The impact of water-based zinc-flake coating on bolt corrosion performance

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ABSTRACT In this study, the coatability of bolts with water-based zinc flake coating for the conditions in which electrostatic coating is not convenient was examined. In the sandblasting stage, two different types of sand were used to determine the impact of the sand type. When the results were compared, no significant difference was observed between the use of the two sand types. However, stainless-steel bolt usage was found to be more appropriate in terms of the filter maintenance of the sandblasting machine. At zinc-flake coating stage, the qualities of the bolts coated twice and coated thrice were compared to determine the impact of the coating number. According to tests of the dry adhesion, no coating error was detected on the both bolt surfaces. The corrosion resistance test showed that, the bolts with 24 g·m^{-2} and 36 g·m^{-2} coating weight had high corrosion resistance.

KEYWORDS Metal; water-based coating; zinc flake coating; corrosion performance.

1. Introduction

Corrosion is the transformation of an element from a low valence into a higher valence. Most metals except for aurum and platinum exist in nature as oxide compounds. Two different categories of corrosion are chemical and electrochemical (Campbell, 2008; Öz et al., 2019).

General corrosion is the type of electrochemical corrosion occurring with the corrosion of the metal on all the surfaces at the same degree. This process leaves residue on the material, and this provides clear information about the life cycle of the material. General corrosion is generally observed in zinc, lead, and aluminum. The metal loss caused by the homogenously distributed corrosion, the most common corrosion type, is much more prevalent than that of other types. Homogenously distributed corrosion could be easily controlled by using different protection methods (Podgornik et al., 2018; Kakani and Kakani, 2004; Ageeva et al., 2021).

Methods of protection against corrosion are mainly separated into two, cathodic protection and protection with surface coatings. Cathodic protection requires the polarization of the rusted metals as cathodes and can be conducted by matching the metal to be protected with a more active metal or by providing the current from an external source. The current necessary for protection in the first method is produced by the cell formed by a metal and anode couple. Anodes dissolve at certain speeds during the protection and lose their weight. In the second method, the metal and anode couple are not needed to produce the current because the current necessary for protection is provided externally (Kakani and Kakani, 2004).

There are three main coating types used for surface protection: organic, inorganic, and metallic coatings (Kakani and Kakani, 2004), and zinc is the inorganic coating used to prevent the corrosion that can occur in metals over a long period of time. First, the foundations of a zinc-flake coating are laid down with the addition of zinc and by adding aluminum to its content for the purpose of increasing the corrosion resistance strength of steel fibers (Sugimura and Liao, 2016). Zinc-flake coating was developed in the 1970s in the automotive industry in the United States of America as a new coating system. Thanks to a fine coating thickness, typically 8-12 μm, it was seen that this system provided a higher protection against corrosion than a zinc coating (Vu, 2012; Kollias et al., 2019).

The zinc-flake system with its high level of corrosion resistance began to be used in the automotive industry in the 1980s and 1990s. Because zinc-flake coatings do not form hydrogen in the process, they have been used for critical applications as an alternative to the electro-coating process. A coating system is one of the most efficient corrosion preventive methods that can increase the life cycle and working capacity of steel structures. In the different coating systems including organic coating and metallic coating, zinc-flake coating is very efficient in the prevention of corrosion because it is able to heal itself after local damage such as scratches and impacts [6]. It is a coating method widely used on many automotive parts including bolts, nuts, support brackets, door hinges, balance mills, brake discs, clutch lining systems, etc. because it is particularly effective on material types exposed to impact, friction, chemicals, and corrosion (Cao et al., 2020; Guo et al., 2020).

Zinc-flake coatings provide good protection against corrosion and are not applied electrolytically. It is one of

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the coating types that bond to each other with an inorganic structure and consists of a mixture of zinc and aluminum piles (Polyakov et al., 2021). Automotive parts are coated in electrostatically coatings by being hung on hooks and dipped into a coating bath. However, zinc-flake coatings can be applied by casting or masonry as an alternative method for the parts such as bolts for which hanging is not possible (Nardeli et al., 2021).

