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PRINTER FOR THIN LAYERS SPRAYING OF NANOPARTICLE DISPERSION

Mihaiela ILIESCU, Maria Magdalena ROȘU, Cristina NIȚU, Octavian MELINTE

Abstract: *Air pollution and the trend for glass walls and large windows in the buildings have focused attention on the need of having self-cleaning glass as affordable and efficient as possible. This paper presents research aspects on the design and prototype of a printer for nanoparticle dispersion spraying. It has been integrated into a technological system for producing self-cleaning and antibacterial glass. Tests carried on the produced glass samples proved very good self-cleaning properties and, relatively, adequate, antibacterial property. Further research development will focus on scaling the equipment for mass production.*

Key words: *printer, spraying, nanoparticle dispersion, self-cleaning, glass.*

1. INTRODUCTION

The high degree of air pollution has serious effects on everyday life of people. The cities are so very crowded with high traffic and impressive glass and metal tall buildings. Even it is about offices, or condominium, the trend is of having large glazed surfaces that allow light gets into the chamber and gives the feeling of huge spaces. One major problem that stands is that of cleaning these glazed surfaces as easy, comfortable and low costs as possible. This is why attention has been focused on self-cleaning glass - meaning technology and, therefore, adequate equipment for producing this type of glass.

In the Glass Coating Market Research [1] there are mentioned the major key trends that boosted the glass coating market: nanotechnologies-based coating; energy-efficient glass coatings; self-cleaning and anti-fog coatings - with application in construction sectors and automotive. Some of the most important key players in this field are: SCHOTT AG (Germany), Kyocera Corp (Japan), Saint-Gobain (France).

This research paper presents aspects of the innovative equipment prototype (printer) and technology for producing self-cleaning glass by spraying deposition of TiO_2 nanostructured thin layers.

The layers has the morphology with peaks and valley [2] that can be optimized by varying spraying parameters values so that to improve the wetting properties of the surface and, consequently, its self-cleaning efficiency.

Most important is that for obtaining the final product, the TiO_2 layers does not specifically require post deposition thermal treatment, neither very high temperature (up to 550°C)

The technological system fit for the new technology of TiO_2 nanostructured layers deposition is concentrated on a new printer for thin layers spraying of nanoparticle dispersion and / or liquid precursors.

On the market there are available various types of equipment for nanomaterial deposition, like the following mentioned:

- high speed disperser [3] - for wet dispersion of liquid - solid material, at variable speed;
- electrostatic spray drying [4] - with electrostatic nozzle in the heat chamber, the material being heated with pressure gas and sprayed due to the elstrostatic field;
- production lines of Pilkington UK [5] - with the sprinkling of metallic TiO_2 atoms during the glass manufacturing process.

Compared to market offers, the new designed printer for nanoparticle dispersion spraying has relevant advantages as: continuous variation and further constant temperature of the support glass surface; deposition in successive layers of liquids / nanoparticle dispersions; high precision (0.005 mm) in positioning the mechatronic subassemblies; integration into industry 4.0 system; scalability.

2. PRINTER DESIGN

The printer concept is that of modular structure (see Figure 1), with four modules: portal module; heating module; command and control module; monitoring module.

Depending on the properties of materials to be sprayed and on the characteristics required for the thin layers, the printer enables successive layers deposition at different spraying parameters: temperature, pressures, speed, spraying jet position relatively to X and Y axes.

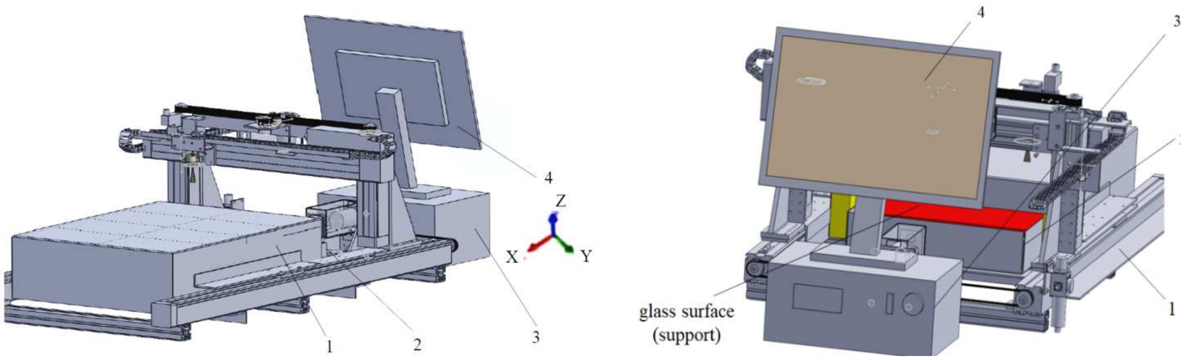
Short description of each module follows next.

