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Wood ashes from electrostatic filter as a replacement for the fly ashes in concrete

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Abstract

Many concrete technologists are looking for a solution to replace Fly Ashes that would be unavailable in a few years as an element that occurs as a major component of many types of concrete. The importance of such component is clear - it saves cement and reduces the amount of CO_2 in the atmosphere that occurs during cement production. Wood Ashes from electrostatic filter can be used as a valuable substitute in concrete. The laboratory investigations showed that the wood ash concrete had a compressive strength comparable to coal fly ash concrete. These results indicate that wood ash can be used to manufacture normal concrete.

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Keywords
Wood ashes; fly ashes; electric filter; replacement; concrete technology.

Introduction

The word "organic" currently has a good reputation worldwide. Everyone wants to eat organic products, have an organic lifestyle or use organic bags in the supermarket, all to protect nature and mother earth and to improve people's healthy lives. There are so many activists who fight every day to save the world. Some of those are more some less successful. They are looking for a solution that very often cannot be achieved for political or economic reasons. There is a product that should take the attention of many activists - cement. The production of this building material generates more CO_2 than the car exhaust in many big cities. Cement is one of the most important binders, a key component of concrete in a world production of 4.1 billion tons. In 2014 cement was the most widely used material overall (Fig. 1) [8]. The amount of CO_2 emitted into the atmosphere by the production of 4.1 billion tons cement is enormous.

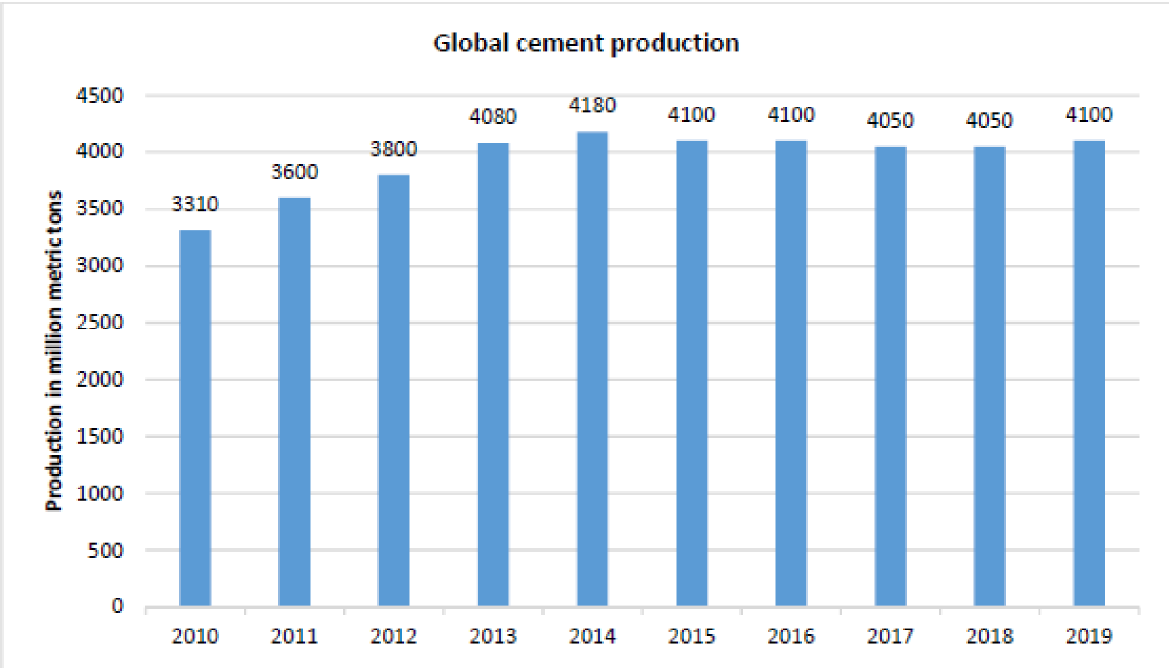

Figure 1 - Cement production globally from 2010 to 2019 worldwide [11]

Nowadays the cement in concrete is irreplaceable. Its properties give the concrete strength and are responsible for its durability. But that does not mean that the concrete could not be made more ecologically. In times where CO_2 reduction is the world most common effort, it is absolutely necessary to think products in the context to bioeconomy. Nothing is more ecological than using available biological materials.