Bolts are fasteners that work by bonding parts to each other in a separable way. On the body, a screw thread is opened with a head of different shapes including hexagon and tetragon; it is generally used with nuts and expressed with the metric system. For instance, bolts whose diameter is 12 mm and whose thread length is 8 mm are expressed in the metric system as M12x8 or M12*8 (Kutay, 2009).

In this study, the coatability of bolts of different measurements with a water-based zinc-flake coating for the situations in which there is no possibility of hanging and where electrostatic coating is not convenient for the metal parts was examined along with the impact of the coating on the corrosion performance of bolts.

2. Methods

The water-based zinc-flake coating process conducted within the scope of the study contained surface preparation and coating stages.

2.1 Surface preparation stage

Degreasing and sandblasting processes were applied to the samples as surface preparation processes before the zinc-flake coating. Bolts were passed through a degreasing machine with the help of a spiral for the degreasing process. This machine was triseptate, and the oil on the bolt surface was cleaned with a spraying method with an alkaline cleaning chemical in the first chamber (Table 1). After that, in the second chamber, pure water was sprayed, and the bolt was rinsed to remove all chemical residue. After the rinsing process, bolts were dried in a drying oven with a temperature of 130 °C in order to have no humidity on the bolts and to prevent sand from filling in the thread spaces. With these processes, the bolts cleaned with oil were made ready for the sandblasting process.

Since the sandblasting process is a mechanical cleaning method, the aim was to remove all chemicals, metal burrs, and rust and to make the metal surface ready for the zinc-flake coating. The degreased and dried bolts were sanded for 12 minutes using two different sand types, S20 and S70, and, after that, air and dust in the environment was removed by means of a fan in order to have no residual dust on the surface.

2.2 Pre-coating performance tests

A screw thread fullness conformity test, a Hogaboom test, and an adhesion test was applied to the bolts after sandblasting in the pre-coating surface preparation stage. Bolts were first thrown into zirblast dust, bolts were checked for any residual sand in the thread zones, and a screw thread fullness conformity test were carried out. The Hogaboom test is the method used to determine whether the metal surface is ready for the flake coating after the sandblasting process. A 30 g copper sulphate solid was dissolved in

Table 1: Degreasing working parametersx.

Property	Value ranges
Time (min)	1-5
Temperature (°C)	70-90
Concentration (g·L^{-1})	20-60

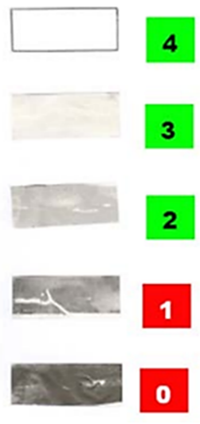

Figure 1: Adhesion test scale.

200 mL pure water while preparing the Hogaboom solution, 30 mL of concentrated sulfuric acid was added, and the solution was completed by adding pure water until the total volume reached 1000 mL. During the test, the bolt was completely submerged in the Hogaboom solution in a beaker, kept there for 15 seconds, and then removed from the solution. An adhesion test was conducted by adhering the adhesive tape to the head part of the bolts (47 N/100 mm adhesive strength on 3 M N°610 steels) as they came out of the sandblasting machine in such a way that there would be no air on the surface. Pressure was applied to the taped surfaces with a 3M wiper three times in the same direction, and the tape was rapidly removed from the surface by applying force from the bottom to the top. Any dust residual on the surface of the tape was measured according to the adhesion test scale (Fig. 1).

2.3 Coating of the samples

The coating process is a chain of processes starting with the coating stage and continuing with preliminary drying, heating, and cooling stages. Within the scope of the conducted experimental studies, bolts were separated into two groups to determine the impact of the coating number on the coating performance, and the process of coating of 15 ea. bolts was started twice. The parts to be coated with the dipping method were loaded in a basket. Bolts were dipped inside the basket in the tank into the coating chemical. They were taken out of the chemical bath after a complete coating of their surface, and, after the centrifuge stage, were processed for the purpose of removing the excessive chemical on the surface of the bolts. The centrifuge speed was kept stable at 320 rpm, and the centrifuge period was kept stable at 60 seconds (30+30 seconds right and left) in the centrifuge process as an important stage in the coating process. Bolts coated af-

Table 2: Degreasing working parameters.

