UTILIZATION OF WOOD BIOMASS ASH (WBA) IN THE CEMENT COMPOSITES

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Abstract
European policy is strongly directed towards renewable energy sources (RES) all in order to achieve a more competitive, secure and sustainable energy system. As part of 2030 Framework for climate and energy, the European Union (EU) has put forward the share of renewable energy increasing to at least a 27 %. Therefore, solid biomass and forestry biomass will continue to be one of the major sources for bioenergy within the EU all in order to transition energy politic towards this goal. The growing trend of using biomass as a RES results also in a growth of the produced wood biomass ash (WBA) as one of the by-product in the energy production. As the amount of biomass ash and the price of its landfill grows, it is necessary to establish the sustainable management as a major challenge in a bioenergy production. The one of the possible option to reduce the environmental and social problems related to the disposal of WBA is its utilization in the construction sector. This paper presents preliminary results of testing mechanical and durability properties of cement composites made with WBA in different amounts per cement mass.

Keywords:
Renewable energy sources, sustainable management, biomass, wood biomass ash (WBA), concrete, mechanical properties

1 INTRODUCTION

The constant increase of the Earth population brings constantly growing need for energy. Increased demand for energy has led to demands for an increase in renewable energy sources (RES) under Directive 2009/28/EC [Directive 2009/28/EC, 2009], respectively under 2030 Framework for climate and energy [COM/2014/015]. Among these resources, biomass resources (forestry and agricultural wastes) and power plants fuelled by them are a promising source of renewable energy with an economically low operational cost and continuously regeneration of the fuel. Wood biomass is considered as a carbon neutral fuel as it absorbs the same amount of carbon dioxide while growing as released by burning it [Chowdhury 2015]. For that reason, combustion of biomass for electricity production is increasing worldwide and consequently the amount of fly ash derived from biomass combustion is also increasing. Biomass electricity generation increased significantly in the EU27, reaching 123.6 TWh in 2010 and contributing 19.3 % in total renewable electricity [SWD (2014)259]. Even though thermal incineration reduces the mass and the volume of the waste [Cheah et al. 2012], the growing trend of using biomass as a RES results also in a growth of the produced wood biomass ash (WBA). Typically burning of wood generates up to 1 % ash by weight whereby a significant waste by-product is created, requiring costly disposal [Pitman 2006]. According to the European regulations to increase the 20 % of RES by 2020 assumes that the amount of ash will growth on 15.5 × 10^7 t [Obernberger et al. 2009]. According to existing data [James 2012], it is considered that the use of forest biomass resulted in production of 1.6 × 10^7 - 3 × 10^7 tons of WBA in Europe for the 2005. Currently, 70 % of WBA is landfilled, 20 % tends to be used as a soil supplement in agriculture and 10 % is used for miscellaneous application [Chowdhury et al. 2015; Campball 1990; Ban et al. 2014]. However, disposal of wood ash in landfills should be properly engineered due to ease of air contamination with fine particles by wind, which can cause respiratory health problems to residents near the disposal site [Ban et al. 2014]. Contamination of ground water resources is also a major problem due to leaching of heavy metals from the ash or by seepage of rain water in case of landfilling, Fig. 1. There is a pressing need for innovation in sustainable construction, particularly in cement based materials as to ensure EU's long term objective of 80 – 95 % reduction of greenhouse gas emissions, but also to contribute to the preservation of natural resources and use of renewable materials. Following, the utilization of WBA in construction is an environmentally motivated choice for conserving natural resources and reducing greenhouse gas emissions.

In concrete industry there is a high potential for substitution of certain components by adequate alternative materials, and in that context the use of WBA has been examined. Depending on the physical and chemical characteristic WBA may be used in manufacturing of concrete products as active pozzolanic material [Shearer 2014; Naik et al. 2001], partly substituting cement [Ban et al. 2012], or as mineral admixture, i.e. inert filler replacing sand and/or fine aggregate [Wang et al. 2008]. Use of WBA in concrete highly depends on the several factors including type and source of wood, design and operating parameters of the boiler, and ash collecting methods [Naik et al. 2001; Carević et al. 2016]. The main objective of the work is to study use of wood biomass ash (WBA) of concrete mixtures produced by partial replacement of cement binder.

