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Modification of the Surface of Objects for the Aviation Industry by the Procedure of Hard Chrome Plating

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Abstract: In the paper, the quality of the hard chrome plating on standard steel plates and shroud-fuel nozzle used in the aviation industry was examined, where the thickness of the coating, hardness, microscopic structure and resistance to bending were determined. The entire galvanization process involved chemical, electrochemical and mechanical preparation of the examined parts prior to chromating, while the chromating itself took place in a solution of chromic acid. The aim of the work is to obtain high-quality hard chrome coatings through the process of reparation of worn shroud-fuel nozzle, which will be able to replace commercial new parts in terms of quality and characteristics. Also, taking into account that some parts are no longer even commercially available, the reparation procedure should enable extended use of the same parts.

INTRODUCTION

Researchers and engineers are concentrating on increasing the operating temperatures of gas turbines and enhancing plant efficiency while minimizing breakdowns. This advancement is largely made feasible through the development of new materials that resist heat, corrosion, and erosion, utilizing various surface engineering techniques. (Prashar and Vasudev, 2024).

The corrosion process can lead to increased maintenance and repair costs for materials. Additionally, failures caused by corrosion can present safety hazards and lead to accidents, which in turn exacerbate the economic impacts (Tamalmani and Husin, 2020).

The process of covering the surface of one material with a thin layer of metal is referred to as metal coating (Artkin, 2023, Ivanov, Alsaraeva, Gromov et al., 2015; Pachurin, Mukhina, Kuzmin, et al al., (2020). Various metal coating techniques are used for different applications, depending on the material being coated and the desired properties of the coating (Artkin, 2023).

The technology of material protection using coatings is very demanding and complex, and it is necessary to know all the steps required for the coating to be applied well, from surface preparation, and application of the coating to drying (Juraga, Alar, et al., 2012; Stupnišek-Lisac, 2007; Esih, 2007). To prevent corrosion and rusting of materials, protective coatings are applied to vehicle bodies, which increases durability and preserves their visual appeal. (Motlalte, Ray, Ojijo et al., 2022). Steel surfaces can be coated with metal using one of four popular techniques. These include sherardizing, electroplating, thermal spraying, and hot-dip galvanizing. The level of corrosion protection provided by metallic coatings is mostly determined by the kind and thickness of the coated metal, with the application technique having a minimal effect (Demirel, Biskiner, Sahin 2023). In addition, corrosion protection coatings play a vital role in the aerospace industry, as aircraft face a range of environmental challenges, such as moisture, high-altitude conditions, and chemical contaminants. (Pecho, Vel'ky, Bugaj et al., 2023).

Galvanization is the most widely used procedure of applying metal coatings to metal and non-metal objects by electrolysis of ionic solutions, i.e. electrolyte (Ozturk, Evis, Kilic, 2017). It is based on the cathodic reduction of metal ions from the electrolyte using an electric current (Munger, Vincent, 1999).

Chromizing or chrome plating is a surface engineering method widely used in industries to obtain a hard metal surface. This method is preferred because it is easy to apply and is more economical (Hasanah, Priadi, Dhaneswara, 2023). The chromium plating process is one of the most effective methods for safeguarding the base material from extreme environments or enhancing its surface properties (Islam, Hasan, Poroma et al., 2024).

Chromium plating, particularly when applied at thicknesses exceeding 2 μm, holds significant industrial importance." (Adachi, Kitaba, Fukami et all., 2020).

Because of its exceptional abrasive resistance, thermal stability, and chemical durability, electroplated chromium coatings are commonly used in high-temperature environments with moving parts, including hydraulic components, turbine blades, gun barrels, and other mechanical equipment and weapons, to reduce failure rates and extend service life. (Podgornik, Massler, Kafexniu, 2018).