The *portal module* (see Figure 2) is the main part of the printer. Its structure, made of aluminum profiles, represents the frame for mounting on the servomotors, the ball screws and nuts, the roller bearings and all other components that generate three translation motions, along the X, Y and Z axes.

The spraying system for liquid precursors and / or nanoparticles dispersion has a pneumatic nozzle. Different values for the jet pressure are obtained by pressure regulator, solenoid valve and throttle.

The zone for heating the glass surface (support) has a thermally insulated cover the moves together with the frame of the spraying nozzle, along the X axis. This is one way of keeping constant temperature of the sprayed layer onto the surface.

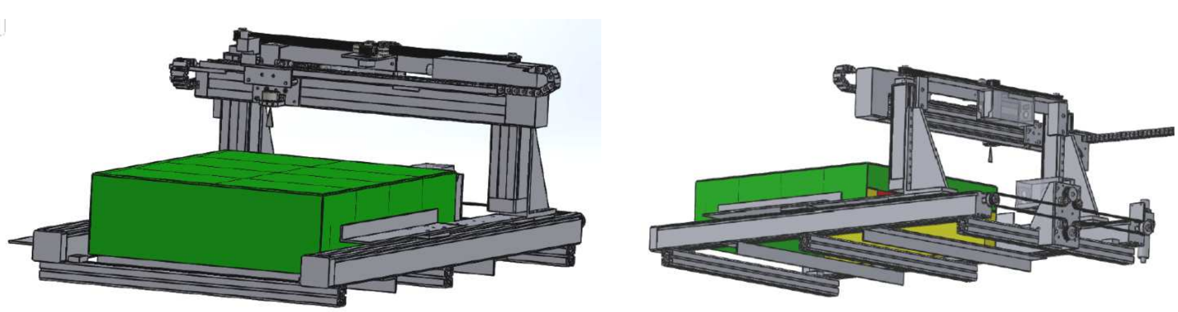
The *heating module* is the printer's part that ensures controlled heating of the glass surface up to 550°C. It is basically made of a aluminium alloy plate in which are mounted six electrical resistors, above them being a ceramic plate for positionig the glass surface on top of it (see Figure 3).



1- portal module; 2 - heating module; 3- command and control module; 4 - monitoring module

a. side view **b.** front view

Fig. 1. The printer 3D model.



a. front view **b.** rear view

Fig. 2. The portal module 3D model.

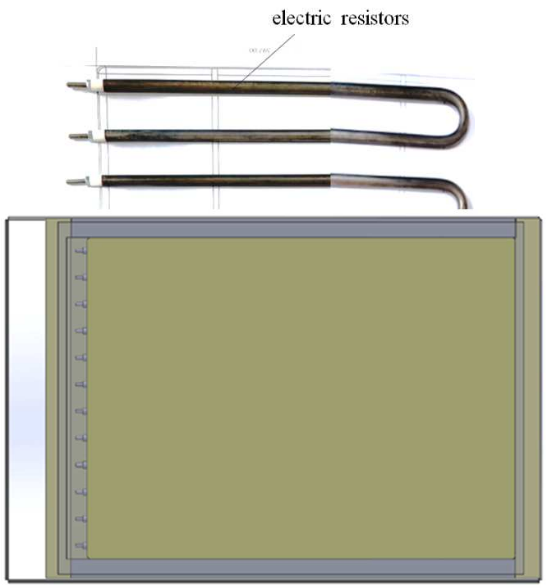


Fig. 3. The heating module.

