MM Science Journal | www.mmscience.eu
ISSN 1803-1269 (Print) | ISSN 1805-0476 (On-line)
Special Issue | TEAM 2024
Transdisciplinary and Emerging Approaches to Multidisciplinary Science
11.9.2024 – 13.9.2024, Ostrava, Czech Republic
DOI: 10.17973/MMSJ.2024_10_2024081

TEAM2024-00021

ANALYSIS OF THE EFFECT OF PRETREATMENT ON THE OVERALL DAMAGE OF THE COATING CREATED BY THE CATAPHORETIC COATING

P. FEJKO[1]*, J. DOBRANSKY[1], L. STRAKA[1], M. GOMBAR[2]
[1]Technical University of Kosice, Faculty of Manufacturing Technologies with seat in Presov, Presov, Slovak Republic
[2]University of West Bohemia Pilsen, Faculty of Mechanical Engineering, Plzen, Czech Republic
*Corresponding author; e-mail: patrik.fejko@tuke.sk

Abstract
Aluminum and its alloys are essential in construction due to their lightweight nature and recyclability. To enhance durability, protection against corrosion is vital, with cataphoretic painting being particularly effective. This study evaluated the damage rate of cataphoresis coatings on AW 1050 H24 aluminum, focusing on the impact of different degreasing solutions. By analyzing temperature, concentration, and deposition time, the study found that concentrations above 5.25 % degrade surface quality due to aluminum dissolution, while temperatures between 37 °C and 50 °C are optimal. At higher temperatures, shorter deposition times improve quality, whereas longer times lead to defects.

Keywords:
Aluminum, surface treatment, cataphoretic coatings, quality of surface, degreasing solution

1 INTRODUCTION

One of the best ways to protect metals from corrosion is by using various coating techniques. These coatings create a barrier that shields the metal from corrosive elements. To ensure effective protection, it's crucial to properly pretreat the surface before applying the coating [Brezinová 2015], [Brezinova 2020], [Guzanová 2014], [Brezinová 2018]. The quality of surfaces and the methods used to assess them are crucial in modern technology. Understanding how surfaces are formed is essential for characterizing their properties in production [Guzanová 2014], [Sternadelová 2023]. Cataphoretic painting is an effective method for achieving an optimal material surface. This electrophoretic coating process, known for its cost-efficiency and environmental benefits, provides strong corrosion protection, making it ideal for the automotive industry. It is used to protect steel, galvanized, aluminum, and stainless-steel parts. Before applying the coating, the surface must be thoroughly cleaned to ensure proper adhesion [Abdalla 2013], [Zhao 2020], [Sinha 2002], [Jegannathan 2006]. Metal corrosion negatively impacts the economy, environment, and public safety. Immediate action is crucial to prevent further damage and protect both human lives and the natural environment [Takanari 2017], [Kirchgeorg 2018], [Flores 2011].

The use of organic coatings with a metal surface is an effective method of slowing down the process of corrosion, which prevents the metal from coming into contact with the corrosive medium. Nevertheless, the corrosion resistance of plated metals is influenced by a number of factors, including the intrinsic nature of the coatings in question, the continuity of the coating phase and the overall thickness of the aforementioned coatings [Babaei 2019]. It is unfortunate that these parameters cannot be readily manipulated through traditional techniques, such as solution spraying, dipping, and brushing. In contrast, these parameters could be controlled by the electrophoretic deposition (EPD) method, whereby coatings of defined thicknesses were prepared on the electrode by the application of a direct current (DC) electric field between the cathode and anode [Moradi 2016], [Aghili 2021]. The utilisation of nanoparticles as inorganic nanofillers in polymer protective coatings has recently garnered significant interest due to their distinctive barrier properties. The homogeneous dispersion of nanoparticles is a critical aspect in the preparation of polymer nanocomposites. In their 2019 study, Živkovič et al. investigated how cerium and zirconium nanoparticles affect the corrosion resistance of a cataphoretic epoxy coating on AA 6060 alloy. Various techniques such as X-ray fluorescence, X-ray photoelectron spectroscopy, scanning electron microscopy, and infrared spectroscopy to analyze the coatings. They also assess coating adhesion using thermogravimetric analysis and adhesion tests.

Olivier's 2008 study explored how stress during the aging process affects the barrier properties of cataphoretic coatings. Aging in organic coatings often leads to increased stress, causing issues like loss of adhesion, increased porosity, and irreversible changes due to humidity or temperature changes. In the automotive industry, new coatings undergo various tests under different manufacturing conditions to ensure their suitability before mass production. Choosing the right test is crucial, especially to distinguish between coatings with similar performance. Accelerated aging tests are essential for quickly predicting coating durability and expediting development. Garcia [Olivier 2008] addressed this issue and proposed the use of EIS and the AC/DC/AC electrochemical test, which combines impedance and cathodic polarization, to quickly and accurately assess coating performance [Olivier 2008], [Garcia 2007], [Romano 2006], [Poelman 2005].

