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Coating with Nano Components for Renovating of Extrusing Shafts

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Abstract: *The main goal of the project described in the paper is the creation of industrially applicable technology and the design of a relevant technological line for laying of coatings with high mechanical wear-resistance and surface-smoothness for renovation of the working area of shafts for extruding sheet material (PVC, Plexiglas, other plastics) by laying and polishing of new types of highly wear-resistant coatings based on ultra disperse nickel coatings with nano-dispersoids and/or nano-particles included.*

Keywords: *Extrusion shafts, nickel layer, nano-elements, mechatronics, robotics.*

I. Introduction

Extruding (pressing by pushing) of sheet material from non-metal materials (Plexiglas, PVC, other plastics) is widely used in households. Gifts, flowers, sugar and chocolate packing is made from thin aluminum sheets. Thin Plexiglas sheets are used to make pack-boxes, and thick nylon sheets are used to make bags, raincoats, etc.

The vast amount of production of smooth sheets of various sizes from these materials has brought to the development of technologies, in which the material is pressed and pushed out (extruded) between shafts of various diameters (100-500 mm) and various lengths (1-3 m). The shafts are **chromed**, they have very narrow tolerances of the diameter size and a very high degree of smoothness by polishing.

With time and at high production rate shafts age, their surface wears out, and sometimes scratches appear in incidents. All this makes the shaft surface not precisely circular and even. Because of a new shaft's very high price, renovation of the defected shaft is applied in such cases by applying a new coating and polishing it to a mirror shine.

Although there are many companies in Bulgaria and Europe which produce smooth folia by extruding, renovation of such shafts is mainly done in Italy and Germany. The operation is a company secret and it is very expensive – between 25 and 35 thousand EU; one has to wait in a queue; transportation is also expensive for remote destinations. Scientific research on the subject exists in Bulgaria (Sofia TU, Space Research Institute – BAS), but there is no working technological line for renovation.

II. Importance of the subject

The creation of an industrially applicable technology and the design of the respective technological line are of great economic importance for the technical support of all kinds of extruding and rolling mills, producing sheets of various plastics and aluminum alloys.

The renovation of working surfaces of extruding shafts for various types of folio – plastics, PVC, Plexiglas, household or packing folio is done outside Bulgaria by the producers of the corresponding equipment or by a small number of specialized companies using their own classified technologies. This creates great difficulties to Bulgarian and South-East European companies in the case of prophylactics or minor repair of their equipment due to:

- High transportation expenses because of the distant locations of renovating companies' sites and the necessity of special measures during transportation of those oversize precise machine details;
- Additional investment is needed to procure spare shafts to minimize idle time losses of those high-productivity machines, working 24/7/365;
- Limited production capacities of the renovating companies and the relatively long technological cycle of the methods used make these services rather expensive and time-consuming;
- The existence of limitations following Bulgarian EU membership connected with the **Directive for prohibition of coatings and activities using highly harmful substances,** as chrome coatings and cyanide baths.

These exploitation and organizational problems obviously create enough motivation in Bulgarian producers and Bulgarian government to ask relevant scientific organizations and experts for technical support. They are also willing to co-finance the research and innovation developments needed to solve this technological problem.

III. Description of the project

IIIA. General description of shaft renovation processes

A technological line for chrome based smooth shaft renovation must include at least the following technological cells and operations:

1. Grinding of the old chrome layer at given roughness.

2. Coating of a new chrome layer in a galvanic (cyanide) bath.

3. Rough grinding of the coating down to a predetermined diameter and roughness.

4. Fine grinding of the shaft down to a predetermined roughness.

5. Polishing of the chrome to predetermined smoothness (Ra ~ 0.02-0.03).

The grinding of the old chrome layer is a routine and easy operation if one has lathes with long guides, accurate screws and good bearings. Usually 120 µm to 150 µm of the old chrome are taken off, where greater roughness is required to enable the new chrome layer to stick better.

The laying of the new layer of chrome can be done in a galvanic bath where a part of the shaft is dipped and it is slowly rotated. Thus relatively big thickness (120-150 µm) and unevenness of the coating is achieved. The evenness is improved through the next operation.

Like the previous stage, if one has lathes with long guides, accurate screws and good bearings, one can achieve enough accuracy of shaft's diameter, a decent smoothness (unlike Operation 1, where bigger roughness is required) and one can take off the excess chrome.

