

A Study on the Application of Cathodic Protection for Anti-Corrosion of Automobile Body

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(Received September 16, 2020; Revised August 23, 2021; Accepted August 24, 2021)

The use of cathodic protection for metals can be achieved by sacrificial anode CP or impressed current CP, or a combination of both. Cathodic protection is a highly effective anti-corrosion technique for submerged metals or metals in soil. But because the non-immersion atmospheric automobile environment is a high resistance environment, it is limited by fundamental cathodic protection. However, the application of cathodic protection to automobiles is attractive because of the possibility of maintaining corrosion resistance while using lower-cost materials. A commercially available product for automobiles that uses both sacrificial anode CP and impressed current CP was tested in a periodic salt spray environment to investigate the performance of the devices. Experimental results show that the metal to be protected has different anti-corrosion effects depending on the distance from the anode of the device, but it is effective for the entire 120 cm long specimen exposed with one anode. The cathodic protection is effective because the conductive tape attached to the anode of the structure to be protected acts as a constant electrolyte in wet and dry conditions. The results show that the entire standard passenger car can be protected by cathodic protection with 4 anodes.

Keywords: Cathodic protection for automobiles, Cathodic protection devices, Electronic rust prevention

1. Introduction

The corrosion of the steel body of automobiles and other automobiles is one of major problem to the automotive industry. Automobile corrosion is caused by the extremely aggressive environment created by the use of road salts, by acid deposition, and by natural factors such as marine environments along coastal areas. The most widely used method of inhibiting the corrosion process is the application of an impervious coating which prevents the access of the chloride ions to the steel surface. This method shows effective while the coating remains intact and covers the entire exposed steel surface. An alternative methodology, widely applied to naval vessels, pipelines and reinforced concrete structures is cathodic protection. Cathodic protection may use either sacrificial anode CP or impressed current CP, or indeed a combination of both. Cathodic protection including sacrificial anode CP and impressed current CP are very effective for metals submerged or metals in soil, but the use of this method for outdoor structures such as automobiles is less efficient and protection is very localized.

So, cathodic protection was applied to automobiles, which was mostly unsuccessful. This paper describes the state-of-the-art in automobile cathodic protection.

Corrosion prevention by sacrificial anode CP involves the galvanic coupling of a more active metal with a more noble metal to be protected in a suitable electrolyte. With the dissimilar metals in electrical and electrolyte contact, the resulting current flow serves to polarize the more noble metal (cathode) to more cathodic potentials resulting in a reduced corrosion rate. On the other hand, the more active metal (anode) is polarized to more active potentials and corrodes at an accelerated rate. Magnesium, zinc, and aluminum are used quite commonly as sacrificial anodes CP. There is no electronic unit in this method but because of the superb electrolyte, salt water, it is quite effective. The method is a very localized effect when used in outdoor structures such as automobiles and provides sufficient protection in very wet conditions.

Corrosion prevention by impressed current CP involves the use of an inert anode and an external DC power source. Polarization of the metal to be protected to a more cathodic potential is achieved through an impressed voltage which drives the current. The circuit is complete with the anode providing non-corrosive oxidation reactions. Impressed current CP (polarization to more cathodic potentials) is the same as that in sacrificial anode CP, however, the driving

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force is provided by the power source. The requirement for impressed current CP includes a suitable power source. Impressed current protection is designed according to the specific environment. Anodes of impressed current CP in seawater are frequently located several hundred meters from the structure because of the low resistivity of that environment. Sometimes, it has been necessary to place anodes of impressed current CP very close to the structure in order to protect the steel structure. The non-immersion, atmospheric automobile environment is also a high resistance environment and is therefore subject to limitations based on fundamental impressed current CP design considerations.

