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Experimental Study on Corrosion of Grounding Metal in Earthing Enhancing Compound

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***Abstract*—The corrosion of grounding metal materials in earthing enhancing compound may be occurred, so the corrosivity of earthing enhancing compound must comply with the provisions of relevant standards. Weight loss method is usually used to test the corrosivity of earthing enhancing compound at present, which consists of two experiment procedures: 1) laboratory experiment; and 2) field experiment. The corrosion rate of earthing enhancing compound is calculated on the basis of the weight change of the sample before and after the test, the value used to determine whether the earthing enhancing compound is up to standard. In this paper, the corrosivity of earthing enhancing compound of one particular brand was tested using weight loss method, the results of which showed that the corrosivity of this earthing enhancing compound does not conform to the requirements of relevant standards. There are deficiencies with traditional tests such as weight loss method, so it is recommended to employ the electrochemical test method to obtain the corrosivity of earthing enhancing compound.**

Keywords- grounding device; corrosion rate; earthing enhancing compound; weight loss method; field experiment; laboratory experiment

I. INTRODUCTION

Earthing enhancing compound is a lightning proof product which has the advantages of easy construction, outstanding longevity and stability and is less vulnerable to weather conditions. It is widely applied in grounding devices [1-4]. As one of the important technical parameters of earthing enhancing compound, corrosivity is typically tested in line with relevant industrial standards [5, 6]. Traditional test methods such as weight loss method are usually used to test the corrosivity of earthing enhancing compound at present, which consists of two experiment procedures: 1) laboratory experiment; and 2) field experiment. The corrosion rate of earthing enhancing compound is calculated on the basis of the measured weight change of the sample before and after the test [7, 8]. This paper is intended to conduct laboratory and field experiments on the corrosion of metal materials in earthing enhancing compound using the weight loss method in accordance with QX/T104-2009 *Grounding Resistance Reduction Agent* [5], for the purpose of examining the corrosion of metal materials in earthing enhancing compound.

II. EXPERIMENTAL PREPARATION

Samples used in this corrosion test include galvanized flat steel, non-galvanized flat steel, galvanized round steel and non-galvanized round steel. Before the test, flat steels were cut into 25mm (L) × 50mm (W) × 2.5mm (H) samples, and round steels were cut into samples measuring 10mm in diameter and 50mm in length, as illustrated in Fig. 1 and Fig. 2. The earthing enhancing compound of a particular brand was selected for laboratory and field corrosion tests. During the test, an analytical balance was used to weigh the samples before and after test. The laboratory test was conducted in a specially designed corrosion chamber, while the field test was performed in outdoor soils collected from Chongqing Field Experimental Base for Lightning Protection.

Figure 1. Galvanized and non-galvanized flat steels

Figure 2. Galvanized and non-galvanized round steels

III. LABORATORY CORROSION TEST

In the laboratory corrosion test, we prepared 40 samples out of galvanized round steel, galvanized flat steel, non-galvanized round steel and non-galvanized flat steel, 10 for each. Then,

rinse the rusted samples with alcohol and dry them at 100±1 °C for 1h in a thermostat. Allow the samples for cooling to the room temperature. Following that, use a balance with a sensitivity of 0.1mg to weigh all the samples. The weights of the samples before test are summarized in Table I. After that, place the dried and weighed samples horizontally in a sample case as shown in Fig. 3, with a 40mm thick layer of earthing enhancing compound paved at the bottom. After all samples were placed into the case, cover the samples with another 40mm thick layer of earthing enhancing compound, as illustrated in Fig. 4. After 1h, spray distilled water at the sample case until the water accumulated on the case surface adds up to 5mm. And then wrap the case with a double-layer plastic film to prevent evaporation of water. Finally, store the sample case in a place not exposed to heat or direct sunlight for 90d. And then take out the samples, rinse, remove dust and weigh them. The weights of all the samples after test are summarized in Table II.

TABLE I. WEIGHTS OF SAMPLES BEFORE LABORATORY CORROSION TEST

Weight before test	W_B/g			
Sample	Galvanized flat steel	Non-galvanized flat steel	Galvanized round steel	Non-galvanized round steel
1#	30.3204	29.7885	24.1145	30.9467
2#	30.6464	30.7745	23.3522	30.6651
3#	29.7878	30.0120	23.3507	30.9463
4#	29.2271	29.7476	22.7140	32.5971
5#	30.3092	29.9339	24.4509	32.3377
6#	29.8488	30.3582	23.9388	31.7900
7#	30.8563	29.6747	24.1169	30.7333
8#	29.3606	30.0701	24.0728	31.8597
9#	29.6157	30.5956	24.1491	31.8156
10#	31.4235	31.2334	23.4927	32.5395