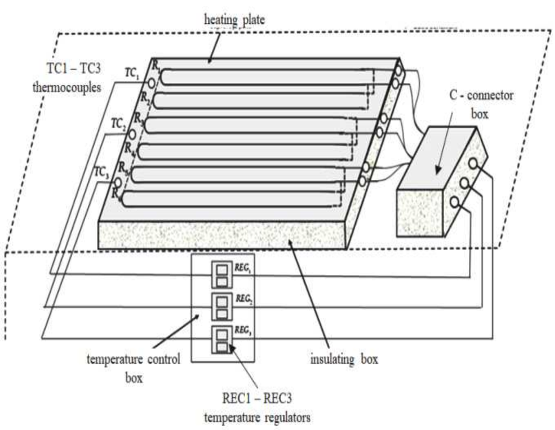


Fig. 4. The scheme for termperature command and control.

The *command and control module* consists in 3 axes controller (icu-EC, Isel®) - for each of the three servomotors (EC 200W, 48V, Isel®), with software control ProNC. [6]

In Figure 4 it is shown the scheme of command and control system for the heating module, so that to have the required temperature (measured in three points of the plate) and time for thermal treatment of the sprayed thin layer (depending on the dispersion materials' properties)

By the *monitoring module* programming and real time monitoring of components' motions and of the temperature on the glass surface are available.

3. SYSTEM PROTOTYPE

New technology of TiO_2 nanostructured layers deposition for producing self-cleaning glass with antibacterial properties has been developed and tested in the technological system with the printer as central equipment.

This new technology has specific stages as mentioned next (see also [7], [8]).

a. Dispersion preparation - from dioxide titanium anatase paste with nanoparticles of 15 ÷ 20 de nm disperssed în terpineol.

b. Turning on the spraying system - nozzle purging and setting the carrier gas pressure;

c. Preparing the glass surface (support) - by acetone and isopropyl alcohol, then wiping with microfiber cloth. Once cleaned, it is positioned on the heating module of the printer for preheating at 100°C.

d. Spraying the self-cleaning thin layers - with optimized parameters values:

- h = 150 mm - height from the nozzle up to the glass surface; pitch of 50 mm, with 5 mm overlapping (along X axis);
- carrier gas pressure (nitrogen 5.0) of 2 kgf/cm^2 ;
- speed along the Y axis is 15 mm/s;
- glass substrate preheating at 100°C;
- glass heating at 150°C -200°C;
- once the spraying process stopped (nozzle cone angle of 54°), theere will be 10 minutes maintanance at 100°C to completely dry the coating
- glass surface, A2 = 420 x 594 [mm x mm]

The start and stop positions of the nozzle must exceed the surface of the glass in order to avoid incomplete layer deposition and, therefore, possible defects.

Planning of specific activities for producing the prototype of glazed surface with antibacterial and self-cleaning properties is important for efficient use of resources (time, financial, work force). Sometimes the cost and time can't be optimized simultaneous because it is efficient to accept a big cost for the first version of prototype and then to reduce the developing time.

The activities are evidenced in table 1.

Table 1

Activities planning for self-cleaning glass technology.		
Stage	**Activity**	**Time [min]**
1. Dispersion preparation	Dispersion preparation	140
2. Turning on the spraying system	A2.1 Nozzle assembly and gas source connection	5
	A2.2 Nozzle purge and carrier gas pressure setting	5
	A2.3 Filling prefabricated dispersion, purging to remove alcohol	5
	A2.4 Heating surface cleaning	5
	A2.5 Hotplate heating	15
3. Preparing the glass surface (support)	A3. Glass surface preparation	5
4. Spraying the self-cleaning thin layers	A4. Self-cleaning film deposition	10

