November 13, 2018

The SAE Product Specification Manual – ConduDisc™ Version 1.3 contains specifications, drawings and test reports for the design and construction of the SAE ConduDisc™.

The SAE ConduDisc™ is designed and manufactured to comply with CSA Standards C22.2 No. 41-13 Section 6.10.4.1 and No. 65-13 Section 9.1.10.2 and as such meets the ESA Technical Guideline for Section 6 "Approval of Electrical Equipment" with regards to Ontario Regulation 22/04.

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2018

CONDUDISC

IT CAN BE DONE

PRODUCT SPECIFICATION MANUAL – CONDUDISC™ VERSION 1.3

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Contents

Standards Met by Encapsulated Galvanized Steel Grounding Plate

ASTM Standards

1) ASTM A123/A123M: Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products
   - This specification covers the standard requirements for hot-dip galvanized zinc coatings on iron and steel products made from rolled pressed and forged shapes, castings, plates, bars, and strips. This specification deals with both unfabricated products and fabricated products, for example, assembled steel products, structural steel fabrications, large tubes already bent or welded before galvanizing, and wire work fabricated from uncoated steel wire. Also covered here are steel forgings and iron castings incorporated into pieces fabricated before galvanizing or those too large to be centrifuged (or otherwise handled to remove excess galvanizing bath metal).

2) ASTM A153/A153M: Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
   - This specification covers standards for zinc coatings applied through hot-drip process on iron and steel hardware. The hot-dip galvanizing process shall form layers of Zn/Fe alloy adhering to the steel surface. This specification is applicable to steel hardware items of Classes A, B, C, and D. The thickness or weight/mass of zinc coating shall conform to specified values for various classes of materials. The coated articles shall be free from uncoated areas, blisters, flux deposits, dross inclusions, and other defects. The coating shall be smooth and reasonable uniform in thickness. Tests shall be performed to determine the minimum coating weight or minimum coating thickness, finish and appearance, embrittlement, adherence, average weight/mass of coating, and average thickness of coating. Guidelines are also given for inspection, rejection and retest, packaging, and certification procedures.

CSA Standards

Galvanized Steel Plate components and assembly procedures follow strict CSA Standards as outlined in CAN/CSA-C22.2 No. 65-13 Section 9.1.10.2 and CAN/CSA-C22.2 No. 41-13 Section 6.10.4.1.

No. 65-13 Section 9.1.10.2 The following hardware shall be used to make the connections mentioned in 9.1.10.1; once the initial assembly is completed, there shall be no subsequent retightening:

a) A bolt shall be plated steel, SAE Grade 2, UNC thread having a maximum standard diameter compatible with the hole or holes in the connector tang and a minimum standard length allowing at least a 2-thread projection through the nut, and the projection shall not exceed 6.4 mm (1/4 in.) after assembly.

b) A single flat washer shall be used on each side of the tang-to-tang or tang-to-bus connection. These washers shall be plated steel having an SAE configuration compatible with the diameter of the bolt.

c) A nut shall be plated steel, and shall have a Class 2B, UNC and a hexagonal configuration.

d) Clean, dry, nonlubricated screws and bolts and nuts shall be used.

e) The assembled hardware shall be torqued to the values in Table 24. (8 N·m for a ¼" screw or bolt)

No. 41-13 Section 6.10.4.1 A plate electrode shall

a) be not less than 6.4 mm (1/4 in) in thickness if of iron or steel, or 1.5 mm (0.06 in) if of nonferrous metal, other than aluminum;

b) have a total surface area of not less than 0.186 m^2 (2 ft^2);

c) if provided with a means of connection to the system grounding conductor, have connections that comply with the requirements of Clauses 6.1.3, 7.1, and 7.5; and

d) shall be marked in accordance with Clause 10.10.

Specifications

ConduDisc™

Physical	Typical Value	Unit	Test Method
Physical State	Black solid		
Odor	None		
Water Permeability	1.72 x 10^{-7}	cm/s	ASTM D5084 (2.6 psi)
Flammability	No ignition		Exposed to a propane torch (~2000 °C) for 60 seconds
Electrolytic corrosion resistance			
Steel	100	%	SAE Inc. Standard 100
Galvanized Steel	99.81	%	
Copper	100	%	
Environmental Impact	Neutral		Ontario Regulation 558/00
Freeze-Thaw Withstand	30	years	SAE Inc. Standard 102

Mechanical	Typical Value	Unit	Test Method
Elastic Compression			
7000 kg	2.2 (4.3)	mm (%)	
12 000 kg	2.6 (5.1)	mm (%)	SAE Inc. Standard 103
14 500 kg	3.0 (5.9)	mm (%)	
16 771 kg	3.1 (6.1)	mm (%)	
Maximum Load Applied	16 771	kg	SAE Inc. Standard 103

Electrical	Typical Value	Unit	Test Method
Electrical Resistivity	30.39	ohm·cm	SAE Inc. Standard 105
Electrical Resistance	0.031	ohms	SAE Inc. Standard 105

Fault Current Withstand

RMS Current (A)	RMS Voltage (kV)	Resistance Before Test (mΩ)	Resistance After Test (mΩ)	Approximate Temperature Rise (°C)	Test Duration (milliseconds)
1040	19.5	30.6	20.3	1	508
2520	124.0	55.5	20.2	2	508
3730	239.0	44.9	46.0	13	234
4990	176.0	34.6	7.28	1	508

ConduDisc™ Freeze-Thaw Testing: Results and Analysis

Contents

1.0 Abstract

The behaviour of the ConduDisc™ material under freeze-thaw conditions is analyzed in this report. Due to the uniqueness of the material, a combination of studies and standards for similar materials were used to develop an appropriate test procedure. The test procedure involved the rapid freezing and thawing of samples with varying water and salt-water exposure. The samples were studied over 90 freeze-thaw cycles, which is equivalent to 30 years of freeze-thaw withstand.

The mass results of the 90 freeze-thaw cycles for the ConduDisc™ indicate that physically none of the samples were adversely affected by freezing. The dry samples and the wet samples all experienced minor fluctuations in their masses during the 90 freeze-thaw cycles however, these were determined not to be a cause for concern since the samples are all within 6 g of the initial mass conditions. The freshwater submerged samples and the saltwater submerged samples all experienced a relatively steady increase in mass as the samples absorbed water. This increase in mass of the submerged samples does not indicate that the samples were adversely affected by the freeze-thaw testing since the samples followed the same trend with no major deviations.

The resistance results of the ConduDisc™ agree with the mass results that no degradation of the samples occurred. All of the samples either returned to the initial resistance value or became more conductive over the 90 freeze/thaw cycles. Any spikes in the resistance of the dry and soaked/wet samples was during freeze measurements and the resistance always dropped during the subsequent thaw measurement. An increase in the conductivity of the ConduDisc™ samples after freeze-thaw testing is a very positive outcome and indicates that ConduDisc™ surround material improves as freeze-thaw cycling occurs.

Both the mass and resistance results strongly indicate that the ConduDisc™ will continue to perform in situ for at least 30 years with no degradation due to freezing and thawing experienced during winter conditions.

2.0 Test Method

2.1 Background and Development

The freeze-thaw stability testing of any products is a topic of great debate, resulting in varying standards and practices even for commonly tested materials such as concrete. Due to its composition and properties the ConduDisc™ cannot be closely compared with other materials that are tested for freeze-thaw stability or withstand. This study aims to estimate the material's freeze-thaw behaviour.

Most existing test methods for building materials were deemed not entirely appropriate for the testing of the ConduDisc™ material. "Masonry: Research, Application, and Problems" (Grogan and Conway) was used as a starting point for the development of the freeze-thaw testing of the ConduDisc™ material. According to Grogan and Conway, a realistic freeze-thaw test method includes subjecting samples to 90 freeze-thaw cycles, which equates to 30 years of exposure to an extreme environment. It is also suggested in the same literature that three freeze-thaw cycles is to be the equivalent of one year of natural weathering. This was also explored in buried samples.

2.2 Experimental Design

The largest factors in freeze-thaw behaviour include freeze-thaw rate and exposure to water. To account for the most extreme cases, samples were frozen and thawed as quickly as possible. The exposure to water was also varied. The conditions for each sample are summarized in Table 2.2.1.

Table 2.2.1: Test Conditions for ConduDisc™ Samples

Sample	Condition
1, 2	Dry
3, 4	Soaked in water, removed prior to freeze cycle
5, 6	Completely submerged in freshwater
7, 8	Completely submerged in saltwater

One freeze-thaw cycle in this study was defined as a freeze period for 16 hrs. +/- 2hrs, a thaw period for 24 hrs. +/- 2 hrs, then samples 3 and 4 were soaked in water for 5 – 7 hrs. and a new cycle began with the freeze period. Testing of these samples continued until 90 freeze-thaw cycles had been completed, roughly equating to 30 years of exposure to an extreme environment.

3.0 Results

3.1 Test Conditions

The ConduDisc™ is expected to face significant exposure to water in-situ. Thus, emphasis is placed on the material's ability to withstand freezing and thawing conditions in water.

Samples 1 through 8 were half-disc samples of the ConduDisc™ material, with approximately 2.0'' radius and 1.0'' thickness. The initial measurements of each sample are described in Table 3.1.1.