Way to organic concrete

Fly Ashes are considered to be one of the most important and popular components used in concrete. Their pozzolanic properties have a certain impact on the properties of fresh and hardened concrete, for example consistency and compressive strength. Unfortunately, in recent years, Germany, as Western Europe, had a huge shortage of this material. The reason for this phenomenon is the decreasing number of coal power plants in which Fly Ashes are a by-product. The use of by-products in concrete is not only strength aspects but also ecological ones. During the production of cement, a huge amount of CO_2 is produced. Using fly ashes as a substitute component and by-product in itself, the need for cement will be reduced, less cement means less CO_2 in the atmosphere. The most important property of fly ashes is that they can be used as a main component with virtually any type of cement and used almost in all types of concrete: normal concrete, lightweight concretes and ultra-high performance concrete [1].

The standard DIN EN 450-1 defines fly ashes as a fine-grained dust consisting of spherical and glassy particles, which are produced by the use of finely ground coal. The pozzolanic properties of the fly ashes are mainly due to SiO_2 and Al_2O_3. The amount of reactive SiO_2 is at least 25 wt.% [9]. According to DIN EN 197-1, lime-rich fly ash with a reactive CaO > 10 wt.% can be used as the main constituent for the production of fly ash cements CEM II/A-W or CEM II/B-W [10].

The application of fly ashes in Germany began in the 1960s with the constant increase in production. In the 90's fly ashes were already almost 100% used in the building industry, 75% of which is used in various types of concrete. It took scientists more than 10 years to see the visible success of fly ashes today. The delay was caused by the lack of approval of fly ashes to be used in concrete [1].

The coal is transported to the power plant by various means, depending on accessibility by truck, rail or ship. There it is added directly to the coal bunkers. The coal is then ground to a fine grain size in the coal mills. The grain fineness is adjusted, which is present at the 80 wt.% < 90 µm. The pulverized coal is further transported to the combustion chamber, where the organic components are burnt (Fig. 2). The fly ash is then obtained by electrostatic separation in multi- stage electrostatic precipitators. The combustion temperatures of hard coal are between 800 °C and 1700 °C depending on the type of furnace [2].

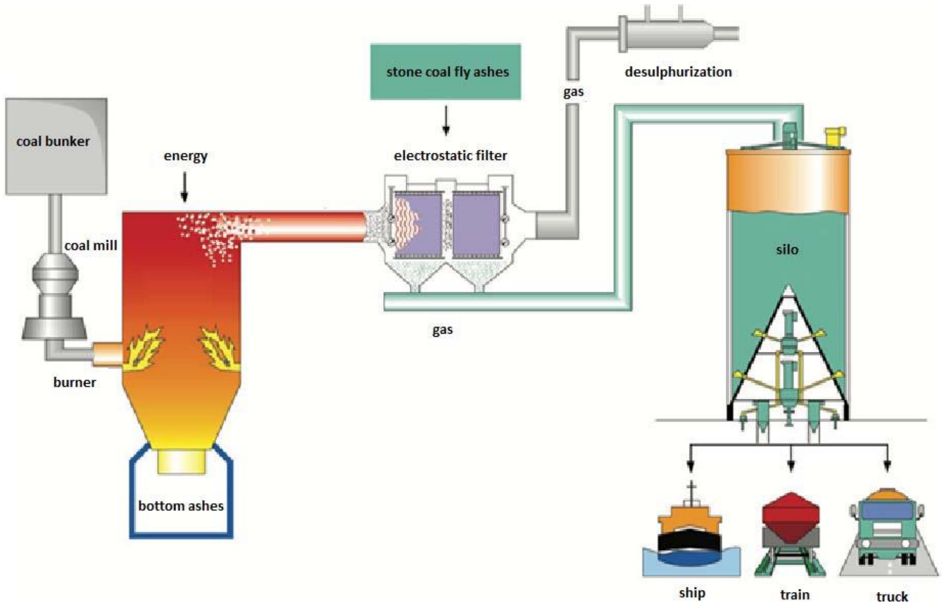

Figure 2 – Production process in the power plant [3]