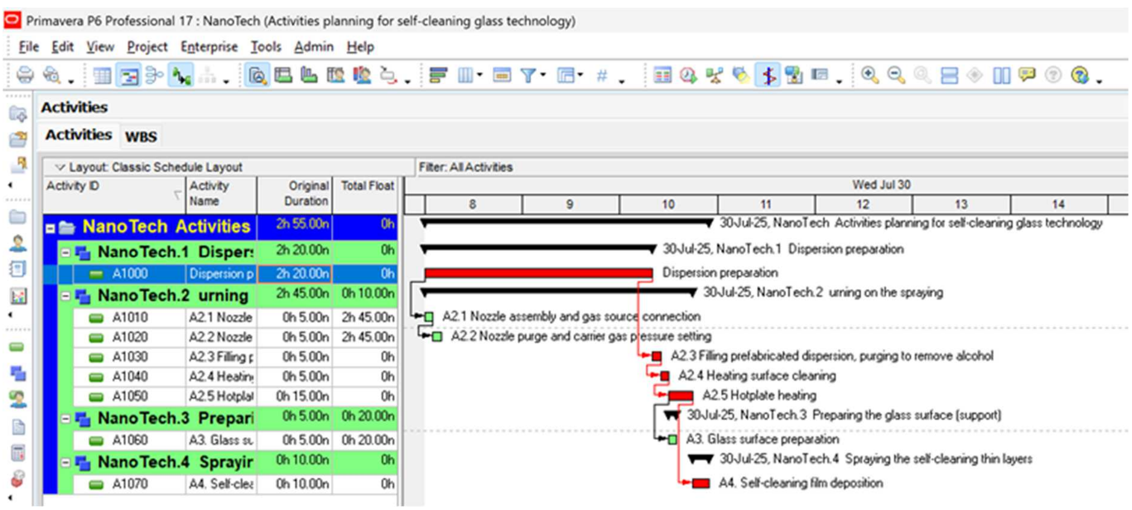


Fig. 5. Activities planning diagram

Tests on the self-cleaning glass produced in the technological system with the printer has been done according to the specific regulation, so that to validate the new technology [7], [9]. Some relevant aspects follow next.

The *photocatalytic efficiency* of the obtained layers was tested by evaluating the decomposition of rhodamine under UV irradiation (254 nm and 362 nm).

The deposited TiO2 layers showed good photocatalytic activity (RhB degradation) with the best degradation rate of 0.045 min-1 when a coated glass degraded in 80 min. 97.3% of 25 ml RhB solution.

Measurement of *the contact angle*, CA where done in order to determine the hydrophobicity/hydrophilicity characteristics of the nanostructured layer on the glass surface. CA measurements indicate that all samples are hydrophilic, with CA close to superhydrophilic (~30°) for post-deposition annealed samples and close to hydrophobic (~75°) for the as-deposited layers.

The *self-cleaning property* of TiO_2 layers was evaluated according to ISO standard EN 1096-5:2016.

The dirt cleaning rate does not only depend on the photocatalytic response of the TiO2 surface, but also increases with the surface roughness. Because of the reticular structure of dioxide titanium, the surface roughness is, relatively high (200 ÷ 300 nm) so that it resulted about 36% after 3 hours of exposure to UV (for the samples with no thermal teratment after spraying).

The *antimicrobial activity* of the samples was tested against Staphylococcus aureus ATCC 6538 (as a model for non-fastidious Gram-positive bacteria) and Escherichia coli ATCC

8739 (as a model for Gram-negative bacteria). The obtained results were not so very eloquent, still it has been noticed that due to the photocatalytic effect of TiO_2 antibacterial activity for Staphylococcus aureus has been slightly strengthened, compared to ordinary glass samples.

The Industry 4.0 concept involves technologies such as: Internet of Things; Cyber Physical System; Cognitive Computing; Data Analysis. To simulate the motion trajectories of printer's components in the virtual environment, migration from CAD environment to a simulation one was carried out. In order to perform the simulation in ROS (Robot Operating System), a URDF file was generated. The .urdf files are used by the two frameworks available in ROS: Rviz and Gazebo, for visualizing the robotic structure and, respectively, performing virtual experimentation. Movements can be generated on all axes using the MoveIt package, forces can be applied at different points and end-of-stroke sensors can be simulated for each axis.