To improve adhesion and corrosion protection of cataphoretic coatings, metal substrates typically undergo surface conversion pretreatment. Since aluminum alloys are susceptible to pitting corrosion, Olivier's research was focused on the evaluation of painted aluminum samples in terms of resistance to fibrous corrosion and delamination [Olivier 2005], [Poulain 1996], [Romano 2009].

The utilisation of protective coatings can markedly enhance the corrosion resistance and tribotechnical behaviour of metallic surfaces. The cost per unit area of coating is higher when the surface is prepared before the coating is applied. In his research, Burkov investigated the effect of substrate surface quality during electrospark deposition, as well as the effect of substrate surface quality on electrospark alloying, as reported by Draganovská (2018) and Burkov (2023).

2 MATERIAL AND METHODS

Structural parts made of aluminum type AW 1050 H24 were used in the experiment. This type of aluminum expresses a specific aluminum alloy that is suitable for welding, is relatively soft and has very good conductivity. It is technically pure aluminum, which contains at least 99 % aluminum [ATREON 2024]. They are used for the production of signs, coverings, perimeter panels, heat exchangers, in the food industry, in hydraulics, for the production of molds, truck spoilers, transformers and reflectors [IMC Slovakia 2024]. It is not possible to apply heat in order to cure the material. An enhancement of strength can be accomplished solely through cold forming techniques, such as rolling and drawing. This strengthening process is accompanied by a reduction in elastic modulus and, consequently, in malleability. Formability is significantly lower in hardened states H14 and H24. In the soft annealed state (0), the material displays excellent malleability, allowing it to withstand deformation by bending and deep drawing, among other methods [Berka 2024]. Tab. 1 illustrates the chemical properties of aluminium, whereas Tab. 2 presents the mechanical properties of the same material.

Tab. 1: The following is the chemical composition of the aluminum alloy EN-AW 1050 H24.

Indication		Structure [%]			
EN-AW	DIN	Si	Fe	Cu	Zn
1050-A	Al 99.5	0.25	0.40	0.05	0.07

Tab. 2: A comprehensive examination of the mechanical properties of aluminium alloy EN-AW 1050 H24 reveals a multitude of insights.

Condition	H24
Thickness t [mm] From – To	0.5 – 1.5
Strength Rm [MPa] MIN – MAX	105 – 145
Yield strength Rp 0.2 MIN	75
HBS hardness	33

2.1 Wedolit CN 5370 – 22

Before degreasing the aluminum structural parts, Wedolit CN 5370-22 type oil was applied to the surface of the material. It is a low-viscosity, water-insoluble, high-performance cutting oil for thread cutting, which is based on the latest base oil technology. The product is also suitable for general cutting of high-alloy steels, cast iron, aluminum and non-ferrous metals. The basic physical properties are listed in Tab. 3 [WEDOLIT 2024].

Tab. 3: Physical properties

Parameter	Results	Tested to
Appearance	Brown	Bright
Density at 20 °C	0.87 g/cm^3	ASTM D 7042
Viscosity at 40 °C	22.0 mm^2/s	ASTM D 7042
Flash point	>170 °C	DIN ISO 2719
Corrosion of copper	-	DIN 51759 – 1

2.2 Degreasing

In our case, degreasing solution 1 was used, the physical and chemical properties of which are shown in Tab. 4. In our case, we used degreasing solution 1, whose physical and chemical properties are shown in Tab. 4. Tab. 5 shows the values of variable input factors. Degreasing solution 1 is a strongly alkaline, low-foaming, medium-emulsifying degreasing preparation intended mainly for immersion and spray degreasing of steel and cast iron. It is used to remove strong deposits of preservatives and various greasy impurities stubbornly clinging to steel objects. It is effective on new types of biodegradable oils and rapeseed oil. It is able to saponify animal fats and metal salts of fatty acids (metal soaps).

Tab. 4: Physical properties of degreasing solution 1

Physical Name	Properties
Physical state (at 20 °C)	Solid substance
Color	Brown
Odor/fragrance	Bland
pH value (at 20 °C)	12.5 – 13 (1 % solution)
Density (g/cm^3)	Is not known
The boiling point	Is not established
Solubility in water	The good
Flash point	Not flammable
Flammability	Is not flammable
Explosive limit	Does not have explosive properties
Evaporation	Is not known

Chemical composition :

a) Sodium carbonate (Na_2CO_3) – concentration 20 – 30 %
b) Sodium metasilicate (Na_2SiO_3 x $5H_20$) – concentration 20 – 30 %
c) Sodium hydroxide (NaOH) – concentration 20 – 30 %
d) Fatty tallowamine (POE), ethoxylate (5EO) – concentration 3 – 5 %.