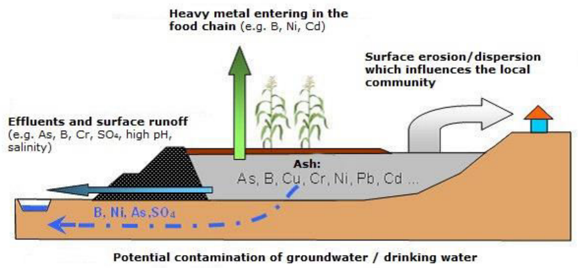

Fig. 1: WBA disposal and possible pollution [RECOAL, 2008]

2 EXPERIMENTAL PART

For laboratory testing, different concrete mixtures were prepared by replacement portland cement (PC) with different amounts of WBA (5 % as M2-5, 10 % as M3-10 and 15 % as M4-15 per mass of cement). All concrete mixtures were produced with cement CEM I 42.5 R. Density of used cement is ρ = 3.01 kg/dm3. WBA is by-product collected from biomass co-generation plant from wood industry. WBA is collected from electrostatic precipitator of a biomass co-generation plant located in Croatia that uses forest waste as fuel resulting from wood processing activities, mostly red oak. Before using, WBA (Fig. 2) was sieved to obtain grading curve, Fig. 3. Also density of WBA was determined using procedure according to ASTM Standard C188 [ASTM 2016]. Density of WBA is ρ = 2.1 kg/dm^3.

As aggregate, it was used natural crushed aggregate of the nominal size 0-4 mm, 4-8 mm and 8-16 mm. Superplasticizer Glenium 51 was used in order to achieve workability classes S3 or S4. Also air entraining admixture META AIR 0.04 % per weight of cement was used. Potable water in amount of 175 l per m^3 concrete mixture was used. The composition of concrete mixtures are summarized in Tab. 1.

Fig. 2: Sieving of WBA

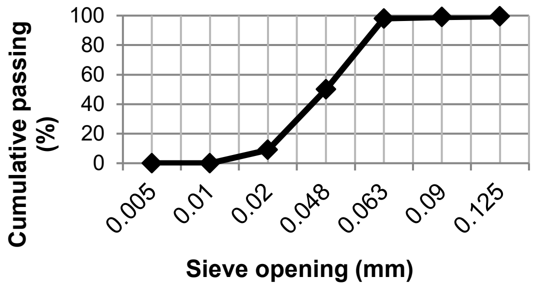

Fig. 3: Particle size distribution of WBA

This work aims to study the mechanical and durability properties where the number of specimens and test methods are given in Tab. 2. Concrete mixture ages 1, 3 and 28 days will be observed.

3 RESULTS OF TESTING

3.1 Results of testing fresh concrete

Testing of the concrete consistency, density, and air content were performed in a fresh state. The consistency was measured using the slump test, according to HRN EN 12350-2:2009 [CSI 2009]. The density was measured according to HRN EN 12350-6:2009 [CSI 2009] and the air content using pressure method according to HRN EN 12350-7:2009 [CSI 2009]. The results of testing fresh concrete mixtures are given in Tab.3.

3.2 Mechanical properties

Compressive strengths of hardened concrete mixtures at ages of 1, 3 and 28 days are presented in Fig. 4.

Compressive strength was tested according to HRN EN 12390-3:2009 [CSI 2009] on the cubes 15×15×15 cm at ages of 1, 3 and 28 days.

Flexural strength is determined according to HRN EN 12390-5:2009 [CSI 2009]. Testing is performed on prisms 100×100×400 mm after 28 days. The results of testing flexural strength are shown in Fig. 5 where it can be seen that there is a small difference between the flexural strengths of the reference and WBA concretes.

Tab. 1: Proportion of constituent materials of concrete mixtures

	M1-0 (reference)	**M2-5 (5 % WBA)**	**M3-10 (10 % WBA)**	**M4-15 (15 % WBA)**
cement (kg)	350.0	332.5	315	295.5
WBA (kg)	0	17.5	35.0	52.5
water (kg)	175	175	175	175
superplasticizer (%)	0.4	0.5	0.8	1.4
air entraining admixture (%)	0.04	0.4	0.4	0.4
aggregate	1766.0	1753.6	1746.2	1739.3

Tab. 2: Testing program

Property	Test method	Specimen dimension (cm)	Age (days)	No. of specimens			
				M1-0	M2-5	M3-10	M4-15
Compressive strength	*HRN EN 12390-3:2009*	15×15×15	1	3	3	3	3
			3	3	3	3	3
			28	3	3	3	3
Flexural strength	*HRN EN 12390-5:2009*	10×10×40	28	3	3	3	3
Gas permeability	*HRN EN 993-4:2008*	Ø10×20	28	1	1	1	1
Capillary absorption	*HRN EN 13057:2003*	Ø10×20	28	1	1	1	1
Freeze-thaw resistance - scaling	*HRN CEN/TS 12390-9:2006*	15×15×15	28	4	4	4	4

