External Wooden Constructions – Protection by Titanium Dioxide

P Svora¹, P Kuklík¹, M Šrámová Slušná², S Svorová Pawelkowicz² and P Ecorchard²

¹ University Centre for Energy Efficient Buildings of Technical University in Prague, Třinecká 1024, 273 43 Buštěhrad, Czech Republic
² Institute of Inorganic Chemistry of the Czech Academy of Sciences, 250 68 Husinec-Řež, Czech Republic

svorapet@fsv.cvut.cz

Abstract. External wooden constructions have their own place in building industry from ages. The external wooden construction easily degrade due to UV radiation, atmospheric conditions and biological aggressors. We are trying to eliminate the negative impact of degradation factors by wood protection. Types of wood protection include all measures which would protect wood from influences of fungi, insects, weather (temperature, humidity, wind,), natural calamities (fire, flood) and they can be divided into chemical protection and radiation protection. In our paper we will discuss a new solution based on titanium dioxide (TiO₂). Titanium dioxide was proved to be an efficient UV absorber and moreover, in its crystalline form, it is able to destroy biological aggressors too. Nowadays, there is no information about the interactions between wooden surface and non-photoactive or photoactive form of TiO₂. TiO₂ exists in many morphological forms. The planar particles were chosen for purpose of the experiment. They can be prepared as non-photoactive and photoactive. This material was applied on wooden surface in the form of dispersion and created a transparent layer.

1. External wood construction – degradation agents and methods of protection

Durability of wood is important in ensuring an appropriate life for the structure being designed. Under ideal conditions wood constructions can be in use for centuries without significant biological deterioration. However, if conditions are not ideal, many of wood species need a preservative treatment. Nevertheless, there is also one simple rule for design – keep wood dry. In this case, the good detailing can be used to reduce the hazard (Figure 1). Maintenance during the service life of the construction is also very important.

The main components of wood are cellulose, hemicellulose, lignin, and other organic compounds, which together form a composite material formed from the initial inorganic substances that stood at the beginning of the biosynthetic process. Therefore, we consider the first destruction of polymeric
Central Europe towards Sustainable Building 2019 (CESB19)  IOP Publishing  
IOP Conf. Series: Earth and Environmental Science 290 (2019) 012033 doi:10.1088/1755-1315/290/1/012033  

structures (i.e. chemical reactions) and second degradation without damaging the polymer structures as the basic ways of wood degradation. The first group includes hydrolytic, dehydration, oxidation, thermooxidation, photooxidation and biochemical reactions, which are caused by degradation agents in the form of aggressive acids and alkalis, immissions, thermal effects, UV radiation and woodworms (white and brown rot). The second group represents the degradation of wood in the form of mechanical cracks, macroscopic holes, and changes in the color of the wood surface, which are caused by changes in temperature and humidity, wood-consuming insects and wood-coloring fungi.

The durability of wood against wood-burning fungi and insects is mainly ensured by impregnation by various chemical means. The method of wood impregnation is given by the exposition in which the wood is to be found. There are a lot of chemical protection chemicals, but not all of them are health-conscious (in general, what damages mushrooms and insects can also harm humans).

In principle, wood impregnation can be divided as follows: so-called black impregnation, such as tar oil impregnation (used on sleepers, telegraph poles, bridges) and so-called white impregnation, which is carried out with water-dilutable substances. According to the embodiment, the impregnation can be divided into pressure impregnation, that is, industrially carried out in boilers (autoclaves) in impregnation stations where the wood is impregnated with a protective substance to a greater depth, and then to impregnation without pressure, which is painting, spraying, dipping, grouting. Besides impregnation of wood with protective substances, other ways of protecting wood, less known, can be used. These include, for example, gassing or gamma irradiation, or heating the wood to a temperature of 60 to 70 °C for about 5 hours, at a maximum of 50% humidity. Normally, gaseous phosphorus or hydrogen cyanide is used for gassing. This intervention has a one-off effect (it is used, for example, in listed buildings). Radiation treatment is based on the use of gamma rays that have biocidal effects. Again, this is a one-off and costly method, and the dimensions of the objects to be irradiated must correspond to the size of the chamber (e.g. used for antique furniture, wooden artwork, parts of altars, etc.).

Resistance to the effects of weathering depends mainly on the structure of the wood. Wood exposed to UV radiation, suffers from discolouring, which is influenced by radiation intensities. At the beginning wood colour is yellow and in course of the time it changes to brown, resulting from dark decomposition of the corroding surface. With the additional influence of fluids or high humidity these decomposition products are washed out, leading to a gray colouring of the wood. The surface thus created is rough and full of corrugations, which reduce the cross section area. Besides this direct reduction of cross section area, the performance of wooden construction decreases, and secondary destruction by fungi is possible, which is usually more significant.

One approach is to enclose wood within a protective film in order to stabilize the moisture content. Coatings will act in this way, provided that they cover completely the wood and are not damaged in any way. Nowadays, the films which are under development are as much as possible microporous to facilitate water evaporation.

Our work is focused on application of transparent coatings based on titanium dioxide in different forms. Those materials are efficient UV absorbers and they are able, when applied in crystalline, photocatalytic form, to destroy biological agents also. Nowadays, there is no information about the interactions between wooden surface and non-photoactive or photoactive form of titanium dioxide. TiO₂ exists in many morphological forms. The planar particles were chosen for purpose of our study.