At higher concentrations of raw material hydroxide (NaOH), chemical interactions occur on aluminum surfaces that are related to surface quality. These interactions lead to different forms of degradation. Sodium hydroxide is a strong additive that reacts with aluminum to produce aluminate and hydrogen. This chemical reaction can be expressed by the following equation:

$$2Al + 2NaOH + 6H_2O - 2Na[Al(OH)4] + 3H_2 \quad (1)$$

As a result of this reaction, sodium aluminate is formed on the aluminum surface, releasing hydrogen. This reaction can lead to the destruction of the surface layer and the formation of a porous structure, which deteriorates the quality of the surface. Sodium hydroxide accelerates the corrosion and erosion of aluminum, breaking down its protective oxide layer and exposing fresh metal that is more susceptible to further chemical degradation. The release of hydrogen can cause the formation of blisters and other defects that reduce the quality of the surface. In order to minimize these negative effects, it is essential to optimize the NaOH concentration and the degreasing conditions. Accurate setting of these parameters helps to maintain surface integrity and ensure high quality of the final surface of aluminum components. Effective optimization of the process will not only improve the quality of the surface, but also contribute to the extension of the life of the products and reduce the risk of further corrosion.

Tab. 5: Values of variable input factors.

Factor Code	Factor	Unit	Factor level				
			-2	-1	0	+1	+2
x_1	k_{ODM}	%	0.782	1.5	4	6.5	7.217
x_2	t_{ODM}	min	1.138	2	5	8	8.861
x_3	T_{ODM}	°C	34.25	40	60	80	85.74

x_1 – degreasing concentration, x_2 – degreasing time deposition, x_3 – degreasing temperature.

2.3 Cataphoretic coating

During cataphoretic painting, paint is applied to the work. It works on the principle of electrophoresis, where the painted object is the cathode in the unidirectional field of the anolyte (aqueous paint solution) and attracts paint cations. Solid anodes made of inoxium are used in the electrolytic bath, which are separated from the organic coating by a selective membrane.

The cataphoretic painting method is among the most modern methods of surface treatment of metal products. More simply explained, the oppositely charged part is lowered into the paint bath and the paint particles are attracted to the metal part. Thanks to cataphoretic painting, coatings are created that are specific with uniform thickness over the entire surface, where the used color reaches even hard-to-reach places. Once the necessary thickness has been achieved, further deposition of the layer is halted, and the coating's final thickness ranges from 15 to 30 micrometers. The given range depends on the magnitude of the voltage used in cataphoretic painting. Tab. 6 shows constant values.

Tab. 6: Constant values of cataphoretic painting.

Factor code	Factor	Unit	Value
x_4	U_{KTL}	V	270
x_5	I_{KTL}	A	225
x_6	T_{KTL}	°C	31.2
x_7	t_{KTL}	min	5

2.4 Polymerization

Polymerization is the next important step after cataphoretic painting, during which a chemical reaction of synthetic macromolecular substances takes place, the molecules of the basic substance are combined into larger units without creating a by-product. The polymerization furnaces themselves ensure the hardening of the components, where the polymerization temperature ranges from 155 – 210 °C. These high temperatures ensure a high-quality surface of the components. In Tab. 7 shows the polymerization values that were constant.

Tab. 7: Polymerization constants

Factor code	Factor	Unit	Value
x_8	$T_{POLYM.}$	°C	200
x_9	$t_{POLYM.}$	min	22

2.5 Quality of surface

The surface quality of an optical component is a specification that measures the component's surface imperfections, such as scratches, gouges (dimples in the surface), blemishes, blisters, and pores. In many cases, surface defects are truly aesthetic and do not significantly affect the optical performance of the product, causing a small loss of system transmittance and a small increase in stray light.

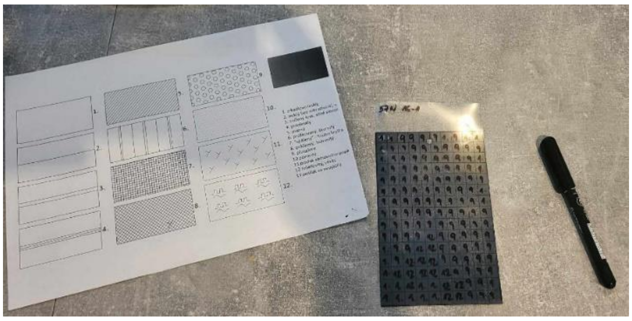

Fig. 1: Evaluation of surface quality appearance.

To evaluate the quality of the surface, the evaluation method was used using a grid that we printed on foils. After applying the film to the material, the quality of the surface was evaluated according to the defined aspects of appearance evaluation, which is shown in Fig. 1.