Step	Property	Value ranges
Coating	Viscosity (s)	69-83
	Density (g·cm^{-3})	1.3-1.4
	Solid Substance Amount (%)	40-42
	Temperature (°C)	18-22
	pH	7-8.5
Pre-heating	Temperature (°C)	80-110
	Time (min)	6-10
Curing	Temperature (°C)	300-320
	Time (min)	15-45

ter centrifuging were spilled onto a conveyor band, taken into in a preheating oven at 110 °C for 10 minutes, and then taken via the same conveyor belt into the cooking (curing) oven at 320 °C for 45 minutes. The curing and cooling process was applied until the surface of the coated bolts reduced to 37 °C, and, in this way, the first layer coating process of the parts was completed. The parts in the first group (Group 1) were subjected to the same process once more, coating the parts twice. A three-layer coating process was applied in the same way to 15 ea. bolts in the other group (Group 2), and the coating stage was completed. Twice and thrice coating processes were applied to M8*, M10* and M12* bolts of different dimensions. The working parameters of the coating stage are given in Table 2.

2.4 Post-coating performance tests

First, the coating weights of the samples were measured for the purpose of determining the coating quality of M8*, M10* and M12* bolts of different dimensions and coated twice and thrice. After that, a dry adhesion test and a salt spray test were applied to these bolt samples. The dry adhesion test applied after the coating was conducted in the same way as the dry adhesion test conducted after sandblasting. In the salt spray test, the coated samples were inserted in the salt fog chamber in which a 5 % sodium chloride solution was applied as a spray with a temperature in the chamber of 35 °C and a humidity ratio of 95 %. At the end of the test, observations were made to check whether red and white rust had occurred on the surface of the samples exposed to this environment. Surface defects such as staining, distortion, cracking, breakage, bulking, exfoliation, separation into layers, and breakage in paint adhesion should not be existent in a sample in which corrosion resistance is good, and red rust should occur on no more than 5 % of the part surface.

3. Results

3.1 Pre-coating performance test results

The degreasing and sandblasting process in the conducted experimental studies were applied in the same way as the pre-coating surface preparation stage to the bolts in the first and second group. Bolts were thrown into the

Figure 2: Zirblast test results (a) sandblasted with S70 sand (b) sand-blasted with S20 sand.

Figure 3: Hogaboom test results (a) sandblasted with S70 sand (b) sandblasted with S20 sand.

zirblast dust after the sandblasting process was conducted in which the bolts were sanded with S70 and S20 sands, and they were checked for residual sand in the thread zones. It may be seen in Fig. 2 that there no accumulation between the threads in both sand types.

The test results of the bolts sanded with S70 and S20 sand to which Hogaboom test was applied are given in Fig. 3. A homogenous color formation was observed on the surface of the bolts, and it was determined that the sanded bolts were ready for coating.

It was observed according to the dry adhesion test results of the bolts sanded with different sand types that there was no residual surface pollution or sand dust on the head part of the bolts (Fig. 4). According to pre-coating

Table 3: Degreasing working parameters.

Sample	Bolt Size	White Rust (240 hours)	Red Rust (720 hours)	Red Rust (1008 hours)
Group 1 (2-Layer coating)	M8*	Not Observed	Not Observed	Not Observed
Group 1 (2-Layer coating)	M10*	Not Observed	Not Observed	Not Observed
Group 1 (2-Layer coating)	M12*	Not Observed	Not Observed	Not Observed
Group 2 (3-Layer coating)	M8*	Not Observed	-	Not Observed
Group 2 (3-Layer coating)	M10*	Not Observed	-	Not Observed
Group 2 (3-Layer coating)	M12*	Not Observed	-	Not Observed

