

CONCRETE MIXTURES WITH PHOTOVOLTAIC PANELS GLASS: A REVIEW OF THE SITUATION IN CZECH REPUBLIC

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ABSTRACT. Solar energy production was initiated in the 1990s following by rapid increase of the use of photovoltaic (PV) technology. Most of older solar panels in the Czech Republic were installed between 2000 and 2006 and a global installed capacity of 222 GW was reached by the end of 2015. With the growing global PV market, a large amount of waste is expected to accumulate after 2030 which is associated with the new industry to process this waste, based on reduce, reuse, and recycle. This article summarizes findings and research conclusions regarding local issues collected by experts from the Czech Republic. Previous research showed that waste glass from photovoltaic panels can be used as a pozzolanic material in high-performance concrete, improving its properties. Further research on the use of waste from photovoltaic panels has been conducted in the Czech Republic since 2019 and the conclusions from various research confirm the suitability of using PV panel glass.

KEYWORDS: Photovoltaic panels glass utilization, pozzolanic properties, concrete production.

1. INTRODUCTION

In recent years, the utilization of photovoltaic (PV) technologies has been growing rapidly, a cumulative global installed capacity of 222 GW was already reached at the end of 2015 [1]. Photovoltaics is used for economically advantageous and ecological electricity production, history of PV dates to the 1990. However, it is a technology whose aging is still insufficiently explored, because during the service years only mechanically damaged panels were disposed. Currently, the lifespan of the PV panels is defined by the time when the performance drops by 20 %, which is usually declared by the manufacturer after 25 years of use. At the same time, most manufacturers declare a maximum decrease of roughly 10 % after 10 years. Nevertheless, the end-of-life period of the first the era of photovoltaic panels is already coming and decommissioning, dismantling and disposal must be figured out. However, this direction is not ideal due to upcoming regulations and stricter requirements for waste management, circular economy, and sustainability [2]. Recycling seems to be the ideal way. However, with such a complicated material, a detailed search of options and ways to recycle the panels is required.

The launch of solar energy production in the early 1990s was supported by the launch of the grant programs, initially mainly used by Germany, but over time they reached the whole world, including the Czech Republic. This act was the main beginning of the period of massive production of photovoltaic panels and their installation and application on constructions of all types and sizes. Despite a few earlier installations, it can be stated that most of the oldest panels in the Czech Republic were installed between 2000 and 2006. However, the total number of installed

panels during this period is very low compared to the following years. In 2006, there was a big turnaround thanks to the introduction of support for the purchase of electricity from renewable sources according to Act No. 180/2005 Coll. And just as the global PV market is growing, so is the volume of discarded PV panels, with a cumulative global flow of 43 500–250 000 metric tons at the end of 2016, roughly 0.1 % to 0.6 % of the cumulative weight of all installed panels. With these numbers, a large amount of waste is expected, which will continue to grow until a certain time. This growth will subsequently be slightly reduced thanks to the effort to develop panels with a longer service life and less material consumption [3].

Total annual global electrical and electronic waste (e-waste) already reached 41.8 million metric tons in 2014, while the annual amount of waste from PV panels was 1 000 times lower in 2014. However, there is an assumption that by 2050 PV waste will exceed this number by up to 10 %. This assumption therefore points to the fact that it is necessary and desirable to use the experience of managing e-waste and turn it into opportunities for the management of waste from PV panels in the future.

2. CURRENT TRENDS IN PV RECYCLING

Due to the lifetime of the panels, a greater number of elements for recycling can be expected after 2030. After 2040, approximately 20 000 tons of panels are expected to be recycled annually [4]. The largest share of the weight of crystalline panels is glass (60–70 %) and aluminum frame (around 20 %). For thin-film panels, the proportion of glass and aluminum is over 95 % [3]. Both of these materials are normally almost 100 % recycled. Other metal materials are valuable

raw materials that are worth recovering from waste. Plastics can be recycled only partially or not at all. A detailed table of materials with possible recycling methods is enclosed below.

Currently, one of the frequently used recycling methods for PV panels is thermal recycling. It is an advanced method of recycling panels that are generally heated to a temperature above 500 °C (the design and testing took place at the German company Deutsche solar AG). This temperature guarantees the evaporation of the plastic elements (with subsequent combustion in the next chamber). The rest of the materials are manually divided and if the panels are undamaged, it is possible to use almost 85 % of the panel with roughly 70 % less energy consumption. However, this method can only be used for panels made of crystalline cells and therefore does not solve thin-film panels.

The second widely used method is mechanical-chemical method, which is mostly applicable for thin-film panels. Although the first step is the dismantling of the aluminum frame, which is done manually, followed by the crushing and sorting of the materials into the specified fractions, this method has a lower proportion of manual labor than the previously mentioned one, but the result is only crushed raw materials. Separation methods are used for fluid and wet floats and electrodynamic separation. Important metals such as silver and others are obtained chemically and pyrometallurgically and can subsequently be used as raw materials in the metallurgical industry, plastics are disposed of with the possible use of heat from combustion [5].

