POTENTIAL OF USE WOOD BIOMASS ASH IN THE CEMENT COMPOSITES

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SUMMARY: Due to high energy dependency, the European Union´s policy is turned to promotion of the use of renewable energy throughout directives with culmination with the agreement at the 21st Conference of the Parties (COP21) in Paris. Within, European Union (EU) has put forward the share of renewable energy increasing to at least a 27 % until 2030. Among these resources, biomass as forestry and agricultural waste, and power plants fuelled by them are a promising source of renewable energy. As one of the consequences of development and investment in the biomass renewable energy is increasing the amount of ash, including wood biomass ash (WBA). During the bioenergy production, ash as a by-product is a major environment pollutant and health hazard in the absence of emission controls, most of which are very expensive. Therefore, it is necessary to establish the sustainable ash management, which is major challenge in the bioenergy production. One of possible solution for its management is utilization of WBA in the construction. This paper describes the process in the biomass power plants which affects on the WBA properties, problems regarding WBA management and the possibility of its application in construction industry, particularly with regard to the concrete industry.

POTENCIJAL UPOTREBE PEPELA OD DRVNE BIOMASE U CEMENTNIM KOMPOZITIMA

SAŽETAK: Zbog velike ovisnosti o energiji politika Europske unije usmjerena je na promidžbu upotrebe obnovljive energije u direktivama što je doseglo vrhunac u sporazumu na 21. konferenciji (COP21) sudionika u Parizu. Prema sporazumu, cilj je da se u Europskoj uniji udio obnovljive energije poveća do najmanje 27 % do 2030. godine. Obećavajući izvori obnovljive energije su, između ostalih, biomasa iz šumskog i poljoprivrednog otpada i energane koje kao gorivo koriste te materijale. Jedna od posljedica razvoja i investiranja u obnovljivu energiju iz biomase povećana je količina pepela, uključujući pepeo iz drvne biomase (engl. wood biomass ash, WBA). Tijekom proizvodnje bioenergije pepeo je kao nusproiuzvod glavni onečišćivač okoliša i zdravstvena opasnost ako nema kontrole emisije od kojih je većina vrlo skupa. Stoga je nužno uspostaviti održivo upravljanje pepelom koji je glavni izazov u proizvodnji bioenergije. Jedno od mogućih rješenja za upravljanje njime upotreba je pepela u gradnji. U radu se opisuje proces u pogonu energane na biomasu koji utječe na svojstva pepela, problemi koji se odnose na upravljanje pepelom i mogućnost njegove primjene u građevinskoj industriji, posebno u industriji betona.

1. INTRODUCTION

In the current years, the concern of our global environment and increasing energy insecurity has led to an increasing demand in renewable energy and their sources [1]. According to European policy, under EU Renewable Energy Directive [1] the European Union (EU) has set the goal to reach a 20% renewable energy share by 2020 where each Member State has set national legally binding targets as well as provisions and measures to reach this ambitious objective. Moreover, an European Council and Commission, within 2030 framework for climate and energy [2], agreed on EU´s long-term commitment target of at least 27% for the share of renewable energy consumed in the EU in 2030. Among these resources, biomass resources (forestry and agricultural wastes) and power plants fueled 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 [3]. For that reason, combustion of biomass for electricity production is increasing worldwide. Consequently the amount of ash derived from biomass combustion is also increasing, including wood biomass ash (WBA). 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 [4]. According to existing data [5], 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., respectively from 5% to 15% (by weight) of biomass processed [6]. These significant quantities of ash requires its sustainable management causing financial and environmental burden. Currently, 70% of WBA is landfilled, 20% tends to be used as a soil supplement in agriculture and 10% is used for miscellaneous application [3, 7, 8].

