Circular Economy-Waste Reuse into a Spongy Oxide Material with Photocatalytic Activity for a Sustainable Development

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IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: Iasmina- Florina Burlacu *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **616** 012068

IOP Conf. Series: Earth and Environmental Science **616** (2020) 012068 doi:10.1088/1755-1315/616/1/012068

Circular Economy-Waste Reuse into a Spongy Oxide Material with Photocatalytic Activity for a Sustainable Development

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Abstract. The most recent studies in the field of heterogenous catalysis are directed towards the diffrent anchoring supports for immobilising commonly employed photocatalysts for the degradation of emergent organic compounds from wastewater. The technique of immobilisation of the catalytic semiconductors helps to avoid one of the main technical issue which concerns the post- recovery process of the classical particles in suspension after the water treatment. In the context of the transition towards a circular economy and sustainable development, this paper presents the results regarding a novel catalyst immobilized on fix support starting from some general waste and its photo catalytically functionalization through deposition of various concentrations of zinc oxide on its surface. The morphological and structural characterization of the synthetized oxide spongy materials was performed. This new oxide material presents a great potential as a low-cost, environmental friendly and sustainable water treatment technology.

1. Introduction

In the present work a special attention has been paid to the anchoring support materials obtained from different type of wastes due to the convergence to the principles of a circular economy but also from environmental considerations in terms of the sustainable development.

At national and international level, previous studies presents as support materials for the immobilization of photocatalytic oxides various types of substrates like glass [1-4], carbon-based support materials such as carbon nanotubes (CNTs), graphene's (rGOs) [5-10], zeolites, clay and ceramics [11-12], polymers [13-17] etc. This work is addressing to the support materials obtained from wastes that through their minimal processing can be reused in various type of new support materials with environmental applications. The immobilised catalysts on fix supports are interesting in the context of heterogeneous photo catalysis in terms of the reusability of the catalysts and high-durability in time as well as there are no need to do the unnecessary step associated with the post-treatment recovery of the particles in suspension from aqueous solutions.

Wastes could represent a valuable resource which can be reused as a raw material; in this paper we focused on waste valorisation using glass from Waste Electrical and Electronic Equipment (WEEE) industry into an anchoring support material for zinc oxide deposition.

IOP Conf. Series: Earth and Environmental Science **616** (2020) 012068 doi:10.1088/1755-1315/616/1/012068

Glass, in various forms, is part of our daily lives, resulting in a high percentage of recyclable glass mass. Globally, between 80% and 85% of the glass industry goes to the food industry (containers), pharmaceuticals, building construction, automotive manufacturing or to the Electrical and Electronic Equipment (EEA) industry. Glass can come from different wastes streams, for example, glass from solar panels, TFT-LCD glass, glass from fluorescent lamps, glass from gas- discharge lamps, etc. E-waste like Waste from Electrical Equipment and Electronics (WEEE) is one of the priority management flows of EU policy, with an estimated increase of 3- 5 %/year to be managed in accordance with the provisions of EU Directive 2002/96/EC.

Fluorescent lamps belong to this category of e-waste, and the annual world production is expected to be of the order of 1.5 billion units. According to EU policies, this is an hazardous waste that must be collected and sent to recycling facilities, where it is treated and sorted in several streams. In the present work, the emphasis was on the recovery of this type of e-waste from fluorescent lamps, given that the glass from fluorescent lamps corresponds to 95 % of the total weight of fluorescent lamps at the end of their life cycle, so their potential to be recycled into new glass-based products is high [18].

This new spongy material with photocatalytic properties could find out its applications in environmental protection on heterogeneous photocatalytic degradation of some emergent pollutants from wastewater treatment using Advanced Oxidation Processes (AOP).

2. Experimental

2.1. Materials and methods

The resulted catalytic material is based on glass Waste from Electrical and Electronic Equipment (WEEA) (94 %), agricultural fertilizer Epsom salt ($MgSO_4$) as binder and eggshells (foaming agent) and it was covered with a layer of zinc oxide through dipping and autoclaving method, which gives it the photocatalytic properties. The synthesized glassy material with photocatalytic properties and the process of obtaining it were developed based on 2 principles converging towards good practices in the field of environmental protection: the process does not generate secondary components and involves the recovery of wastes (glass from WEEE) into a spongy material thus helping to reduce the impact on the environment generated by the volume of waste stored improperly.

The resulted catalytic material was mineralogical analysed using an X-ray diffractometer- XRD, Bruker D8 Advance, equipped with a 1D Lynxeye detector measuring 3° simultaneously on 192 channels. The XRD diffractrograms was registered using a Copper anode (Cu $K\alpha1 + 2\lambda = 1.418$ Å) with 0.02° steps between 10 and 60°, measurement time equivalent to 288s per step, Low-background sample holder in monocrystalline silicon for spongy composite material samples.

