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Corrosion of all Aluminium Alloy Stranded Conductors-A Case Study

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Aluminium conductor Steel reinforced (ACSR) material has been in use since the beginning of 20th century for transmission and distribution of electrical energy. All over the world ACSR gained acceptance and is still being used. All Aluminium Alloy Conductors (AAAC) made of Al-Mg-Si alloy, first introduced in France gained popularity because of its higher strength compared to EC grade Aluminium of equivalent size, less weight, higher corrosion resistance and non-magnetic nature compared to ACSR. Over the years different combinations of Al, Mg, Si, have been adopted to meet the desired strength and conductivity. The first alloys introduced were non-heat treatable. Later, heat treatable and artificially aged conductors with still higher strength were introduced.

The application of AAAC has been widely accepted in India. However, instances of corrosion damage are reported despite the fact that all the quality norms are followed for the procurement of conductors. This paper deals with various aspects of corrosion damage occurred to the conductors. The damage occurred to the conductors have been investigated from the point of view of its composition, manufacturing process, strength, resistance to corrosion and method of storage.

1.0 INTRODUCTION

The major deficiencies of Aluminium Conductor Steel Reinforced (ACSR) material like heavy weight and inferior corrosion resistance led to the development of Aluminium-Magnesium-Silicon alloy conductors. The Al-Mg-Si alloys have different trade names in different countries and the alloy 64401 used in India is equivalent to alloy 6201 of USA. The Al-Mg-Si alloy wire rod is produced by two ways i.e. Batch process and continuous process. The continuous process is preferred to the batch process in view of the consistent properties of the wire rod produced. Corrosion resistance of Al-Mg-Si alloy has been a controversial subject in many countries for many years.

Godard etal discussed the corrosion aspects of Al-Mg-Si alloy in detail(1).

A case of corrosion damage to All Aluminium Alloy Panther Conductors was reported from a utility site. The corrosion problem was noticed both in the originally supplied drums as well as replaced ones. All the quality assurance procedures followed in the procurement of these bundled conductors conform to IS standards (2,3). The failure analysis of these conductors involved visit to the utility site, on the spot assessment of corrosion problem, collection of conductor samples and polythene sheet for Laboratory investigations.

2.0 VISUAL EXAMINATION AND COLLECTION OF SAMPLES

On the spot assessment of corroded Panther Conductors was made by visiting the utility site. The conductor drums each containing 37 strands with individual strands measuring 2.88 mm diameter were placed in an open yard. Out of six drums inspected, corrosion occurred in conductors of drums A, B, C and E. No corrosion was noticed in

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the conductors belonging to drums D and F. The conductor bits reported to be from drum G was also not corroded. Severe corrosion occurred in conductor A. Substantial corrosion along with condensation of moisture was noticed in conductor B. In the case of conductor C, the Polythene wrapping had marking on inner surface which appeared to be a corrosion product. Corrosion occurred at the middle and top portion as well as edges of the drum. Figures 1 & 2 show corrosion in conductor A an no incidence of corrosion in conductor D respectively.

FIG. 1. CORROSION IN CONDUCTOR-A

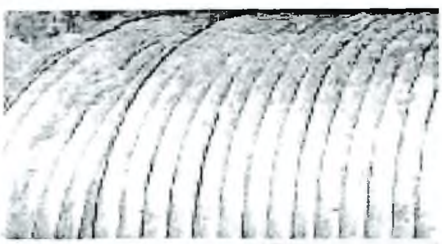


FIG. 2. NO CORROSION IN CONDUCTOR -D

During the site visit, the samples of conductors pertaining to drums A, B, C, D, G and a sample of Polythene wrapping with white mark from drum B were collected for Laboratory investigations.

3.0 LABORATORY INVESTIGATIONS

The samples collected at site were subjected to various tests/analysis at the laboratory as outlined below.

The elemental analysis of conductor strands was carried out using Optical Emission Spectrometer. The elemental analysis of corrosion products was conducted using SEM with Energy Dispersive X-ray Analyser. The portions of corroded conductors were cut, cleaned as per ASTMG-1 90 procedure for quantifying the corrosion product (4). The weight loss measurements of the conductors were carried out by immersing the conductor specimens in 1 M Hydrochloric acid solution for a period of 2.5 hours at 30 ± 1°C.