On the other hand, in the EU-28 construction accounts for 10% of the GDP, 20 million jobs (30% of the industrial employment), and 3 million enterprises [9]. Furthermore, the European construction sector is a major contributor to exports, realizing over 50% of the major international contracts. In a recent communication [10], the European

Commission (EC) has established that the construction sector plays an important role in the delivery of the Europe 2020 Strategy on smart, sustainable and inclusive growth [11]. There is a pressing need for innovation in sustainable construction, particularly in cement based materials so 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 saving disposal costs but also for conserving natural resources and reducing greenhouse gas emissions. This supports the Waste Framework Directive (2008/98/EC) [12] in which a waste hierarchy is established giving a higher priority to prevention, then reuse or recycling and finally to disposal. The Roadmap to a Resource Efficient Europe (COM 2011, 571) [13] and the Eco-Innovation Action Plan (COM 2011, 899) [14] also promotes recycling and reuse over landfilling. The Directive of Waste Management (2006/12/EC) [15] even prohibits landfilling of waste in Europe and encourages recovery. Also there is an exponential increase in the demand of cement, which is the primary constituent in the production of mineral composites in construction industry. Researchers have shown that for every 1000 kg of cement, approximately 850 kg of CO_2 is released into the atmosphere [16, 17]. Therefore, application of WBA in construction composites is a promising solution of the disposal problem.

This paper describes problems regarding WBA management, the process in the biomass power plants which effects on the WBA properties and the possibility of its application in construction industry, particularly with regard to the concrete industry.

2. WBA MANAGEMENT

When land filling is carried out in the EU, it has to be done according to the regulations set in the Landfill Decree [18] in order to minimize the effects of adverse environmental impacts of the landfill of waste, particularly due to the effects of pollution caused by emissions of substances in surface water, groundwater, soil and atmosphere, and in the context of global environmental pollution to reduce greenhouse gas emissions and prevent risks to human health. This decree sets limiting values for concentrations of certain elements and components in the waste (i.e. ash) as well as in the leachate. In most cases, taxes need to be paid for each ton of waste disposed. Regarding the biomass ash waste management, most of the biomass ash generated in thermal plant is either disposed of in a landfill or recycled in open agricultural fields without any control. The costs of the biomass ash waste management are between 200 and 500 EUR/ton, while in future, increase of costs of landfill in the form of waste tax or deposit fee, as well as the difficulties in acquiring new landfill sites, and stricter EU landfill directives, may be expected [6]. Several studies performed that WBA from the combustion of natural solid biomass contains valuable plant nutrients such as K, P, Mg and Ca [6, 19, 20]. Some of the European country with a long history of using biomass for energy production, such as Finland, Sweden, Denmark, Austria, Germany, Netherlands, have established legal frameworks that allows and control the re-use of ash from biomass power plants. For example, the German Fertilizer Decree (Düngemittelverordnung) [21] enables the use of biomass ashes as fertilizer but different conditions (limit values for heavy metals) are set based on different types of fertilizer. In the Netherlands, there are no specific regulations for the use of biomass ash or WBA in forestry. This means that the use in forestry should be qualified as spreading of waste, which is forbidden [22]. Even though the idea of sustainability of biomass power plants is to return the minerals from the ash back into the soil from which they originated during biomass growth, relatively high heavy metal content of the ash restricts such a practice [23]. Additionally, in recent days, land filling is becoming limited due to scarcity of waste land, increasing environmental concerns and the ever increasing volume of ash. Contamination of ground water resources is a major problem due to leaching of heavy metals from the ash or by seepage of rain water in case of land filling. Moreover, the use of biomass ash as a soil supplementary material is getting increasingly restrictive due to significantly high metal content in ashes, especially biomass ash, which may cause hazards in case of groundwater contamination and infertility of agricultural fertile land, Figure 1.

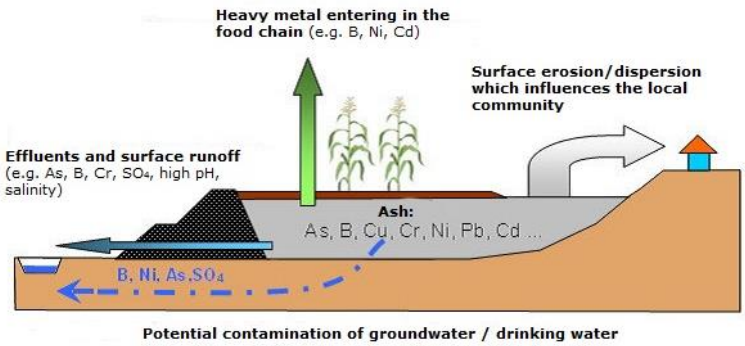

Figure 18: Inadequate methods of disposing of ash with pollution possibilities [24]

