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Investigation of the physical properties of armor steel after cataphoresis coating

Zırh çeliğinin kataforez kaplama sonrasında fiziksel özelliklerinin araştırılması

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Abstract

It is very important that the materials generally used in the defense industry are suitable for environmental conditions, have a long service life, and do not lose their functionality. The resistance of armor steels to environmental conditions and corrosion is increased by coating. In this study, 'Miilux 500' armor steel was used. 'Cataphoresis coating', which has high resistance to environmental conditions, was selected as the coating method. In this study, it was observed that the corrosion resistance of armor steel, which is indispensable for the defense industry, is resistant to salt fog for 480 hours with cataphoresis coating. In the hardness measurement test and tensile test applied to see the values affected by the heat input during cataphoresis coating, it is evaluated that there are deteriorating features compared to the value given in the product catalogs. In the current situation, the applicability of cataphoresis coating on armor steel has been shown, provided that the superior corrosion effect and the deteriorating material strength values after heat input, the design area and expectations are evaluated.

Keywords: Cataphoresis, Armor steel, Corrosion, Miilux500, Environmental conditions test

Öz

Savunma sanayinde genel olarak kullanılan malzemelerin çevre koşullarına uygun olması, uzun ömürlü olması ve işlevselliğini kaybetmemesi oldukça önemlidir. Zırh çeliklerinin çevre koşullarına ve korozyona karşı dayanıklılığı kaplama ile arttırılmaktadır. Bu çalışmada 'Miilux 500' zırh çeliği kullanılmıştır. Kaplama yöntemi olarak çevre koşullarına karşı yüksek dayanımı olan 'Kataforez kaplama' seçilmiştir. Bu çalışmada, savunma sanayinin vazgeçilmezi olan zırh çeliğinin korozyon direncinin, kataforez kaplama ile 480 saat tuz sisi etkisine dayanıklı olduğu görülmüştür. Kataforez kaplama sırasında maruz kalınan ısı girdisinin etkilediği değerleri görmek için uygulanan sertlik ölçüm testi ve çekme deneyinde, ürün kataloglarında verilen değerine göre kötüye giden özellikler olduğu değerlendirilmektedir. Mevcut durumda üstün korozyon etkisi ve ısı girdisi sonrası kötüye giden malzeme mukavemet değerleri, tasarım alanı ve beklentilerin değerlendirilmesi koşuluyla zırh çeliği üzerine kataforez kaplamanın uygulanabilirliği gösterilmiştir.

Anahtar kelimeler: Kataforez, Zırh çeliği, Korozyon, Miilux500, Çevre koşulları testi

1 Introduction

Steels; It is the most widely used metal material with its ability to add new features through research and development studies in the field of technology, ergonomics in the field of use, permanent and appropriate production costs. Alloy elements such as chromium, nickel, manganese, molybdenum are elements used in addition to iron [1]. Armor steels are known as low carbon steels. Changing the carbon ratio at a certain value affects the weldability and toughness-hardness values negatively. Other alloying elements are used to prevent these negative effects; Since the addition of molybdenum prevents grain growth, it prevents carbide precipitation and increases the hardening ability. Manganese addition increases corrosion and impact resistance. Chromium additive improves the bonding properties of the grains by increasing the hardening ability [2]. Armor steels are used much more commonly than glass, fiber, ceramic and aluminum reinforced armor composites [3]. Some of the companies leading the world market in armor steel production are as follows; SSAB, Arcelor Mittal, Thyssenkrupp, Astralloy and Evraz [4].

Armor steels are mostly used in the exterior of vehicles. Therefore, some metallurgical properties must be provided to maximize the level of exterior surface protection [5]. It is expected that defense industry vehicles covered with protective armor will resist cracking, breaking of particles and breaking against the impact of bullets of different characters with highly explosive properties [6]. For example, armor steel is selected considering the damage power and kinematic explosions that both defensive and offensive vehicles will receive, such as a tank [7].