Table 3.1.1: Initial Measurements of ConduDisc™ Samples

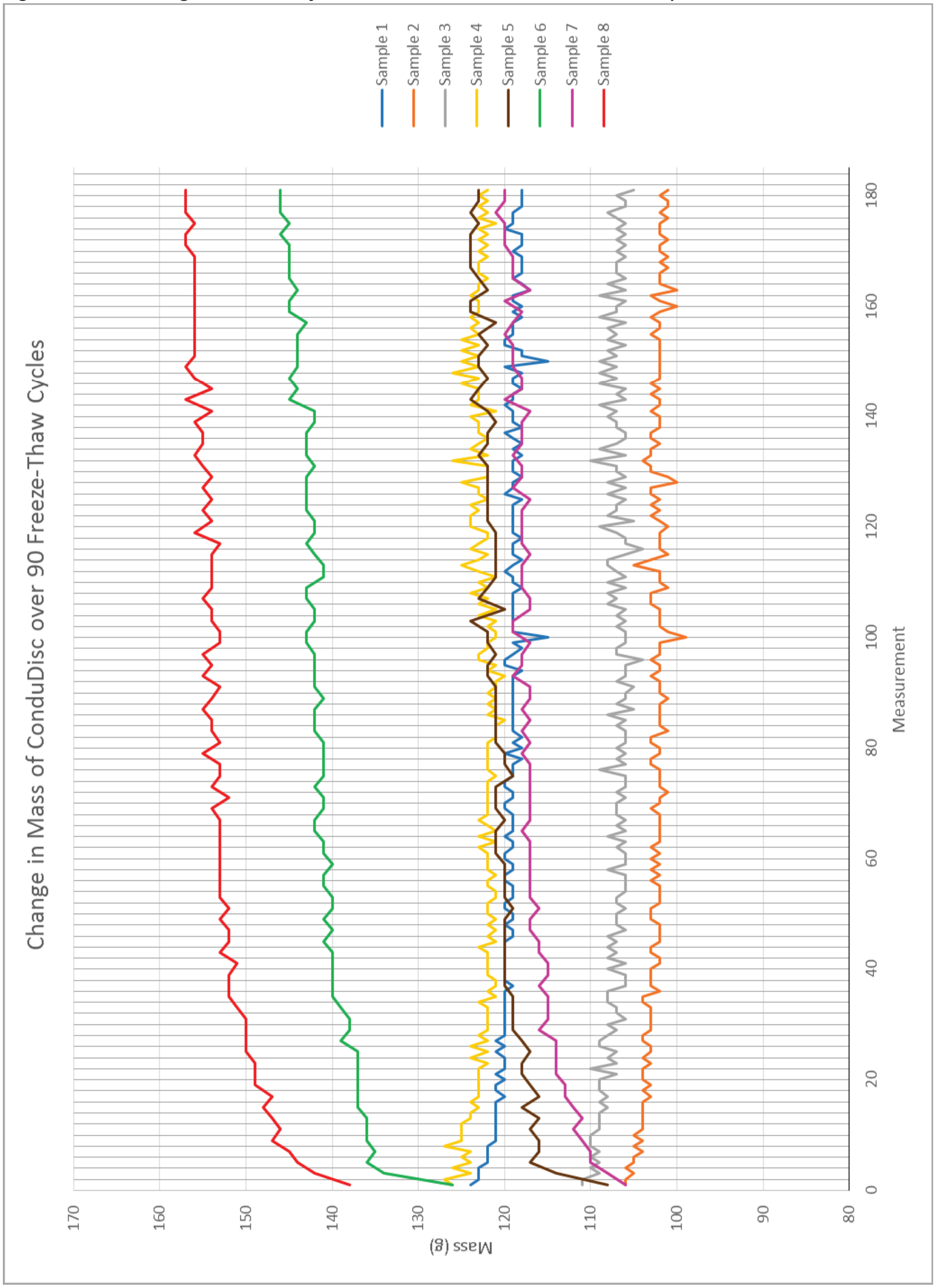
Sample	Date	Temperature (°C)	Resistance (Ω)	Mass (g)	System mass* (g)
1	Oct. 16/2017	15.4	6.0	124	-
2	Oct. 16/2017	15.4	5.7	106	-
3	Oct. 16/2017	15.2	6.0	111	-
4	Oct. 16/2017	15.1	6.1	126	-
5	Oct. 16/2017	15.1	6.0	108	1058
6	Oct. 16/2017	14.4	5.5	126	1058
7	Oct. 16/2017	14.3	5.7	106	1069
8	Oct. 16/2017	14.3	5.4	138	1069

**System mass is defined as the combined mass of the samples, water, and container.*

The test procedure was followed immediately after initial measurements were taken. The measurements were taken during each freeze or thaw period and the results were analyzed at the 90-cycle mark.

3.2 Changes in Mass over 90 Freeze-Thaw Cycles

Figure 3.2.1: Changes in Mass of ConduDisc™ over 90 Freeze-Thaw Cycles



Analysis:

The physical condition of the sample serves as the best indicator of freeze-thaw stability. Ideally, no changes to the appearance of the material should be observed. Cracking and other physical damage should not be observed. The mass of the samples may be used as another indicator of freeze-thaw stability; large deviations from the original mass of the sample signal material instability. Finally, the samples should not experience extreme deviations in resistance readings. Note that the vertical lines in Figure 3.2.1 above indicate data obtained during a freeze period, and the spaces between the vertical lines indicate thaw periods.

For the dry samples (1 and 2), the mass did fluctuate on occasion, however these fluctuations were small and were likely due to the inherent scale error, it is accurate to +/- 1 g. The data for these samples indicates that both samples have lost a small amount of mass over the 90 cycles, however this loss in mass is only 6 g or 4.8% for sample 1 and 5 g or 4.7% for sample 2 and does not indicate that the samples are adversely affected by freezing.

For the wet samples (3 and 4), the mass generally increased when measured after a freeze cycle, since these samples are soaked in water prior to freezing, this indicates that some water is absorbed. The samples expel the water and return to approximately their initial mass or lower during thaw periods. There were periods when both samples experienced no change in mass between freeze and thaw cycles which indicated that no water was absorbed or expelled by the samples at this time.

The two samples submerged in freshwater (5 and 6), demonstrate a relatively steady increase in mass as the samples absorbed water for the first 15 cycles. During the remaining 75 cycles the samples still demonstrated an increase in mass as the samples absorbed water however the rate of water absorption had significantly decreased, the samples appeared to be approaching constant mass. These samples can only be measured during thaw cycles since they are frozen in their containers during freeze cycles. The increase in the mass of the submerged samples does not indicate that the samples were adversely affected by the freeze-thaw testing since there were no significant deviations from the trend. Both of the samples had absorbed a similar amount of water after the 90 cycles. Sample 5 had increased in mass by 15 g or 13.9% and sample 6 had increased in mass by 20 g or 15.9%.

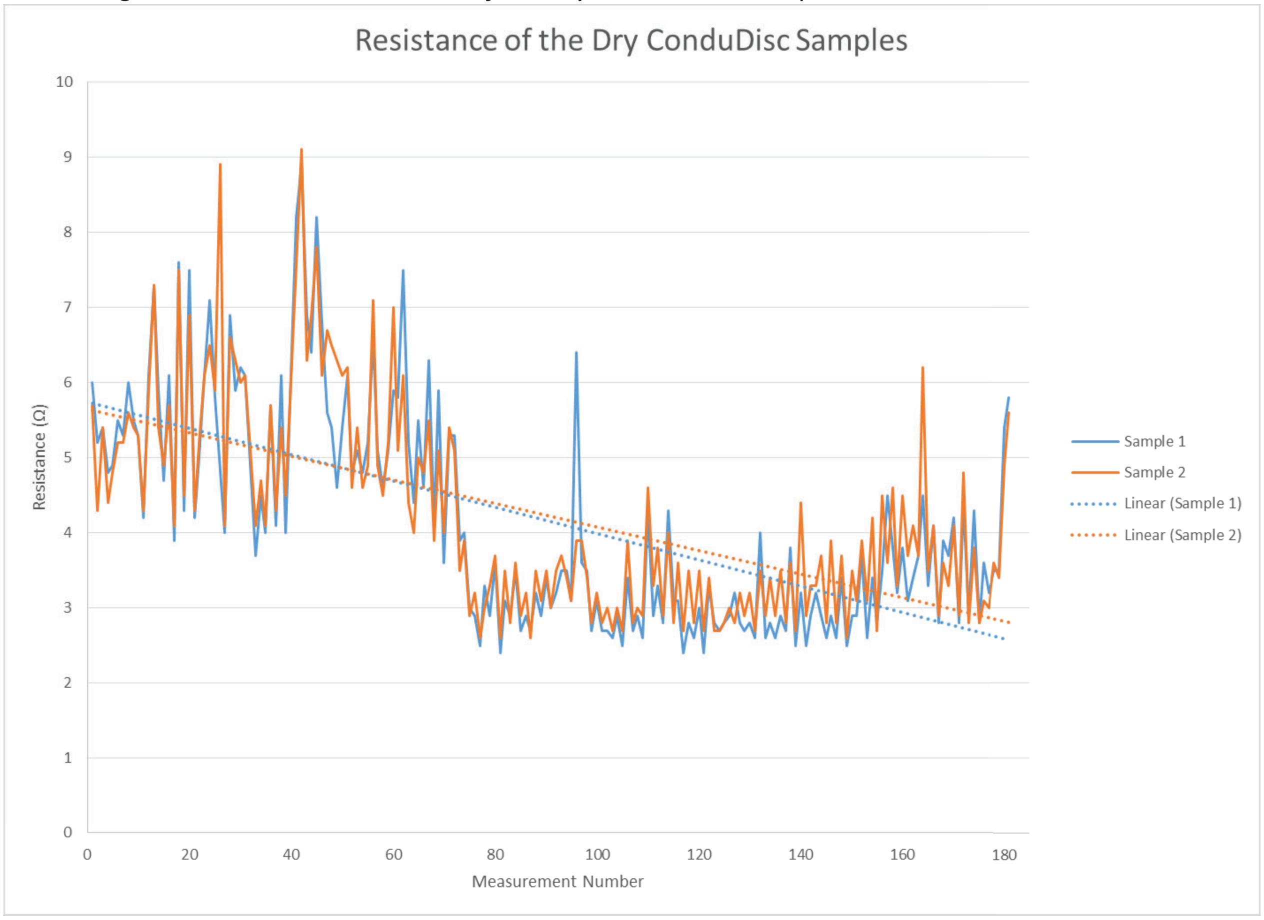
The two samples submerged in saltwater (7 and 8), also demonstrate a relatively steady increase in mass as the samples absorbed water for the first 15 cycles. During the remaining 75 cycles the samples still demonstrated an increase in mass as the samples absorbed water however the rate of water absorption had significantly decreased, the samples appeared to be approaching constant mass. These samples were also only measured during thaw cycles since they were frozen in their containers during freeze cycles. The increase in mass of the samples does not indicate that the samples were adversely affect by the freeze-thaw testing since there were no significant deviations from the trend. Both of the samples had absorbed a similar amount of water after the 90 cycles. Sample 7 had increased in mass by 14 g or 13.2% and sample 8 had increased in mass by 19 g or 13.8%.

None of the samples in this study experienced any change in the appearance of the material after 90 freeze-thaw cycles. No cracking or other physical damage to the samples was observed.