Microscope Keyence VHX – 7000

The VHX – 7000 series digital microscope offers users a high-precision 4K microscope capable of capturing high-resolution images and measuring data for inspection and damage analysis at the push of a button. Two – and three – dimensional measurement capabilities are available for use in conjunction with the device. The device can be utilised for a plethora of measurements, including those pertaining to roughness, contamination analysis, grain size and a myriad of additional variables.

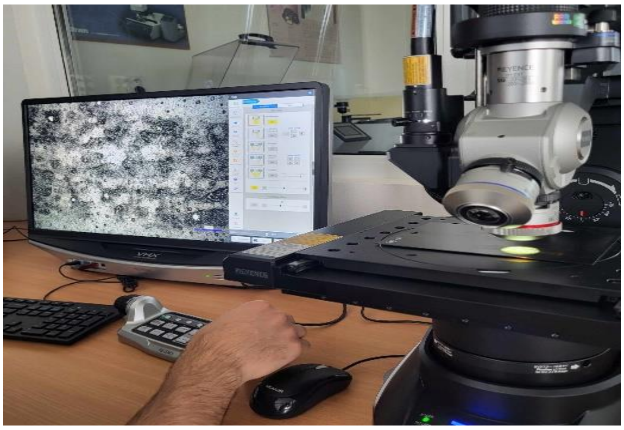

Fig. 2: Analysis of the damaged spot on the surface of the component.

2.6 Decision – making process

Decision-making processes are among the aspects of life that we normally encounter but do not think about because they seem to be taken for granted. From the point of view of machine learning, we see them as an excellent tool for solving a wide variety of tasks. The decision-making process can be defined as an individual assessment of the situation based on available information and resources and subsequent evaluation of the sequence of events, or activities that will follow. It is clear from this definition that the decision-making process as such is directly based on the individually received information of the individual and their correct interpretation. In everyday life, we encounter decision-making processes all the time.

It is necessary to implement the decision-making function if the given task must be solved or some needs (requirements) must be met. We can think of the task formulation step as a sub-task of the basic task, that is, in the decision-making cycle, feedback is inside feedback. A decision tree is a classifier with a tree structure, whereby each node represents a binary choice, and each branch represents a subsequent choice that can be made. The internal nodes are responsible for the decision-making process. In this context, an instance may be defined as an object over which a decision-making process occurs. Each potential result of the test is represented by a distinct branch. The value assigned to the target property of the examples is represented by the leaf node of the tree. In order to classify an instance, one must first start at the root of the decision tree and traverse the individual nodes until reaching the leaf that provides the classification of the instance [Sasmita 2024].

3 RESULTS

The quality of the surface was evaluated in the Statistics program. When evaluating the surface quality, the decision tree method used for classification and prediction was chosen. The CART algorithm was used to create the decision tree, which is one of the oldest algorithms designed for regression trees. Decision models are shown in Fig, 3 and Fig. 6.

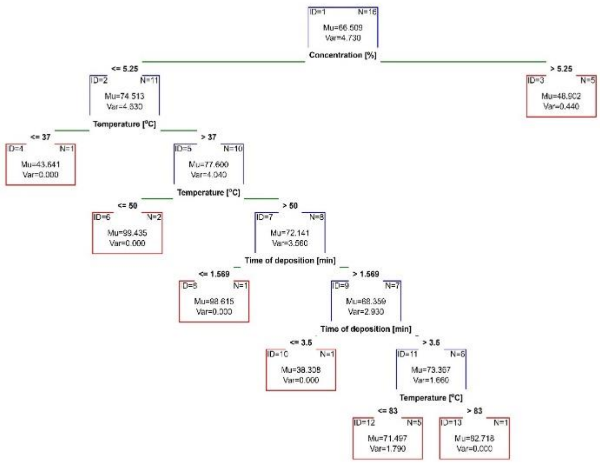

Fig. 3: The impact of inputs variables on the alteration in the quality of the surface of the cataphoresis layer when employing degreasing solution 1.

Fig. 3 depicts the decision tree utilized for the analysis of the impact of pretreatment on the overall damage of the coating produced through the cataphoretic coating method. Analyzed parameters include degreasing concentration, degreasing temperature and degreasing deposition time. Based on these parameters, the decision tree creates a tree model. The machine infers the result by checking the state at each node of the tree and reaching the leaf nodes. The decision tree starts with the parameter concentration [%] at the root node, which divides the data into two branches according to whether the concentration is less than or equal to 5.25 % or greater than 5.25 %.

If the concentration is higher than 5.25 %, then the consistent value of the surface quality will reach a lower quality than with a concentration less than or equal to 5.25 %. This is due to the fact that the degreasing solution 1 contains the chemical substance sodium hydroxide, which when in contact with aluminum causes the material itself to dissolve, thereby reducing the quality of the surface.