Cataphoresis coating is the process of electrically coating metal parts with complex geometry. Cataphoresis coating is one of the most effective and unrivaled methods. Cataphoresis coating technology has led to the prolongation of the life of the parts used in the automotive industry. The prolongation of usage time and the increase in resistance to environmental conditions have increased customer satisfaction [8]. Compared to other coating methods,

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cataphoresis coating is homogeneous surface distribution on the part, smooth appearance, giving a soft form with the coating of sharp edges, and perfect coating of closed volume welded areas. In addition, other advantages can be stated as production speed, low environmental pollution, low fire and health risk [9].

In this study, surface coating process was carried out by applying cataphoresis coating process to Miilux 500 armor steel. In order to apply the test processes to the armor steel to be coated, it was cut by giving a special form with a laser CNC cutting device. The cut materials were made ready for cataphoresis after surface cleaning. After the cataphoresis coating, mechanical and physical tests were applied to the samples, and environmental tests and most importantly corrosion resistance were measured. In these tests, the corrosion resistance and mechanical properties of the armor steel with cataphoresis coating were determined.

2 Material and methods

In this study, 500 series armor steel of Miilux brand was used as test material. The thickness was chosen as 8 mm and all the materials to be used in the experiments to be carried out proceeded over a single thickness. Its chemical component is presented in Table 1.

Table 1. Chemical composition of Miilux 500 armor steel [10]

Element	C	Si	Mn	P	S	Cr	Ni	Mo	B
wt.%	0.30	0.70	1.57	0.03	0.0015	1.50	0.40	0.5	0.004

The mechanical properties of Miilux 500 armor steel to be used in the test studies are presented in Table 2. In the studies, comparison and initial situation analysis were made according to this table.

Table 2. Miilux 500 armor steel mechanical properties [10]

Thickness	Yield Strength Rp 0.2 N/mm²	Tensile Strength N/mm²	Stretching A5 %	Impact Effect 40°C Kv Joule	Hardness Range HBW	Carbon Ratio CEV
2.5-40mm	1250	1600	8	20	480-560	0.64

In the coating method, if the material to be coated becomes the cathode of the electrical circuit, the resulting process is called "cataphoresis", and the resulting coating is called "cataphoretic electroplating" or "cathodic electroplating" (CED). The general structure of the products used in cataphoresis coatings mainly consists of water, resin, pigments and solvents as in other paint formulations [11].

A typical surface preparation processes applied before cataphoresis coating; It consists of degreasing, rinsing, activation, phosphate coating, 2nd rinsing, passivation and Deionized rinsing stages. The purpose of degreasing is to remove the dirty surface from the metal to be coated.

The purpose of the rinsing process is to prevent the degreasing chemicals from being carried to the next baths [12].

The failure of the adhesion test of the plates processed starting from the cataphoresis coating baths, which is a direct electroplating process, without immersing different types of materials in the pretreatment baths, and the failure of the appearance and gloss tests of the plates processed by immersing in the pretreatment baths and then cataphoresis coating processes, show the importance of the pretreatment process [13].

Activation bath is an important process before phosphating processes. It creates an initial reaction for the formation of the crystal structure. Thanks to its crystal structure, it is aimed to form a covering and homogeneous crystal layer [14]. Figures 1 and 2 show the Crystal appearance of activated and non-activated phosphate coatings. The more the activation affects the surface, the more effective the phosphate coating.

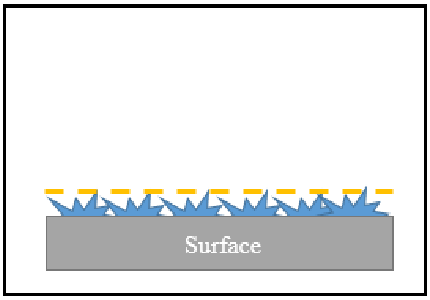


Figure 1. Phosphate coating without activation

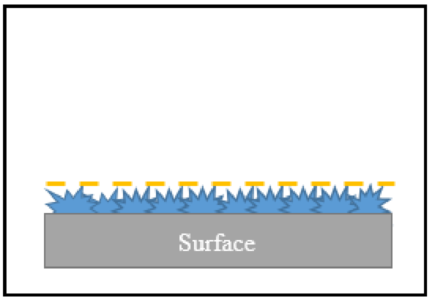


Figure 2. Phosphate coating with activation

The main purpose of phosphate coatings is to form a protective layer between the metal surface and the paint, to increase the corrosion resistance of the painted metal surface, to improve the paint adhesion performance, to prevent rust formation in case of a stoppage in the conveyor flow and to improve the corrosion performance on open metal surfaces [15]. It is widely used in the automotive industry and the appliance industry because it is the coating that gives the best result in terms of corrosion performance.