Most interesting obtained samples of the support material coated with ZnO (SpongeMat/ZnO) were studied to investigate the microstructural development with back scattered electron imaging (BSE) mode in a scanning electron microscope (model FLEXSEM 1000). In order to reduce electrical charging of non-conducting specimens which could be induced by the incident electron beam, all sample surfaces were sputter coated with chromium.

3. Results and Discussions

3.1. Morphological characterization of the spongy catalytic material by scanning electron microscopy

The microstructure of the synthetized material consists in a spongy- like architecture and could be observed in figure 1 a) and b) (with the red arrows). The amount of exhaust gases (CO_2 and N_2) caused by the calcination of the eggshell and creation of high temperature (750°C) during the autoclaving process led to the formation of porous structure. Because of the irregular distribution of the eggshell powder in different regions of the material, the inhomogeneous distribution of pores in size and shape occurred. The particles mean diameter is between 18.6 – 33.7 μm and it has been shown in the micro- images of the figure 1, c).

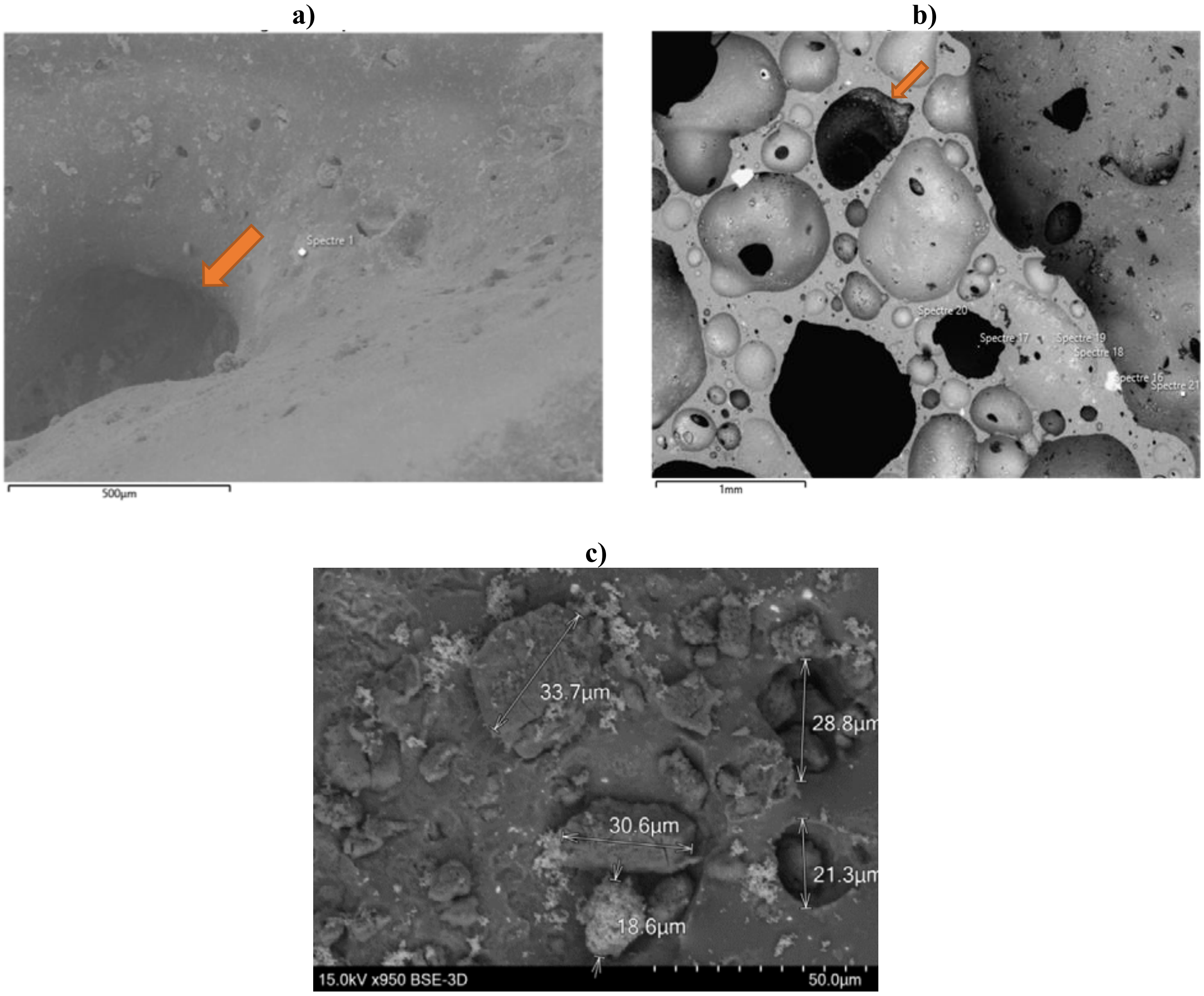

Figure 1. Scanning electron microscopy images of the SpongeMat/ZnO spongy structure a) bottom view and b) top view of the sample coated with 17.5 % ZnO and c) sample porosity size, top view 1 % ZnO.

The presented SEM images confirm a fairly homogeneous distribution of components in the microstructure of the synthesized material. The phases were differentiated by SEM analysis, using the BSE detector that captures the retro-scattered electrons in the analyzed sample, so that the specific phase of the glass is highlighted by the light gray color. Homogeneity is particularly important for the stabilization of ZnO oxide films that have been deposited on the surface of the support material and also the spongy structure of the synthesized material is also an important aspect as it allows the thin ZnO film to adhere better to the sample surface and makes the material interesting for heterogeneous photocatalytic degradation applications.

3.2. *XRD pattern of the Sponges material covered with zinc oxide*