One month after testing of the ConduDisc™ samples was completed the samples were analyzed. The dry samples, 1 and 2, had not changed from the final reading after 90 cycles and had lost 6 g (4.8%) and 5 g (4.7%) respectively from their initial mass. The wet samples, 3 and 4, had also only experienced a small change in mass from their initial values. Sample 3 was still the same value as the final reading after 90 cycles and had lost 6 g (5.4%) from its initial mass. Sample 4 had lost 2 g of water mass since the final reading after 90 cycles and had lost a total of 6 g (4.8%) from its initial value. All of the submerged samples, freshwater and saltwater, had lost all of the water mass they absorbed during the testing and were slightly lower than their initial mass. Sample 5 was 6 g (5.6%) lower than its initial mass, sample 6 was 6 g (4.8%) lower than its initial mass. Sample 7 was 6 g (5.7%) lower than its initial mass, sample 8 was 7 g (5.1%) lower than its initial mass.

3.3 Resistance Measurements over 90 Freeze-Thaw Cycles

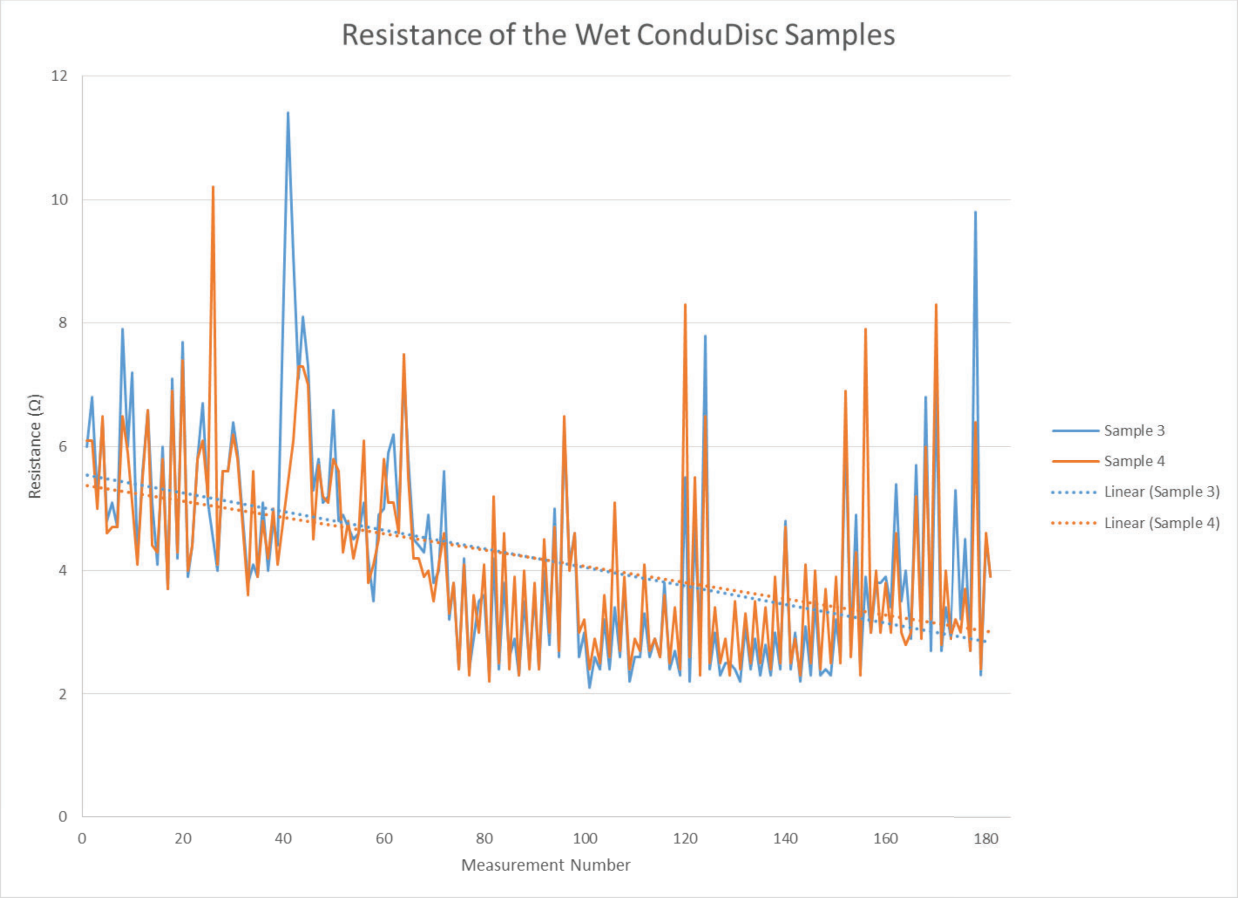
Figure 3.3.1: Resistance Trends of the Dry ConduDisc™ Samples



Analysis:

Both dry ConduDisc™ samples demonstrated very similar resistance trends. There were fluctuations between the resistances of the samples when measured during a freeze cycle or a thaw cycle. In general, both dry ConduDisc™ samples were more resistive when frozen and less resistive when thawed. After 90 cycles the resistance of both dry ConduDisc™ samples was slightly lower than their initial values, sample 1 had decreased in resistance by 0.2 ohms (3.3%), and sample 2 had decreased in resistance by 0.1 ohms (1.8%). One month after testing of the samples was complete the resistance was checked. The samples had decreased in resistance significantly, sample 1 was 3.4 ohms (56.7%) lower than the initial resistance and sample 2 was 2.9 ohms (50.9%) lower than the initial resistance. This is a very positive result, indicating that the performance of the samples is not negatively affected, and actually improves when subjected to the freeze-thaw conditions. The less resistive the samples are, the easier the flow of electrons through the material to ground.

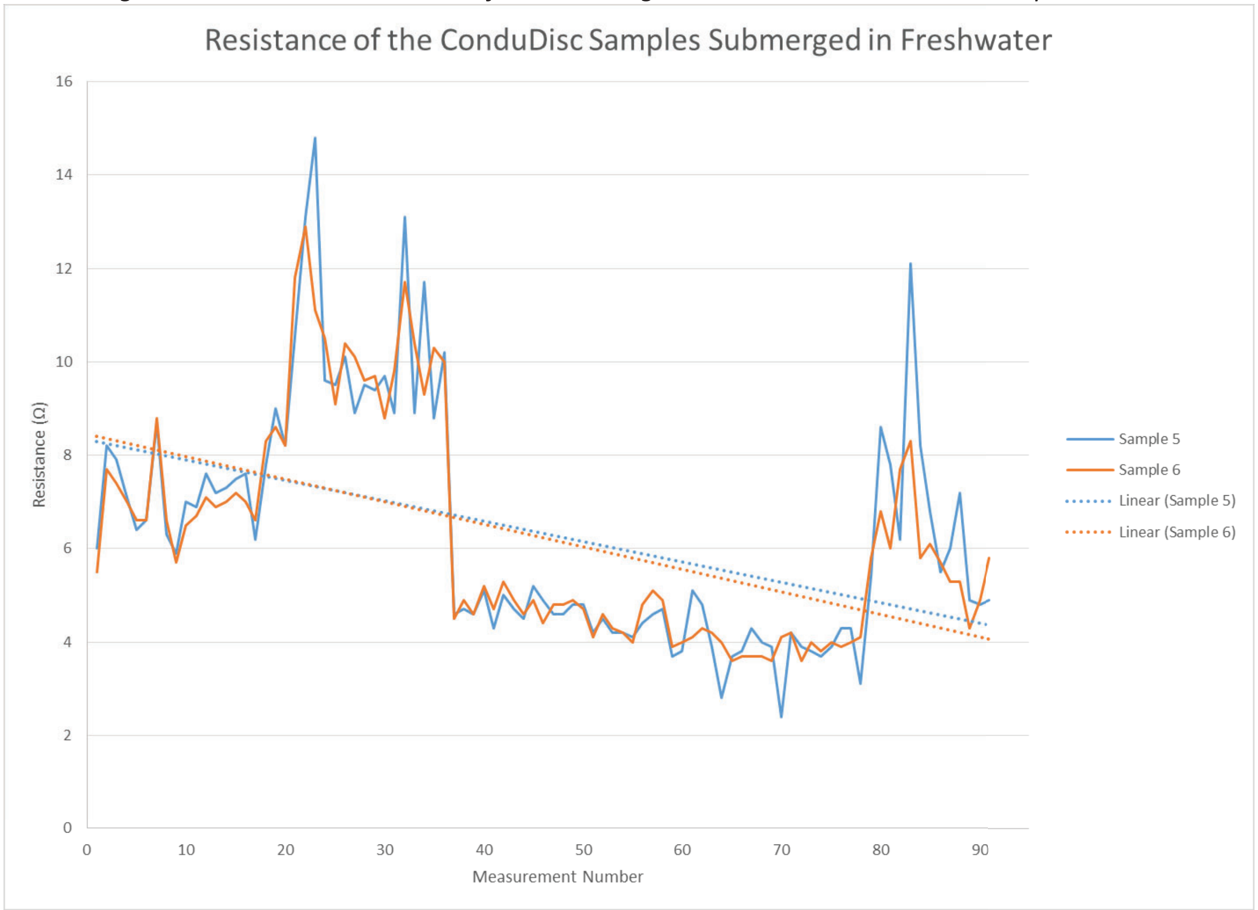
Figure 3.3.2: Resistance Trends of the Wet ConduDisc™ Samples



<u>*Analysis:*</u>

Both wet ConduDisc™ samples demonstrated very similar resistance trends. There were fluctuations between the resistances of the samples when measured during a freeze cycle or a thaw cycle. In general, both wet ConduDisc™ samples were more resistive when frozen and less resistive when thawed. After 90 cycles the resistance of both wet ConduDisc™ samples had decreased by approximately 2.1 ohms (35%). One month after testing of the samples was complete the resistance was checked. The samples further decreased in resistance from their initial values, sample 3 was 3.8 ohms (63.3%) lower than the initial resistance and sample 4 was 4.0 ohms (65.6%) lower than the initial resistance. This is a very positive result, indicating that the performance of the samples improved when subjected to the freeze-thaw conditions. The more conductive the samples are, the easier the electrons flow through the material to ground.

