INFLUENCE OF THE WASTE ASH OF COMBUSTED WOOD BIOMASS ON THE PROPERTIES OF CEMENT MATERIALS

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The growing interest in saving materials and energy, in parallel with the growing concern for environmental issues and the uncertainty in the evolution of the economy, encourages the research for ways into full or partial replacement of the constituent elements of composite materials. Due to its many advantages, concrete is widely used composite, and in general, the most used material in construction. Being also the second most used substance (after water) in the world, it is inevitable that its impact on the environment is significant and unavoidable. Knowing that the production of cement clinker produces large amounts of carbon emissions worldwide, ways are sought to reduce the required amount of cement through the manipulation of other components of concrete. Thus, new materials can be added that would replace the cement and reduce the need for it. The focus is placed on materials that are usually leftovers from other industrial processes and have no other purpose, so they end up in a landfill. The ash obtained from the combustion of wood biomass is a material that is a good candidate for researching its potential to replace cement in cement composite materials. The ash obtained by burning wood biomass is a material that is often thrown away or used in small quantities for individual household needs.

The aim of this paper is to investigate the influence of the different percentages of ash in relation to cement, on some of the mechanical properties of fresh and hardened concrete: consistency, content of fresh concrete, compressive strength and density at the age of concrete of 3, 7 and 28 days. By increasing the amount of ash, and thus decreasing the consistency of the fresh concrete, insignificant differences are observed in the measured pore content and density of the samples. Compressive strength shows decrease with increasing amount of ash.

Keywords: cement, carbon emissions, consistency, bulk density, compressive strength

1. INTRODUCTION

The research activity nowadays is significantly directed towards preservation of the environment by way of finding alternatives to the current destructive industrial processes. Given that each year the produced waste increases, and that it requires handling, the idea of circular economy has become gradually more popular, even in the construction sector. Concrete production, and specifically cement production are one of the main carbon emission contributors, hence the growing interest of finding replacement materials whose sourcing, processing and production would be less environmentally destructive. Economic benefit provides an additional stimulation for exploring the reusability of waste materials.

There have been multiple studies examining composite concrete with waste materials such as: rice husk ash [2], ceramic ash from ceramic sanitary waste [15], eggshell powder [14], basalt powder from quarries [9], marble waste [10] etc.

This paper, however, strives to add value to the research of composite concrete with waste wood ash, including, but not limited to studies from Akhter, [1], Chowdhury, [4], Siddique, [11], Štirmer, [12]. The aim was to investigate the influence of the different percentages of ash in relation to cement, on some of the mechanical properties of fresh and hardened concrete. Consistency, content of fresh concrete, compressive strength and density at the age of concrete of 3, 7 and 28 days were analysed and conclusions were drawn.

2. MATERIALS AND METHODS

The aim of the experimental research was to vary only the ash/cement ratio (0.05 to 0.20) and measure the consistency, porosity, density and compressive strength of the samples. However, the mixture produced at the 0.1 mark proved to be barely workable, which implied that yielding mixtures by further increasing the ash/cement ratio would be unfeasible. This imposed altering the initial vision of the experiment by preparing new mixtures where water would be added to achieve a desirable consistency of the mixtures.

Consequently, the mixtures where the water/binder ratio is kept constant are referred to as first round of tests, while the mixtures where water is added are referred to as second round of tests. The interpretation of the mixture nomenclature is shown in the following example: P5-S2, where P denotes a mixture with ash replacement, 5 represents the percentage of replacement, and S2 signifies the consistency class the mixture belongs to. The control mixtures are denoted with E.

1.1 ASH OF WOODEN BIOMASS

Ash obtained by combusting plain wood and wood products (bark, shavings, pellets, briquettes, chips) is a powdery substance with highly variable chemical composition. Its properties depend on geographical location, type and age of the tree, part of the tree (roots, stem, branches, bark, leaves), the industrial process through which the ash is obtained (burning temperature and contamination) and the condition of the wood before combustion (painted and/or varnished). Nevertheless, the most common oxides present in wood ash are CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O and NaO, which are also important compound oxides of cement, thus suggesting that wood ash could potentially be used as (partial) substitution for cement.