Tab. 3: Properties of the fresh concrete

	M1-0	M2-5	M3-10	M4-15
Slump (mm)	210	160	120	125
Concrete temperature (°C)	23.8	21.5	20.8	25.3
Density (kg/m^3)	2325.0	2289.95	2337.7	2357.75
Air content (%)	5.1	7.0	5.5	4.0

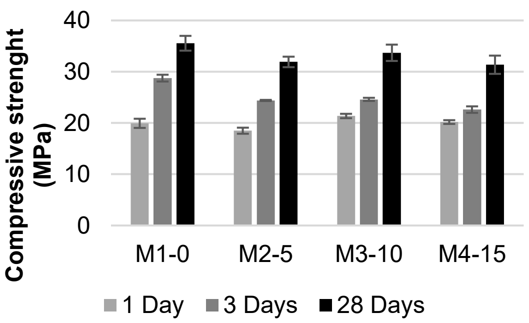

Fig. 4: Compressive strength of concrete mixtures

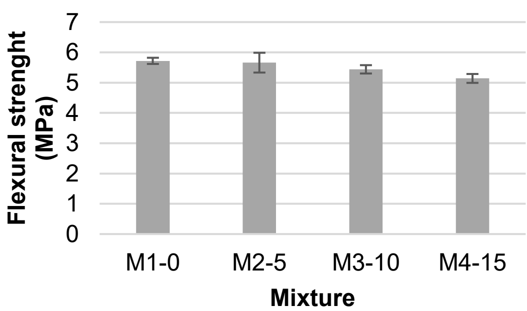

Fig. 5: Flexural strength of concrete mixtures

3.3 Durability properties

By this research program, the intention was also to analyse durability properties of concrete mixtures produced by partial replacement of cement binder with use of WBA. Specimens were evaluated in terms of gas permeability, capillary absorption and resistant to freezing and thawing.

Tab. 4: Criteria for evaluation of the concrete quality based on gas permeability testing [Ukrainczyk 1995; RILEM, 2016]

Gas permeability (m^2)	Concrete gas permeability	Concrete quality
$<10^{-18}$	Small	Good
$10^{-18} – 10^{-16}$	Middle	Middle
$>10^{-16}$	Large	Poor

Testing of the gas permeability is carried out according to HRN EN 993-4:2008 [CSI 2008] in the age of 28 days. Tests were carried out on the series of 3 cylinders by measuring flow of the gas through the specimen for at least three different rates of flow and from these values, the permeability coefficient is calculated, Tab.6. Criteria for evaluation of the concrete quality based on the gas permeability [Ukrainczyk 1995] are given in the Tab. 4.

Capillary absorption is determined according to HRN EN 13057:2003 [CSI 2003]. By testing capillary absorption on the series of three specimens in the age of 28 days, in duration of 24 hours, obtained results are shown in the following Fig. 6.

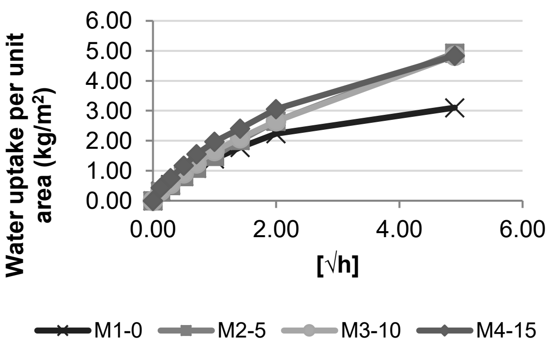

Fig. 6: Results of testing capillary absorption

Criteria for evaluation of concrete quality regarding to capillary absorption are given in the Tab.5.

Testing of freeze-thaw resistance - scaling is carried out according to HRN CEN/TS 12390-9:2006 [CSI

2006]. Testing of the freeze-thaw resistance – scaling was carried out on the four concrete specimens 150×150×150 mm for each concrete mixture M1-0, M2-5, M3-10 and M4-15, Tab. 2. Concrete mixtures M1-0 and M2-5 were tested 56 cycles on freeze-thaw - scaling, concrete mixture M3-10 was tested 42 cycles and M4-15 was tested 14 cycles on freeze-thaw – scaling. Testing of freeze-thaw resistance – scaling for 56 cycles for concrete mixture M3-10 is still in progress, Fig 8.