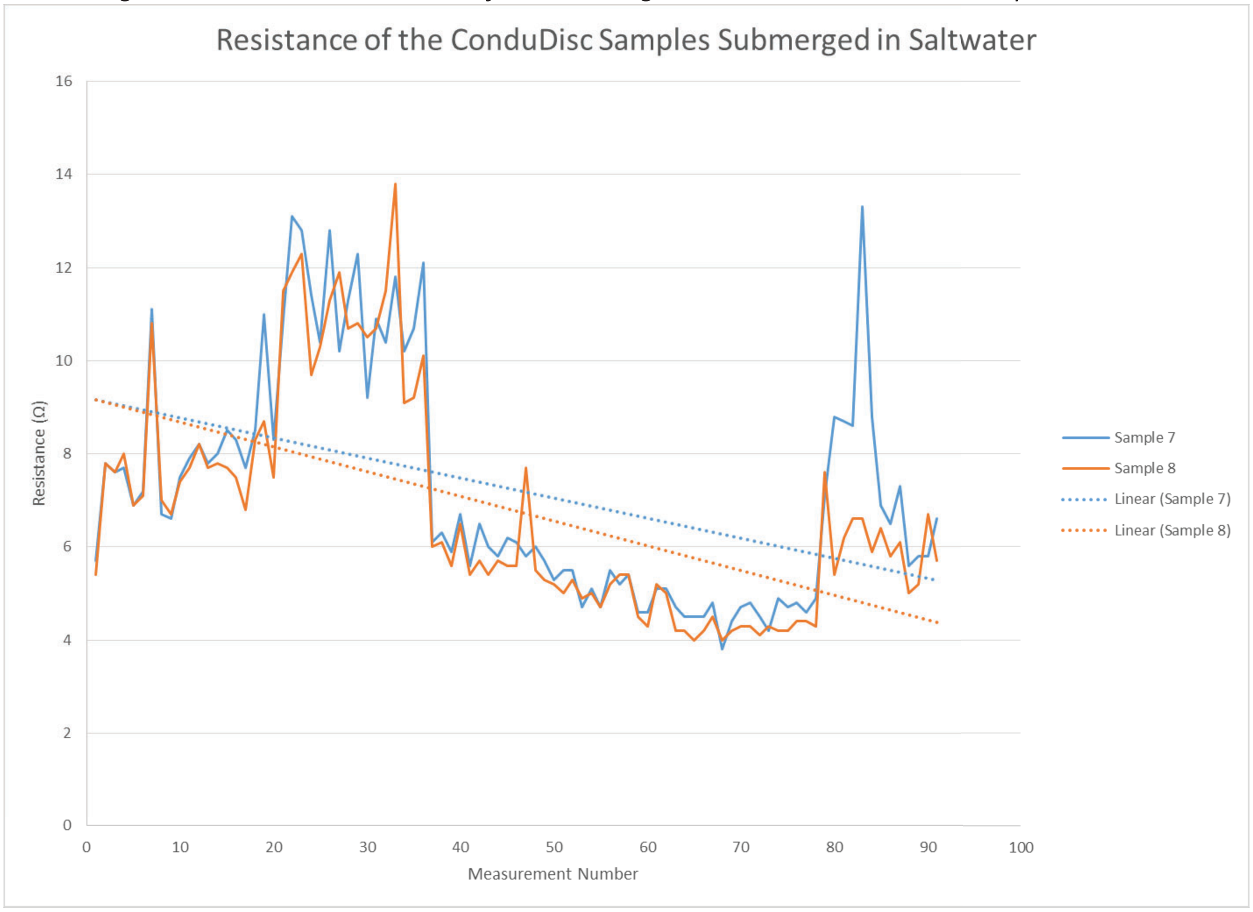
Figure 3.3.3: Resistance Trends of the Submerged Freshwater ConduDisc™ Samples



<u>*Analysis:*</u>

Both ConduDisc™ samples submerged in freshwater demonstrated fairly similar resistance trends. The values shown in Figure 3.3.3 above are the resistance readings taken during the thaw cycles, the samples were frozen in their containers during the freeze cycles and the resistances could not be measured. There were fluctuations in the resistances of the samples however all of the measured values are within +/- 9 ohms of the initial resistance value. After 90 cycles the resistance of ConduDisc™ sample 5 submerged in freshwater had decreased by 1.1 ohms (18%) and the resistance of sample 6 submerged in freshwater returned to approximately the original value, it increased by only 0.3 ohms (5.4%). One month after testing of the samples was complete the resistance was checked. The samples further decreased in resistance from their initial values, sample 5 was 4.2 ohms (70.0%) lower than the initial resistance and sample 6 was 3.8 ohms (69.1%) lower than the initial resistance. This is a very positive result, indicating that the performance of the samples improved when subjected to the freeze-thaw conditions. The more conductive the samples are, the easier the electrons flow through the material to ground.

Figure 3.3.4: Resistance Trends of the Submerged Saltwater ConduDisc™ Samples



<u>*Analysis:*</u>

Both ConduDisc™ samples submerged in saltwater demonstrated fairly similar resistance trends. The values shown in Figure 3.3.4 above are the resistance readings taken during the thaw cycles, the samples were frozen in their containers during the freeze cycles and the resistances could not be measured. There were fluctuations in the resistances of the samples however all of the measured values are within +/- 8 ohms of the initial resistance value. After 90 cycles the resistance of both ConduDisc™ samples submerged in saltwater had returned to roughly the initial resistance value, the small increases in the resistance can be attributed to the method for measuring the resistance. One month after testing of the samples was complete the resistance was checked. The samples had decreased in resistance significantly, sample 7 was 3.9 ohms (68.4%) lower than the initial resistance and sample 8 was 3.6 ohms (66.7%) lower than the initial resistance. This is a positive result, indicating that the performance of the samples improved when subjected to the freeze-thaw conditions. The more conductive the samples are, the easier the electrons flow through the material to ground

4.0 Conclusions

The results of the 90 freeze-thaw cycles when analyzing the changes in mass of the samples indicate that none of the samples were adversely affected by freezing. The dry samples and the wet samples all experienced minor fluctuations in their masses during the 90 freeze-thaw cycles however, these were determined not to be a cause for concern since the samples are all within 6 g of the initial mass conditions. The freshwater submerged samples and the saltwater submerged samples all experienced a relatively steady increase in mass as the samples absorbed water. This increase in mass of the submerged samples does not indicate that the samples were adversely affected by the freeze-thaw testing since the samples followed the same trend with no major deviations. Also none of the samples experienced any physical deterioration in the form of cracking, or other physical damage.

The resistance results agree with the mass results that no degradation of the samples occurred. All of the samples became more conductive or returned to their initial resistance values over the 90 freeze/thaw cycles which is a very positive result. One month after the completion of the testing all of the samples were significantly more conductive than their initial resistance values. This indicates that the performance of the ConduDisc™ will improve when subjected to freeze-thaw conditions.

The results of this study strongly indicate that the ConduDisc™ will perform in situ for at least 30 years with no significant degradation due to freezing and thawing experienced during winter conditions.

These results are a summary of results generated from testing conducted by SAE Inc. at their Midhurst, ON location. Testing was performed by Chris Allison, R&D Assistant; David Sisti, R&D Assistant; and Caitlin Hughes, R&D Coordinator, from October 16, 2017 to September 28, 2018.

Resistance of Bare and Galvanized Steel Encased in ConduDisc™ Surround to Electrolytic Corrosion

Contents

1.0 Introduction

SAE Inc. is currently developing the ConduDisc™, a product which will be used for the grounding of utility poles and transformers. The purpose of this product is to dramatically improve the lifetime of the ground plates currently in use by significantly reducing the rate of corrosion of the plate. In order to determine the effectiveness of ConduDisc™ surround material on both bare and galvanized steel for grounding applications, the following testing was conducted.

2.0 Procedure

Four pieces of steel (approx. 1"x 3/4") were cut using an angle grinder and weighed using an electronic balance. Single barrel 1-hole mechanical lugs were bolted to two of the samples and one end of a dual-insulated #8 AWG copper wire was crimped into the lug for each sample, as seen in Figure 1. The other two samples were soldered to one end of a dual-insulated #8 AWG copper wire and a shrink tube was used to prevent corrosion at the site of connection.

Figure 1: Samples made with mechanical lugs. (Bare Steel sample on left, Galvanized Steel sample on right)

Figure 2: Samples made with shrink tube and soldered connection. (Bare Steel sample on left, Galvanized steel sample on right)

Three coats of Rustoleum Cold Galvanizing Compound were applied to two of the samples so that a comparison between bare and galvanized steel could be made. Rectifier leads were soldered to the end of the dual-insulated #8 AWG copper wire opposite to the connected steel for each sample. The mass of the system (i.e. sample, wire and lead) was measured using an electronic balance. The samples from Figure 1 were encased in ConduDisc™ surround and allowed to cure for 3 weeks. Each sample was placed into a pail and surrounded with a mixture of top soil and sand. A length of steel rebar was placed in each pail approximately six inches from the steel samples. One litre of water and 20 g of sodium sulfate was added to each pail to ensure that the soil was conductive enough for the test. As shown in Figure 4, each pair of samples, one directly in contact with the soil and the other encased in ConduDisc™ surround, were connected in a series circuit to an individual channel of a 30 V rectifier, to ensure an equal current load.

Figure 3: An image of the experiment set-up.

The power source was set to provide 3 mA of current throughout the duration of the test. A schematic of the layouts can be seen below in Figure 4. Two hundred and fifty milliliters of water was added to each pail once a week to ensure the soil remained moist. Voltage and current readings were taken throughout the experiment. All samples were removed from the soil after one month, cleaned, and weighed using an electronic balance.