In *figure 2* is presented the XRD pattern of the synthesized *SpongeMat/ZnO*, we saw that the broad band is between 20° and 40° which is typical of an amorphous material and it is normal because of the presence of more than 90 % of the fluorescent lamp residue in the composition of the synthetized spongiest support material. We also observe some peaks at 29° and 39°, which could be associated with the eggshell patterns, also present in the composition of the support material in a small amount a peak corresponding to 36.5° due to ZnO covering of the support material.

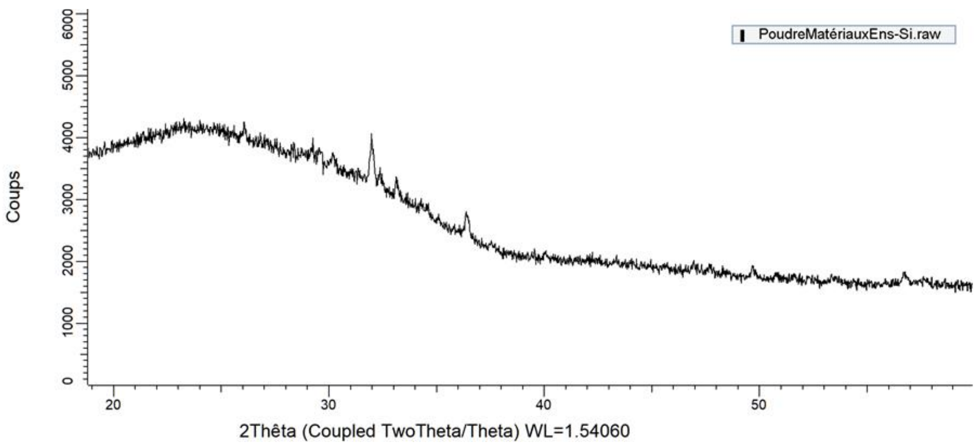

Figure 2. Room temperature X- ray diffraction pattern for the synthetized spongy material.

4. Conclusions

The immobilised catalysts on support materials have been researched by many researchers in the past years because of the advantages presented by this type of catalysts, representing a step forward in the field of heterogeneous photo catalysis allowing avoidance of the post-treatment recovery of the particles in suspension issue as well due to the material capacity of reusing. The proposed material, it was synthesised from glass from Electrical and Electronic Equipment Waste (WEEE) combined with some foaming and binder agents and covered with an oxide semiconductor which gives it the photocatalytic properties, this material comes to solve the above mentioned issues and in the same time to contribute to the circular economy through the integration of a waste into a useful product for a sustainable development. The surface SEM micrographs of the analysed samples confirmed a fairly homogeneous distribution of the components in the microstructure of the synthesized material, which is an important factor, as homogeneity is particularly important for stabilizing of the semiconductor oxide films on the surface of the anchoring material. The preliminary results are promising and make this material interesting for heterogeneous photocatalytic degradation of some organic compounds from wastewater.

Acknowledgements

Observations and analyses by SEM and XRD were performed at the electron microscope and Diffraction RX equipment's at University of Lille with the support of Chevreul Institute, the European FEDER, and the Région Nord-Pas-de-Calais (France). The financial support for the professional stage at University of Lille was supported by the Embassy of France in Romania through Romanian French Institute.