Hard chrome coatings are becoming more prevalent in the contemporary protective industry, as they enhance resistance to wear, corrosion, and abrasion. Additionally, these coatings alter the physical and mechanical properties of material surfaces, improving the quality of the coated objects. (Kvashrin, Oganov, Samtsevich et al., 2017; Liang, Li, Ni et all., 2017). In addition to protection against corrosion, galvanic chrome coating is applied for reparation of damaged and robust parts worn in places of friction, such as turbine rotors, machine shafts, etc. (Astanin, Pukhov, Stekolnikov, et al., 2018). Chrome coatings are resistant to atmospheric corrosion at normal and elevated temperatures, are very hard and wear-resistant, have a low coefficient of friction, and can be obtained shiny without subsequent processing (Fedrizzi, Rossi, Bellei, et all, 2002). Chromium has several valence states, divalent chromium salts are not stable in air and, like electrolytes, are not suitable for chroming. Cr (III) ions in aqueous solutions are also not favorable for chroming, as they highly hydrate and are difficult to reduce. Therefore, Cr (VI) in the form of chromate and Cr (VII) in the form of dichromate are suitable because they can be reduced at the cathode when the electrolytes contain certain anions that act as a catalyst (e.g. sulfate or fluoride ions (Abys, 2011). Preparation before the galvanization process itself can be mechanical, chemical, or electrochemical (Đorđević, Maksimović, Pavlović, et all., 1998). By preparing the substrate, it is necessary to ensure good adhesion of the coating and its specific properties, and this is achieved by cleaning the surface from greasy substances, corrosion products, dust, etc., and achieving the optimal level and form of roughness (Fedrisi, Rossi, Bellei, 2002). The process of modifying and coating the surface with hard chrome plating is the process of returning used parts for exploitation/reuse (De Mello, Goncalves, Costa, 2013). The most commonly coated materials are stainless steel and its alloys. Stainless steels are iron-based alloys that contain at least 12% Cr to form a passive film, the presence of which ensures their corrosion resistance (Petrović, Stojanović, 2007). Additional surface protection of stainless steel provides increased corrosion resistance, and depending on the deposited coating, some other properties are also improved (abrasion resistance, hardness). Compact, fine-grained electrochemical chrome coatings are a good choice for solving functional requirements (Petrović, 2000).

Aircraft encounter a range of environmental influences, such as chemical contaminants, moisture, and special well as high-altitude conditions (CAP1570, 2019). Coatings on aircraft exteriors safeguard against corrosion, preserve aerodynamic efficiency, and enhance overall safety (Pecho, Veľký, Bugaj, 2023). The work aims to carry out the process of applying hard chrome to the shroud-fuel nozzle used in the aviation industry to repair worn parts and to achieve a certain thickness of the coating that will meet the required characteristics of hardness and specific resistance. At the same time, the process of hard chrome plating on standard steel plates was also carried out to compare the results and simplify the characterization. Moreover, a suitable alternative to hard chrome has not yet been found for all applications and is unlikely to be indicating that hard chrome coatings will continue to be essential (Podgornik, *Massler*, Kafexhiu, et al., 2018).

EXPERIMENTAL

In the experimental part of the work, the aim was:

- determine the chemical composition of the basic material of the shroud-fuel nozzle;
- prepare the material;
- perform the technological inspection of materials and defects;
- perform the inspection for cracks;
- measure the existing coating to accurately determine the application of chrome coating in the plating process;
- carry out the tempering process at the required temperature to relieve stress in the base material.";
- perform the hard chrome plating process;
- measure the thickness of the new forms of coating (hardness of the coating on the standard steel plate, bending test of the standard steel plate, microscopic observation of the coating);
- visual comparison of the parts before and after the repair procedure.

MATERIAL AND METHODS

- To determine the surface chemical composition of the material, the XRF method was used on the "X-Met 8000 Expert" device;
- A "Carl Zeiss" microscope, type "Neophot 21" was used for metallographic examinations;
- The "Karl Frank" device, type "38536" was used to test the microhardness of the coating;
- A microscope and a coating thickness measuring device "QuaNix 1500" were used to determine the coating thickness.
- Test for bending using a bending tool and coating adhesion using a comb.