The ash for this experiment is obtained from a local bakery which burns beech wood for heating up its ovens, Figure 1. The cement used has a grain size of up to 0.09 mm, so the ash was also sieved through sieves with aperture size of 0.09 mm.

Figure 1. Beech ash

The ash was acquired on two occasions, and despite the difference in colour, the difference of chemical composition between the two samples was insignificant. The chemical composition of the ash was determined according to MKS EN 196-2:2014, [16]. The average results of the two samples of ash are shown in Table 1.

Table 1. Average chemical composition of the two samples of beech ash

Measured	%
Loss on ignition	31.72
SO_3	0.49
Insoluble residue	1.82
SiO_2	14.35
Fe_2O_3	1.84
Al_2O_3	1.08
CaO	39.14
MgO	4.27
Cl^-	0.09

1.2 SAMPLE PREPARATION

In the first round, three different mixtures have been prepared: a control one, and two with 5% and 10% ash replacement, respectfully. As previously stated, the percentage replacement could not be further increased due to the very low consistency of the 10% mixture, and the subsequent failed attempt at preparing a 15% ash replacement mixture.

Figure 2. Preparation of samples

In the second round, water was added to the concrete mixtures with the objective of producing concrete that falls within the range of the S4 consistency class according to MKS EN 206:2013+A2:2022, [17]. In the process of experimentation, mixtures which can be classified in both S3 and S4 consistency class were obtained. Subsequently, the samples were divided into two groups: G-S3 (control, 5%, 10% and 15% ash replacement) and G-S4 (control, 5%, 10%, 15% and 20% ash replacement).

The materials used in the preparation of the mixtures are: cement type CEM I 52,5 R with maximal grain size of 0.09 mm, crushed limestone (calcite marble) with three fractions (0-4 mm, 4-8 mm, 8-16 mm), water from public water supply, and superplasticizer which enables water reduction from 15% to 20%. All materials used in the experimental research are in accordance with the current standard for concrete production and definition of concrete as a construction product - MKS EN 206:2013+A2:2022, [17].

Figure 3. Fresh concrete samples for testing compressive strength

The compressive strength of the hardened concrete was tested on samples with dimensions 150 mm x 150 mm x 150 mm, in accordance with MKS EN 12390-1:2021, [18]. After being cast in moulds (Figure 3), the samples were cured in standard laboratory conditions, in accordance with MKS EN 12390-2:2019, [19].

1.3 TESTING FRESH CONCRETE

Assessing the properties of fresh concrete is of crucial importance for the production process

Figure 4. Consistency (slump) test

Figure 5. Pore content testing

since it can be an indicator of the properties of hardened concrete, and it also discloses the casting aptness of the concrete.

This experimental research explored the consistency, density and pore content of all the prepared fresh samples, following the requirements and procedures of MKS EN 12350-2:2019, [20], MKS EN 12350-6:2019 [21] and MKS EN 12350-7:2019, [22]. Consistency and pore content tests are presented in Figures 4 and 5, respectively.

1.4 TESTING HARDENED CONCRETE

Testing and proving the mechanical properties of hardened concrete is imperative for ensuring that the finalized concrete product meets the material requirements and ensures the safety of the structure.

In this experimental research, two properties of hardened concrete have been examined: density and compressive strength, in agreement with MKS EN 12390-7:2019, [23] and MKS EN 12390-3:2019, [24], accordingly. Both properties were tested on three samples from each concrete mixture, at concrete age of 3, 7, and 28 days.

3. RESULTS

The slump, pore content and average density of the 3 mixtures of fresh concrete of the first round of concrete preparation (control, 5% and 10% ash replacement) are shown in Table 2.

The results of the properties of fresh concrete for group G-S3 (control, 5%, 10%, and 15% ash replacement) from the second round of concrete preparation are shown in Table 3.