Tab. 5: Criteria for evaluation of concrete quality regarding capillary absorption [RILEM 1982; RILEM 2016]

Capillary absorption (%)	Concrete absorption	Concrete quality	A_w (kg/m²/h$^{-0,5}$)
<3	Small	Good	<0,3
3-5	Middle	Middle	0,3-0,6
>5	Large	Poor	>0,6

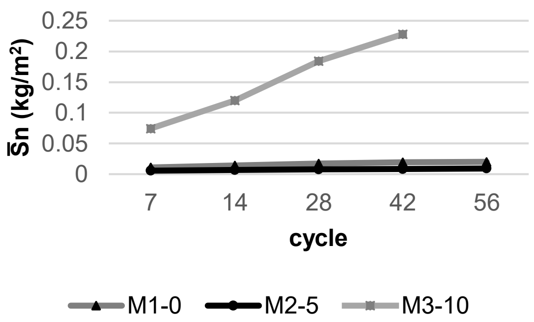

Fig. 7: Results of testing freeze-thaw resistance - scaling

Results of freeze-thaw resistance – scaling testing for four concrete mixtures (mean value of the scaled material per test area – cumulative) with different amount of WBA are given in Fig.7.

4 DISCUSSION

Results of testing fresh concretes properties show that different amounts of WBA per mass of cement does not have any significant influence on the density and temperature of fresh concrete. The results indicate that as the level of cement replacement with WBA increase, the workability of the mixes decrease. Therefore, higher dosages of superplasticizer were required to maintain workability of the mixtures and to achieve required consistency class. Also it was noticed that by increasing the WBA per mass of cement, air content is decreased.

From the results of compressive strength testing, it can be seen that all concrete mixtures have achieved compressive strength of 30 MPa in age 28 days with its slightly decrease with the levels of cement replacement, except for M3-10. Concrete mixture M3-10 has the largest compressive strength in the age of 1 day (better than reference mixture – M1-0), as well as in the age of 28 days where compressive strength decreased for 11 % in relation to M1-0. The observation is probably due to fine particles of WBA which acted as filler.

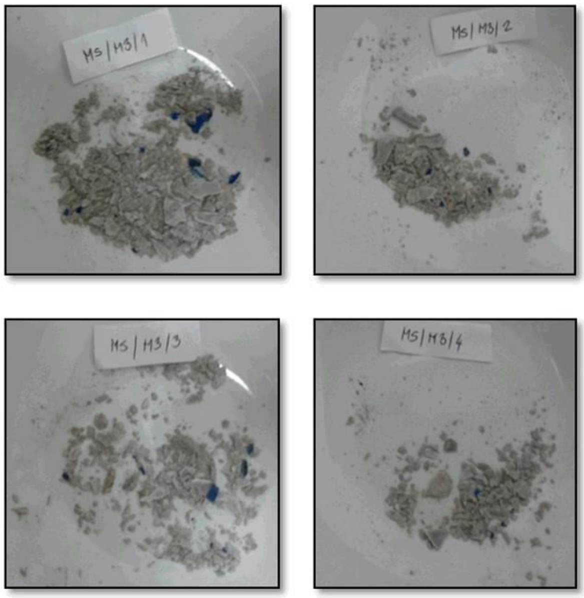

Fig. 8. Scaling of concrete M3 after 7 cycles

Values of flexural strength are approximately the same for all concrete mixtures. The highest value was obtained for concrete with 5 % of WBA (M2-5) in comparison with reference concrete wherein the value is decreased for only 1 %. With increased amount of WBA in concrete mixtures, flexural strength decreases up to 10 % (M4-15) compared to the reference mixture (M1-0). Similar trend was observed by [Ban et al. 2012].

Results of coefficient of gas permeability of concrete with various amounts of WBA are given in Tab. 6. The concrete with 10 % of WBA (M3-10) has the lowest coefficient of gas permeability value of $1{,}994\times10^{-16}$ m². All concrete mixtures are same quality according to criteria for gas permeability given in Tab. 4. In general, it can be concluded that partial replacement of cement with WBA has beneficial effect on gas permeability of the concrete. This could be due to the dominating effect of micro filler action of WBA particles.

According to criteria for evaluation of concrete quality regarding capillary absorption (Tab. 6 [RILEM 1982; RILEM 2016]), all concretes have middle capillary absorption and are of middle concrete quality. Also it can be noticed that specimen with 5 % of WBA (M2-5) has the largest capillary absorption, and capillary absorption coefficient slowly decreases with further increasing of WBA content in concrete.