Today supplementary cementitious materials (SCMs) are widely used in concrete either in blended cements or added separately in the concrete mixer. The use of SCMs such as blast-furnace slag, a by-product from pig iron production, or fly ash from coal combustion, represents a viable solution to partially substitute Portland cement (PC) [25]. The fraction of coal fly ash (FA) that qualifies under the interpretation of EN 450-1 [26] for use in mortars or concretes is in rapid decline due to issues such as co-firing fuels with coal and injecting a variety of materials for emissions control [27]. WBA may be considered as its possible replacement, depending to a large extent on gained chemical characteristic.

3. COMPOSITION OF WOOD BIOMASS ASH

In order to establish beneficial application of WBA, it is necessary to understand technology processes in biomass power plants and composition of WBA as by-product of this processes. The characteristics of WBA may differ and chiefly depend on:

(1) tree species – type and source of wood

(2) combustion technology (especially combustion temperature)

(3) and the location where collection of ash is done [3].

Among the technologies available for power and heat production, biomass combustion is a proven technology in which technologies of fluidized bed and grate furnace combustion are mainly used [28, 29, 30]. In plants with efficient fluidized bed furnaces, ash produced is predominantly fine fly ash with only a small fraction of coarse ash retained within the combustion chamber but when grate fired furnaces are used, wood ash produced is coarser in nature and tend to settle inside the combustion chamber as bottom ash [31]. Bottom ashes (the coarser ash fraction) can usually be used as fertilizing agent on fields as it contains valuable elements for soils and plants and only minor concentrations of heavy metals. Fly ashes (the finer ash fraction) are in most cases disposed as their heavy metal concentrations are too high for a usage as soil enhancer [32, 33]

The chemical characteristics of WBA, which govern its credibility to be used as a replacement for cement or other SCMs, such as silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) and quicklime (CaO) differ significantly from one species of trees to another, Table 1. Factors such as an origin of the biomass, location of ash collection, as well as combustion conditions, strongly affect chemical and mineralogical composition(s) of ashes.

Table 1 Chemical composition of WBA from various species of timber and from different origins [3]

Ash type	Timber species	SiO_2	CaO	K_2O	P_2O_5	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	TiO_2
Fly (coarse and fine)	Birch bark	4.38	69.06	8.99	4.13	0.55	5.92	2.24	2.75	1.85	0.13
	Forest residue	20.65	47.55	10.23	5.05	2.99	7.2	1.42	2.91	1.6	0.4
	Pine bark	9.2	56.83	7.78	5.02	7.2	6.19	2.79	2.83	1.97	0.19
	Pine chips	68.18	7.89	4.51	1.56	7.04	2.43	5.45	1.19	1.2	0.55
	Poplar	3.87	57.33	18.73	0.85	0.68	13.11	1.16	3.77	0.22	0.28
	Poplar bark	1.86	77.31	8.93	2.48	0.62	2.36	0.74	0.74	4.84	0.12
	Sawdust	26.17	44.11	10.83	2.27	4.53	5.34	1.82	2.05	2.48	0.4
	Spruce bark	6.13	72.39	7.22	2.69	0.68	4.97	1.9	1.88	2.02	0.12
	Spruce wood	49.3	17.2	9.6	1.9	9.4	1.1	8.3	2.6	0.5	0.1
	Wood residue	53.15	11.66	4.85	1.37	12.64	3.06	6.24	1.99	4.47	0.57
	Average [26]	**26.5**	**16.0**	**5.00**	**-**	**9.00**	**3.00**	**5.40**	**4.80**	**-**	**0.51**
Bottom	Ground wood ash (GWA) [13]	69.5	8.10	3.60	-	4.18	1.24	1.99	< 0.1	1.40	-
	Average [25]	**42.3**	**11.40**	**1.30**	**-**	**17.90**	**2.50**	**12.60**	**0.40**	**-**	**-**

4. USE OF WBA IN CONCRETE INDUSTRY

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 [34; 35], partly substituting cement [36], or as mineral additive [37], i.e. inert filling replacing sand and/or fine aggregate.