If the concentration is less than or equal to 5.25 %, the next branch parameter will be the degreasing temperature with a threshold value of 37 °C. At a temperature lower than or equal to 37 °C, the average value of the surface quality reaches 43.641 %. This phenomenon can be caused by several factors that negatively affect the quality of the surface at lower temperatures.

One of the factors that can cause a low-quality surface at a lower temperature is the formation of microcracks due to thermal stress. The degreasing temperature, which is in the interval from 37 °C to 50 °C, achieves the highest surface quality, which results in an optimal thermal range, which can reduce the risk of surface damage that can arise from thermal damage.

At a temperature higher than 50 °C, the degreasing deposition time factor plays an important role. At a temperature higher than 50 °C and a deposition time shorter than or equal to 1.589 min, we reach an average quality value of 98,615 %. If the deposition time ranges from 1.589 min to 3.5 min, the surface quality reaches an average value of 38.308 %, which results in too short a time to create a homogeneous and uniform coating. To ensure a high-quality surface, it is necessary to introduce a temperature branch whose deposition time is higher than 3.5 min and the temperature is less than or equal to 83 °C. Under this condition, the average quality value is 71.447 %.

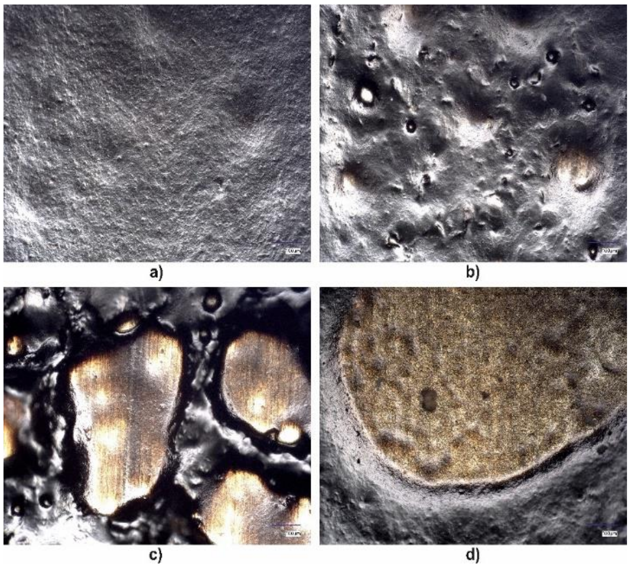

Fig. 4: This study examined the effect of different parameters on the nature of the surface of the cataphoretic layer and on the occurrence of basic errors when using degreasing solution 1, specifically:

[a) k_{ODM}=1.5 %, t_{ODM}= 2 min, T_{ODM}=40 °C]; [b) k_{ODM}=1.5 %, t_{ODM}= 8 min, T_{ODM}= 80 °C]; [c) k_{ODM}=6.5 %, t_{ODM}= 2 min, T_{ODM}=40 °C]; [d) k_{ODM}= 6.5 %, t_{ODM}= 8 min, T_{ODM}=80 °C];

With the concentration of the used degreasing solution 1 at the level of 1.5 %, the deposition time in the degreasing solution 2 min and the temperature of the degreasing solution 1 is shown in Fig. 4a) We can see that the surface of the material looks relatively smooth, without significant pores or defects. The surface has a fine structure, which indicates higher quality and uniform application of the coating.

By increasing the deposition time to 8 min and the temperature of degreasing solution 1 to 80 °C (Fig. 4b)), we can see that the surface shows us several small cavities and pores. The surface looks rougher, which can lead to a poorly degreased surface. It can also be caused by thermal conditions or a too long deposition time, which can also be seen in Fig. 3.

When increasing the concentration of the used degreasing solution 1 to 6.5 %, the deposition time to 2 min and the temperature of the degreasing solution 1 to 40 °C (Fig. 4c)), where the surface shows significantly large cavities, which may be caused by the high concentration. In the decision tree in Fig. 3 we can notice that at concentrations greater than 5.25 % the consistent value of the surface quality reaches a lower quality. Degreasing solution 1 contains sodium hydroxide, which when in contact with aluminum causes dissolution of the surface and thus leads to the formation of defects. Significant defects and pores can reduce mechanical strength and overall surface quality.

When the deposition time is increased to 8 min and the temperature of the degreasing solution 1 to 80 °C and the concentration is at the level of 6.5 %, Fig. 4d). The surface is shown with an irregular structure that is bounded by the base material. The presence of such large structures may be an indicator of higher concentration, high temperature and longer deposition time. We can say that Fig. 4a) represents the best surface quality with a minimum of defects and a fine structure, while Fig. 4b), 4c) and 4d) show different levels of surface defects. From this we can conclude that with optimal technological conditions we will achieve a high-quality surface.