Before the hard chrome plating process, the material was prepared. For testing the application of chrome coating, and in accordance with the tested parameters, the standard plate made of alloy steel and shroud-fuel nozzle, which was used in the aviation industry, was selected as the base material (Figure 1). The standard plates on which the hard chrome plating process is to be performed are first electrochemically degreased in an alkaline solution to remove all impurities (Li, Jia, Chen, et all., 2023), followed by a grinding process using abrasives. In this case, there is no specified requirement for the fineness or roughness of the surface when grinding reference tiles. The surface must be uniform, smooth, and clean. However, with a shroud-fuel nozzle, it is necessary to sand to remove the old coating, and the sanding is done to a certain extent. For the proper and even application of the chrome coating, the surfaces to be chromed must be placed on appropriate tools of special construction and then degreased. Mask surfaces that are not subject to chrome plating using PVC foil, lead tape, or special tools. Degrease surfaces electrochemically in a solution for electrochemical degreasing. An alkaline solution of the appropriate composition was used for this. After degreasing, the surface should be thoroughly rinsed in clean, cold water. Before applying the hard chrome coating, the parts were thermally treated to reduce the risk of hydrogen brittleness at temperatures from 130º to 150 ºC for 5 hours. Etching of the surface was carried out anodically in a chromate acid solution for 20 to 30 seconds at a voltage of 6 V.

Figure 1: View of the standard plate and shroud-fuel nozzle prepared for the hard chrome plating process

Electrolyte composition and chroming:
CrO_3 - 289 g/dm^3
Cr_2O_3 - 1.28 g/dm^3
H_2SO_4 - 2.86 g/ dm^3
bathtub volume 1200 dm^3

The anode is made of lead, which also contains antimony, silver, and other elements.

The prepared surfaces are chrome-plated in a chromate acid solution at a temperature range of 50-55 ºC and a current density of 45 - 55 A/dm^2. The surfaces to be chrome plated are placed as cathodes, in relation to anodes in a ratio of 2:1. The chrome plating time depends on the application, taking into account that an average thickness of chrome of 0.0254 mm is deposited in 1 hour at the specified working conditions. When placing the parts in the tub for chrome plating, it is ensured that the parts are 10-15 cm away from the walls of the tub, 10 cm from the upper level of the liquid, and at least 15 cm from the bottom of the tub. The parts are placed vertically in the tub and are equidistant on both sides from the anodes. Chrome plating is done in a layer that is sufficient to compensate for machining. In the case of a shroud-fuel nozzle that is mounted on tools made for this type of part, the protected parts that are not chrome-plated in this case are the nuts. The shroud-fuel nozzle is exposed to chrome plating. After the chrome plating, the plates are rinsed with water in a tub for “saving” rinsing and then in a tub with clean and cold running water. The tiles are then rinsed in a tub of hot water. After rinsing and drying, the parts are removed from the tool and the protective masks are removed. The chrome-plated surfaces were then subjected to the dehydrogenation process by heating the object at the highest possible temperature for about 2 hours. After heating, a visual control of the chrome-plated surface is performed. After inspection, the surface is sanded to the prescribed dimension, and after sanding, a visual control is performed. The coating must not be in the form of pitting, spots, and cracks. The obtained results were not compared with the experiments and results of other studies due to the lack of similar research.

The appearance of the reference plate and the injector jacket after the chrome plating process is shown in Figure 2.

Figure 2: The appearance of the standard plate and shroud-fuel nozzle after the hard chrome plating process

RESULTS AND DISCUSSION

Table 1 presents the results of testing the chemical composition of standard plates following surface preparation for the hard chrome plating process, along with the chemical composition of the shroud-fuel nozzle. X-ray fluorescence spectrometry is a non-destructive analytical method employed to identify and quantify the mass concentration of chemical elements in liquid, solid, and powder samples. The XRF spectrometer analyzes the specific wavelength components of the fluorescence emissions from a sample exposed to X-rays (Ivanek, 2016; Morgui, Queralt, de Almeida, 2022).