The application of cathodic protection for automobile was numerous problems due to the high resistance environment. First of all most devices use the straight +12 V from the battery on the anodes, which is not enough charge to protect an automobile. Because the anode has to be + charged, in this case +12 V, they cannot be fitted directly to the body of the car, which is -12 V, and so would cause a direct short circuit. So the anodes are insulated from the body of the car and so few limitation effectiveness is achieved until the anode is submerged in water which becomes the electrolyte for the current to flow through. Most commercial products also use one technology, either sacrificial anode CP or impressed current CP and although many have tried to combine the two, it is a very complicated process and most have failed.

There is a cathodic protection devices for automobile by RustStop RS-5[®] (hereinafter referred to as dc supplier or dc module) which is the registered trademark of anti-corrosive cathodic protection device from RustStop which use both sacrificial anode CP and impressed current CP. Dc module outputs a stepped up voltage of 45 V onto the anode and the higher the potential difference the greater the amount of current impressed and so the greater the area of protection. But now with +45 V on the anodes and -12 V on the car, they cannot be connected directly to the metal. Dc supplier has developed an “adhesive conductive tape” that allows current flow to pass through while still maintaining a higher voltage. This means that the tape becomes an ever present electrolyte and so dc module is effective even in dry conditions. Under wet conditions the tape becomes even more conductive and so greater effectiveness is achieved in the wet, when it is needed most.

Fig. 1 shows the application of dc module for automobiles. The automobile body is coated with intrinsic car paint and is connected to the cathode ground. In order to apply the cathodic protection to such an automobile body, it is possible by peeling off the paint on the area where the anode will be located and attaching it using an adhesive conductive tape. The current flows from the anode of the electrode plate,

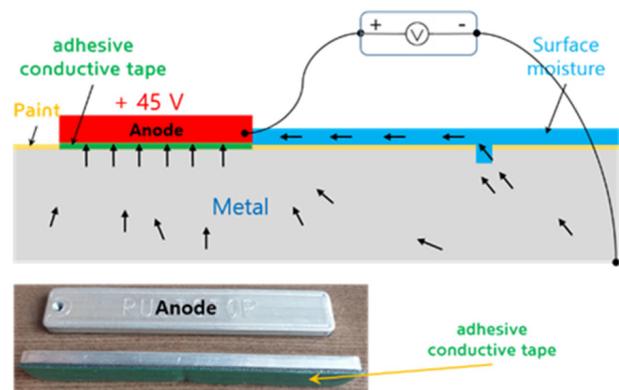


Fig. 1. It shows the movement path of free electrons in the metal through the anode by the open cell adhesive tape. It indicates how efficiently the DC module operates in response to moisture, even atmospheric humidity, present on the metal surface being protected

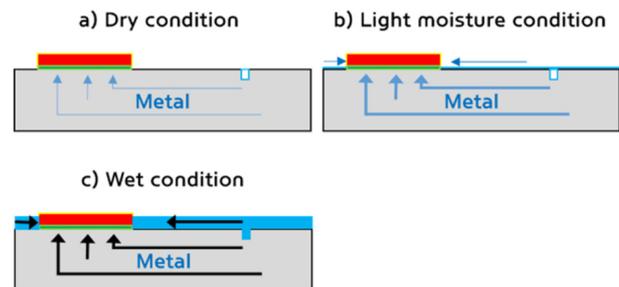


Fig. 2. When the anode of the adhesive tape is applied, the current passes even in dry conditions, but in light moisture or wet conditions, the conductivity of the adhesive tape increases, which increases the current

which is a positive voltage, to the automobile body, which is a negative voltage. This flow of current eventually prevents rust on the automobile body. In dry condition, current flows inside the metal to protect it. When rain or snow falls like wet condition and water flows to the automobile body surface, the water becomes an electrolyte and additional current flows to the automobile body surface, causing dc module to reach the maximum current do. The tape is more conductive in the wet, so the attraction of free electrons become more active. It is shown in Fig. 2.

The application of cathodic protection to automobiles is attractive because of the possibility of maintaining corrosion resistance while using lower cost materials. Therefore, we conducted a study on the feasibility of using dc module on automobiles. Laboratory corrosion test has been undertaken to investigate the performance of dc module for cathodic protection.