Figure 3. Sample case used in laboratory corrosion test

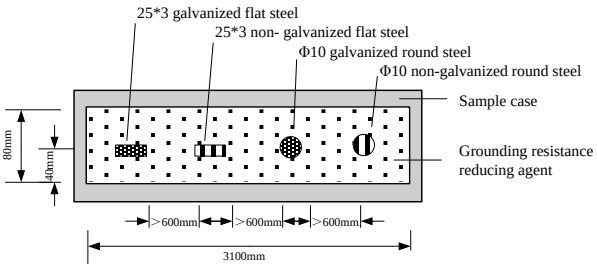

Figure 4. Placement of samples in laboratory corrosion test

TABLE II. WEIGHTS OF SAMPLES AFTER LABORATORY CORROSION TEST

Weight after test	W_F/g			
Sample	Galvanized flat steel	Non-galvanized flat steel	Galvanized round steel	Non-galvanized round steel
1#	30.1329	29.7295	23.9913	30.8553
2#	30.5050	30.7462	23.2703	30.5583
3#	29.6688	29.9366	23.1822	30.8885
4#	29.1352	29.5606	22.5754	32.3530
5#	30.1317	29.6605	24.3309	32.1507
6#	29.5564	30.2262	23.8139	31.4630
7#	30.5460	29.5611	23.9858	30.6724
8#	29.1455	29.9010	23.9412	31.6823
9#	29.4424	30.4560	24.0144	31.7614
10#	31.2660	31.2082	23.3831	32.5112

After the test, we calculated the yearly average corrosion rate of galvanized steel and that of non-galvanized steel respectively using equation (1). The calculated corrosion rates of all samples are summarized in Tables III-VI.

$$V = (\Delta W / S \cdot t) \cdot (3650/\mathrm{d}) \qquad (1)$$

Wherein: V – Yearly average corrosion rate, mm/a;

$\triangle W$ – Weight loss, g;

S – Surface area, cm^2;

t – Duration of sample embedment in earthing enhancing compound, d;

d – Specific gravity of sample material, g/cm^3.

TABLE III. STATISTICS OF CORROSION RATES OF GALVANIZED FLAT STEEL SAMPLES MEASURED IN LABORATORY CORROSION TEST

Galvanized flat steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity d/g/cm^3	Yearly average corrosion rate V/(mm/a)
1#	0.1875	28.6878	7.6197	0.0348
2#	0.1414	28.9178	7.6550	0.0259
3#	0.1190	28.1369	7.6793	0.0223
4#	0.0919	27.7539	7.6066	0.0177
5#	0.1775	28.6626	7.6606	0.0328
6#	0.2924	28.1655	7.6670	0.0549
7#	0.3103	29.1634	7.6560	0.0564
8#	0.2151	27.7617	7.6041	0.0413
9#	0.1733	28.1358	7.5968	0.0329
10#	0.1575	29.7476	7.6370	0.0281

TABLE IV. STATISTICS OF CORROSION RATES OF NON-GALVANIZED FLAT STEEL SAMPLES MEASURED IN LABORATORY CORROSION TEST

Non-galvanized flat steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity $d/g/cm^3$	Yearly average corrosion rate V/(mm/a)
1#	0.0590	28.5532	7.4589	0.0112
2#	0.0283	29.3687	7.4437	0.0053
3#	0.0754	28.8708	7.4258	0.0143
4#	0.1870	28.2176	7.4949	0.0359
5#	0.2734	28.5936	7.5215	0.0516
6#	0.1320	28.5784	7.4392	0.0252
7#	0.1136	28.2724	7.4214	0.0220
8#	0.1691	29.0483	7.4202	0.0318
9#	0.1396	29.4983	7.2602	0.0264
10#	0.0252	29.9515	7.4169	0.0046

TABLE V. STATISTICS OF CORROSION RATES OF GALVANIZED ROUND STEEL SAMPLES MEASURED IN LABORATORY CORROSION TEST

Galvanized round steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity $d/g/cm^3$	Yearly average corrosion rate V/(mm/a)
1#	0.1232	14.1203	7.8339	0.0452
2#	0.0819	13.8322	7.7354	0.0310
3#	0.1685	13.7267	7.7500	0.0642
4#	0.1386	13.3793	7.7344	0.0543
5#	0.1200	14.3582	7.7670	0.0436
6#	0.1249	13.9923	7.8660	0.0460
7#	0.1311	14.1008	7.8365	0.0481
8#	0.1316	14.1025	7.7944	0.0486
9#	0.1347	14.1352	7.7922	0.0496
10#	0.1096	13.8941	7.6944	0.0416