Wood ashes from electrostatic filter and cyclone filter as a replacement for the fly ashes in concrete

The delivered wood chips are first collected in a fuel store. The combustion chamber consists of three systems: grate, combustion chamber and afterburner. The furnace grate is located in the central point of combustion. Different types of construction are burned in the furnace. Thermo-chemical processes take place in the combustion chamber. Then they pass through the first filter stage, which is a cyclone separator, where most of the inorganic components are separated thanks to the air flow. In the meantime, another filter stage can follow in the form of an electrostatic precipitator, as in the case of fly ashes [4].

Due to the shift to regenerative energy (e.g. wood energy) several hundred tons of wood ashes from electric and cyclone filter are produced in Germany and the every year, in the UK even more. The wood from which the wood ashes arise are usually garden wastes, shrubs on the roadsides and tons waste from sawmills. In contrast to the bottom ash, filter ashes cannot be used for nutrient recycling in agriculture and forestry but is mostly deposited. Only few researches are done to find their usage in construction, to put it in another way - in concrete [10]. The construction sector is so huge that there can certainly be found a place for them instead of storing them up. In order for this to happen, it is necessary to undertake appropriate tests. Without proper investigation, an acceptance to be used in construction is unlikely to be permitted.

Chemical composition of fly and wood ashes

In the first place, it is necessary to closely study the chemical structure of the wood ashes, and try to find similarities with fly ashes. Nowadays we know exactly how fly ashes behave. There are many chemical and physical methods with which to test the components of wood ashes, for example ICP. The content of heavy metals and other elements, which can cause problems in the binding of concrete must be eliminated. Only in this way their impact on the strength and durability of various types of concrete will be improved.

Table 1 - Characteristics of wood ashes from cyclone and electrostatic filter [4]

Characteristic	Cyclone ashes	Electrostatic ashes
Production	Cyclone separator	Electrostatic filter
Particle size	2-160 µm	<10 µm
Mean particle size (kg/m^3)	2400-2700	2300-2600
Density	0.3-0.5	0.15-1.12
pH	10-13	10-13

The chemical composition is characterized by three main components - SiO_2 (silicic acid), Al_2O_3 (alumina) and Fe_2O_3 (iron oxides). Most fly ashes from lignite-fired power plants are low in sulphate and rich in silicon. Table II shows the composition of silicon-rich fly ash and Portland cement from 1997-2004.

Table 2 - Chemical components of fly ashes and portland cement [5,6]

Component (wt%)	Silicon-rich fly ash[1]	Portland cement[2]
SiO_2	36-59	19-23
Al_2O_3	20-35	3-6
Fe_2O_3	3-19	0.2-7
CaO	1-12	61-67
MgO	0.7-4.8	0.6-4
K_2O	0.5-6	0.4-1.5

Na_2O	0.1-3.5	0.06-0.4
SO_3	0.1-2	2-4
TiO_2	0.5-1.8	0.11-0.3

[1]Values from monitoring of silicon-rich fly ash from 1997 to 2004, Testing according to DIN EN 450-1 [5]
[2]Average range limits of Portland cement of strength class 42.5, containing loss on ignition [6]

In order to determine the components of wood ashes and to compare them with fly ashes, four different types of wood ashes from electrostatic precipitators and cyclone filters were investigated. The results were recorded in Table III.

Table 3 - Chemical components of wood ashes and selected fly ash

Component (wt%)	Wood ashes				Fly ashes
	1[1]	2[2]	3[3]	4[4]	
SiO_2	1.1	11.2	5.5	52.7	57.4
Al_2O_3	0.2	2.4	0.7	7.9	19.0
Fe_2O_3	0.1	1.8	0.5	3.3	13.1
CaO	3.8	31.1	37.9	17.3	3.5
MgO	1.5	4.3	4.8	2.4	1.4
K_2O	41.2	16.4	13.8	5.2	2.0
Na_2O	0.4	0.9	0.2	0.9	0.8
SO_3	16.4	17.7	4.9	2.4	0.9
TiO_2	<0.1	0.2	<0.1	0.6	0.9

[1] electrofilter ashes (tree species Beech); [2] mixed electrofilter ashes - different tree species; [3] cyclone ashes (tree species Beech); [4] cyclone ashes different tree species.