2. Experimental Methods

The first experiment was conducted to verify the

performance of dc module for cathodic protection, especially in water. It is shown in Fig. 3. Two 15 cm test cell with a cube glass partition and two specimens are used. The specimen is made of carbon steel and is 12 × 20 cm in size. One specimen with cathodic protection and another with no treatment are left submerged in water at the same time. Therefore the test was performed until the specimen with no treatment is significantly corroded.

The specimen to be protected from corrosion is applied with the cathode, and the electrode plate with + 45 V. The current flows from the electrode plate to the specimen which is a negative voltage. In the area of the electrode plate in contact with air, most of the current flows through the conductive tape to the specimen. It is indicated by a black arrow in Fig. 4. On the other hand, in the area of the electrode plate in water, the conductivity of the conductive tape increased due to water, causing more current to flow into the specimen than in the air contact area. In addition, the additional current from the electrode plate flows into the specimen through water, which is an electrolyte. It is indicated by the red arrow in Fig. 4. Therefore, it is effectively



Fig. 3. This is a test cell to check the performance dc module

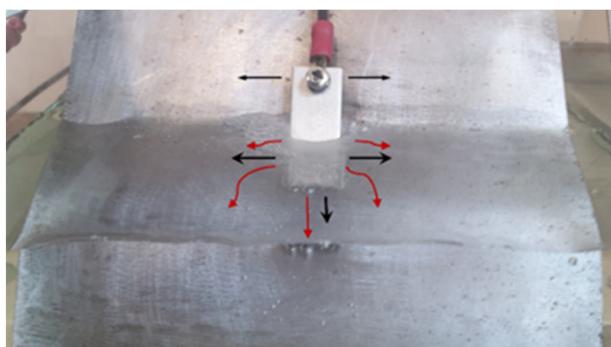


Fig. 4. It shows the path of the current flowing through the anode in the water or outside the water to the protected specimen. Black arrows shows path through metal and red arrows shows the path through water

prevents corrosion in wet condition. It is shown in Fig. 4.

Experiments with the test cell is about the principle and verification of cathode protection of dc module in water with an electrolyte. However, water and salt water (electrolytes in which the deicing is dissolved), which are the main causes of corrosive environments, rarely completely cover the vehicle body like this in actual use. In most cases, it is necessary to check the performance of dc module in an environment where the processes of wet and dry conditions are repeated.

Accelerated corrosion test was conducted to verify the performance of dc module. The equipment is shown in Fig. 5. The accelerated corrosion test is designed to simulate and accelerate the impact of the environment on metallic materials exposed to the outdoor atmosphere where salt contaminated conditions occur and corrosion is promoted. This test includes a periodic exposure test in which the specimen is exposed to salt spray, dried, and allowed to stand in high humidity for a certain period of time. The test

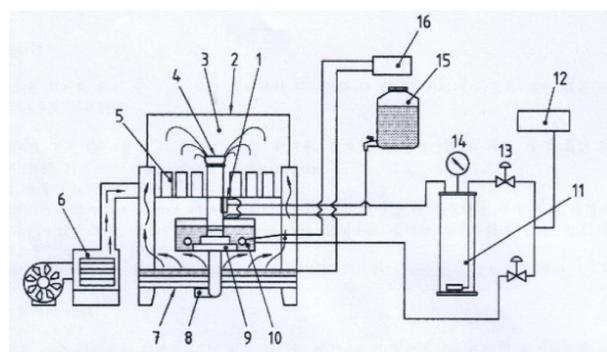


Fig. 5. The components of accelerated corrosion test equipment are shown; Identifier code 1.spray 2.cover 3.test space 4.top of spray 5.shelf of specimen 6.air dryer 7.heated water tank 8.humidifier 9.bubbler 10.heating device 11.air blower 12.air compressor 13.solenoid valve 14.pressure gauge 15.solution tank 16.thermostat

Table 1. Test procedures and conditions of accelerated corrosion test equipment

Salt spray condition	Temperature (35±2)°C Saltwater (50±5) g/L NaCl
Dry condition	Temperature (60±2)°C RH 30%
Wet condition	Temperature (50±2)°C RH 95%
1 Cycle (8 hours)	Saltwater spray 2 hours Dry condition 4 hours Wet condition 2 hours
Time to reach each condition	Salt spray to dry within 30 min. Dry to wet within 15 min. Wet to salt spray within 30 min.

procedure is shown in Table 1. KS D ISO 1499 3:2001 is applied for the corrosion test. This technique is a Korean industrial standard based on ISO 14993 without any change in technical content.