The operations enlisted are common, traditional and well-known. They can be done using the available machinery in the majority of machine-building plants after a certain renovation of machinery. Next a transportation method has to be developed to move the shafts between operations – conveyers, inter-operations-stations – as well as whether there is a necessity of fitting details – industrial hardware and controlling software.

The following characteristics of the existing situation should be taken into account when discussing the eventual new innovative technology:

1. Currently, according to company information and own marketing research there is no place in Bulgaria to make quality **chrome** coating with such thickness and shaft dimensions (detail). The nearest chroming companies are in Turkey.

2. There are **EU Directives** (which we have to follow since 01.01.2007 as EU members) forbidding chrome coatings as exclusively harmful. Furthermore, the waste (cyanides) from chrome baths is also highly harmful and banned.

3. As a rule the finishing and polishing of steel (from which shafts are made) is more developed, cheap and successful, as well as less harmful than processing with chrome, especially for big details and smooth-finish.

The idea of polishing the steel base of the shaft to the necessary smoothness emerged on the basis of these studies and it also included laying a thin (15-25 µm) nickel coating with nano-particles in it, or a thicker one (25-40 µm) including other micro- and nano-dispersoids for increasing hardness and wearing out resistance.

Plastics are pushed through a pair of shafts at about 200°C working temperature (Fig. 1). To maintain constant working temperature all along the shaft, channels are made inside it, where hot oil is circulated at controlled temperature. The extruded material has the same temperature as the circulating oil.

Note: The high working temperature is an advantage with the chosen renovation method, because the hardness and wear-resistance of the suggested coatings is increased through tempering, which is naturally obtained in our case during normal operation.

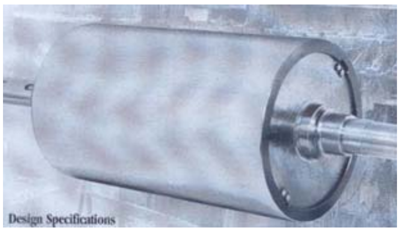


Fig. 1. A hollow smooth shaft for extruding of folio

IIIB. Chemical nickelling and disperse coatings on its base

Chemical nickelling as an applicable technology started in the 1950-ies. For several decades this technology was rightfully called NONELECTRIC NICKELLING, as it is carried out without the use of external electric current source. In these processes, also called AUTOCATALITIC, the role of electric driving force is played by specific reductors: sodium hypophosphite and more rarely – sodium boron hydride [1]. Being in the solutions, these reductors inevitably bring their “noncleanings” in metal coatings. A certain percentage of PHOSPHORUS/BORON is embedded in the nickel matrix. The respective phosphides/borides are formed during low temperature processing, e.g., 200-400°C. These are solid phases, which bring to increased hardness and wear resistance [2].

The chemical nickel coatings are 6-8 times more expensive compared to galvanic nickel coatings. Nevertheless they are being increasingly introduced in new areas. The reason lies in their unique qualities. The most important are [3]:

- High evenness in the layer thickness, i.e., they are sized coatings, requiring minimal finish processing.
- High hardness and wear resistance. Friction coefficient with many partners is relatively low.
- Low porosity/high corrosive resistance.
- Excellent polishing ability because of great hardness and microcrystal structure.
- Convenient disperse coatings matrix. They can be MICROSCALE и NANOSCALE.

The application of disperse coatings with nickel-phosphor matrix started in the 1980-ies. The variety is comparatively big. It comes from the possibility of management of matrix contents as well as from the increased supply of MICROSCALE DISPERSOIDS and NANOSCALE PARTICLES in the last decade [4]. Micro-scale insertions are mainly on the basis of carbides of titanium, tungsten and cobalt, characterized by high hardness and good bonding with the nickel matrix. Nano-scale particles are mainly nano-diamonds obtained through various technologies [5]. The research on the project requires design and development of:

- A tribo-tester for evaluation and comparative testing of tribo-technical characteristics of technological micro- and nano-composite coatings.
- A testing device for measuring the geometrical parameters of renovated shafts and the evenness and smoothness of the coating.

The described production process includes some negative characteristics and conditions such as:

– high working temperature – 200°C;
– abrasive effect of the extruded material;
– significant normal efforts on the contact surface of the shafts;
– non-interruptive working process.

The new type of coating offers improved characteristics and exploitation advantage regarding:

– wearing resistance and micro-hardness;
– corrosion resistance;
– reduced porosity;
– rapid reduction of the friction coefficient;
– increased cohesion and adhesion.