The passivation process is carried out in order to increase the corrosion resistance and to remove the residual ions on the surface. Another purpose of the passivation process is to prevent the formation of rust that may occur on the surface by passivating the surfaces that are not coated with phosphate.

The purpose of rinsing with deionized water before cataphoresis coating is to add Ca, Mg, etc. to the cataphoresis coating bath. to prevent the transport of ions. When these ions stay on the surfaces, they adversely affect the adhesion performance after cataphoresis coating. After the cataphoresis coating pool, it is aimed to destroy the filtrate deposits that may remain on the material surface with the deionized rinsing method.

Although the cooking time varies according to the condition of the material and the coating, the baking process takes place between 25-35 minutes on average. Even if the material varies according to the coating structure, it is necessary to bake at the desired temperature for at least 20 minutes. Convection ovens are the most used oven type in cataphoresis coating processes. In cataphoresis coating ovens, the firing process is usually carried out at a temperature of 200-225 degrees. This temperature may vary according to the value given by the coating company. The loss in the furnace walls in the burner calculation; Appropriate selection should be made by paying attention to the heat received by the coated material, the heat taken by the conveyor or hanger carriers, the heat lost at the entrances and exits, and the heat given to the fresh air taken into the oven [16]. In this study, the tests applied on cataphoresis coated armor steel.

2.1 Cross-cut test

Cross-Cut or adhesion test is a particularly desired measurement method for tools and equipment used in the defense industry. The purpose of the Cross-Cut test is to see the adhesion levels of the armor steels treated with cataphoresis and to give an idea about their resistance to environmental conditions. This study was tested according to ASTM D3359 standard after cataphoresis coating applied on Miilux 500. The parameters to which the tests will be applied are shown in Table 3.

Table 3. Cross-cut test parameters [17]

Blade Type	6		6		6	11	11
Cutting Range	1 mm		2 mm		3 mm	1 m	1,5 mm
Standart	ISO 2409	ASTM D3359	ISO 2409	ASTM D3359	ISO 2409	ASTM D3359	ASTM D3359
Surface Thickness	0-60 µm	0-50 µm	61-120 µm	50-125 µm	121-250 µm	0-50 µm	50-125 µm

The thickness of the sheet cut for Cross-Cut is 8 mm. Its dimensions are determined as 100x100 mm. The tests were prepared as 3 different samples and the pre-test images are shown in the Cataphoresis images in Figure 3.

Figure 3. Cataphoresis armor sheet

2.2 Salt fog test

Salt fog test is performed to observe the resistance to environmental conditions and the adhesion of the coating to the surface. Salt fog test is required for the products used in the defense industry and the test period is determined according to the place of use in design. The salt fog tests were applied as 480 hours according to the ASTM B117 standard [18]. The parameters to which the samples in the test cabinet are exposed are given in Table 4.

Table 4. Salt fog parameters

Test Parameters	Nominal	Findings
NaCl Concentration	% 5±0,5	% 5.0
NaCl pH Value	6-7	6.9
NaCl Density Value	1.029-1.036	1.034
Collected Solution pH Value	6.5-7.2	6.9
Collected Solution Density Value	1.029-1.036	1.035
Cabin Temperature (C°)	35±2	35
Humidifier Temperature (C°)	50±2	50
Amount of Collected Liquid (ml/h)	1.5±0.5	130
Pure Water Conductivity		2.77 ms
Salt Ratio		%99

A total of 6 samples were prepared for the salt fog test, 3 without scratches and 3 with cross scratches, made of Miilux 500 armor steel with dimensions of 100x150 mm and a wall thickness of 8 mm (Figure 4).

Figure 4. Salt fog cataphoresis coated specimen

It is a Liebisch brand 1000-ATR model (See figure 5.) used in the salt fog test.