Specimens are supplied by a steel manufacturer for specimens used in automobile bodies. Among the specimen, the 7×15 cm specimen is a raw metal, and the 7×120 cm specimen is treated with phosphate coating and electrocoating. This is to achieve the same state as the vehicle body. No.5 in Fig. 5 is the shelf on which the specimen is placed, No.4 is the salt spray nozzle, and No.3 is the space of the exposure chamber. The salt spray from this nozzle is not sprayed directly onto the specimen, but is indirectly sprayed to the top of the shelf, and it is designed so that the indirectly sprayed salt spray droplets do not fall directly onto the specimen surface. Therefore, the first experiment is to check whether the salt spray effect is evenly distributed within the exposure chamber. A 7×120 cm specimen is used and there are three scratches on the painted surface. The scratch locations are marked on the specimen in the exposure chamber as shown in Fig. 6. The first experiment checks whether the three locations are in the same corrosive environment.

Additional experiments are performed to verify the performance of dc module depending on the scratched position and the electrode plate attachment position. In the second experiment, two 7×120 cm specimens are used simultaneously, one with dc module installed and another with no treatment. This is the case where the position of the electrode plate attached to the bottom of the specimen. It is shown in Fig. 7. In the third experiment, the position of the electrode plate position is attached to the top of the specimen. In the second and third experiments, two sites are scratched on the painted surface of the specimen. This experiment is to check the performance of dc module according to the position of the electrode plate attached to the specimen.

The schematic diagram of dc module installed on 7×120 cm specimen is shown in Fig. 8. Dc module is connected to a constant voltage power source as directed in the instructions provided. The power source is set to 12 V to replicate a car battery. A constant power source is used to prevent the need to charge a car battery over the course of the test. This enabled the power to be maintained throughout, as would be the case on an actual automobile.

The conditions of the test equipment are designed to better simulate the environment of salt contaminated outdoors. The salt spray is a 5% NaCl solution, and sodium chloride is used to promote rapid corrosion. However, exposure condition of such a cyclic salt spray can be much more extreme than the case of daily driving of a car when exposed

to deicing salts for only a small period of a year at low concentrations of chloride ions. 6 cycles are recommended

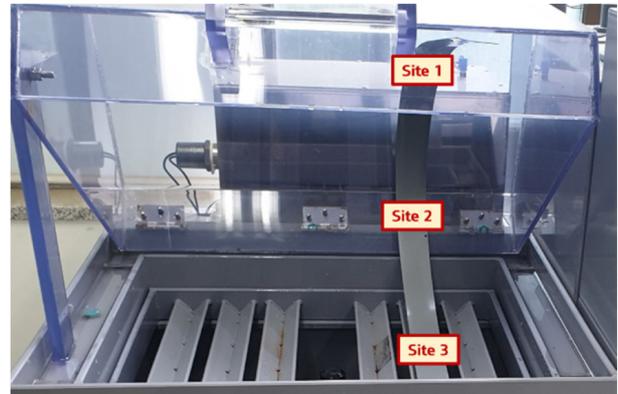


Fig. 6. In order to check whether the exposure chamber on which the specimen is placed is the same corrosive environment, three scratches – Site1, Site2, Site3 – were made on the specimen



Fig. 7. It is to check the correlation between the position of the anode attached to the specimen and the corrosive environment in the exposure chamber. The specimen on the left in the figure is when the anode of dc module installed on the bottom of the exposure chamber, and the specimen on the right is no treatment. Two scratches – Site1, Site2 - were created on the specimen