The electrical resistance of conductor strands was determined using a Digital micro ohmmeter. The breaking load and elongation of the conductor strands were measured by Universal Testing Machine.

The SEM photomicrographs of cleaned conductors were taken to examine the extent of corrosion.

The corrosion potential and corrosion rate of conductors were estimated in accordance with ASTMG 69-81 (Reapproved 1994)(5). The Aluminium conductors were cut into one-metre length specimens and rolled into coils. For each conductor, 4 specimens were prepared, cleaned as per ASTMG 1-90 and weighed in an electronic balance. These specimens were exposed to salt spray solution (5% NaCl solution) for 15 days in a corrosion chamber as per ASTMB 117-95 (6). After 15 days of exposure the specimens were cleaned as per ASTMG 1-90 dried and weighed. The rate of corrosion of conductors was calculated from the loss in weight.

4.0 RESULTS AND DISCUSSION

The Table 1 shows the results of elemental analysis of conductor strands which indicate that the elemental composition of corroded conductors A, B & C are as per AAA conductor specifications.

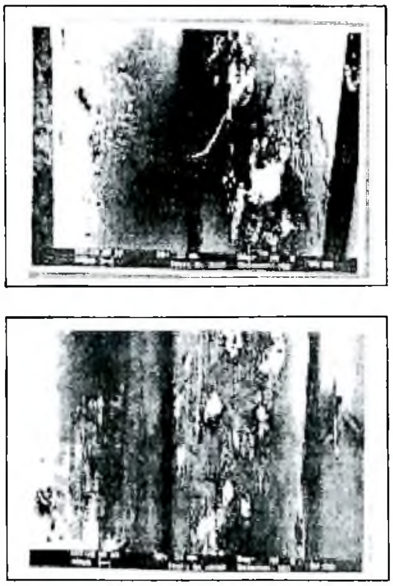
TABLE 1

ELEMENTAL ANALYSIS OF CONDUCTOR STRANDS (PERCENTAGE BY WEIGHT)

Element	Sample from Drum No.					AAA Conductor Specification
	A	B	C	D	G	
Copper	0.078	0.043	0.049	0.021	0.05	0.10 (Max)
Magnesium	0.59	0.75	0.070	0.69	0.54	0.60–0.90
Silicon	0.51	0.53	0.57	0.43	0.45	0.50–0.90
Iron	0.37	0.50	0.54	0.36	0.38	0.50 (Max)
Manganese	0.057	0.0030	0.006	0.045	0.049	0.03
Nickel	0.001	0.002	0.005	0.001	0.001	*
Zinc	0.053	0.006	0.002	0.018	0.069	*
Lead	0.005	0.004	0.004	0.005	0.005	*
Titanium	0.004	0.002	0.002	0.003	0.002	*
Chromium	0.005	0.002	0.002	0.003	0.002	0.03 (Max)
* Other elements total						0.10 (Max)

The electrical resistance of conductors A, B, C, D, E are 5.36, 5.25, 5.05, 4.98, 5.03 mΩ/M against a specified value of 5.141 mΩ/M. The corroded conductors exhibited poor mechanical strength. In the case of conductor A breaking load and % elongation values are 1.49 kN and 0.5% respectively against a requirement of 1.83 kN and 4%. In the case of conductors B & C, the breaking load values 2.06 kN and 2.16 kN respectively meet the requirements. However the elongation values 3.02% and 2.15% in these conductors are lower than the requirements.

Figs. 3a & b show the SEM photomicrographs of severely corroded conductor A. Corrosion pits, corrosion product and peeling are clearly seen in these photomicrographs establishing severity of corrosion attack in the conductor A.



(a)

(b)

FIG. 3. CORROSION PITS, CORROSION PRODUCT AND PEELING IN CONDUCTOR-A

Table 2 shows the elemental analysis results of corrosion product present on the conductors and polythene wrapping. The major elements present in the corrosion product are Aluminium, Carbon and Oxygen. The concentrations of Sodium, Sulphur and Chlorine are higher in all the conductors except in conductors D & G. The corrosion product is a carbonate of Aluminium.

Table 3 shows that the corrosion rate of conductors determined on as received basis and in 1M Hydrochloric acid is in the order A>B>C>G>D.

Table 4 shows the results of electrochemical measurement of conductors accomplished as per ASTMG 69-81 which reveal that the corrosion resistance of conductors A, B & C are lower than that of D & G.