2.1. REDUCE, REUSE AND RECYCLE

The end of the life of PV panels signals the possibility of the emergence of a new industrial sector, which is also a possibility for the emergence of new economic values in accordance with the global path to sustainable development. This industry can go into both the public and private sectors. The basic ideas are reduce, reuse and recycle.

The composition of solar panels is expected to require less raw materials as research and development and technological advances continue to mature the industry. Currently, two-thirds of globally manufactured PV panels are crystalline silicon (c-Si) which includes hazardous materials such as silver, tin, and lead traces. Thin-film panels have a higher percentage of non-hazardous materials like glass, polymer, and aluminum. By 2030, current trends in panel efficiency suggest that the raw material inputs for c-Si and thin-film technologies could be significantly reduced, decreasing the use of hazardous and rare materials in the production process, and improving the recyclability and resource recovery potential of end-of-life panels.

Rapid growth in the global solar panel industry is expected to create a strong demand for used or

repaired panels and components. Early failures in the lifetime of a panel can be repaired and resold at a lower cost, providing an opportunity for countries with limited financial resources to access the solar PV market. This secondary market for used panels and components also presents an opportunity for buyers to purchase partly repaired panels or components.

As solar panels reach the end of their lifespan, recycling and material recovery is becoming a preferable option to disposal. The PV recycling industry currently processes end-of-life panels through separate batches within existing recycling plants, allowing for the recovery of major components such as glass, aluminum, and copper at yields greater than 85 % of the total panel mass. In the long term, specialized panel recycling plants can increase treatment capacities, maximize revenues, and recover a greater fraction of the embodied materials. Research on PV-specific recycling technologies has been ongoing for the past decade, and it is important to learn from this research to develop cost-efficient and material-efficient recycling plants [1].

However, technical, and regulatory systems need to be established to ensure that PV panel waste streams are sufficient for profitable operation. For the preparation of specific plants for the recycling of entire panels, which according to studies are extremely financially demanding, the Czech Republic is apparently not currently ready. This assumption is based on the amount of panels to be processed (recycled), which does not lead to the efficient production of the required recycling line until 2040 [3]. Although there are efforts not only in the Czech Republic to reuse the majority of PV panel components, the most likely scenario is when parts of the panels will have to be used in a different way than before. It is necessary to consider the possibility of impurities on existing parts, especially glass ones. In case of increased contamination of glass parts, it is advisable to look for alternative use. In the Czech Republic, around 2020, leading technical universities and their research teams began to look into the possibility of using glass waste from PV panels in concrete mixtures, including the possibility of subsequent applications from these mixtures. In the following chapters, the current findings on the use of glass parts from PV panels in concrete mixes in the Czech Republic are briefly summarized.

2.2. CONCRETE MIXTURES CONTAINING PV PANELS GLASS

Our previous research describes a study that investigates the potential of using waste glass from photovoltaic panels in high-performance concrete. The research team founds that the waste glass can be an excellent pozzolanic material, and that it can improve the mechanical and durability properties of the concrete. This research highlights the potential of using the waste glass from photovoltaic panels in other industries [6]. The study was already published in

Material	Recycling Method
Glass	The advantage of glass is that in most cases the material can be recycled into the original product, but often due to unwanted impurities, glass cannot be used in this way, and it is advisable to look for it.
Aluminum	Easily recycled with very low energy consumption.
Plastic Components	Usually degrade due to the climate conditions and it is not possible to reuse them.
Photovoltaic Cells	At the end of their life, crystalline cells are essentially unchanged, and there is already practical experience with recycling whole cells or plates. For thin-film cells, their recovery is more efficient than production from primary raw materials.
Heavy Metals	Due to toxicity, it is necessary to separate heavy metals from the environment, even though they represent minority components (weight, price, power consumption). They will probably be replaced by other material in the future (depletion of economically extractable reserves).

TABLE 1. List of the materials used in PV panels and current trends in their recycling.

2019 and was among the first of its kind in the Czech Republic, so it was desirable to follow up with further research. However, in the meantime, the work of other research centers in the Czech Republic also began, and the results for the period from 2019 to today are summarized below.

In our subsequent research, glass from photovoltaic panels was crushed and then sorted into two fractions – fine sand and glass powder (flour). Both fractions were used as a substitute for individual components in concrete and the resulting properties and their differences were monitored. At the same time, efforts were still being made to save the amount of primary resources and eliminate the production of carbon dioxide. For this reason, great emphasis was placed in the research on ecotoxicity tests (daphnia acute toxicity test, freshwater algae toxicity test, duckweed growth inhibition test) and subsequently on the effect of the alkali-silica reaction and the assumption of its elimination due to the use of glass powder. In leachates, all tested risk metals were below detection limit. All tested samples were classified as non-toxic [7].