Table 1: Display of the results of the chemical composition of the material

Element	Chemical composition % (m/m)	
	Standard plates	Shroud-fuel nozzle
Si	0.33	0.35
Cr	11.81	12.27
P	0.01	0.03
Mn	0.74	0.24
Ni	2.59	0.73
V	0.33	0.02
Mo	1.64	0.07
Fe	the remain	the remain

The composition of the tested standard plates consists of steel alloyed with 12% of chromium and 2% of nickel. Based on the obtained chemical analysis for the shroud-fuel nozzle, it can be concluded that it is made of a very similar material as the tested standard plate. In addition to the visual inspection of the applied coating, the thickness of the hard chrome on the standard plates was also measured. The measurement of the thickness of the hard chrome coating was carried out on two standard plates at several measuring points, and the obtained results are shown in Table 2. The thickness of the coating is an important parameter for almost all types of coatings (Tadić, 2013; Bammer, Huemer, 2019). Effective control of coating thickness can lead to outcomes such as producing a product that meets customer specifications, achieving cost savings by preventing material waste, and increasing yield through the use of in-line control (Jones, Uggalla, Li et all., 2021). Methods for testing coating thickness are divided into two primary categories: destructive and non-destructive measurements (Petrili, 2021).

Table 2: Results of coating thickness measurements on standard plates

Sample	Coating thickness (μm)										The mean value of the coating thickness (μm)
	Number of measurements										
	1	2	3	4	5	6	7	8	9	10	
1	32	37	34	39	36	33	31	44	39	34	35.9
2	28	30	32	31	33	29	25	33	27	27	29.5

The obtained results show differences in the thickness of the layer at different measuring points. Namely, the different thickness of the coating is the result of the electrochemical deposition of the coating on the standard plates, which are flat and have sharp edges compared to the roundness of the surface of the shroud-fuel nozzle. The thickness of the coating was measured using the destructive microscopy method. Table 3 presents the results of coating thickness measurements from one section.

Table 3: Display of obtained coating thickness values for a standard plate by measuring with a microscope

Sample	Coating thickness (μm)										The mean value of the coating thickness (μm)
	Number of measurements										
	1	2	3	4	5	6	7	8	9	10	
1	31.25	31.2	31.0	30.31	31.1	31.56	31.2	31.0	31.1	31.1	31.18

Deviations in this measurement compared to the measurement using the QuaNix contact device are acceptable because the thickness of the section coating is measured on a much smaller surface (about 20 mm), while the measurements using the device were made at different measuring points, measuring 50x70 cm. Figure 3 displays the appearance of the plate section magnified at 400x, used for measuring the coating thickness.

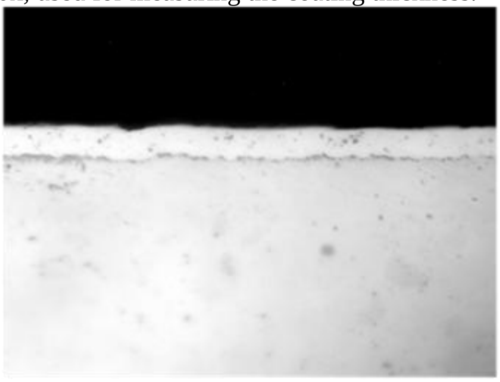

Figure 3: Microscopic observation of coating thickness at 400x magnification

Hardness tests fall into the category of destructive methods. The fundamental principle involves applying a load to the material by pressing a test specimen with a specific geometric shape, using a defined force for a set duration (Svoboda, Lysonkova, 2020).

Hardness is a key factor influencing tribological properties and serves as an indicator of a material's resistance to plastic deformation. Hardness most effectively indicates a material's resistance to wear. The hardness of the hard chrome coating was assessed using the Vickers method. Microhardness measurements were conducted on two standard plates, with the results presented in Table 4.

Table 4: Display of the measuring results of the hard chrome coating microhardness

Sample	Microhardness HV 0.2				
	Number of measurements				
	1	2	3	4	5
1	883	927	927	905	883
2	883	862	862	905	862

Based on the obtained results, it can be concluded that the microhardness of the coating on the tested standard plates met the requirements of the SNO 2328/91 standard. The standard plates were also tested for bending, where the bending was performed at an angle of 90º (Figure 4). The hard chrome coatings passed this test, meaning that there was no tearing or peeling of the coatings and that the part on the bends was still coated with hard chrome. If there is separation, peeling or cracking, the coating is not acceptable.

Figure 4: The appearance of the plate after bending at an angle of 90º

The adhesion of coatings is crucial in the coating industry, and a deeper understanding of adhesion behavior is necessary (Sweden, 2019).