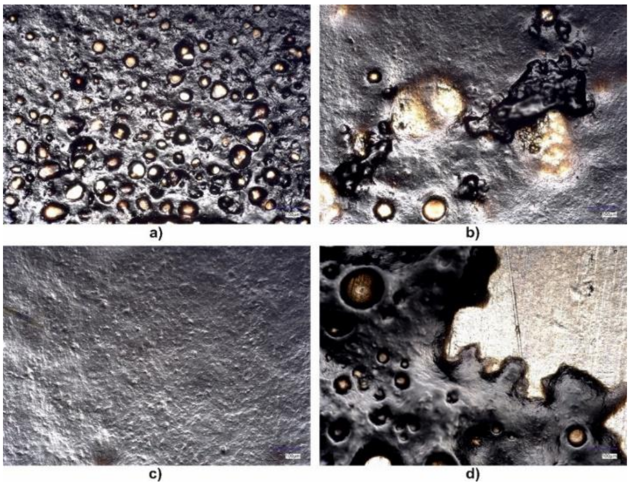

Fig. 5: The characteristics of the surface of the cataphoretic layer and common errors when using degreasing solution 1: [a) k_{ODM}= 0.782 %, t_{ODM}= 5 min, T_{ODM}= 60 °C]; [b) k_{ODM}= 7.218 %, t_{ODM}= 5 min, T_{ODM}= 60 °C]; [c) k_{ODM}=4 %, t_{ODM}= 1.138 min, T_{ODM}= 60 °C]; [d) k_{ODM}= 4 %, t_{ODM}= 8.861 min, T_{ODM}= 60 °C];

In the context of the technological conditions pertaining to the concentration of the utilised degreasing solution 1 at a level of 0.782 %, the deposition time within the degreasing solution of 5 minutes and the temperature of solution 1 at a level of 60 degrees Celsius, it can be observed that there is a notable correlation (Fig. 5a). The surface contains various pores and defects scattered over the entire surface. This is caused by a lower concentration of degreasing, which cannot clean the material properly from the rest of the oil and other impurities. When the concentration of the used degreasing solution 1 is increased to the level of 7.218 %, the deposition time is 5 min and the temperature of the degreasing solution 1 is shown in Fig. 5b). The surface shows large cavities and pores, which are created at an extremely high concentration of the used degreasing solution 1, which can also be seen in Fig. 3, which shows us the decision tree. At concentrations greater than 5.25 %, the quality of the surface decreases. We can also notice particles of residual paint that are created during the uneven application of the coating in the process of cataphoretic painting.

When the concentration is reduced to the level of 4 % and the deposition time is 1.138 min, which is shown in Fig. 5c) we can see that the surface of the material looks relatively smooth, without significant pores or defects. Under these technological conditions, we can say that Fig. 5c) represents the best surface quality with a minimum of defects and pores. This is also proven in the conditions of the tree model, when the quality reaches an average value of 98.615 % when combining concentrations less than or equal to 5.25 % and a deposition time shorter than or equal to 1.569 min.

When increasing the deposition time to 8.861 min, which is shown in Fig. 5d) has a surface with an irregular structure that is bounded by the base material. This may be due to the longer deposition time.

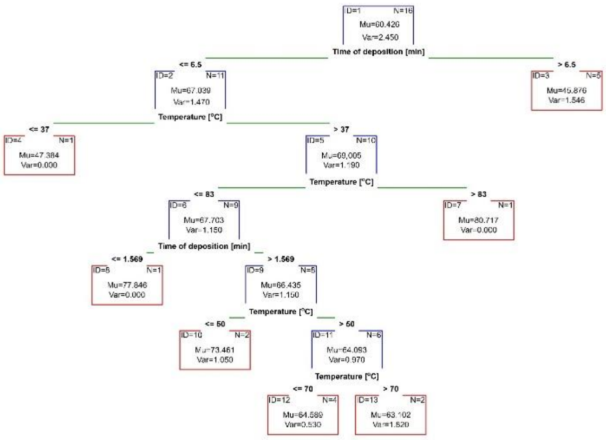

Fig. 6: This study examines the impact of input factors on the alteration in the quality of the surface of the cataphoretic layer when utilising water 1.

As illustrated in Fig. 6, the quality of the material surface is contingent on the specific parameters governing both the degreasing deposition time and the temperature of the degreasing process. Based on these parameters, the decision tree is employed to construct a tree model. Average values of quality (Mu) and standard deviation (Var) are given for different conditions, which makes it possible to identify optimal and suboptimal conditions for achieving high surface quality. The decision tree starts with the parameter deposition time [min] in the root node, which divides the data into two branches according to whether the deposition time is less than or equal to 6.5 min or longer than 6.5 min. It can be observed that if the time allocated for a deposition exceeds 6.5 minutes, the average quality value will approach a lower level of surface quality. This is due to too long a deposition time, which can lead to excessive layer growth and defect formation. Otherwise, on the left side of the branch, with a deposition time shorter than or equal to 6.5 min, the average surface quality reaches a value of 67.039 %, which means that a shorter deposition time generally contributes to a better surface quality. The branch with the deposition time is divided into another branch, in which the degreasing temperature is the main factor.