Results of testing freeze-thaw resistance – scaling on tested specimens M1-0 and M2-10 for 56±1 cycles show that cumulative scaled material per test area was less than 0.5 kg/m². Also, concrete mixture M3-10 which was tested after 28±1 cycles show that cumulative scaled material per test area was less than 0.5 kg/m². When comparing specimens produced with WBA (M2-5 and M3-10) and reference concrete, it can be seen that concrete with WBA has larger value of the scaled material per test area, Tab. 6. On the other hand, concrete mixture with 15 % of WBA shows that cumulative scaled material per test area was more than 0.5 kg/m² and therefore does not satisfy requirements according to HRN CEN/TS 12390-9:2006 [CSI 2006]. From the results obtained, it can be concluded that specimens of concrete mixtures M1-0, M2-5 and M3-10 are resistant to freezing and thawing.

Concrete mixtures M1-0 and M2-5 satisfy requirements for XF4 (56 cycles) exposure classes and M3-10 satisfy requirements for XF2 (28 cycles) exposure classes according to HRN CEN/TS 12390-9:2006 [CSI 2006]. Testing of freeze-thaw resistance – scaling for concrete mixture M3-10 is still in progress in order to determine its freeze-thaw resistance for 56 cycles.

All results of testing are shown in Tab. 6.

Tab. 6: Results of testing concrete with WBA

Property	Concrete mixture			
	M1-0	M2-5	M3-10	M4-15
CONSISTENCY, slump (mm)	S4	S4	S3	S3
COMPRESSIVE STRENGTH, 1 days (N/mm^2)	19.93	18.49	21.36	20.18
COMPRESSIVE STRENGTH, 7 days (N/mm^2)	28.75	24.39	24.60	22.61
COMPRESSIVE STRENGTH, 28 days (N/mm^2)	35.55	31.91	33.69	31.36
BULK DENSITY, 28 days (kg/dm^3)	2.31	2.28	2.32	2.35
FLEXURAL STRENGTH, 28 days (N/mm^2)	5.72	5.66	5.44	5.14
COEFFICIENT OF CAPILLARY ABSORPTION ($kg/m^2\sqrt{h}$)	3.55	4.55	4.34	4.30
FREEZE-THAW RESISTANCE - SCALING (kg/m^2)				
7±1 cycles	0.01	0.01	0.07	1.98
14±1 cycles	0.01	0.01	0.12	6.45
28±1 cycles (≤ $0.5 kg/m^2$ for XF2)	0.02	0.01	0.18	-
42±1 cycles	0.02	0.01	0.23	-
56±1 cycles (≤ $0.5 kg/m^2$ for XF4)	0.02	0.01	-	-
COEFFICIENT OF GAS PERMEABILITY ($\times 10^{-16}$ m^2)	7.426	6.395	1.994	2.012

5 CONCLUSION

After using all energy potentials of the biomass, a by-product WBA remains which has to be properly treated. As the amount of WBA and the price of its landfill grows, it is necessary to establish the sustainable ash management, which is major challenge in bioenergy production. Using WBA as a new raw material in the construction industry offers an interesting alternative to today's materials.

Preliminary results of testing mechanical and durability properties of cement composites made with WBA in different amounts per cement mass are shown in the paper. From obtained results, the following conclusions can be derived:

The workability of the concrete mixtures decreased as an amount of WBA increase where additional dosages of superplasticizer were required to maintain workability of the mixtures.

Concrete mixtures with WBA content up to 15 % show slightly decrease (up to 10 %) of flexural strength in comparison to reference mixture (M1-0).

The optimum level of cement replacement using WBA to ensure the best compressive strength performance is 10 % per cement mass. It is also possible to use higher amounts, but the workability will be decreased.

Partial replacement of cement with WBA has beneficial effect on gas permeability.

It was shown that concrete with amount of WBA up to 10 % satisfies requirements for freeze-thaw resistance and can be successfully applied in outer concrete elements.

By this investigation, it was shown that WBA can be successfully used in concrete for application even in amount of 15 % per cement mass. However, it is recommended to carry out further testing of mechanical and durability properties of concrete in later ages.

6 ACKNOWLEDGMENTS

This research was performed within research project: “Transformation of Wood Biomass Ash into Resilient Construction Composites”, IP-06-2016, funded by Croatian Science Foundation.

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