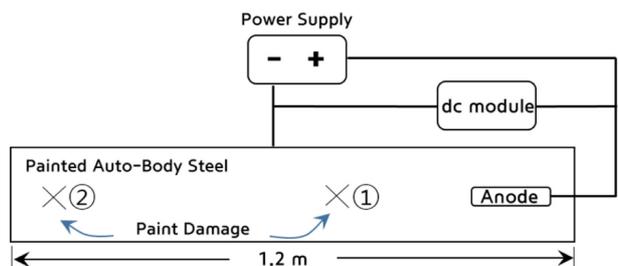


Fig. 8. Diagram of dc module installed and scratch location on a specimen

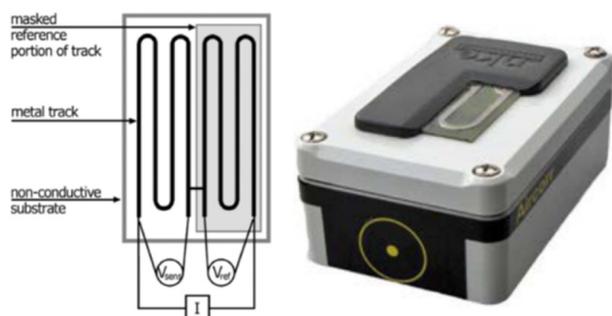


Fig. 9. Corrosion monitoring device to obtain the quantitative value of one cycle of the accelerated corrosion test.

as the period for corrosive evaluation, and additional experiments are conducted to find out how much the 6 cycles of the experiment correspond to the outdoor expose period. Two 7×15 cm specimens are used to obtain a quantitative value of one cycle of the accelerated corrosion test, and up to two cycles are accumulated and performed to obtain the degree of corrosion of one cycle. In addition, a corrosion monitoring device is used to obtain the qualitative value of corrosion test of 6 cycles, and the result of 6 cycles of accelerated corrosion test using the same device is compared and analyzed with the result of performing at an outdoor for a certain period of time.

The corrosion monitoring device is a unit for real-time monitoring of corrosivity and air quality. The technique is described in, e.g., ASTM standard G96 [5]. The device measures and registers the change over time in the electrical resistance of a thin metal track applied on an insulating substrate. If the metal corrodes, the cross-sectional area of the track decreases and the electrical resistance increases. The changes in the electrical resistance can be directly translated into corrosion depth and corrosion rate. Therefore, if the device is mounted at the position to check the corrosivity, the corrosion depth and the corrosion rate at that position are obtained from the device.

3. Results

The test cell experiment is a review of the effectiveness of dc module's cathodic protection when a continuous water film is formed on the surface of the metal to be protected. The test is performed until the specimen with no treatment is significantly corroded. The experimental results are shown in Fig. 10.

Most of the hydrogen gas is observed at the anode of the electrode plate, and almost no hydrogen gas is observed on the surface of the specimen to be protected. It is observed that aluminum of the electrode plate is ionized by oxidation reaction and detected on the surface of specimen and in water.



Fig. 10. Performance results of dc module by test cell

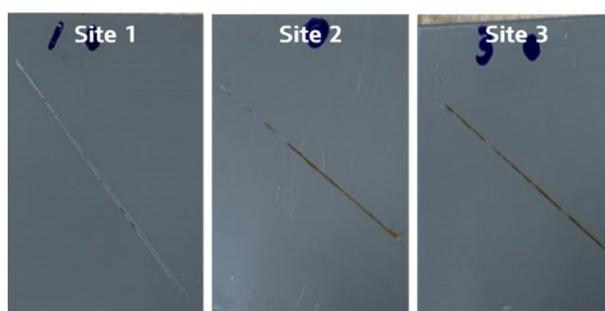


Fig. 11. Corrosive evaluation results for each site in the exposure chamber

Compared with the unprotected specimen, cathodic protection effect of dc module in the continuous water film is confirmed. The result of this experimental is that the electrode plate is attached to the structure to be protected with a conductive tape, and the electrode plate is not only located at a very close distance to the structure to be protected, but is also arranged symmetrically, so that the current required for cathodic protection is provided with an appropriate voltage.

