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Enhancement on Al–Mg–Si alloys against failure due to lightning arc occurred in energy transmission lines

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A B S T R A C T

This article has been prepared to share some experience and technical investigation related to lightning and short circuit strength of the OPGW type conductor used in transmission lines. It is well known that overhead ground wires are vulnerable to strand breakage due to lightning strikes. Recently applications of composite fiber optic ground wire have become more important to protect them from such damage. In this paper, we present test results before and after application of modification to the main conductive part of the conductor, which is composed of AA-6101 alloy, galvanized steel and SS-steel tube with fibers. Modification of AA-6101 aluminum alloy was performed by adding 3% AlB_2 into molten metal. After having completed manufacturing of the improved feedstock at CCL, we performed the drawing and stranding of wires.

1. Introduction

Overhead ground wires (OPGWs), installed on the upper portions of overhead transmission lines to protect conductors from lightning, may have their strands broken when struck by lightning with extremely powerful energy [1]. Particularly, those lines passing through areas where winter lightning with big energy frequently occurs or areas total days on which lightning occurs, is comparatively high require upgraded lightning resistance overhead ground wires to increase reliability of the power transmission systems [2–6]. Two types of OPGW are available at present [7]. One is a tight buffer type, where the optical fibers are housed with tension members. The other is a "loose buffer type", where the optical fibers are loosely housed inside the tube. The representative tight buffer type called "spacer type" has an aluminum spacer inserted in the aluminum tube to suppress fiber movement. It is mainly used by Japan domestic power companies and has proved extremely reliable in actual installations. The representative looses buffer type, predominantly produced in Europe and called the "stainless steel tube type" has fibers having surplus length and a jelly compound inserted into the stainless steel tube. Grease is used to fill up spaces between the tube and aluminum clad-steel or galvanized steel and aluminum alloy wires AA-6101 or AA-6201 to avoid galvanic corrosion due to different metal contacts with each other. However, if the stranding of the wires is not formed perfectly, the gaps between wires cause the grease to leak during heavy rain. The other issue is that grease can become hardened by sunlight or a dry atmosphere; prolonged exposure to these environmental conditions causes the grease's anti-corrosion effect to weaken. This phenomenon is exacerbated in particularly harsh environments. These events

Abbreviations: GW, ground wire (≅ground conductor); OPGW, Optical ground wire; AA, aluminum alloy (AA-6101 or AA-6201); AAI, aluminum alloy inoculated with AlB_2; ACS, Aluminum-clad steel wire; CST, Aluminum-clad steel tube; GSW, galvanized steel wire; SST, stainless steel tube; CCL, continuous casting line; RTS, rated tensile strength; UTS, Ultimate tensile strength.

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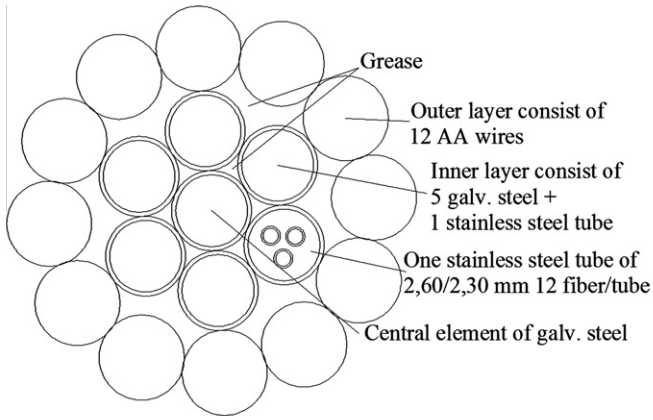

Fig. 1. Cross sectional view of OPGW.

cause galvanic corrosion problem, the solution of which is recently applied as a cladding steel fiber tube with EC grade aluminum. OPGW consists of such material as steel tube, aluminum clad steel tube [8,9], aluminum alloy AA-6101, galvanized steel wires, and aluminum clad steel wires. Manufacturing of various types of combinations is possible by choosing one of the materials. Most of the overhead line projects are performed mainly 6 galvanized steel wires and 1 SS tube and 12 aluminum alloy wires.

One explanation should be noted that when comparing different OPGW types, the combination with Al clad steel wires is better than galvanized steel wires due to the absence of galvanic action between different materials. The tensile strength of the conductor constructed with Al clad steel wire is lower than conductor reinforced with galvanized high strength steel wires due to decreasing of the diameter for coating of aluminum. That is why; the most demanding design for the ground conductor is related to material combination with extra high galvanized steel, loose tube and Al–Mg–Si alloy wires in transmission lines. Then the proposed design indicated in Fig. 1 was exposed to lightning tests. But most of the aluminum wires were damaged completely in the first trial. To get rid of the failing problem under lightning current, it has been decided that main conductive part should be improved to pass required test specifications. Application of the test procedure for a new product can be categorized according to product properties and country specifications. Some of them are very important also the satisfaction of the test requirements may be very arduous. Hence manufacturers have to improve some parts of proposed construction. Another primary parameters for the specification of the OPGW is that the short-circuit current that circulates during the occurrence of a phase-to-ground fault near the substation.

In this study, theoretical calculation of short-circuit the OPGW has been verified perfectly by means of the laboratory results. However, theoretical studies of the OPGW related to lightening test were verified due to broken the outer layer wires. Thus, material improvement (Al–Mg–Si alloy) has been performed in CCL by feeding of 3% AlB_2 compound into a tundish located between holding furnace to casting wheel. Then the wires drawn modified feedstock were used in OPGW. The final product passed lightening test perfectly.

2. Design and construct of the OPGW

By considering the environmental conditions of the line district, a versatile type has been designed and manufactured [10]. Cross sectional view and properties of sub-parts are explained in Fig. 1. The most important part in design parameters is the conductive part which is Al–Mg–Si alloy (AA6101 or AA6201) section. Spectral analyses of the conductive material

Table 1
Spectral analysis of AA-6101 sample in % wt.

Mg	Si	Fe	Cu	Zn	B	Cr	V	Ti
0.58	0.52	0.20	0.07	0.08	0.05	0.03	0.022	0.02

Table 2
Test results of drawn wires in T-8 condition from AA-6101 feedstock non-inoculated with AlB_2.

Diameter (mm)	Cross-section (mm^2)	Resistivity (ohm mm^2/m)	DC resistance at 20 °C (ohm/km)	Condition (% IACS)	Breaking load (N)	Tensile strength (N/mm^2)	Elongation at 250 mm (%)
3.04	7.26	0.032347	4.457	53.3	2469.07	340.17	6.7
3.05	7.31	0.032653	4.469	52.8	2522.53	345.26	6.5
3.06	7.35	0.032715	4.449	52.7	2524.39	343.26	7.0
3.07	7.40	0.032408	4.378	53.2	2593.03	350.3	7.1
3.08	7.45	0.032469	4.358	53.1	2624.18	352.21	7.5