References

[1] Dumitru F D, Moncea M A, Baraitaru A, Panait A-M, Olteanu M and Deak G 2020 *Rev.Romana de Materiale* Effect of mesoporous silica with TiO_2/ZnO nanocomposites in wastewater treatment **50** 3
[2] Habibi M H and Sheibani R 2013 Nanostructure silver-doped zinc oxide films coating on glass prepared by solegel and photochemical deposition process: application for removal of mercaptan *J. Ind. Eng. Chem* **19** 161
[3] Jiang G, Li X Wei, Wang X, Jiang T, Du X and Chen W 2014. Immobilization of N, S-codoped BiOBr on glass fibers for photocatalytic degradation of rhodamine B *Powder Technol* **261** 170
[4] Ozkan F T, Quesada-Cabrera R and Parkin IP 2015 Silicalite-1/glass fibre substrates for enhancing the photocatalytic activity of TiO_2 *RSC Adv.* **5** 6970

[5] Ayoubi-Feiz B, Aber S, Khataee A and Alipour E 2014 Electrosorption and photocatalytic one-stage combined process using a new type of nanosized TiO2/ activated charcoal plate electrode *Environ. Sci. Pollut. Res.* **21** 8555
[6] Chen P, Wu Q, Zhang L and Yao W 2015 Facile immobilization of LnVO4 (Ln¼Ce, Nd, Gd) on silica fiber via a combined alcohol-thermal and carbon nanofibers template route *Catal. Commun.* **66** 6
[7] Hakamizadeh M, Afshar S, Tadjarodi A, Khajavian R, Fadaie M R and Bozorgi B 2014 Improving hydrogen production via water splitting over Pt/TiO2/activated carbon nanocomposite *Int. J. Hydrogen Energy* **39** 7262
[8] Kim J R and Kan E 2016 Heterogeneous photocatalytic degradation of sulfamethoxazole in water using a biochar-supported TiO_2 photocatalyst *J. Environ. Manag.* **180** 94
[9] Pan X, Zhao Y, Liu S, Korzeniewski C.L, Wang S and Fan Z 2012 Comparing graphene-TiO2 nanowire and graphene-TiO2 nanoparticle composite photocatalysts *ACS Appl. Mater. Interfaces* **4** 3944
[10] Huang M, Xu C,Wu Z, Huang Y, Lin J and Wu J 2008 Photocatalytic discolorization of methyl orange solution by Pt modified TiO_2 loaded on natural zeolite *Dye. Pigment.***77** 327
[11] Mohamed R M and Mohamed M M 2008 Copper (II) phthalocyanines immobilized on alumina and encapsulated inside zeolite-X and their applications in photocatalytic degradation of cyanide: a comparative study *Appl. Catal. A Gen.* **340** 16
[12] Jansson I, Yoshiiri K, Hori H, García-García F J, Rojas S, Sanchez B, Ohtani B and Suarez S 2016 Visible light responsive Zeolite/WO3ePt hybrid photocatalysts for degradation of pollutants in air *Appl. Catal. A Gen.* **521** 208
[13] Daels N, Radoicic M, Radetiz M, Van Hulle SWH and De Clerck K 2014 Functionalisation of electrospun polymer nanofibre membranes with TiO_2 nanoparticles in view of dissolved organic matter photodegradation *Sep. Purif. Technol.* **133** 282
[14] Gilmour, C R, Ray A, Zhu J and Ray M B 2013 Photocatalytic performance of titanium dioxide thin films from polymer-encapsulated titania *Ind. Eng. Chem., Res.* **52** 17800
[15] Lei P, Wang F, Gao X, Ding Y, Zhang S, Zhao J, Liu S and Yang M 2012 Immobilization of TiO_2 nanoparticles in polymeric substrates by chemical bonding for multi-cycle photodegradation of organic pollutants *J. Hazard. Mater* **227** 185
[16] Yoo W-J and Kobayashi S 2014 Efficient visible light-mediated cross-dehydrogenative coupling reactions of tertiary amines catalyzed by a polymer-immobilized iridium-based photocatalyst *Green Chem.* **16** 2438
[17] Moncea M A, Panait A-M, Dumitru F D, Baraitaru A, Olteanu M, Boboc M and Deak G 2019 Metakaolin - waste glass geopolymers. The influence of hardening conditions on mechanical performances *IOP Conf. Ser.: Mater. Sci. Eng.* **572** 012057
[18] John H B and Paul D H 2019 *Glass Waste*, Trevor Letcher Daniel Vallero (Manchester, United Kingdom/Elsevier) chapter 15 p 307-319