Table 2. Results of testing fresh concrete of first round of tests

Mixture	Slump [mm]	Pores [%]	Avg. den. [kg/m^3]	w/b
E-S2	80	2.6	2430	0.56
P5-S2	80	2	2420	
P10-S1	30	1.5	2420	

Table 3. Results of testing fresh concrete of second round of tests (group G-S3)

Mixture	Slump [mm]	Pores [%]	Avg. den. [kg/m^3]	w/b
E-S3	130	2.4	2430	0.57
P5-S3	150	2.6	2370	0.59
P10-S3	130	2.1	2380	0.59
P15-S2	90	1.8	2340	0.67

Table 4. Results of testing fresh concrete of second round of tests (group G-S4)

Mixture	Slump [mm]	Pores [%]	Avg. den. [kg/m^3]	w/b
E-S4	190	2.2	2370	0.6
P5-S4	190	2.6	2340	0.64
P10-S4	190	2.5	2360	0.63
P15-S4	170	2.4	2380	0.64
P20-S4	190	2.2	2350	0.67

The results of the properties of fresh concrete for group G-S4 (control, 5%, 10%, 15% and 20% ash replacement) from the second round of concrete preparation are shown in Table 4.

The development of the average density of the 3 samples of hardened concrete during concrete aging (3, 7 and 28 days) for both rounds of concrete preparation are shown in Figures 6-8.

The development of the average compressive strength of hardened concrete for 3, 7 and 28 days for both rounds of concrete preparation are shown in Figures 9-11.

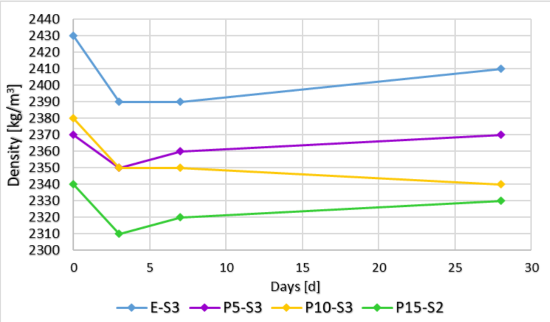

Figure 7. Average density of second round of tests (group G-S3)

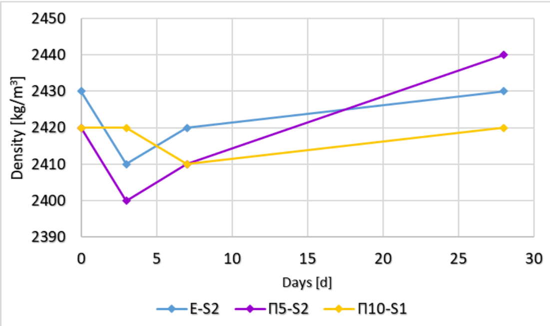

Figure 6. Average density of first round of tests

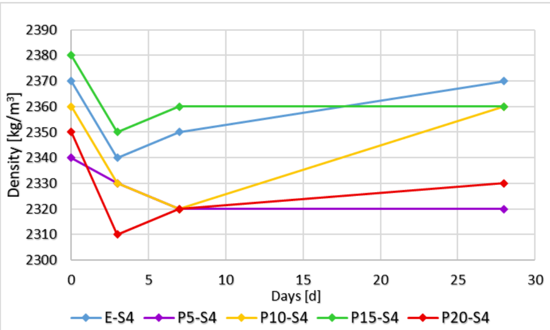

Figure 8. Average density of second round of tests (group G-S4)

4. ANALYSIS OF THE RESULTS

The chemical composition of the wood ash showed that the presence of CaO, SiO_2 and Al_2O_3 is lower than the usual content of these compounds in cement. Considering that these compounds are the forming blocks of the main minerals of the cement clinker, which influence the compressive strength, it could be suggested that this is a possible cause of the decrease in the concrete compressive strength. Also, the loss on ignition of the ash is 1/3 of its mass and 6 times higher than the limits for cement defined in MKS EN 197-1:2012, [25], which is caused by the higher content of water and CO_2.