TABLE VI. STATISTICS OF CORROSION RATES OF NON-GALVANIZED ROUND STEEL SAMPLES MEASURED IN LABORATORY CORROSION TEST

Non-galvanized round steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity $d/g/cm^3$	Yearly average corrosion rate V/(mm/a)
1#	0.0914	15.9554	7.8051	0.0298
2#	0.1068	15.7616	7.8371	0.0351
3#	0.0578	15.8395	7.8700	0.0188
4#	0.2441	16.7687	7.8305	0.0754
5#	0.1870	16.5847	7.8544	0.0582
6#	0.3270	16.2925	7.8520	0.1037
7#	0.0609	15.8027	7.8183	0.0200
8#	0.1774	16.3580	7.8376	0.0561
9#	0.0542	16.2987	7.8553	0.0172
10#	0.0283	16.7188	7.8400	0.0088

IV. FIELD CORROSION TEST

The field corrosion test was conducted in outdoor soils, using 40 samples out of galvanized round steel, galvanized flat steel, non-galvanized round steel and non-galvanized flat steel, 10 for each. The samples were then dried and weighed as described above for the laboratory test. The weights of the samples before test are summarized in Table VII. After that, place the dried and weighed samples horizontally in outdoor soils in a 600-700mm deep pit in the way described above for laboratory test. After all samples were buried in the pit, cover the samples with earthing enhancing compound and smooth down. Then backfill and compact the soils after 1h. Finally, take out the samples 90 days later, rinse, remove dust and weigh them. The weights of all the samples after test are summarized in Table VIII.

TABLE VII. WEIGHTS OF SAMPLES BEFORE FIELD CORROSION TEST

Weight before test	W_Bg			
Sample	Galvanized flat steel	Non-galvanized flat steel	Galvanized round steel	Non-galvanized round steel
11#	30.4495	29.3257	23.7570	32.3734
12#	30.5396	29.6220	23.2648	30.9528
13#	29.8826	30.1149	24.7378	32.1331
14#	28.8732	29.0197	23.6201	31.3352
15#	30.2753	29.4426	24.6430	31.6236
16#	29.9738	29.5413	24.6532	32.0422
17#	30.3581	29.8236	24.0700	32.8520
18#	29.9816	30.5626	24.4469	32.2894
19#	30.7932	29.5864	23.3957	30.7063
20#	29.5195	31.5236	24.3181	31.1465

TABLE VIII. WEIGHTS OF SAMPLES AFTER FIELD CORROSION TEST

Weight after test	W_Fg			
Sample	Galvanized flat steel	Non-galvanized flat steel	Galvanized round steel	Non-galvanized round steel
11#	28.9212	29.0164	23.5786	32.1613
12#	30.3381	29.3447	23.1502	30.6847
13#	29.7589	30.0012	24.6322	31.9087
14#	28.5754	28.8770	23.5303	31.1558
15#	30.0680	29.0476	24.4508	31.4658
16#	29.7377	29.1973	24.4788	31.7315
17#	29.5257	29.6911	24.0202	32.7405
18#	29.6787	30.3498	24.3083	32.1907
19#	30.6419	29.4645	23.1670	30.4779
20#	29.3373	31.3664	23.9025	30.7304

After the test, we calculated the yearly average corrosion rate of galvanized steel and that of non-galvanized steel respectively using equation (1). The calculated corrosion rates of all samples are summarized in Tables IX-XII.

TABLE IX. STATISTICS OF CORROSION RATES OF GALVANIZED FLAT STEEL MEASURED IN FIELD CORROSION TEST

Galvanized flat steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity $d/g/cm^3$	Yearly average corrosion rate V/(mm/a)
11#	1.5283	28.7555	7.6523	0.2817
12#	0.2015	28.9189	7.6464	0.0370
13#	0.1237	28.4465	7.5941	0.0232
14#	0.2978	27.5683	7.5861	0.0577
15#	0.2073	28.7066	7.6189	0.0384
16#	0.2361	28.2422	7.6771	0.0442
17#	0.8324	28.7556	7.6469	0.1535
18#	0.3029	28.3877	7.6545	0.0565
19#	0.1513	28.9946	7.6138	0.0278
20#	0.1822	28.0667	7.6466	0.0344

TABLE X. STATISTICS OF CORROSION RATES OF NON-GALVANIZED FLAT STEEL MEASURED IN FIELD CORROSION TEST

Non-galvanized flat steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity $d/g/cm^3$	Yearly average corrosion rate V/(mm/a)
11#	0.3093	28.3225	7.3532	0.0602
12#	0.2773	28.3164	7.4688	0.0532
13#	0.1137	28.7559	7.3291	0.0219
14#	0.1427	28.0793	7.4420	0.0277
15#	0.3950	28.3752	7.4206	0.0761
16#	0.3440	28.7522	7.3421	0.0661
17#	0.1325	28.2926	7.5128	0.0253
18#	0.2128	29.2835	7.4332	0.0396
19#	0.1219	28.3442	7.4288	0.0235
20#	0.1572	30.2463	7.4044	0.0285