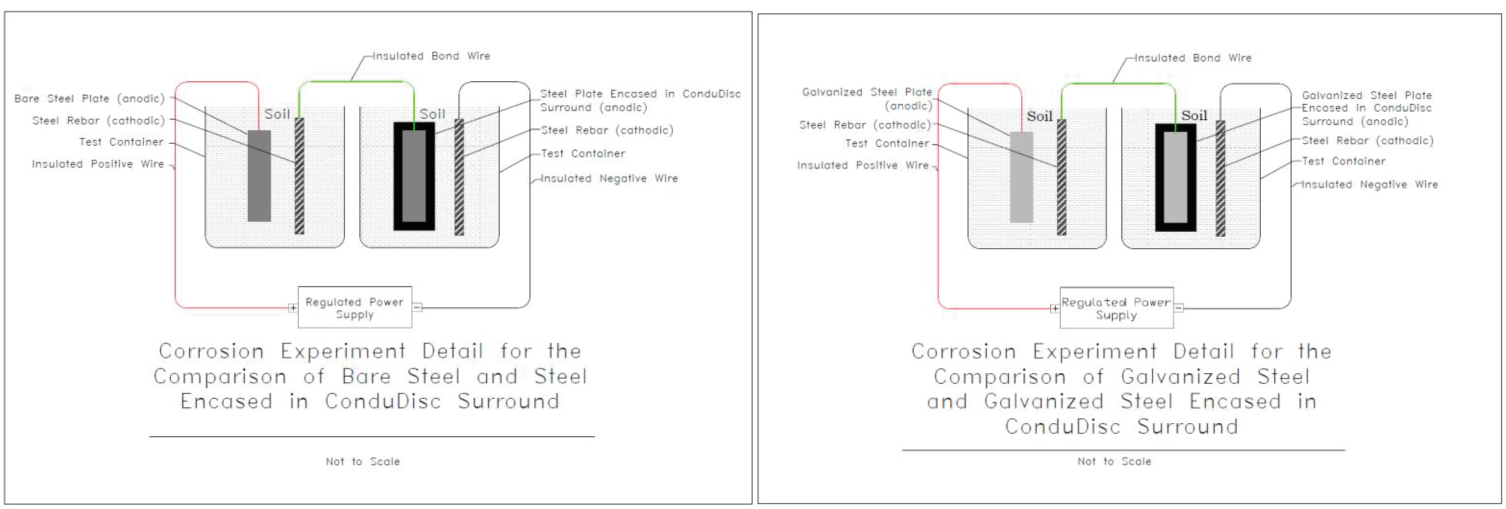


Figure 4: Schematics of the circuit configuration for each sample

3.0 Results and Analysis

The resistance data for each system was recorded throughout the experiment and can be seen below in Table 1.

Table 1: Resistance Data for Bare Steel and Galvanized Steel Samples

Date	Sample	Voltage (V)	Current (A)	Circuit Resistance (Ω)	Water Added (L)
21-Jun-17	Bare Steel	2.26	0.003	753.3	0
	Galv Steel	2.915	0.003	971.7	0
22-Jun-17	Bare Steel	2.799	0.003	933.0	0
	Galv Steel	3.54	0.003	1180.0	0
23-Jun-17	Bare Steel	2.691	0.003	897.0	0.25
	Galv Steel	3.483	0.002	1741.5	0.25
26-Jun-17	Bare Steel	2.888	0.004	722.0	0
	Galv Steel	4.305	0.004	1076.3	0
27-Jun-17	Bare Steel	2.935	0.004	733.8	0
	Galv Steel	4.558	0.004	1139.5	0
28-Jun-17	Bare Steel	2.85	0.003	950.0	0.25
	Galv Steel	4.535	0.003	1511.7	0.25
29-Jun-17	Bare Steel	2.779	0.003	926.3	0
	Galv Steel	4.197	0.003	1399.0	0
30-Jun-17	Bare Steel	2.715	0.003	905.0	0
	Galv Steel	4.031	0.002	2015.5	0
04-Jul-17	Bare Steel	2.857	0.003	952.3	0
	Galv Steel	4.668	0.003	1556.0	0
05-Jul-17	Bare Steel	2.785	0.002	1392.5	0.25
	Galv Steel	4.141	0.002	2070.5	0.25
06-Jul-17	Bare Steel	2.715	0.002	1357.5	0
	Galv Steel	3.836	0.002	1918.0	0
07-Jul-17	Bare Steel	2.691	0.002	1345.5	0
	Galv Steel	3.743	0.002	1871.5	0
10-Jul-17	Bare Steel	2.74	0.003	913.3	0
	Galv Steel	4.145	0.002	2072.5	0
11-Jul-17	Bare Steel	2.749	0.002	1374.5	0
	Galv Steel	3.998	0.002	1999.0	0
12-Jul-17	Bare Steel	2.749	0.003	916.3	0.25
	Galv Steel	3.942	0.002	1971.0	0.25
13-Jul-17	Bare Steel	2.784	0.004	696.0	0
	Galv Steel	4.122	0.003	1374.0	0
14-Jul-17	Bare Steel	2.817	0.003	939.0	0
	Galv Steel	4.632	0.003	1544.0	0
17-Jul-17	Bare Steel	2.833	0.003	944.3	0
	Galv Steel	4.822	0.003	1607.3	0
18-Jul-17	Bare Steel	2.836	0.003	945.3	0
	Galv Steel	4.678	0.002	2339.0	0
19-Jun-17	Bare Steel	2.795	0.003	931.7	0.25
	Galv Steel	3.699	0.002	1849.5	0.25
21-Jun-17	Bare Steel	2.833	0.002	1416.5	0
	Galv Steel	5.489	0.002	2744.5	0
24-Jun-17	Bare Steel	2.857	0.003	952.3	0
	Galv Steel	3.596	0.003	1198.7	0

After one month of testing, all samples were removed from the soil. The figures below show images of the samples not encased in ConduDisc™ surround before and after the experiment, note that the bare steel sample had begun to oxidize prior to the start of testing resulting in the discolouration of the sample. It is clear from Figure 5 that significant corrosion had occurred and some of the bare steel had been consumed. From Figure 6 it is clear that some of the galvanized coating has been consumed from the sample, and that consumption of the steel itself had begun.

Figure 5: Bare Steel sample not encased in ConduDisc™ surround before (left) and after (right) the experiment.

Figure 6: Galvanized sample not encased in ConduDisc™ surround before (left) and after (right) the experiment.

Figures 7 and 8 show both ConduDisc™ encased samples before and after the experiment. Both the steel and galvanized steel samples appear to be unaffected. The discolouration of the samples in the images is due to residual surround remaining on the steel and galvanized steel samples.

Figure 7: ConduDisc™ surround encased bare steel sample before (left) and after (right) the experiment.

Figure 8: ConduDisc™ surround encased galvanized steel sample before (left) and after (right) the experiment.

All samples were cleaned using acetone and weighed using an electronic balance. The data for the mass change of each sample can be seen in Table 2 below. Both samples not encased in ConduDisc™ surround lost just under 20% of their mass during the one month test running at 3 mA of current, whereas the ConduDisc™ surround encased samples both experienced negligible changes in mass of +/- 0.19%. The small loss of mass from the ConduDisc™ surround encased galvanized sample can be attributed to the galvanized coating bonding to the ConduDisc™ surround and peeling off when the sample was removed (see Figure 9). The small gain of mass from the ConduDisc™ surround encased bare steel sample can be attributed to residual surround material remaining on the sample during the final mass check.

Table 2: Percentage of Mass Consumed from Each Sample

Sample	Initial Mass (±0.01g)	Final Mass (±0.01g)	Mass Consumed (±0.01g)	Percent Loss (±0.25%)
Bare Steel	35.65	29.18	- 6.47	- 18.15
ConduDisc™ Surround Encased Bare Steel	37.61	37.68	0.07	+ 0.19
Galvanized Steel	36.77	29.80	- 6.97	- 18.96
ConduDisc™ Surround Encased Galvanized Steel	36.13	36.06	- 0.07	- 0.19

As seen in Figure 9 below, the cross-section of one of the test samples is shown. The encased galvanized steel sample had been removed from the ConduDisc™ surround, and there was a light grey/white layer of material where the sample was housed. This is a layer of the galvanizing coating which had peeled off the galvanized steel sample itself. This layer of material remaining on the ConduDisc™ surround explains the small loss in mass of the galvanized steel sample encased in ConduDisc™ surround.

Figure 9: Cross-section of ConduDisc™ surround that had encased the galvanized steel plate sample

4.0 Conclusion

This experiment compared the consumption rates of bare and galvanized steel in damp soil at low current to the consumption rates of bare and galvanized steel encased in ConduDisc™ surround in damp soil at low current. The bare and galvanized steel samples that were in direct contact with the damp soil had both experienced a fairly significant loss in mass at the completion of the test. The steel consumption was 18-19% for both samples in direct contact with the damp soil. In comparison the bare and galvanized steel samples encased in ConduDisc™ surround both experienced a negligible change in mass of +/- 0.19% at the completion of the test. Therefore, this experiment demonstrates that applying the ConduDisc™ surround effectively reduces the rate of corrosion of both bare and galvanized steel in buried grounding applications.

These results are the summary of results generated from testing conducted by SAE Inc. at their Midhurst, ON location. Testing was performed by Tim Sirola, R&D Assistant, from June 21, 2017 to July 21, 2017.

Compression Testing of the ConduDisc™

In order to determine how the ConduDisc™ will perform when attached to the bottom of a utility pole in situ, varying loads were applied to full sized ConduDisc™ samples using an Instron. Our research found that the heaviest wooden utility poles are 125 ft. class H-6 Douglas Fir Poles which weigh 15 480 lbs., or 7022 kg, and the heaviest spun concrete utility poles are 118 ft. class K poles which weigh 24 088 lbs., or 10 926 kg. This does not include the weight of the wires, transformers, and any additional equipment attached to the pole after installation. Table 1 below outlines how much the ConduDisc™ compressed when subjected to varying loads.

Table 1: ConduDisc™ Compression Testing

Applied Load (kg)		Applied Pressure		Compression of ConduDisc™ (mm)	
kg	**lbs.**	**MPa**	**psi**	**mm**	**%**
7000	15 432	0.693	100.51	2.2	4.3
12 000	26 456	1.185	171.91	2.6	5.1
14 500	31 967	1.436	208.27	3.0	5.9
16 771	36 975	1.677	241.43	3.1	6.1

As shown in Table 1 the ConduDisc™ only experienced minimal compression even when subjected to a load over two times the weight of the heaviest wooden utility poles. The compression of the ConduDisc™ was elastic compression, as once the load was released the samples returned to their original thickness with no deterioration of the sample. None of the ConduDisc™ samples in this experiment experienced cracking or deterioration of the surround material at any of the loads applied.

These results are the summary of results generated from testing conducted by SAE Inc. at Georgian College's technology laboratory located in Barrie, ON. Testing was performed by Tim Sirola and Duncan Wishart, R&D Assistants, on July 26, 2017.

Permeability Testing

Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter by ASTM D5084 – Constant Volume

Sample Type: Tube
Permeant Fluid: De-aired Distilled water
Orientation: Vertical

Sample Preparation: Placed into permeameter at as-received density and moisture content.