2. Protection of wood by coatings based on titanium dioxide

2.1. Methods. Instrumentation

UV-VIS spectroscopy was measured with Perkin Elmer Lambda 35 spectrometer. The spectra were recorded in a diffuse reflectance mode and transformed to absorption spectra through the Kubelka-Munk function.

Electron microscopy was done with HRSEM FEI Nova NanoSEM 450 equipped with ETH imaging detector.
X-ray diffraction pattern were acquired with Bruker D2 diffractometer equipped with a conventional X-ray tube (CuKa radiation, 30 kV, 10 mA).

2.2. Results

Titanium dioxide belongs to the most known material with the photocatalytic properties. It is mainly used in its photocatalytic form for decomposition of organic compounds, but in our work we are studying also other properties, such as UV absorbance. We present in our paper new results concerning UV absorbance of amorphous titanium dioxide (Figure 2).

Experimental data from UV-VIS spectroscopy clearly show that the planar particle of TiO\textsubscript{2} absorbed wide range of UV light (UVA, UVB). In this case, TiO\textsubscript{2} was annealed at 200 °C, 250 °C and 300 °C in order to remove residual peroxide used during the synthesis process. We wanted to know whether the annealing temperature could have an impact on the UV-light absorption. Interestingly, TiO\textsubscript{2} annealed at 200 °C and 300 °C have the maximum at the same wave length (310 nm), while the maximum of TiO\textsubscript{2} annealed at 250 °C is slightly shifted (320 nm). Nevertheless, shapes and maximums of the absorbance curves are in all cases similar. On the basis of experimental data, we concluded that titanium dioxide particles annealed at temperature range between 200 °C and 300 °C have similar properties as far as UV absorbance is concerned.

High resolution scanning electron microscopy (HRSEM) is a powerful tool for studying the morphology of specimens. SEM images of the studied material showed thin planar particles in the range of several micrometers large (3–5 microns). It is assumed that planar particles create a more compact layer, better one than particles with other morphology. Planar particles form a sort of snake's skin structure (Figure 3). The surface of the particle is not plain but wavy and also it is not completely continuous. The holes cover 20% of the surface and aggregates 10%. Holes and aggregates in this amount have no negative impact on the UV absorption of the material as was proven by UV-VIS spectroscopy.

The X-ray diffraction (XRD) pattern proves amorphous structure of the studied material though the small wide peaks indicate nuclei of anatase. According to diffractogram intensity the size of nuclei could be measured in nanometres, and such material we consider amorphous.
On the basis of our preliminary tests we assume that this material is not photoactive. Nuclei do not generate electron-hole pairs in sufficient amount which could cause decomposition of organic matter. For photoactive and photocatalytic coatings we synthetized crystalline titanium dioxide particles annealed at 800 °C. HRSEM image (Figure 5) shows that the planar structure is composed of nanocrystals. In this case, we are interested mainly in evaluating the interaction between the titanium dioxide particles and the binding medium used to produce the transparent coatings, and the interaction between photocatalytic particles and the wood itself as an example of organic matter. Research is underway.

Tests are performed on pine and beech wood as (Figure 6) – as representatives of conifer and broad leaves tree. The samples were coated with dispersions of amorphous and crystalline titanium dioxide in different concentrations in mixtures with water, potassium water glass, and acrylic binder. In Figure 7 pine and beech wood samples coated with dispersions of 1wt% planar, amorphous titanium dioxide mixed with acrylic binder are shown. When compared to samples shown in Figure 6 with reference sample, it is evident that the achieved coating is fully transparent.
3. Conclusion
The wood as a construction material plays an important role in building industry. In the past there was a tendency to replace wood with other materials e.g. in the construction area by steel, organic composites, and in the building material area by concrete and ceramic. Nowadays, all factors considered, in many applications wood appears to be the best material for building. Especially the combination of new ways of design and new technologies, in particular advances in material studies and nanotechnologies, helped to improve the properties of wooden constructions. Micro and nanoscale technologies and materials are widely used for modifying surface properties. Titanium dioxide planar particles discussed in this work have a big potential to protect wood against the UV-degradation. It was proved by UV-VIS spectrometry that this material absorbed only UV light. Electron microscopy confirmed the planar morphology of synthetized titanium dioxide. Photos of coatings show that this material can be applied on the surface in transparent layer. There is no doubt that planar particles of titanium dioxide can extend the life time of wood structure which is a clear benefit and makes it a sustainable material.

Acknowledgments
This work is supported by the project GA18-26297S “Study of interactions in system: wooden surface – amorphus layer of TiO2 – crystalline layer TiO2”.

References
[1] Nikolic M, Lawther J M and Sanadi A R 2015 Use of nanofillers in wood coatings: a scientific review J. Coat. Technol. Res. 12 445–61
[2] Kato K and Masuo F 1964 Liquid phase oxidation of tetralin over titanium oxide as a photocatalyst Kogyo Kagaku Zasshi 67 1136–44
[3] Honda K and Fujishima A 1972 Electrochemical Photolysis of Water by Semiconductor Electrode 238 37–8
[4] Šubrt J, Pulišová P, Boháček J, Bezdička P, Pližingrová E, Volfová L and Kupčík J 2014 Highly photoactive 2D titanium dioxide nanostructures prepared from lyophilized aqueous colloids of peroxy-polytitanic acid Mater. Res. Bull. 49 405–12