Figure 5. Machine view used in salt fog testing

The device, which has a working capacity of 1000 liters and a working pressure of 0.9-1 bar, has a hanger / shelf system that allows more than one different sample to be placed. [19]

2.3 Hardness test

Three Miilux 500 armor plate samples were used in the hardness measurement test. The size is 100x100mm and the wall thickness is 8 mm. The Brinell hardness measurement method was applied to the samples. In order to carry out Brinell hardness measurement tests, 0.5 mm deep chip removal was performed from the surfaces of the cut uncoated and cataphoresis coated armor steel in order to make accurate hardness measurements. This process is critical for the tests to give accurate results (Figure 6).

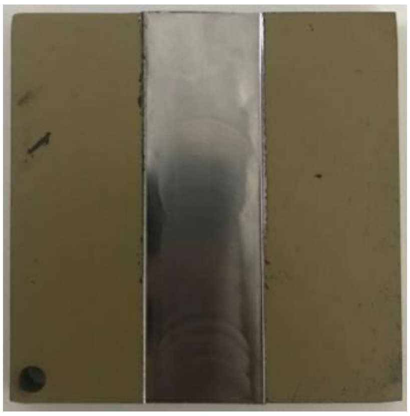


Figure 6. Coated surface cleaned sample

The ISO 6506-1 standard was applied to Miilux 500 armor steel, which was tested with and without coating. HBW 10/3000 hardness measurement values were used for the samples connected to the device as shown in Figure 7 [20].

Figure 7. Sample view connected to the device for hardness testing

2.4 Tensile test

The pull rods made of Miilux 500 armor steel have been tested according to the TS EN ISO 6892-1 standard [21]. Three samples of 8 mm thickness were cut for the test.

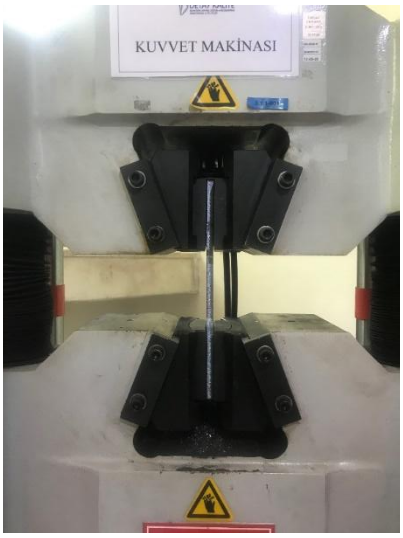


Figure 8. Tensile test specimen connection view

The test parameters and device information of the materials connected to the test device as shown in Figure 8 are given in Table 5.

Table 5. Tensile test parameters and device information

Test Parameters		
Test Standard	**Micrometer**	**Measuring Length**
TS EN ISO 6892-1	Watan 0101013662	80 mm
Test Speed	**Test Temperature**	**Humidity Ratio**
20 mm/dk	23°C	54%
Device	**Device Calibration**	**Digital Caliper**
Hardway / WAW 600D	D-14162-003	Mitutoyo 500-181-20

3 Results and discussion

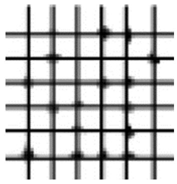
3.1 Cross-cut measurement results

The test result should be evaluated by taking into account the factors affecting the cross-cut test (surface cleaning, performing the cataphoresis processes perfectly and in accordance with the rules). Armor steel has been tested and evaluated with reference to the ASTM D3359 standard. The standard includes a table on how to evaluate the results obtained from the tests. The sample image obtained as a result of the test performed in this study is given in Figure 9.

Figure 9. Cross-cut test image of cataphoresis coated armor steel

When the image is examined, it is seen that the square regions between the parallel lines do not separate from the part or that there are breaks in the form of very small particles from the corners. When this image is evaluated according to the table in ASTM D3359 (see Table 6), it is understood that it falls within the 4B class. This situation clearly shows that the cataphoresis coating application is in accordance with the standard.