Assumed Specific Gravity: 1.18

Parameter	Initial	Final
Height, in	7.13	7.095
Diameter, in	3.96	3.96
Area, in^2	12.34	12.34
Volume, in^3	87.95	87.65
Mass, g	1639	1672
Bulk Density, pcf	70.8	72.55
Moisture Content, %	3.8	6
Dry Density, pcf	68.25	68.55
Degree of Saturation, %	58	97

B COEFFICIENT DETERMINATION

Cell Pressure, psi:	89.99	Increased Cell Pressure, psi:	94.96	Cell Pressure Increment, psi:	4.97
Sample Pressure, psi:	87.38	Corresponding Sample Pressure, psi:	92.16	Sample Pressure Increment, psi:	4.78
				B Coefficient:	0.96

FLOW DATA

Date	Trial #	Pressure, psi		Manometer Readings			Elapsed Time, Sec	Gradient	Permeability K, cm/sec	Temp, °C	R_t	Permeability K @ 20 °c, cm/sec
		Cell	Sample	Z_1	Z_2	Z_1-Z_2						
8-May-17	1	90	87.4	23.75	23.5	0.25	43	16.6	1.70E-07	19.5	1.013	1.70E-07
8-May-17	2	90	87.4	23.75	23.5	0.25	45	16.6	1.83E-07	19.5	1.013	1.84E-07
8-May-17	3	90	87.4	23.75	23.5	0.25	49	16.6	1.59E-07	19.5	1.013	1.60E-07
8-May-17	4	90	87.4	23.75	23.5	0.25	51	16.6	1.58E-07	19.5	1.013	1.63E-07

PERMEABILITY AT 20° C: 1.72 x 10^{-7} cm/sec (@2.6 psi effective stress)

These results are the summary of results generated from testing conducted by GeoTesting Express located in Acton, MA. Testing was performed by Ethan Marro, Assistant Laboratory Manager, from May 5, 2017 to May 9, 2017.

Leachate Data

ConduDisc™ is environmentally neutral. It is provided as a solid that does not leach, dissolve or migrate into the soil or water. A table of toxicity characteristic leaching procedure (TCLP) results for ConduDisc™ surround material is included below. The ConduDisc™ surround material was tested to EPA Standard SW846-6020A. TCLP is a soil sample extraction method for chemical analysis employed as an analytical method to simulate leaching through a landfill. Because the testing methodology is used to determine if a waste is characteristically hazardous, similar conditions are not expected in a typical groundwater environment, and the results overestimate the amount of leaching that would occur.

The TCLP results are compared to the Maximum Contaminant Level (MCL) established by the U.S. Environmental Protection Agency (USEPA) for each constituent in the table below. The MCL is the highest level of a contaminant that is allowed in drinking water. For those constituents detected in the leachate, none exceeded USEPA regulatory standards for drinking water. Additionally, because of TCLP conditions, these constituents would not be expected to present a risk for migration in a typical groundwater environment.

Table 1: TCLP Results for ConduDisc™

Constituent	ConduDisc™ TCLP Concentration (mg/L)	USEPA Maximum Contaminant Level (mg/L)
Arsenic	< 0.010	0.010
Barium	1.490	2.000
Boron	1.067	2.000ƚ
Chromium	0.026	0.100
Mercury	< 0.001	0.002
Selenium	0.013	0.050
Silver	< 0.010	0.100*
Uranium	< 0.010	0.030
Fluoride	0.190	2.000*
Nitrate (as Nitrogen)	< 0.10	10.000
Nitrite (as Nitrogen)	< 0.050	1.000
Cyanide	< 0.050	0.200

ƚ No MCL established; value shown is USEPA's Lifetime Drinking Water Health Advisory.

* No MCL established; value shown is USEPA's secondary drinking water standard.

Note: < denotes less than method detection limit (MDL).

These results are the summary of results generated from testing conducted by Testmark Laboratories Ltd. located in Kirkland Lake, ON. Testing was performed by Brad Woodward, Laboratory Director, from October 12, 2017 to October 18, 2017.

Fault Current Withstand

Contents

Powertech

REPORT OF PERFORMANCE

CLIENT / MANUFACTURER	SAE Inc. 19 Churchill Drive Barrie, ON, L4N 8Z5, Canada
TEST OBJECT	ConduDisc Serial number/identification: N/A Description, Condition: Design Investigation
TESTED BY	Powertech Labs Inc. 12388 - 88th Ave, Surrey, BC Canada V3W 7R7 www.powertechlabs.com
TEST DATE	2017-11-27
TEST SPECIFICATION	Client Specifications

Powertech Labs Inc. does not accept any liability for any damages resulting from the use of this report. The results relate only to the item tested, and it is the responsibility of the manufacturer to maintain conformity of any object having the same designations. Information regarding the estimated measurement uncertainty is available upon request. The test report shall not be reproduced except in full, without written approval of Powertech Labs Inc.

Prepared by:

Erik Groom, P.Eng.
Senior Project Engineer,
T&D Technology and Testing
Powertech Labs Inc.

Reviewed by:

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — C. P. MORTON # 20747
2018-01-05

Chris Morton, P.Eng.
Specialist Engineer, Substations
Technology and Testing, High Power Lab
Powertech Labs Inc.

1.0 Introduction

Four ConduDisc™ samples, manufactured by SAE, Inc., were subjected to short-circuit tests at the High Power Laboratory of Powertech Labs, Inc. The tests were performed for investigative preliminary fault current testing in accordance with the client's requirements.

2.0 Test Object Information

The ConduDisc™ test objects were identified by the client with the following information:

- Labelled as sample Numbers 1 through 4
- Samples were made using formulation #1117
- Surround encapsulated a 1/8" thick galvanized steel plate
- Lead wire was #2 copper clad steel equivalent to #4 AWG all copper wire

3.0 General Information

3.1 Purpose

The purpose of the test was to determine the amount of fault current that the ConduDisc™ samples can withstand within a 500 millisecond test duration.

3.2 Test Standards/Specifications

There were no specific standards to guide the testing. The tests performed were directed by the client as follows:

- Fault current at levels specified by the client.
- Fault duration of up to 500 milliseconds.

4.0 Fault Current Testing

General Information:

Standard:	None
Test Date:	November 27, 2017

Environmental Conditions:

Ambient temperature:	6 – 10 ^{o}C

Test Conditions:

Test Voltage:	3.7 kV_{rms} phase-to-ground
Test Current Levels:	1.04 kA_{rms} to 4.99 kA_{rms}
Phases:	1
Test Frequency:	60 Hz

The samples were tested using a single-phase circuit as shown in Figure 1. The current level in the tested sample was controlled by adjusting the current-limiting source reactance of the circuit.

Test Setup:
The testing was performed in the High Power Lab test cell with the following configurations:

Tests on Sample Number 1-2, sample setup #1

The test sample assembly consisted of:
- A ½" aluminum plate which acted as a lower grounded electrode
- The ConduDisc™ placed on top of the electrode
- A fiberglass board placed on top of the ConduDisc™
- 2-4 concrete blocks weighing approximately 70-140 lbs. placed on top of the fiberglass board to hold the ConduDisc™ against the lower electrode
- The assembly was placed on an insulated table for the tests

Current was applied to the ConduDisc™ through a 43.5 inch long #2 copper-clad steel ground wire which was embedded in the ConduDisc™. The configuration of the typical test sample set-up is shown in Figure 2.

Tests on Sample Number 3, sample setup #2

It was found during testing that the #2 copper-clad steel ground wire was insufficient to carry higher fault current levels, and it fused during some of the tests. The test sample assembly was therefore modified to consist of:
- A ½" aluminum plate which acted as a lower grounded electrode
- The ConduDisc™ placed on top of the electrode
- A second ½" aluminum plate which acted as an upper energized electrode placed on top of the ConduDisc™
- 4 concrete blocks weighing approximately 140 lbs. placed on top of the upper electrode to hold the ConduDisc™ against the electrodes
- The assembly was placed on an insulated table for the tests

The configuration of the test set-up is shown in Figure 3.

Tests on Sample Number 4, sample setup #3

The test sample assembly consisted of:
- A ½" aluminum plate which acted as a lower grounded electrode
- The ConduDisc™ placed on top of the electrode
- A second ½" aluminum plate which acted as an upper energized electrode placed on top of the ConduDisc™
- A large concrete block weighing approximately 2000 lbs. placed on top of the upper electrode to hold the ConduDisc™ against the electrodes
- The assembly was placed on an insulated fiberglass board which was placed directly on the concrete floor of the test cell for the tests.

The configuration of the test set-up is shown in Figure 4.

Requirements:
Test samples are required to withstand the applied current for up to 500 milliseconds.

Results:
The following table shows the test data for the tests performed on the tested objects.

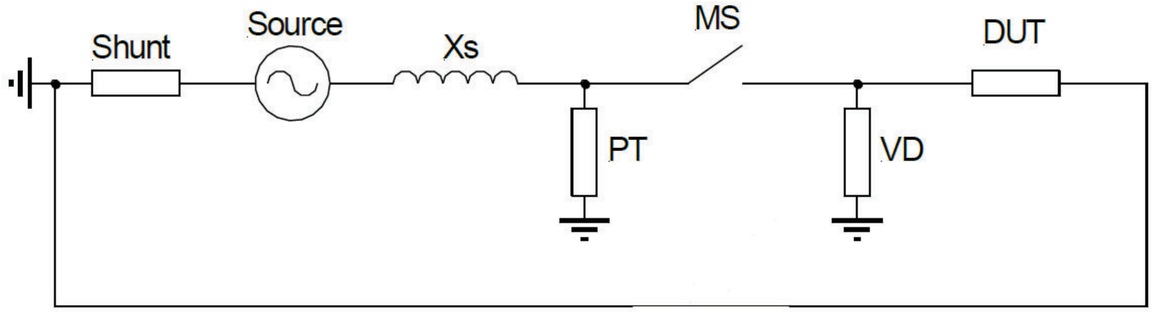
Table 1: ConduDisc™ Fault Current Test Data

Test No.	Test Setup No.	RMS Current (A)	RMS Voltage (kV)	Resistance Before Test (mΩ)	Resistance After Test (mΩ)	Approximate Temperature Rise (^{o}C)	Test Duration (milliseconds)
Sample #1, Test #2	#1	1040	19.5	30.6	20.3	1	508
Sample #2, Test #1	#1	2520	124	55.5	20.2	2	508
Sample #3, Test #2	#2	3730	239	44.9	46.0	13	234
Sample #4, Test #1	#3	4990	176	34.6	7.28	1	508

The above report is the summary of results generated from testing conducted by Powertech Labs Inc. in Surrey, British Columbia.