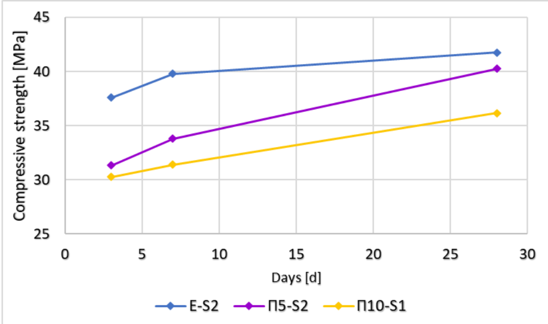

Figure 9. Average compressive strength of first round of tests

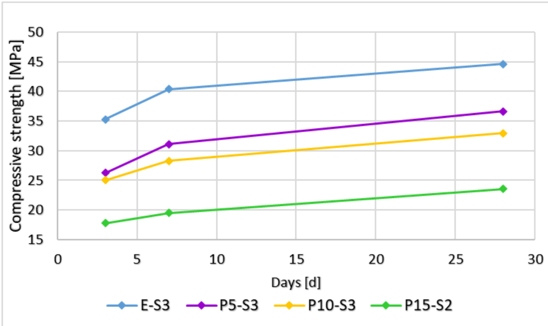

Figure 10. Average compressive strength of second round of tests (group G-S3)

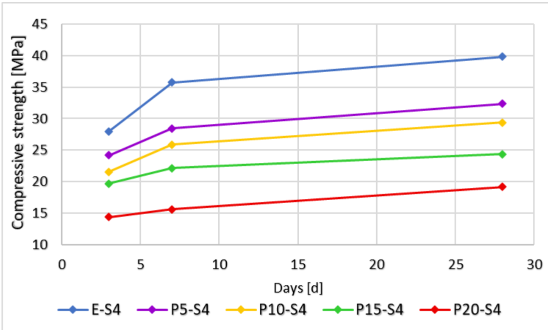

Figure 11. Average compressive strength of second round of tests (group G-S4)

From the first round of concrete mixtures, it can be noted that by increasing the ash content and keeping the water/binder ratio constant, the consistency decreases drastically after 5% ash replacement. The pore content of the concrete decreases steadily, with approximately 23-25% loss for each 5% ash content increase. The difference in density of fresh concrete is insignificant. The progression of density of the hardened concrete in time is characterised by a drop around the 3rd-7th day, after which there is a steady increase until the 28th day. However, the density variations are trivial (up to 0.8% difference), and all the samples have normal density (around 2400 kg/m^3). The progression of compressive strength of the hardened concrete in time demonstrates decline with increase in ash content. However, the ash samples have a higher rate of strength increase compared to the control sample, which is most notable in the sample with 5% ash replacement.

From the second round of concrete mixtures, it can be discerned that in order to maintain the same consistency or the same class of consistency, an increase in the ash content also requires increase in the water content.

Furthermore, the timing of the addition of water is of crucial significance because the setting time of the concrete is sped up. This is the reason why sample P15 in group G-S3 has a lower consistency (i.e. lower consistency class) - the water was not added in a prompt manner. Concerning the pore content of the concrete, the results indicate that the pore content of the concrete increases at 5% ash replacement, otherwise it decreases up to 25% of the control sample. The density of concrete shows an inconclusive decreasing trend with increase of ash content; nevertheless, the density variations are negligible (up to 3.7% difference), and all the samples have normal density. The progression of compressive strength of the hardened concrete in time in this round of concrete mixtures complies with the progression in the first round, i.e. the compressive strength declines with the increase of ash content, and probably, to a large extent, this is due to the addition of water.

5. CONCLUSIONS

In this paper, the influence of partial replacement of cement with various quantities of wood ash has been examined. Properties of fresh and hardened concrete have been tested on mixtures with 5%, 10%, 15% and 20% replacement of cement with wood ash. The experimental tests have been conducted in compliance with the requirements of the current standards in the country.

From the obtained results, it can be concluded that partially replacing cement with wood ash causes decrease in consistency/increase in water demand and speeds up the setting time of the fresh concrete. The pore content and density of the concrete do not have significant variations, as all concrete mixtures have normal porosity and normal density, accordingly. In contrast, the compressive strength of the concrete decreases, and special attention should be paid to the amount of water added.

The application of this composite would be most acceptable in non-bearing structure elements. Nonetheless, more research is needed to establish the right interconnection between the ash and water content. Additionally, further research about tensile strength, creeping, water permeability, freeze and thaw resistance etc. should be conducted.

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