Table 6. Tensile test parameters and device information

Standard		Explanation	Scratched Surface Appearance (For 6 parallel lines)
ISO	ASTM		
1	4B	Minor flaking of the coating is seen at the intersections of the cuts. Does not affect more than 5% of the cross cut	

3.2 Salt fog measurement results

In this study, salt fog test was applied to armor steel with two different methods according to ASTM B 117 standard. In the first method, the cataphoresis coated sample was exposed to salt fog for 480 hours without scratching. Figure 10 shows the image of the tested armor steel. It is visually inspected whether there is any swelling or rust on the sample surfaces. When the sample, which was not scratched and exposed to the salt fog test, was examined, it was determined that there was no problem in adhesion, no rust walking or swelling. This shows that the cataphoresis coating application is appropriate. This coating is not impact resistant, the surface integrity will provide superior protection as long as there is no external impact.

Figure 20. Salt fog test view

In the second method, the surface of the sample was scratched and exposed to the salt fog test for 480 hours. Figure 11 shows the image of the sample that has been scratched on its surface and exposed to the salt fog test. When the image was examined, it was seen that there was no coating swelling in the non-scratched part. Rust has occurred in the scratched area, but no damage in the form of rust walking has occurred. One of the most important purposes of leaving a scratch is to see the scenario that may occur in case of scratching the surface and to observe the adhesion performance of the cataphoresis to the surface. This result shows that the cataphoresis coating application is appropriate.

Figure 31. Salt fog scratch test view

3.3 Hardness test results

Armor steel samples with and without surface coating were subjected to hardness measurement tests according to ISO 6506-1 standard. Measurements were made from three different points for each sample and average values were taken. These values are compared with the values predicted and measured by the manufacturer for Miilux 500 armor steels. The images of the tested samples are given in Figures 12 and 13.

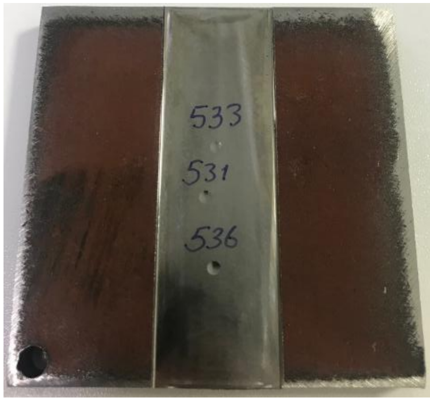


Figure 42. Images of uncoated samples after hardness measurement test

Figure 53. Images of coated samples after hardness measurement test

The values given by the manufacturer for Miilux 500 armor steel and the test result values for uncoated and coated armor steel are given in Table 7. When the table is examined, it is seen that the average hardness values of the coated and uncoated samples are between the values measured by the manufacturer for armor steel. It was determined that the hardness value decreased by approximately 6% by applying cataphoresis coating to the samples. The most important reason for this is the 220-225 °C heat input in the baking process during the cataphoresis coating. This heat input is required to cure the cataphoresis and ensure full surface adhesion.

Table 7. Hardness test results and factory data comparison

	Miilux 500 Armor Steel Factory data	Uncoated Hardness measurement results	Coated Hardness measurement results
Point 1	x	533 HBW	510 HBW
Point 2	x	531 HBW	505 HBW
Point 3	x	536 HBW	503 HBW
Average	480-560 HBW	533 HBW	506 HBW

3.4 Tensile test results

Tensile tests were applied to uncoated and coated armor steel in accordance with TS EN ISO 6892-1 standard. Tensile test results were compared with the manufacturer's predicted and measured values for Miilux 500 armor steel. The appearance of uncoated and coated Miilux 500 armor steel as a result of the tensile test is given in Figures 14 and 15, respectively.

Figure 64. Cataphoresis uncoated tensile test result general view

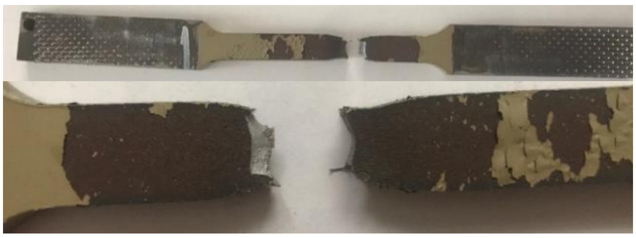


Figure 15. General view of the tensile test result with cataphoresis coating

The tensile graph of the tensile specimen with cataphoresis coating is given in Figure 16.