TABLE 2

ELEMENTAL ANALYSIS OF CORROSION PRODUCT (PERCENT BY WEIGHT)

Element	Sample from Drum No.					Polythene Wrapping Drum B
	A	B	C	D	G	
Carbon	4.43	4.15	9.44	5.21	3.99	9.89
Oxygen	47.10	57.50	55.26	15.03	18.89	55.7
Sodium	0.11	0.07	0.54	-	-	0.65
Magnesium	0.21	0.16	1.46	0.80	1.09	1.21
Aluminium	44.70	34.91	27.99	76.26	68.36	27.5
Silicon	0.94	1.15	1.43	1.71	4.69	1.59
Phosphorous	0.16	0.18	0.75	0.09	0.23	0.61
Sulphur	0.57	0.13	0.45	0.10	0.06	0.41
Chlorine	0.40	0.19	0.30	0.05	0.05	0.23
Potassium	0.17	0.09	0.85	0.10	0.32	0.92
Calcium	-	0.02	1.03	0.05	0.10	0.73
Iron	1.15	1.46	0.49	0.61	2.23	0.51

TABLE 3

CORROSION RATE OF CONDUCTORS: (1) AS RECEIVED BASIS (2) 1M HCL

Sample Drum No.	Rate of Corrosion as received basis g/m^2 . hr.	Rate of corrosion in 1M HCl	
		% Weight loss	Corrosion rate $mg/cm^2/day$
A	13.29	20.7	488
B	10.02	17.8	417
C	1.49	15.4	293
D	0.82	3.9	90
G	1.29	7.4	172

TABLE 4

ELECTROCHEMICAL MEASUREMENTS

Sample Drum No.	E(mV)	Corrosion Current ($\mu A/cm^2$)	Corrosion Rate (mpy)
A	−737	806	245
B	−745	769	234
C	−743	712	217
D	−742	242	74
G	−736	578	178

Table 5 provides the results of Salt spray experiment conducted on conductor specimens as per ASTMB-117-95. These results further demonstrate that the corrosion resistance of conductors A, B & C are lower than that of D & G.

TABLE 5

CORROSION RATES BY SALT SPRAY TEST AS PER ASTMB 117-95

Sample from Drum No.	Rate of Corrosion in $g/m^2.hr$
A	0.0054
B	0.0060
C	0.0051
D	0.0048
G	0.0043

During the site visit, out of 6 conductor drums inspected, corrosion was observed in 4 conductor drums. The degree of corrosion varied from drum to drum. The conductor drums were kept in the open yard over brick soling. It was noted that uncorroded conductors D & G were received at site one year earlier to the corroded conductors A, B & C.

It is reported that the corrosion resistance of group 6000 (Al-Mg-Si) alloys has been a highly controversial subject in many countries for many years and complete agreement has not been reached (1). It is also reported that as the diameter of the wire gets reduced the material becomes more prone to corrosion. Another point to be noted is that when extruded alloy is air quenched or heated for several hours at 530°C, the surface film contains sufficient magnesia (MgO) to impair its corrosion resistance.

Further, it is emphasized that the most common causes of Aluminium corrosion have been improper choice of alloy, poor designs or faulty constructions/manufacturing process.

In the present instance, the conductor drums were kept in the open yard. As the drums were kept for sufficiently longer period (more than 6 months), the alternate wet and dry conditions seems to have affected the conductors. Further, as the diameter of the individual strands is 2.8 mm it is also having a bearing on corrosion resistance as discussed earlier.

5.0 CONCLUSIONS

1. Severely corroded conductors A, B & C were lying in the open yard for a shorter duration than the uncorroded conductors D & G under the same environmental conditions. This fact indicates that there is inconsistency in the conductor material behaviour. This material behaviour is attributable to the batch to batch variations in the production cycle.
2. The corroded conductors while compositionally meet the specifications, exhibit higher electrical resistance and lower mechanical strength.
3. The SEM photomicrographs of corroded conductors clearly show the corrosion of pitting type and peeling of the conductor material
4. The corrosion experiments demonstrated the variations in the corrosion behaviour of the conductors indicating again the inconsistency in the material. The corrosion appears to have occurred due to the material inconsistency. The alternate wet and dry conditions at the site and the diameter of the strand appear critical

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