An experiment is conducted to confirm whether the space in the exposure chamber is a uniform corrosive environment. One cycle is carried out for corrosive environment evaluation. The result is shown in Fig. 11. Site 3 is the location where the specimen is originally placed in the exposure chamber. Since the prepared specimen is so long that it could not be placed in Site 3, a corrosive environment evaluation is performed for the other site along with site 3.

The degree of corrosion by location is in the order of site 3 > site 2 > site 1. This means that a different corrosive environment exists for each site on one long specimen, Site 3 where the exposed specimen is originally placed is the most severe corrosive environment. Additional experiments is conducted to check how dc module works effectively in different corrosive environments for each site.

As shown in Fig. 7, the test results of the specimen in which the electrode plate is located at the bottom of the exposure chamber is shown in Fig. 12a. From the corrosion performance test of dc module, according to the accelerated corrosion test manual, the bent position site 2 in Fig. 11 is excluded from the test results. Therefore, a new site is set up. The bottom is site 2, and the top is site1. In addition, the test results of the specimen in which the electrode plate is located at the top of the exposure chamber are shown in Fig. 12b. Comparing only the untreated specimen through the

two experiments, a difference in the degree of corrosion occurs even at the same location, which means that the test equipment has not good reproducibility. In all experiments, the bottom of the exposure chamber appears to have a more severe corrosive environment than the top. The experimental result in Fig. 12b shows that the performance of dc module is more improved than the result in Fig. 12a. These results are related to the operating principle of the accelerated corrosion test equipment. Since salt spray or wet conditions are applied from the top of the exposure chamber and descend into the space below, the experiment in Fig. 12a continues the non-continuous water film state of the metal surface of the specimen for a certain period of time. Based on these experimental results, the process of Fig. 12a and Fig. 12b is repeated during the 6 cycles of evaluating the performance of dc module. The experimental results are

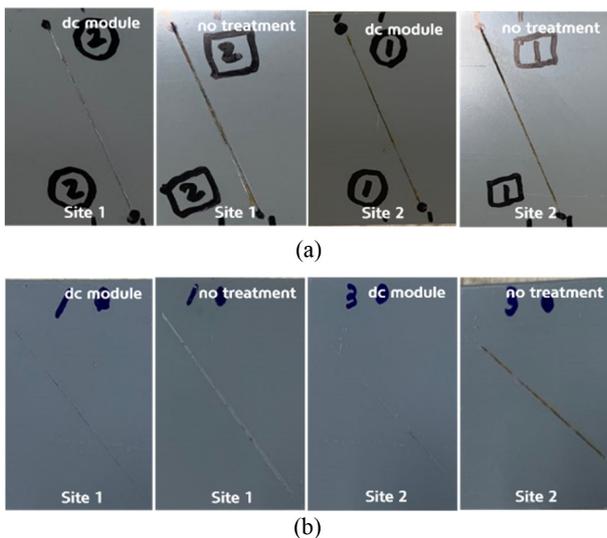


Fig. 12. As a result of the performance according to the position of anode, a) is the bottom of the exposure chamber and b) is the top of the exposure chamber