The listed improvements and physical-mechanical features, due to the nano-structured nickel coatings, increase the exploitation time of the extruding shafts from 2 up to 10 times while at the same time reducing the thickness of coatings from 3 up to 5 times. The reduced thickness compensates for the higher price of the operation. The increased working time is an additional advantage. Furthermore, the replacement of the chrome coating by a nickel one satisfies the requirements of the EU Directives on pollution.

IV. Basic idea

The applied idea for development of combined (composition, dispersed) coatings including nano-particles for invariant metal formers is fundamental based on technologies, well known after 70-ies. We are calling them ***DISPERSOID COATINGS***.

Essentially these are a metal matrix, received in a galvanic or chemical (reducing) method and distributed (more or less uniformly) micro-particles – the second phase.

Principally, the combining of metal matrix (coating) features and the type of particles (dispersoids) improves some characteristics, such as hardness, wear-resistance, a low rubbing coefficient, a high rubbing coefficient, corrosion-resistance, etc. As a rule the second phase is non-metal, for example: graphite, silicon carbide, corundum, polymer dusts, diamonds and others.

IVA. Dispersoids. Classifications of dispersoids with a tribologycal purpose

To elucidate some steps of the main task we will review some most used dispersoid groups. In this review, the accent will be on the micro-area or nano-area.

Dispersoids of the micro-area

Physical and chemical features of particles from the second phase have a main role in the formation of dispersoids. They have an influence also in the process of building as well as in in coating's operating quality. To receive dispersoids with a good physical and mechanic quality the specific features of dispersoids are used in managing the control of a technological process.

Dispersoids with different size and ingredients have a different conduction in electrolyte. For example, dispersoids "conductors" and dispersoids "insulators", have different conduction, large dispersoids (10-50 μm) and small dispersoids – (0.1-5 μm).

New features assume dispersion coatings, where particles have a specified orientation in relation to the detail surface. It is a perspective trend to use dispersoids with specified physical features for orientation. Their movement and their precipitation could be controlled.

As dispersoids can be used micro-dusts of hard-fusible oxides, carbides, silicones, borides, nitrides, diamonds, etc. (Table 1). Micro dusts are produced in two ranges of grains – wide and tight. The size of the grains of the basic fraction set by screening through two sieves – allowing and holding for tight range micro-dusts, and for wide range – through three.

Table 1. Micro-area dispersoids

Diamond	Silicon Carbide	Electro-Corundum	Wolfram Carbide	Boron Carbide	Titan Carbide

Dispersoids of the nano-area

It is considered that nano-technologies are one of the high achievements in science for the last few years and they have found hundreds applications in the wide range of areas – from medicine to solar panels, from ecology to coating fills with surprising new features.

Some of the companies offer different nano-elements, mainly nano-powders. These are Oxides, Carbides & Nitrides. Some of them, included in our experiments are:

C – Diamond Synthesized – 4-25 nm;

SiC – Silicon Carbide – 50-60 nm;

Al_2O_3 – Aluminum Oxide – alpha, 200 nm.

We foresee two types of experiments:

1. Investigations in small prototypes of different types of Nickel-based coatings including micro- and nano-dispersoids under laboratory conditions.
2. Investigations under working-like conditions (t = 200°C) of hardness and weariness in prototypes of moving shafts.

IVB. Experimental results

The laboratory experiments were realized for chemical nickeling with nickel-phosphorus matrix with micro/nano scale dispersoids addition – silicon carbide, diamond synthesized. As optimal temperature is assumed 90-92°C, optimal pH from 4.7 up to 4.9 and relation between the cultivated area and volume of the solution $S(V)$ is 1-2 dm^2/l.

In approximate observing of the parameters above, the mass percents of phosphorus are between 8-10 mass %. This value is corresponding to the matrix relative weight. From here we deduced a theoretical (average) speed for coating – 24-25 μm/h.

The coating for combination of the experimental models was made (Fig. 2). The combinations for the different models were chosen to be close to the assumed value of the relation $S(V)$.

In this series of experiments, where silicon carbide nano-filter of 700 nm was used, the concentration of the working solution was chosen to be 0.4 g/l. In the experiments we added the dispersoid at the 15th minute from the beginning of the process.

The weight measures of the polishing plates from 0.25 dm^2 proved calculated deposition speed – 23.8-25.2 μm/h. The coating follows the relief of the base and keeps the same smoothness [6].