Appendix A – Test Circuit

Figure 1: Test circuit schematic



Notes:

1. *Shunt – Current measurement*
2. *X_s – Source reactance*
3. *PT – Source voltage measurement*
4. *MS – Make switch*
5. *VD – DUT voltage measurement*
6. *DUT – Device under test*

Appendix B – Diagrams and Photographs of the Tests

Figure 2: ConduDisc™, Test Setup #1

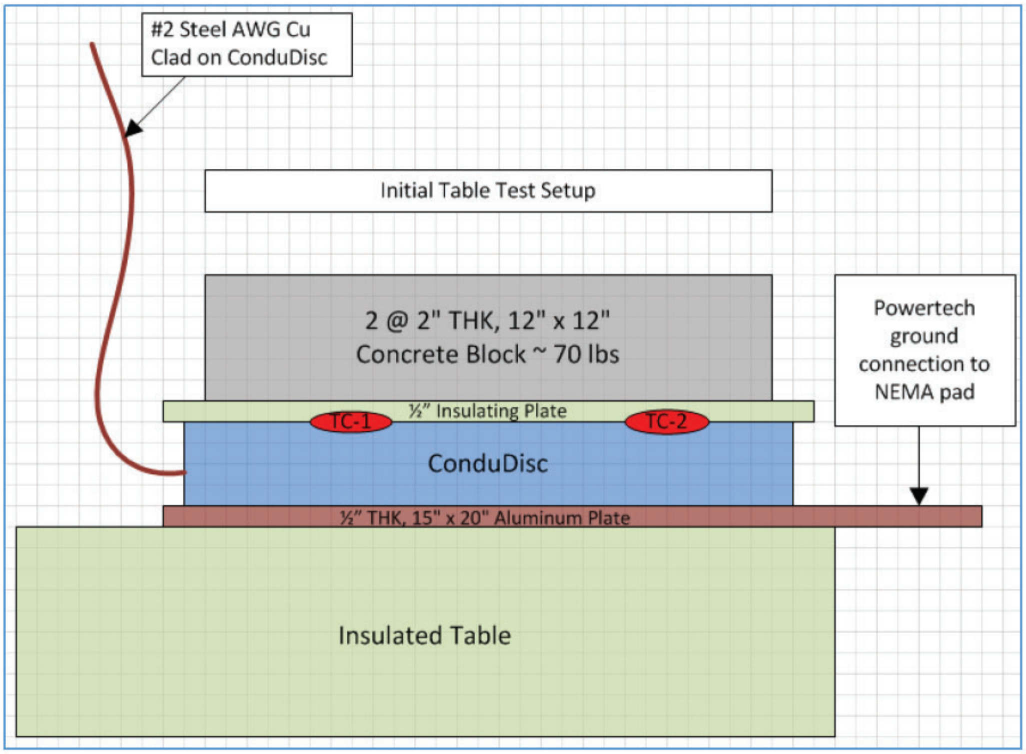
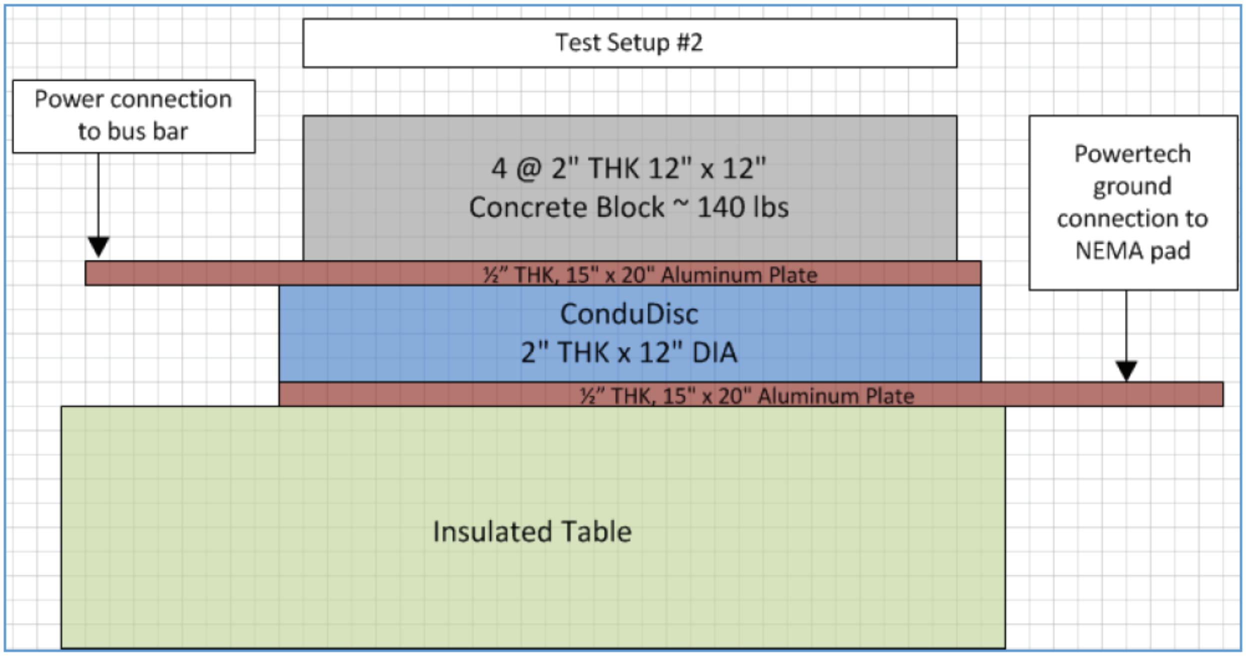


Figure #3: ConduDisc™, Test Setup #2



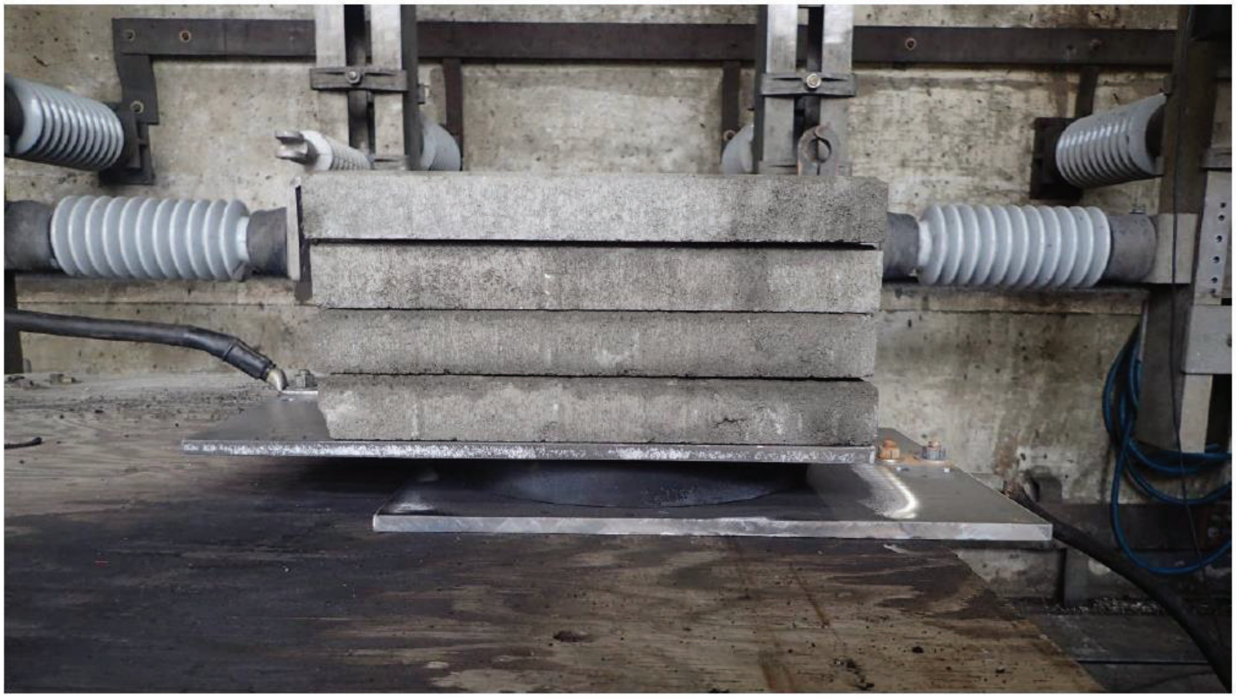
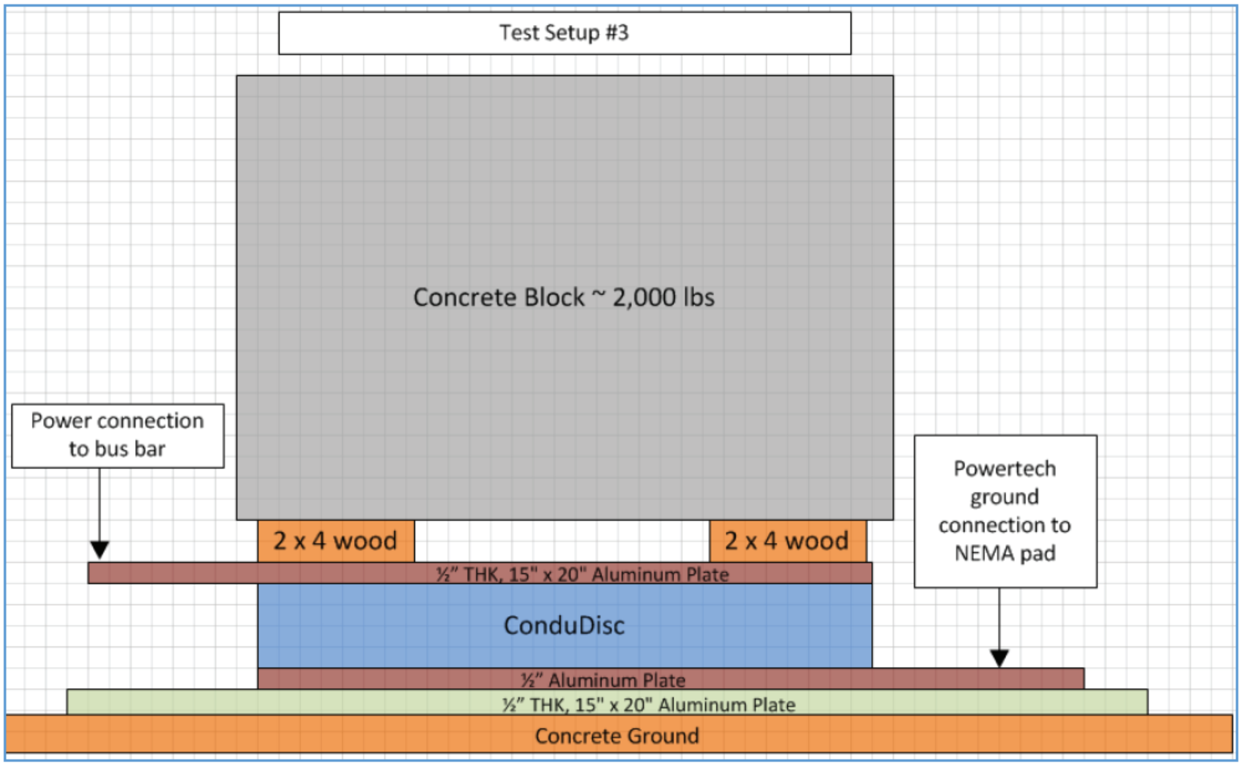
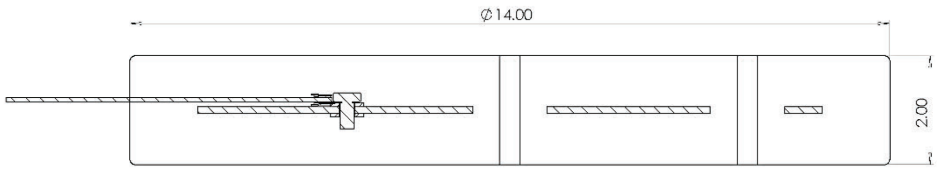