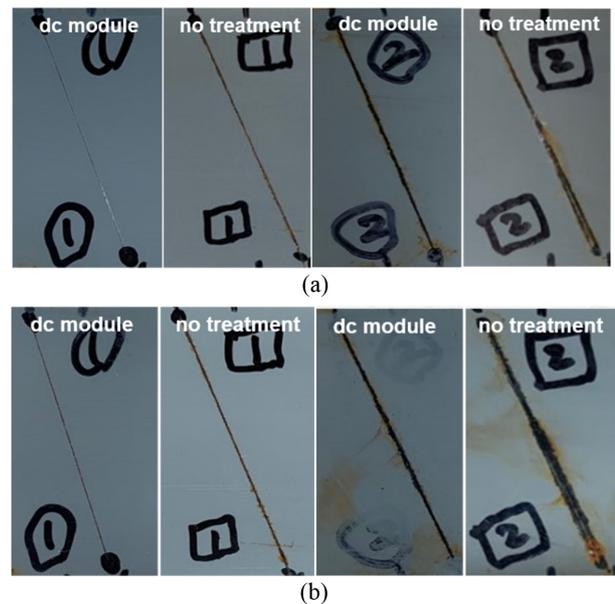


Fig. 13. The anode positions were alternately performed, and (a) is a result of 3 cycles and (b) is a result of 6 cycles

Table 2. Grading of exposure specimens

Cycles	grading
3	Site 1 of Specimens with dc module is no surface corrosion. Site 2 is severe and widespread corrosion rather than site 1. There is a significant difference between specimens with dc module and specimens with no treatment. Dc module is effectively controlling the corrosion process.
6	All specimens are displaying surface corrosion on the exposed metal. The corrosion levels of all specimens increase again from those observed after 3 cycles. Site 2 is severe and widespread corrosion rather than Site 1. There is a significant difference between specimens with dc module and specimens with no treatment. Dc module is effectively controlling the corrosion process.

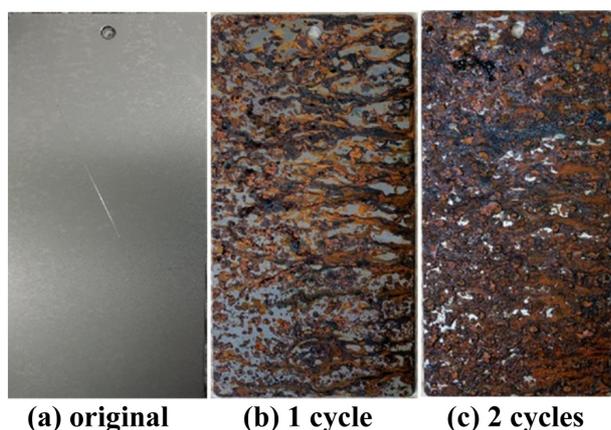


Fig. 14. It is the result of cumulatively performing up to two cycles to obtain the quantitative value of one cycle of the accelerated corrosion test

shown in Fig. 13.

Visual inspection of the specimens is undertaken after 3 and 6 cycles. The level of corrosion is noted, a photographic record made and the specimens graded according to performance. The grading of the specimens at 3 and 6 cycles is given in Table 2. In the specimen with dc module, site 1 is at a close distance from the anode and site 2 is at a far distance.

In order to obtain the quantitative value of one cycle of the accelerated corrosion test, additional experiments are carried out and up to two cycles are cumulatively performed. The results are shown in Fig. 14. In addition, a corrosion monitoring device is used to obtain the qualitative value of 6 cycles of corrosion test. The corrosion depth from a corrosion monitoring device indicated 23 μm during 6 cycles. This figure is almost similar to that measured on Jeju Island for two years at the most corrosive location where the device is attached to the automobile.

4. Discussion

Accelerated corrosion test provides a qualitative, rather than quantitative measure of the performance of a corrosion inhibiting treatments. In addition, the test were performed on simple metal plate, not a real vehicle. The specimen made it possible to easily apply the current by an impressed current CP to the entire surface. It may not be so smooth in a real vehicle. Since the specimen is much longer (120 cm) than the exposed shelf size (40 cm) of the accelerated corrosion test, the corrosive environment differs according to the site in the specimen, and the performance of dc module was different depending on the attachment position of the electrode plate. The reason for the difference in performance