If the degreasing temperature is lower than 37 °C, the average surface quality will be 47.384 %. Low temperature may be insufficient to achieve optimal diffusion and reaction conditions, leading to lower surface quality. Another way that can affect the quality of the surface at low temperature is higher viscosity, which can lead to dispersion of the layer application. Therefore, temperature is considered a key factor that affects the physical and chemical properties of a material. In the event that the temperature exceeds 83 degrees Celsius, the average surface quality will attain a value of 80.717 percent. Extremely high temperatures can improve surface quality due to intensive diffusion processes, provided that there is no material degradation, but this is inadequate from an economic point of view. At extremely high temperatures, electricity consumption is higher, resulting in higher costs. At a temperature lower than or equal to 83 °C, a combination of deposition time and temperature occurs.

If the temperature is lower than or equal to 83 °C and the deposition time is shorter or equal to 1.569 min, then the average quality of the surface is 77.846 %. A short deposition time with an appropriate temperature leads to a high-quality surface.

If the degreasing temperature is lower than or equal to 83 °C and the deposition time is longer than 1.569 min, the average value drops to 67.703 %. This is due to the longer time, which can slightly reduce the quality of the surface. A temperature higher than 50 °C may cause a slight improvement in quality, but not optimally. We can consider the combination of a lower degreasing temperature (lower or equal to 50 °C) and a longer deposition time (longer than 1.569 min) as an optimal improvement of the surface quality. The decision tree shows that the surface quality depends on the optimal combination of deposition time and degreasing temperature. The best results are achieved at an appropriate temperature above 37 °C and a deposition time of up to 1.569 min. Extremely high temperatures and excessively long deposition times can reduce surface quality due to excessive layer formation.

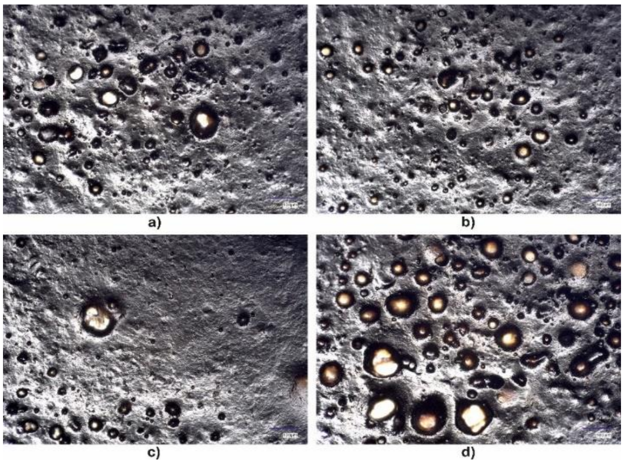

Fig. 7: This section will address the nature of the surface of the cataphoretic layer and the basic errors that may be made when utilising degreasing solution 1: [a) t_{ODM}= 2 min, T_{ODM}= 40 °C]; [b) t_{ODM}= 2 min, T_{ODM}= 80 °C]; [c) t_{ODM}= 8 min, T_{ODM}= 40 °C]; [d) t_{ODM}= 8 min, T_{ODM}= 80 °C].

Under the technological conditions of the water deposition time 2 min and the temperature of water 1 at the level of 40 °C, Fig. 7a). The surface contains a higher density of pores, many small craters and cavities of various sizes, which are located over the entire surface of the material. This may be due to the fact that water at a lower temperature contains a higher viscosity, which can lead to dispersion of the coating. Another factor that affects the quality of the surface is the properly degreased surface of the material. We can also see this in the decision tree in Fig. 6. Upon increasing the water temperature to 80 °C and allowing for a deposition time of 1 to 2 minutes, the surface exhibits a multitude of minute craters and cavities, bearing resemblance to the formation depicted in Fig. 7a. The craters appear to be smaller and more evenly distributed over the entire surface. The surface is overall more beautiful than in Fig. 7a). In Fig. 7c) shows a surface with technological parameters with increased water deposition time to 8 min and water temperature to 40 °C. The surface contains fewer craters and cavities compared to Fig. 7a) and 7b). The craters present are mostly of medium size and are not so densely distributed over the surface. The surface is relatively smoother. As illustrated in Fig. 6, the mean quality value declines with an extended deposition time, falling to a surface quality rating of 45.876 % when the deposition time surpasses 6.5 minutes. Fig. 7d) illustrates the surface with the technological parameters of a deposition time of 8 minutes and a water temperature of 80 degrees Celsius. The surface displays a prevalence of larger craters and cavities, which are more conspicuous and frequent in occurrence. The surface is therefore the least homogeneous and has the coarsest structure of all four images. This is caused by a combination of technological parameters, while the decision tree shows that with a deposition time longer than 6.5 min and a temperature lower than or equal to 83 °C, the quality of the surface decreases rapidly.