Adhesion refers to the energy needed to detach the coating from the substrate (Figure 5). "Perfect" adhesion would be in case the bond between the atoms of the coating and the substrate is stronger than the bond between the atoms in the coating and the atoms in the substrate (Bajat, Mišković–Stanković, Dražić, 2007). Coating adhesion was measured by the standard notch method.

Figure 5: The appearance of the plate examined by the notch method

The results showed that the coating has good adhesion because there was no separation or peeling in any place.

Metallographic tests were performed to assess the microstructure. Three samples were taken from the plate on which the hard chrome coating was applied, and based on them, it can be said that the first two positions have an even coating that is slightly wavy, while damage to the coating can be observed in the third position, and it can be seen that it is wavy and uneven (Figure 6).

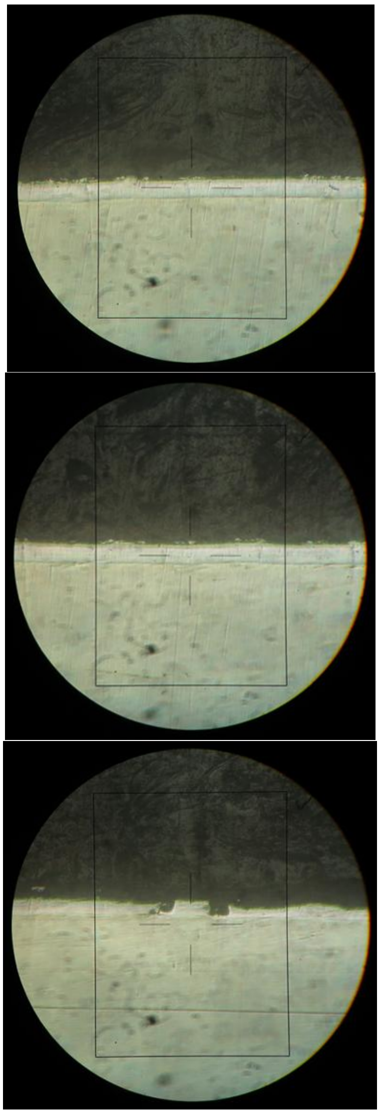

Figure 6: The appearance of three sections under a microscope

CONCLUSIONS

1. By modifying the surface of the material with the process of hard chrome coating, the quality of the processed object surface being coated increases, as well as the lifetime of the material.
2. One of the most important procedures before the hard chrome coating process is surface preparation. Preparation of the surface results in a firmer adhesion of the coating to the base material, i.e. good adhesion.
3. The results of measuring the coating thickness satisfied the thickness of about 30 microns for one hour of deposition which was predicted based on the given parameters of current density and the deposition time The measured coating thickness was approximately 30 microns after one hour of deposition, as anticipated based on the specified parameters of current density and deposition time during the hard chrome coating process. Thus, the coating thickness met the requirements for the shroud-fuel nozzle diameter.
4. The microhardness of the coating met certain requirements and increased the hardness of the part itself as an essential characteristic to obtain a fully functional part for reuse.
5. The coating also passed the bending test as well as the adhesion test in terms that there is no peeling, nor the separation of the coating from the base material. The bond between the base material and the coating is satisfactory.
6. The microstructure of the coating is good and unique, without major deviations, with one very small break in the form of an inclusion present in only one place out of three tested samples.

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Summary/Sažetak

U radu je ispitan kvalitet prevlake tvdog hroma na etalonskim čeličnim pločicama i plaštu brizgača goriva koji je korišten u avioindustriji, pri čemu je određena debljina prevlake, tvrdoća, mikroskopska struktura i otpornost na savijanje. Ukupan proces prevlačenja podrazumjevao je proces mehaničke, hemijske i elektrohemijske pripreme ispitivanih dijelova prije procesa hromiranja, a proces hromiranja proveden je u rastvoru hromne kiseline. Cilj rada je dobiti kvalitetne prevlake tvrdog hroma postupkom reparacije istrošenog plašta brizgača goriva koji će kvalitetom i karakteristikama moći zamjeniti komercijalne nove dijelove. Također, uzimajući u obzir da pojedini dijelovi nisu više ni komercijalno dostupni uvođenje postupka reparacije treba omogućiti produženo korištenje istih dijelova.