an environmental chamber operated for 1000 hours (Before salt spray test, shown in Figure 8).

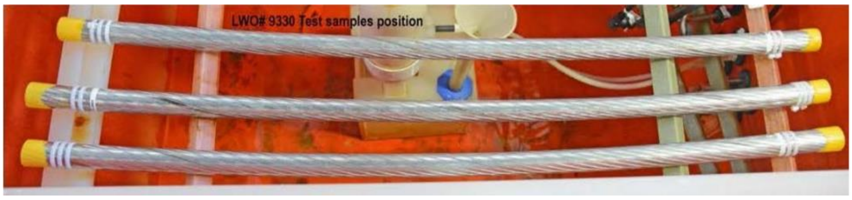


Figure-8 550 mm² ACFR/TW Conductor specimens of salt splay test

The condition of the samples after the salt-spray exposure is shown in Figure 9. Minor discoloration of the aluminum wires was noted after 1,000 hours salt spray exposure samples. Overall there were no significant signs of pitting, corrosion or deterioration noted on any component of the conductor after the 1,000 hours salt-spray exposure.

Figure-9 550 mm² ACFR/TW Conductor specimens of salt splay test

Material property test results after 1,000 hour salt spray exposure are shown in Table 4. The measured tensile strength of the CFCC core is 119.8% RTS and aluminum wires are 117% RTS after completing the 1,000 hour salt spray exposure (Table-4).

The sample of 550 mm² ACFR/TW conductor including 7/3.2, 9.6 mm CFCC core, as tested, met the requirements for the salt spray test as defined in Cigre Technical Brochure TB 426 “Guide for qualifying high temperature conductors for use on overhead transmission lines”.

Table-4 Tensile strength test results after salt spray exposure

Conductor Component	Aluminum Wires (Outer Layer)	Aluminum Wires (Middle Layer)	Aluminum Wires (Inner Layer)	7/3.2, 9.6 mm CFCC Core
Average Tensile Strength	66.82 MPa (117.2% RTS)	67.67 MPa (118.7% RTS)	66.22 MPa (116.2% RTS)	144.96 kN (119.8% RTS)

8. Conclusion

- ✓ Regarding ACFR, since the CFCC core is covered with protection layer, the progress of galvanic corrosion is much slower than ACSR. And ACFR has excellent corrosion resistance performance.
- ✓ It was confirmed that there was no change in mechanical properties in the 1,000 hour salt spray test conducted in Kinectrics in accordance with Cigre Technical Brochure TB 426.

BIBLIOGRAPHY

[1] The Institute of Electrical Engineers of Japan, Technical report No.968, Page5-6, June 2004

[2] I. Ito et al. “Corrosion Characteristics on an Investigation of Sampled OHTL Conductors and a Probabilistic Lifetime Estimation Method” CIGRE B2_213_2012