As mentioned earlier, the first three components listed in Table III are responsible for the pozzolanic properties. As can be seen from the table, for the first three grades, the amount of reactive SiO_2 is less than 25 wt.% (according to standard EN 450-1 should be at least 25 wt.%). If one wants to compare the values with the requirements of standard EN 450-1 with fly ashes, the sum of the three components SiO_2, Al_2O_3 and Fe_2O_3 must be at least 70 wt.-%. In this case, the values are significantly lower. The values of reactive calcium oxide CaO should not exceed 10 wt.%. The criterion was only met in electoral filter ashes Nr. 1. In accordance with DIN EN 197-1, wood ash with CaO > 10 wt.% can be used as the main constituent for the fly ash cements CEM II/A-W or CEM II/B-W. However, to confirm the evidence, the strength tests (compressive strength) on normal concrete (2300 kg/m^3) with the water-cement value 0.4 were carried out and showed that despite much lower values of SiO_2, Al_2O_3 and Fe_2O_3, the wood ashes have reached almost the same strengths as the fly ashes. This leads to an important result, that the wood ashes must not be compared literally with the fly ashes standard EN 450-1.

A reference concrete with a water-cement value of 0.4 was produced, consisting only of cement CEM I 42, 5 N, aggregate and water. Afterwards the cement quantity was replaced by 25 wt.% each with fly and wood ashes from electrostatic precipitators (No. 1 and 2 in Table III). The compressive strength was verified in accordance with the DIN EN 206-1/DIN 1045-2 standard on test specimens aged 28 days.

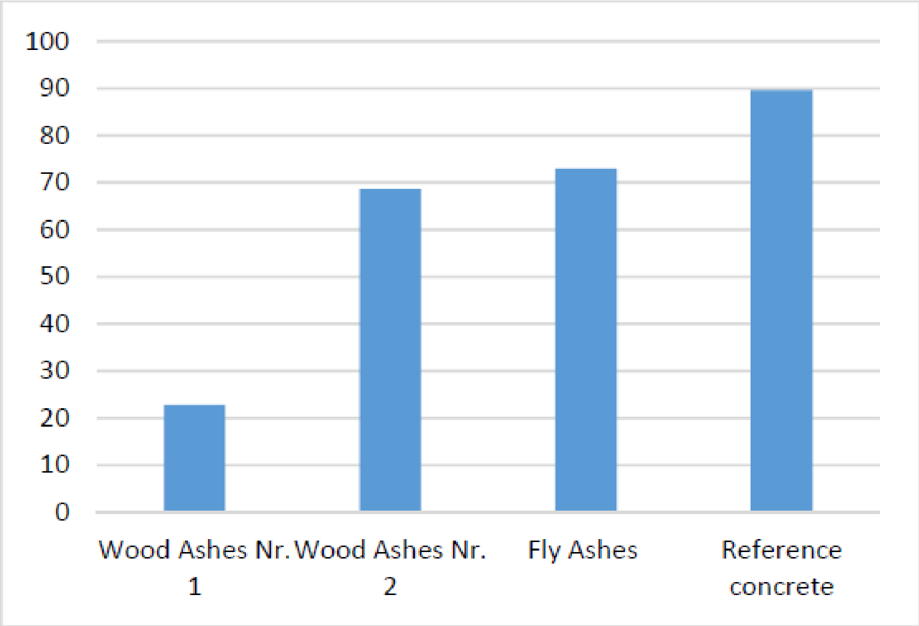

Figure 3 - Composition of compressive strength on concrete with wood and fly ashes

The heavy metals in concrete can have unexpected consequences. German Institute for Structural Engineering has prescribed the limit values for fly ashes on heavy metals. The limits must meet the requirements of the Principles for the Assessment of the Effects of Construction Products on Soil and Groundwater in the currently valid version with regard to environmental compatibility. [7]

A detailed analysis was carried out for fly ashes and the same for all wood ashes types as in Table III. The results are listed in Table V. There are currently no requirements for heavy metals in wood ashes in concrete, so they will be compared to fly ashes.