Another research presents the conclusions of a study on replacing natural aggregate in cement composites with recycled glass from PV panels. The research came to similar findings as was done in our research. Replacement of natural aggregate with recycled glass fraction 0/10 mm is possible and the densities of recycled glass fractions are similar and reach approximately 2.5 mg m^{-3} . The consistency of fresh cement mixture based on recycled glass was within an acceptable range. The flexural and compressive strengths of the cement composites are almost identical and within an acceptable range. With 100 % replacement of natural aggregate with recycled glass, there is a decrease in flexural and compressive strength by 20–30 %. The results of the image analysis confirm the non-disruption of the contact zone between the grains of the recycled glass and the cementing compound. The permeability of cement composites with recycled glass from PV

panels shows similar values to conventional cement composites.

Future research will focus on increasing the flexural strength to a minimum of 6 MPa and testing the alkali-silica reaction of recycled glass grains from solar panels, as well as the surface treatment of the designed cement composites for potential use in interior paving or tiling material. Alkali-silica reaction is one of the fundamental problems that can arise, and within the study of concrete mixtures it is advisable to prevent ASR if possible. Our research was dealing with ASR during last year [8]. Testing was carried out according to the American standard ASTM C1260 and the Czech technical conditions TP137. After testing according to ASTM C1260, one reference sample showed cracks of up to 1 cm, while after testing according to TP137, no cracks were seen on the surface of the samples. Regarding the expansion, for the concrete mix containing 100 % PV glass as a substitute for silica flour, the expansion after 28 days was higher than 0.1 % (but lower than 0.2 %) and therefore further testing is necessary to clarify the results. The concrete mixture containing 50 % PV glass as a substitute for quartz flour was verified as safe from the point of view of ASR due to the fulfillment of the conditions for the exclusion of the occurrence of ASR [8].

Other major problems include, for example, corrosion. Thereby, another experimental study dealt with the biocorrosion of cement composites in beams and crumbling, using photovoltaic glass as a replacement for natural aggregate in four different grain fractions. Three species of microscopic algae were used in the experiment as they were found to be part of the biofilm involved in biocorrosion. The results show that the growth of the microscopic algae was small and low in abundance due to the lack of supporting microorganisms and the high pH value of the samples. The high level of recycled glass in the samples also affected the growth of the algae as it affected the availability of nutrients for their nutrition [9].

2.3. CONCRETE MASONRY UNITS

The research of concrete mixtures containing PV glass began to acquire useful information, and other studies began to deal with the design and testing of applications from these materials. Another research [10] describes an experiment in which the authors determined the loose bulk density and voids of recycled glass from PV panels according to the standard ČSN EN 1097. The authors also prepared two concrete recipes, recipe A and recipe B, with recipe A containing both recycled glass and one fraction of aggregate, and recipe B containing only recycled glass. The average density of recipe A was 2160 kg m^{-3} and the average density of recipe B was 1880 kg m^{-3} . The compressive strength of the two recipes was also measured after 28 days and the results were found to be satisfactory. The average compressive strength of recipe A is 21.8 MPa and the average compressive strength of recipe B is 11.7 MPa. The authors also compare the compressive strength and density of their concrete with YTONG, a widely used lightweight aerated concrete and concluded that the strengths of concrete units with recycled glass from PV panels are satisfactory for use in building foundations and load-bearing structures of low-rise buildings [10].

The studies states that the results of the experiment indicate that concrete units made with glass from PV panels have satisfactory strength for use in building foundations and load-bearing structures of low-rise buildings. The authors suggest that the addition of polymer fibers could potentially improve the mechanical properties of the material. They also mention that a combination of coarse recycled concrete with fine recycled glass is worth considering when developing new concrete recipes. However, one limitation is the smoothness of the glass surface in relation to cement and the potential reaction between glass and calcium hydroxide, which has been studied in several scientific studies.

3. CONCLUSION

The use of waste glass from photovoltaic panels as a replacement material in high-performance concrete has been extensively studied in recent years in the Czech Republic. Results from these studies have shown that crushed and sorted glass can be used as a substitute for individual components in concrete and can improve its mechanical and durability properties. Additionally, the use of glass from photovoltaic panels in concrete has been found to have a low impact on the environment, as well as on biocorrosion and the alkali-silica reaction. Further research is necessary to increase the flexural strength and clarify the results of the alkali-silica reaction, as well as to test the surface treatment of cement composites for potential

use in interior paving or other applications. The overall research has shown promise for the use of waste glass from photovoltaic panels in high-performance concrete.

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