Based on performed research high calcium WBA can be used as a supplementary cementitious material for the production of structural grade concrete of acceptable strength and durability and even self-compacting concrete [31]. Pozzolanic activity for ground coarse bottom WBA is negative, thus confirming that ground WBA cannot be considered a Type II addition based on requirements set in HRN EN 206 [38] and should therefore be considered as filler [31]. The pozzolanicity of biomass ash can be significantly less than coal fly ash depending on their chemical composition (especially SiO_2 and Al_2O_3 contents) [34].

The option of combining WBA with blended cements, is the most interesting option due to synergic advantages of individual main constituents, and thus for developing these blends into even more robust systems. High alkali content of the biomass ashes will activate the hydration of CEM II (i.e. clinker and pozzolanic admixtures) [25, 35]. Studies shown that the strength (both compressive and flexural) of cementitious mixtures is lowered at early and late ages after incorporating WBA, with a correlation between increasing ash content and lower strength [34]. Such results have prompted the suggestion that WBA, depending on its composition, can be used at low percentages of replacement or as a filler material. Others report the marginal decrease in strength with increasing WBA percentage in concrete, but increased with age due to increased pozzolanic reactions.

The preliminary result of use of WBA in the concrete mixtures produced by partial replacement of cement binder were made at the Laboratory of materials, Faculty of Civil Engineering University of Zagreb in order for better understanding of WBA use in concrete. 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. For laboratory testing, different concrete mixtures were prepared by replacement PC with different amounts of WBA (5 % as M2-5, 10 % as M3-10 and 15 % as M4-15 per mass of cement).

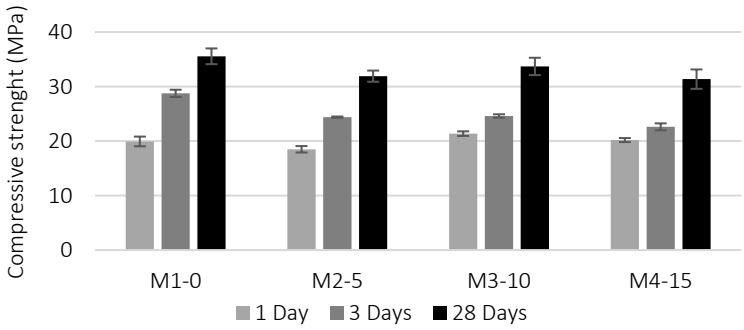

Figure 2: Compressive strength of concrete mixtures with WBA

From the results of compressive strength testing (Figure 2), 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. Compressive strength was tested according to HRN EN 12390-3:2009 [39] on the cubes 15×15×15 cm at ages of 1, 3 and 28 days.

5. CONCLUSION

The growing trend of using biomass as a renewable energy source results also in a growth of the produced ash, including the amount of WBA. 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. Currently, 70% of WBA is landfilled, 20% tends to be used as a soil supplement in agriculture and 10% is used for miscellaneous application. Reviewing the available knowledge in the field of research there is great potential of WBA utilization in concrete industry and therefor the possibility of its successful and sustainable management. Using WBA as a new form of raw material in the construction industry offers an interesting alternative to today's materials. Benefits of using coal fly ash have already been repeatedly demonstrated at commercial scale. For WBA, the same approach is not fully demonstrated yet. Results of worldwide research show considerable differences of WBA composites in solid state. As shown, several factors influence on physical and chemical composition of WBA and consequently on produced

composites. These factors include combustion temperature, types and hydrodynamics of the furnace and the species of trees from which the wood is derived. Given the number of variables that effect on the mineralogical and chemical compositions of WBA, additional researches are required for its reuse in the concrete industries. In case of application in the agriculture, it is necessary to transparently monitoring of the chemical composition of the WBA in order to ensure the appropriate use of WBA and to prevent the risk on the environment.

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