Table 4 - Permissible heavy metal content on volatility of construction products on soil and groundwater ashes according to German Institute for Structural Engineering [7].

Element	Symbol	Limit value (mg/kg TS)	Analysis procedure
Cadmium	Cd	10	DIN EN ISO 5961, DIN EN ISO 11885
Copper	Cu	600	DIN 38406-7, DIN EN ISO 11885
Nickel	Ni	600	DIN 38406-11, DIN EN SO 11885
Mercury	Hg	10	DIN EN 1483
Zinc	Zn	1500	DIN 38406-8, DIN EN ISO 11885

Table 5 - Heavy metal content in investigated wood and fly ashes.

Element [mg/kg TS]		Wood Ashes				Fly Ashes
	Symbol	1	2	3	4	
Antimony	Sb	<1	52	< 1	6,0	3,0
Arsenic	As	3,0	149	3,7	14,7	31,3
Cadmium	Cd	16,0	36,2	16,7	4,7	1,2
Copper	Cu	298,0	321,0	160,0	172,0	35,0
Molybdenum	Mo	< 2,0	34,0	8,0	6,0	36,0
Nickel	Ni	47,0	34,0	67,0	35,0	43,0
Mercury	Hg	< 0,07	0,43	< 0,07	< 0,07	0,10
Selenium	Se	< 1,0	9,0	< 1,0	1,0	14,0
Thallium	Tl	< 0,2	6,9	0,8	< 0,2	1,6
Zinc	Zn	1840	8970	666,0	722,0	118,0

As can be seen from the analysis, the amounts of zinc and copper in wood ashes differ significantly from the values for fly ashes. The two elements, zinc and copper, are among the most common heavy metals found in wood ashes. Since the pH-value of the concrete must remain alkaline to ensure corrosion protection of the steel, a few mixtures were made for each type of wood ashes and the pH-values of the fresh and hardened concrete were investigated. In both fresh and hardened concrete, all values showed alkaline environment. The result is clear; the wood ashes despite increased amounts of heavy metals do not lower the pH of the concrete.

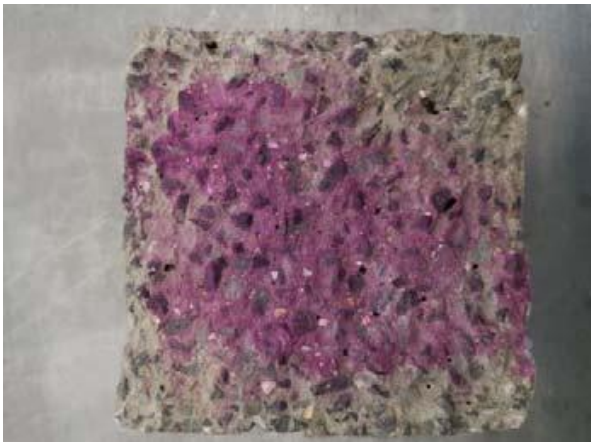

Figure 4 - Determination of the pH value on hardened concrete with the wood ashes No.2 Table5, phenolphthalein as indicator.

Conclusion

Survey was carried out with many construction companies and this confirmed that companies have a great interest in this material. A positive signal comes from the industry. First investigations and results which have been done, showed, that there is a huge potential in the wood ashes from electric and cyclone filter. But there's still so much to do. The replacement of at least 20% of the amount of cement in every cubic meter of concrete with other components like wood ashes and at the same time maintain the strength of the concrete, will be an enormous success worldwide. The cement plants cannot be closed, they can only produce less cement and therefore the CO_2 emission is possible to decrease. This is the most simple, feasible and rational solution. Yet, there are other environmental methods to reduce the carbon footprint of concrete such as carbon capture, novel managerial approaches, and of course use of recycled aggregate in concrete which are all under further investigation by scholars across the world [12-27].

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