The same experiments were accomplished also with a nano-filter of 150 nm.

The same experiments were done also with dispersoid – nano-diamond dust. The following depositions were made:

- Pure nickel – phosphorus matrix;
- + Diamond Synthesized – 4-25 nm.

The relief and smoothness of the coating remain.

In some of the experiments the temperature was increased (for about 40 min up to 96°C). Harmful effects (decomposition of the solution) were not observed.

Some of the models were used in preliminary experiments for chemical coloring (oxidation) of nickel-phosphorus coatings (Fig. 3).

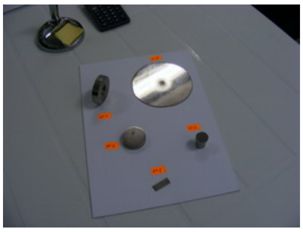


Fig. 2. Coating of experimental models

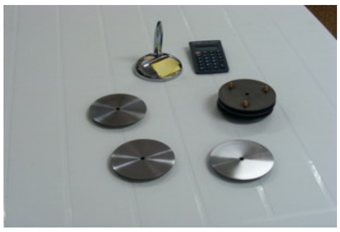


Fig. 3. Chemical coloring – oxidation

For the test under working conditions we designed a stand for high temperature testing (200°C – Fig. 4).

The stand consists of a hollow shaft, driven by an electric AC motor and a heater, blowing the shaft with hot air. A heat-resistant Teflon roller is pressed to the shaft, which serves as extruded material.

PLC Allen Bradley is used for the stand control and an inverter SEW Eurodrive (Fig. 5) – for a driving mechanism. A personal computer is used to collect the data regarding tests of wear resistance after continuous work.

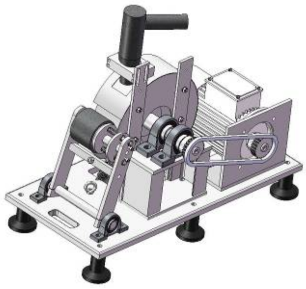
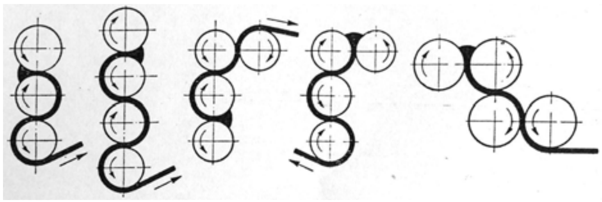


Fig. 4. Experimental stand for testing under work conditions

Fig. 5. Control system of the stand

IVC. Extruding and producing schemes

Handing of the material to shafts could be done from the bottom or from the top – Fig. 6, but from the top scheme is more frequently used. Fig. 7 describes the structural scheme of a producing line for sheet production.



a *b* *c* *d* *e*

Fig. 6. Scheme of the material handing in calendering of elastomers:
a – a three-shafts calender; *b* – four-shafts calender; *c* – four- shafts Γ-shape calender with bottom material handing; *d* – four-shafts Γ-shape calender with top handing; *e* – Z-shape calender

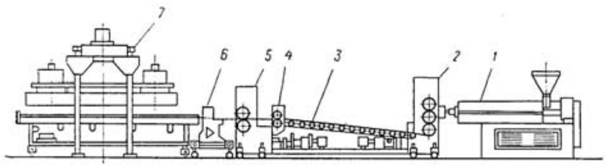


Fig. 7. A producing line structural scheme for sheet producing:
1– extruder; 2 – calender; 3 – rolling for the sheet cooling; 4 – unit for longitudinal cutting; 5 – stretching shafts; 6 – guillotine for crosswise cutting; 7 – packing unit

V. Conclusions and results

As a **final result** in the long term (3-5 years) we are expecting:

– A successful development of a new type of nickel coating with micro- and/or nano-structures included;

– Development of a project of a technological line for renovation of smooth extruding shafts;

– Installment and testing of the technological line in a production plant;

– Market realization of the ready technological line for renovation of shafts.

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Нано покрытие для обновления экструдирующих валов

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(Р е з ю м е)

В статье описан проэкт, основная цель которого создание промышленно применимой технологии, а также и реализация технологической линии для выработки покрытия высокой механической устойчивости и гладкости поверхности при обновлении рабочей площи экструдирующих валов для продуктов из PVC, Plexiglas и других пластмасс путем нанесения и полирования новых типов покрытий, основаных на дисперсии никеля, размера нано-диспероидов или наночастиц.