TABLE XI. STATISTICS OF CORROSION RATES OF GALVANIZED ROUND STEEL MEASURED IN FIELD CORROSION TEST

Galvanized round steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity $d/g/cm^3$	Yearly average corrosion rate V/(mm/a)
11#	0.1784	13.9687	7.7394	0.0669
12#	0.1146	13.6578	7.7604	0.0439
13#	0.1056	14.4490	7.7999	0.0380
14#	0.0898	13.9411	7.7100	0.0339
15#	0.1922	14.3256	7.8728	0.0691
16#	0.1744	14.5426	7.6969	0.0632
17#	0.0498	14.0906	7.7824	0.0184
18#	0.1386	14.2428	7.8376	0.0504
19#	0.2287	13.7560	7.7661	0.0868
20#	0.4156	14.3324	7.7036	0.1527

TABLE XII. STATISTICS OF CORROSION RATES OF NON-GALVANIZED ROUND STEEL MEASURED IN FIELD CORROSION TEST

Non-galvanized round steel	Weight loss ΔW/g	Surface area S/ cm^2	Specific gravity d/cm^2	Yearly average corrosion rate V/(mm/a)
11#	0.2121	16.6264	7.8354	0.0660
12#	0.2681	15.8617	7.8528	0.0873
13#	0.2244	16.5453	7.8154	0.0704
14#	0.1794	16.0640	7.8576	0.0576
15#	0.1578	16.2456	7.8334	0.0503
16#	0.3107	16.4610	7.8332	0.0977
17#	0.1115	16.8636	7.8394	0.0342
18#	0.0987	16.5890	7.8328	0.0308
19#	0.2284	15.7400	7.8505	0.0750
20#	0.4161	15.9335	7.8663	0.1346

V. TEST RESULTS AND DISCUSSION

We calculated the yearly average corrosion rates (Table XIII & Table XIV) of the four types of sample, i.e. galvanized round steel, galvanized flat steel, non-galvanized round steel and non-galvanized flat steel, on the basis of measured yearly average corrosion rates of all samples summarized in Tables III-VI for laboratory test and Tables IX-XII for field test. The samples taken out from earthing enhancing compound after 90d are illustrated in Fig. 5. We noted clear signs of corrosion from the surface of the samples.

TABLE XIII. LABORATORY CORROSION TEST RESULTS

Laboratory corrosion test (samples 1#-10#)	Galvanized flat steel	Non-galvanized flat steel	Galvanized round steel	Non-galvanized round steel
Yearly average corrosion rate (mm/a)	0.0347	0.0228	0.0472	0.0423

TABLE XIV. FIELD CORROSION TEST RESULTS

Field corrosion test (samples 11#-20#)	Galvanized flat steel	Non-galvanized flat steel	Galvanized round steel	Non-galvanized round steel
Yearly average corrosion rate (mm/a)	0.0754	0.0422	0.0623	0.0704

Figure 5. Corrosion of Samples in Earthing Enhancing Compound

As stipulated in Section 4.4 of QX/T104-2009 *Grounding Resistance Reduction Agent*, the yearly average corrosion rate of galvanized round and flat steels in earthing enhancing compound must be not higher than 0.03mm/a, and that of non-galvanized round and flat steels in earthing enhancing compound must be not higher than 0.05mm/a. Test results: we found in the laboratory test that both the average corrosion rate of galvanized flat steel and that of galvanized round steel were higher than the values specified in QX/T104-2009 standard, and the average corrosion rates of non-galvanized round and flat steels conformed to the standard; also, we found in the field test that the average corrosion rates of galvanized flat and round steels and non-galvanized round steel were higher than the specified values, and only the average corrosion rate of non-galvanized flat steel complied with the standard. In conclusion, the corrosivity of the earthing enhancing compound of the particular brand sampled does not conform to the standard.

VI. TEST RESULTS AND DISCUSSION

In this study, we tested the corrosion of metal in earthing enhancing compound using weight loss method and derived corrosion rate data from the test. We noted that the corrosivity of the earthing enhancing compound samples collected did not meet the requirements of relevant national standard. Also, we found there are some deficiencies with the weight loss method in testing the corrosivity of earthing enhancing compound: a) tedious preparatory work is required and test site must satisfy a series of requirements and limitations; b) the test consumes

enormous human and material resources and spans a long period; c) when derusting the samples, some samples may have residual rusts that are not removed and others may have unrusted parts that are removed mistakenly, which is likely to cause errors in test data. Therefore, it is not so operable to test the corrosion rate of metal materials in earthing enhancing compound using the weight loss method. Corrosion of metal is essentially an electrochemical process [9-11], so it is advisable to test the corrosion rate of metal materials in earthing enhancing compound using the electrochemical test method where possible.

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