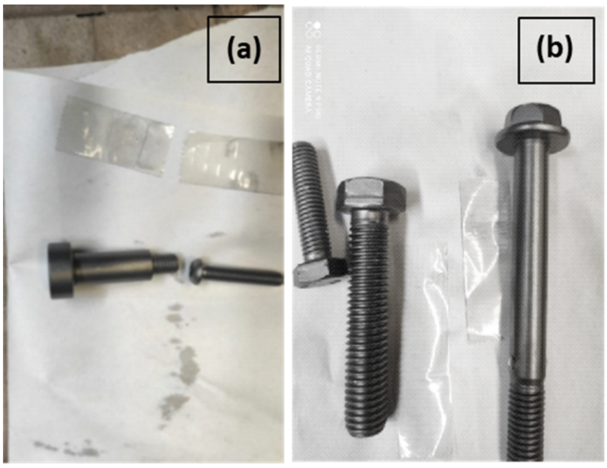

Figure 4: Adhesion test results (a) sandblasted with S70 sand (b) sandblasted with S20 sand.

performance test results, no significant difference was observed when the parts sanded with S70 sand and S20 sand were compared. However, because S20 is composed of stainless-steel balls, its usage was found more appropriate in terms of the filter maintenance of the sandblasting machine.

3.2 Post-coating performance test results

First, the coating weights of the samples were measured after the zinc-flake coating. Coating weights of 26.8 g·m^{-2}, 25.8 g·m^{-2}, and 26.2 g·m^{-2} ($\approx$ 5-8 μμm) were detected for the bolts with the dimensions M8*, M10*, and M12*, respectively, on the surface of the two-layer coated parts and coating weights of 39.7 g·m^{-2}, 38.3 g·m^{-2}, and 36.9 g·m^{-2} ($\approx$ 9-12 μm) were detected for the bolts with the dimensions M8*, M10*, and M12*, respectively, on the surface of the three-layer coated parts. As a result of the dry adhesion test conducted on the two-layer and three-layer bolts in different dimensions, it was seen that effective adherence had been ensured by the coating, and it had not peeled off the surface with the band test (Fig. 5). However, it was determined that there had been coating residuals on the band surfaces as a result of the test applied to the two-layer coating.

According to the results of the salt spray test applied to the bolts in different dimensions (M8*, M10*, and M12*) for the purpose of measuring the resistance performances of the bolts against corrosion, red rust was not observed at the 720th hour in the two-layer coated bolts, and red rust was not observed at the 1008th hour in the three-layer coated bolts (Fig. 6 and Table 3).

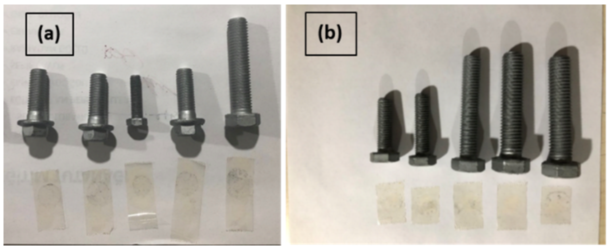

Figure 5: Adhesion test results (a) 2-layer coated bolt (b) 3-layer coated bolt.

Figure 6: Bolt samples after salt spray test (a) M8*2-layers (720 hours) (b) M8*3-layers (1008 hours) (c) M10* 2-layers (720 hours) (d) M10* 3-layers (1008 hours) (e) M12* 2-layers (720 hours) (f) M12* 3-layers (1008 hours).

4. Conclusions

Bolts from whom alkaline pollution had been removed via a degreasing process were sanded for 12 minutes at a 12-Amper force with S20 and S70 sands whose diameter was 0.35 mm, and a check of the surfaces was conducted after sandblasting. When the parts sanded with S70 and

S20 sand types were compared, no significant difference was observed in the performance test results, and the use of S20 was found more appropriate in terms of the filter maintenance of the sandblasting machine because it is composed of stainless-steel balls. Regarding the coating weights measured after the coating process, the coating weights of the bolts coated twice and thrice were determined to be at least 25.8 g·m^{-2} in the two-layer coating and at least 36.9 g·m^{-2} in the three-layer coating. As a result of the corrosion test of the first group bolts coated twice, white rust was not observed at the end of 240 hours, and red rust was not observed at the end of 720 hours. As a result of the corrosion test of the first group of bolts coated thrice, white rust was not observed at the end of 240 hours, and red rust was not observed at the end of 1008 hours. Conducted studies and the applied tests showed that water-based flake coating which is applied as casting or masonry and which does not contain any dissolver could be used instead of electrostatic coating in the bolt type metal materials that are not able to be hung due to their geometrical structure.

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