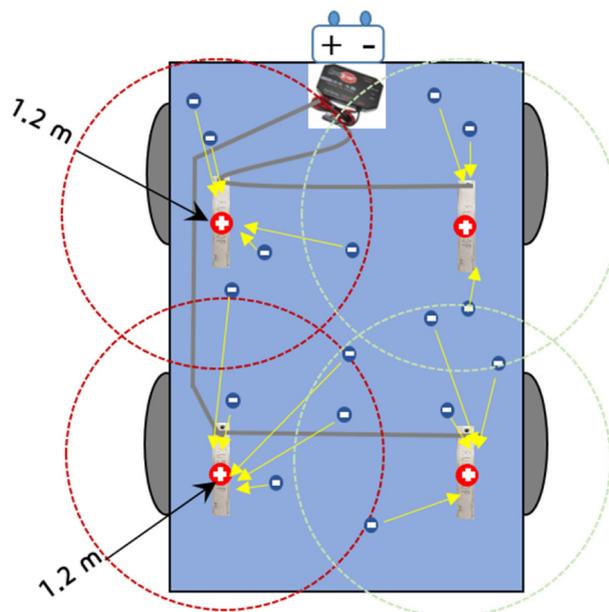


Fig. 15. It shows the configuration diagram of a cathodic protection device with four anodes applied to a vehicle

is that because the specimen is very long, if a salt spray or wet condition is applied from the opposite position to which the electrode plate is attached, cathodic protection through the water film on the specimen surface cannot be applied for a certain period of time. Accelerated corrosion test were carried out including half of these environmental conditions. Meanwhile, a corrosion monitoring device was used to obtain a qualitative value for the accelerated corrosion test, which was measured to be similar to the corrosive environment exposed in Jeju Island for two years. The location near the electrode plate installed on the specimen was set to site 1 and the remote location was set to site 2. As a result of the accelerated corrosion test, site 1 achieved a significant corrosion inhibition and reached an initial corrosion state. The corrosion inhibition rate at site 2 was approximately 75% compared to the corrosion of the specimen to which dc module was not applied. This is a value converted to a simple ratio by comparing the maximum corrosion diffusion distance.

The diagrams in Fig. 15 show cathodic protection with four anodes applied to a vehicle. It has been found that is effective through laboratory tests for metals that will protect up to 120 cm distance with one anode, so it is possible to protect the entire vehicle with only 4 anodes. The reason why there is an anticorrosive effect up to 120 cm distance even if the cathodic protection by the electrolyte is not performed on the metal surface to be protected is because of the adhesive conductive tape on the electrode plate of dc

module. This tape is a specially made graphite-based open-cell partial conductive tape, which can hold the anode 45 V, but still allows current to pass through. Thus, the tape becomes a constant electrolyte in both wet and dry conditions. On the other hand, the cathodic protection distance cannot be definitive as a result of one experimental study. There may be differences in the results depending on the environmental conditions, and the details are described in, e.g., Reference [6]. It deals with the cathodic protection range depends on water film thickness, exposed defect size, and the resistivity of electrolyte. As shown in Fig. 15, by overlapping protection from other anodes, the anticorrosive effect can be increased.

5. Conclusions

In a laboratory test in a periodic salt spray environment, dc module was found to be effective for specimen with a length of 120 cm even under non-immersion conditions, i.e., discontinuous water film on the metal surface. The reason cathodic protection is effective is that the conductive tape attached with the anode acts as a constant electrolyte to protect it in dry as well as in wet conditions.

Based on the experimental results effective on a 120 cm long specimen, only four anodes can be used to provide cathodic protection for a standard passenger car size. However, this does not mean that dc module with 4 anodes is very effective against corrosion in automobiles. In automobiles with tens of thousands of parts, localized severe crevice corrosion occurs. For crevice corrosion, the anode area is in dry, but the area where crevice corrosion occurs is in wet and discontinuous water film conditions are continuous, so the effect of cathodic corrosion protection may be limited.

Compared to the most typical anti-rust coating, where only the applied area has anti rust effect, dc module provides anti-rust effect to the entire metal of the vehicle. In addition, dc module does not require re-applying due to damage and has the advantage of continuously providing a constant rust prevention. By properly combining the two anti-rust methods by applying a coating to the area where the car's crevice corrosion frequently occurs, the maximum effect on car corrosion can be obtained.

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