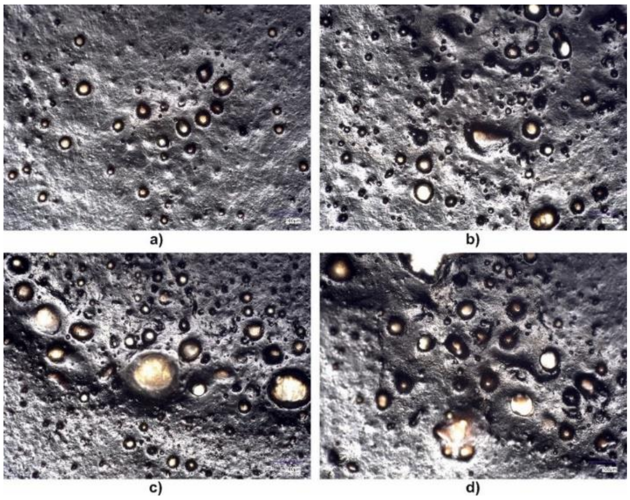

Fig. 8: The nature of the surface of the cataphoretic layer and the basic errors when using degreasing solution 1:

[a) t_{ODM}= 1.138 min, T_{ODM}= 60 °C]; [b) t_{ODM}= 8.861 min, T_{ODM}= 60 °C]; [c) t_{ODM}= 5 min, T_{ODM}= 34 °C]; [d) t_{ODM}= 5 min, T_{ODM}= 86 °C].

In Fig. 8a) shows the surface with the technological conditions of a water deposition time of 1.138 min and a water temperature of 60 °C. We can see that the surface contains many pores and craters that are relatively scattered over this surface. Most craters are small to medium. When the deposition time is increased to 8.861 min and the water temperature is 60 °C (Fig. 8b)), the surface contains more medium-sized craters and cavities, which results in poor degreasing of the surface of the material and may also be the cause of temperature leakage from the tub in which they were samples placed. The craters are evenly distributed compared to Fig. 8a). When reducing the water deposition time to 5 min and simultaneously cooling the water to 34 °C (Fig. 8c)), the surface contains more large craters and pores that are clearly visible over the entire surface. The surface is the roughest and most irregular of all four images. This is caused by a very low temperature, when water cannot rid the surface of greasy dirt at such a temperature, which can also be seen in the decision tree in Fig. 6.

When the water is heated to 86 °C (Fig. 8d)) and the deposition time is 5 min, the surface contains different sizes of craters and pores, which are more densely distributed. We can summarize that figure 8a) has a smoother surface with evenly distributed small craters, compared to Fig. 8b), when the surface is moderately rough with medium-sized craters. In Fig. 8c) the surface is the roughest and significantly affected with large craters and an irregular structure. Fig. 8d) has a rough surface with dense craters of different sizes. These differences in surface structure are influenced by various processing factors such as water temperature, deposition time, material composition, etc.

4 SUMMARY

The conclusion of this study emphasizes the importance of optimizing pretreatment parameters, such as concentrations, temperature and application time of the degreasing solution, to achieve high quality surface treatment of aluminum alloys. Findings show that optimum results are achieved between 37 °C and 50°C, with a concentration above 5.25 % resulting in surface degradation due to the dissolution of aluminum by sodium hydroxide. The results of this study have significant practical implications for various industries. In the automotive industry, optimized pretreatment parameters can contribute to increasing the durability and aesthetic quality of vehicle bodies, improving their appearance and resistance to corrosion. In the aviation industry, it can improve the quality of the surface treatment of the longest-lasting aluminum components and increase their resistance to aggressive external conditions. In the field of electronic equipment manufacturing, better surface treatment of metal parts can lead to higher reliability and aesthetics of products. Future research should be reduced to the most appropriate optimization of the parameters, the examination of alternative solutions with less requirements to achieve these impacts, and the evaluation of the economic environmental efficiency of the processes. This can contribute to a longer service life and higher quality surface treatment of products in various industries.

5 ACKNOWLEDGMENTS

This research has been elaborated in the framework of the projects VEGA no. 1/0371/23 and KEGA no. 009TUKE-4/2024 were granted by the Ministry of Education, Science, Research and Sport of the Slovak Republic and this publication is the result of the Project implementation: Development of excellent research capacities in the field of additive technologies for the Industry of the 21st century, ITMS: 313011BWN5, supported by the Operational Program Integrated Infrastructure funded by the ERDF.

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