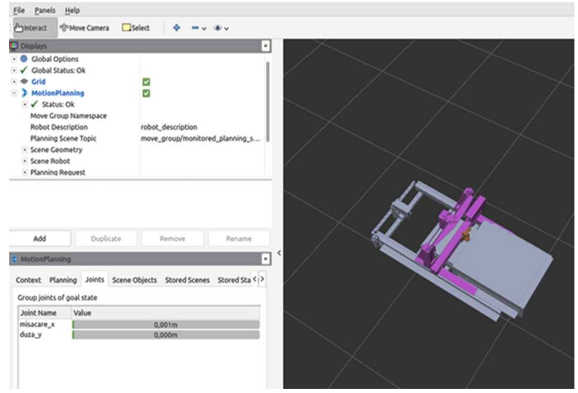
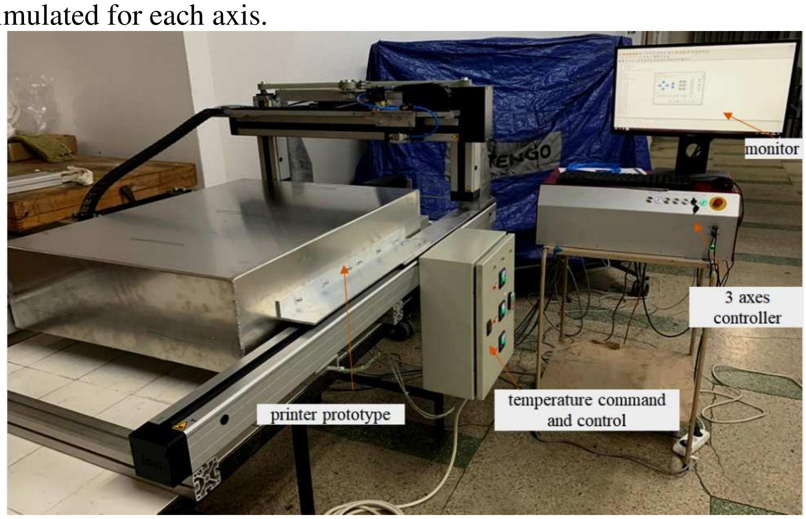


Fig. 6. Nozzle motion simulation in virtual environment

An image while de virtual environment simulation process is shown in Figure 5 - for the transversal motion (along Y axis) of the spraying nozzle.

The technological system with the printer prototype and an image of the produced self-cleaning glass are to be noticed in Figure 6.



a. printer prototype

b. self-cleaning glass

Fig. 7. Production of self-cleaning glass.

4. CONCLUSION

Research results on concept and design of printer prototype for spraying thin layers of (TiO_2) nanoparticles dispersion on glass are highlighted in this article. The main objective was to produce glazed surfaces with self-cleaning and antibacterial properties, in relatively low temperature conditions (up to 550°C). Basic tests on the self-cleaning glass produced in the technological system with the printer proved good photocatalytic activity and low antimicrobial activity against Staphylococcus aureus. Further testing the characteristics and properties of the deposited TiO_2 nanostructured thin layers are envisaged.

Scaling the equipment for mass production of self-cleaning glass will be the objective for further research development.

5. ACKNOWLEDGMENT

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Printer pentru depunerea prin pulverizare a straturilor subţiri din dispesie de nanoparticule

Poluarea aerului și tendința de a utiliza pereți de sticlă și ferestre mari în clădiri au atras atenția asupra necesității de aavea sticlă autocurățantă într0un mod cât mai accesibil și eficient posibil. Această lucrare prezintă aspecte de cercetare privind proiectarea și prototipul unui printer pentru pulverizarea dispersiei de nanoparticule. Acesta a fost integrat într-un sistem tehnologic pentru producerea de sticlă cu proprietăţi de autocurățare și antibacteriane. Testele efectuate pe mostrele de sticlă produse au dovedit proprietăți de autocurățare foarte bune și proprietăți antibacteriene relativ adecvate. Dezvoltarea cercetărilor ulterioare se va concentra pe scalarea echipamentului pentru producția de masă.

Mihaiela ILIESCU, PhD., Senior researcher (CSI), Institute of Solid Mechanics, Romanian Academy, mihaiela.iliescu@imsar.ro, Constantin Mille 15 street, Bucharest, Romania.

Maria Magdalena ROȘU, PhD, Eng. Associate Professor, National University of Science and Technology, POLITEHNICA BUCUREŞTI, magdalena.rosu@upb.ro, Splaiul Independenței, 313, Bucharest, Romania.

Cristina Marilena NITU, Ph.D, Researcher (CSII), Institute of Solid Mechanics of the Romanian Academy, cristina.nitu@imsar.ro, Constantin Mille 15 street, Bucharest, Romania.

Octavian MELINTE, Ph.D, Researcher (CSII), Institute of Solid Mechanics of the Romanian Academy, octavian.melinte@imsar.ro, Constantin Mille 15 street, Bucharest, Romania.