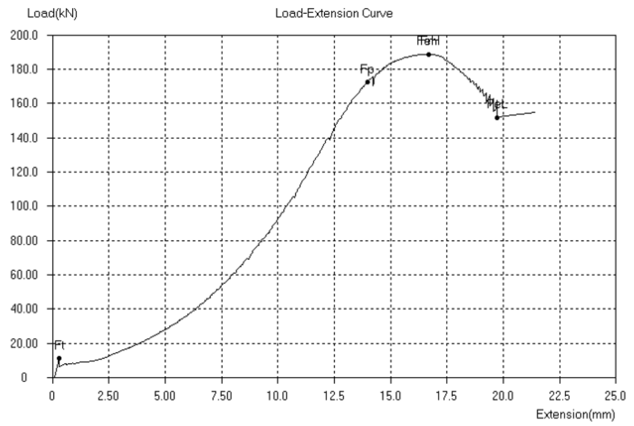


Figure 76. Tensile test chart

The values predicted and measured by the manufacturer for Miilux 500 armor steel and the tensile strength, yield strength, percent elongation values obtained from the tensile tests of uncoated and coated samples are given in Table 8. When the results obtained are examined, it is seen that the yield strength of the cataphoresis coated sample has increased compared to the catalogue data, and this increase will be resistant to permanent changes that may occur after plastic deformation. On the other hand, tensile strength and percentage elongation values decreased compared to the catalog data.

Table 8. Tensile test results

Tensile Tested Samples						
	Thickness (mm)	Width (mm)	Yield Strength (N/mm²)	Tensile Force (N)	Tensile Strenght (N/mm²)	Percent Elongation (%A)
Average of Uncoated Sample Values	8.55	13.1	1337.5	185602.5	1654	12.2
Average of Cataphoresis Coated Sample Values	8.5	13	1434	181197	1635	9.35
Factory Values	2.5-40	x	1250	x	1600	8

4 Conclusion

If we examine the changes on the Miilux 500 armor steel of the studies and tests, in substance;

As a result of the cross-cut (Adhesion) test application, it was determined that the adhesion level of the cataphoresis coating to the surface of the armor steel sheet was sufficient.

The salt fog test was applied in two different methods in the factory environment and no swelling or progression was observed on the Miilux 500 armor steel, surface swelling, rust or scratches from the bottom. With this result, it was concluded that the adhesion and surface protection levels are sufficient in cataphoresis coatings on armor steels.

It is stated in the catalog data of Miilux 500 armor steel that the hardness values should be between 480-560 HBW. For reference to the study, one of the samples was tested as raw, after surface cleaning, and the average of the data obtained from three points was 533 HBW. The average of the data taken from the three points of the armor steel, which has been cataphoresis coated and whose surface has been treated for testing, is 506 HBW. When we evaluate these data, it has been observed that there is a 5% decrease in the hardness of the armor steel with cataphoresis coating.

In the tensile test, the values of an uncoated raw material and a cataphoresis coated material were compared. Uncoated raw material; The average yield value was 1329.5 N/mm², the average tensile value was 1654 N/mm² and the yield percentage was 12.2%. As for the coated armor steel; The average yield value was 1434 N/mm², the average tensile value was 1635 N/mm² and the yield percentage was 9.35%. According to the factory catalog values, the yield, tensile strength and elongation percentage of the uncoated material are high. Miilux 500 armor steel sheet with cataphoresis coating; An increase of approximately 7.9% in yield strength, a decrease of approximately 1.2% in tensile strength and a decrease of approximately 18.4% in percent elongation were observed. These changes support the warning of armor steel manufacturers to change their mechanical properties. In this study, it was determined that the application of heat input to the armor steel after the cataphoresis process caused a decrease in its mechanical properties. Considering the superior corrosion resistance of the cataphoresis coating and the decrease in its mechanical properties, the place of use of the armor steel should be determined and design studies should be carried out accordingly.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Similarity Rate (iThenticate): 11%

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