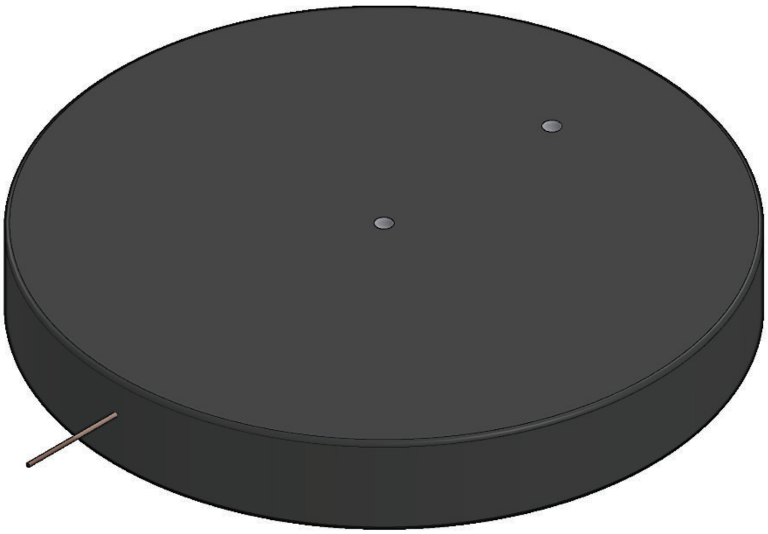
Figure #4: ConduDisc™, Test Setup #3

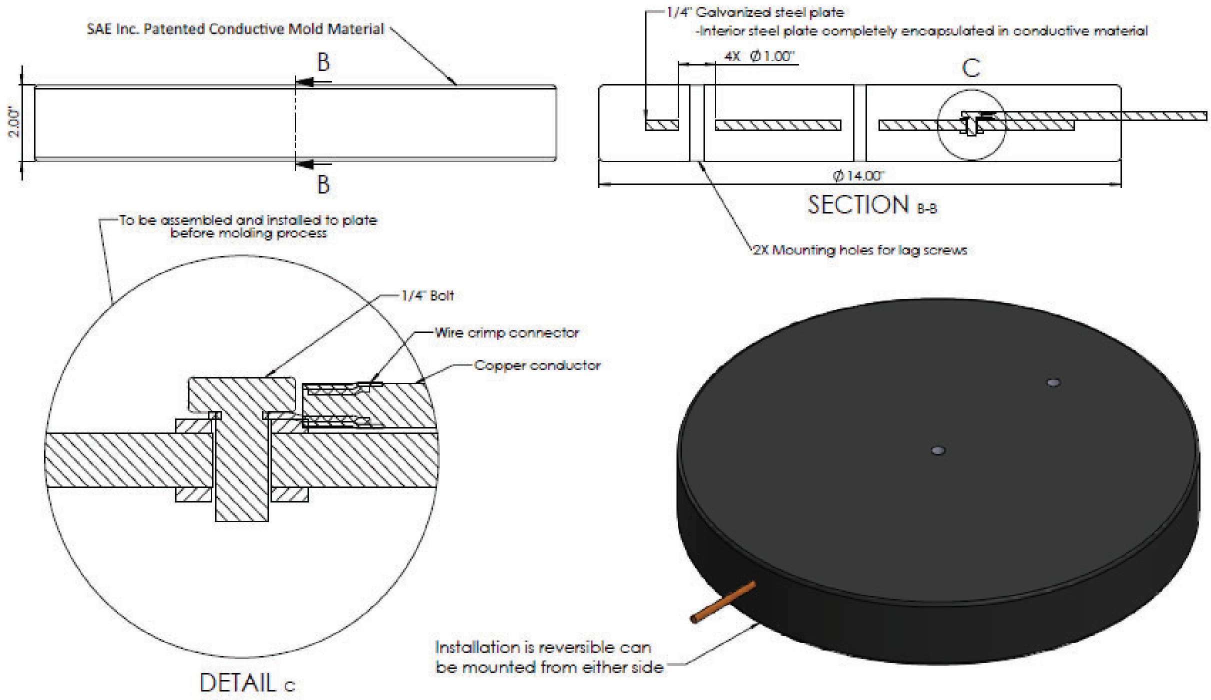


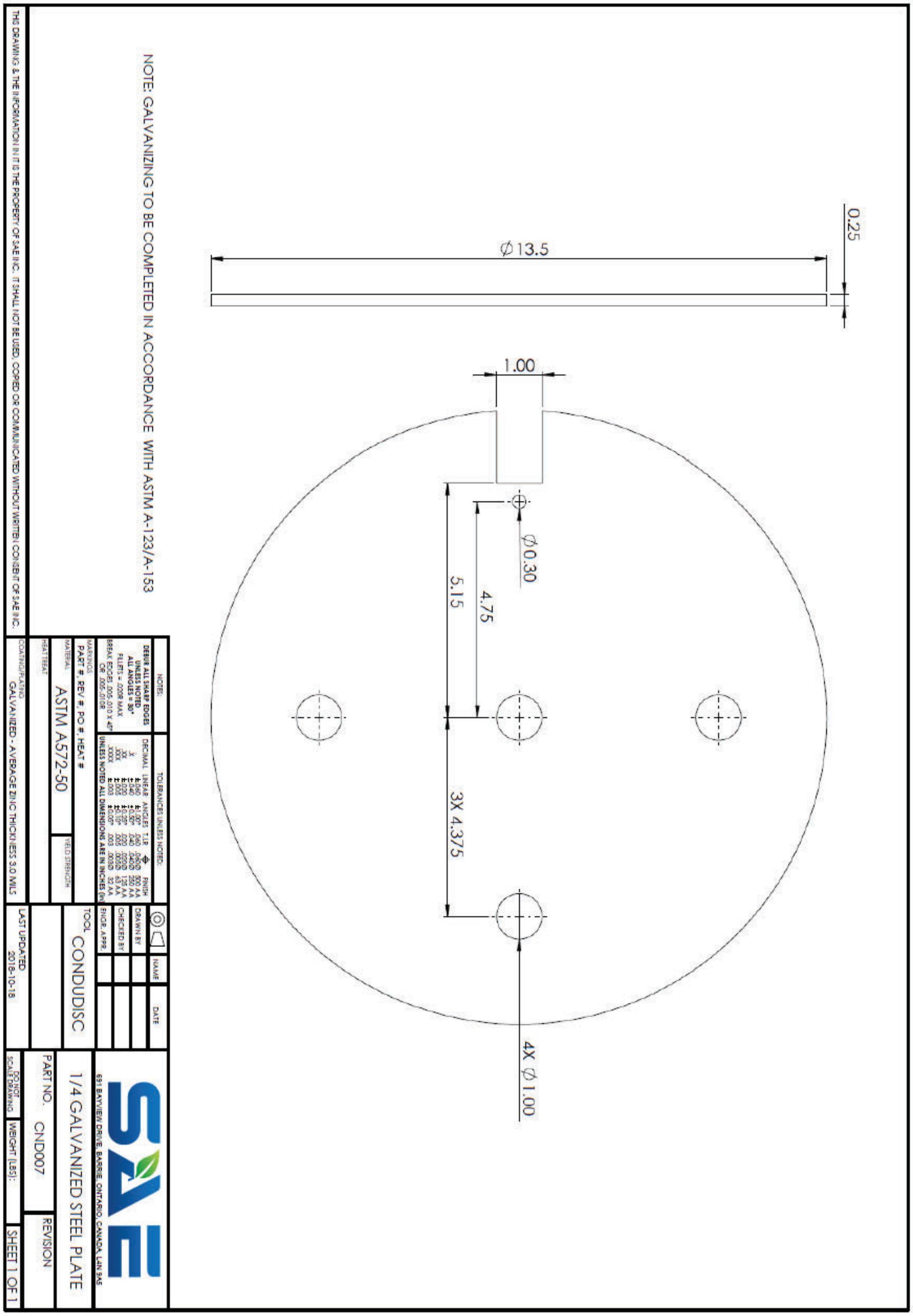
Engineering Drawings



SECTION A-A
SCALE 1 : 1.5




SAE Inc. Patented Conductive Mold Material
B
B
2.00"
1/4" Galvanized steel plate
-Interior steel plate completely encapsulated in conductive material
4X Ø1.00"
C
Ø14.00"
SECTION B-B
2X Mounting holes for lag screws
To be assembled and installed to plate before molding process
1/4" Bolt
Wire crimp connector
Copper conductor
DETAIL C
Installation is reversible can be mounted from either side


NOTE: GALVANIZING TO BE COMPLETED IN ACCORDANCE WITH ASTM A-123/A-153
∅13.5
0.25
1.00
∅0.30
4.75
5.15
3X 4.375
4X ∅1.00
ASTM A572-50
PART #, REV #, PO #, HEAT #
GALVANIZED - AVERAGE ZINC THICKNESS 3.0 MILS
CONDUDISC
LAST UPDATED 2018-10-18
1/4 GALVANIZED STEEL PLATE
PART NO. CND007
REVISION
SHEET 1 OF 1
WEIGHT (LBS):
DO NOT SCALE DRAWING
691 BAYVIEW DRIVE, BARRIE, ONTARIO, CANADA, L4N 9A5
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