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Nordic Concrete Federation

ISSN online 2545-2819
ISSN print 0800-6377

DOI: 10.2478/ncr-2020-0017

Received: Oct. 1, 2020
Rev. received: Dec. 22, 2020
Accepted: Dec. 22, 2020

Utilization of Bio Ashes in Cement-based Materials: A Case Study in Cooperation with Pulp and Paper and Energy Production Industries in Sweden

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ABSTRACT
Worldwide increased concern of the CO_2 emissions has led to the replacement of coal by biomass in combustion-based power plants. However, this would cause the scarcity of fly ash, one of the most well-known rest products from coal combustion, which is used as supplementary cementitious materials (SCM) in construction sector to reduce the large environmental footprint of cement production. Seeking to find alternative SCMs, this article aims to demonstrate the viability of using bio ashes in Sweden as SCM, which, due to lack of studies validating their value, are landfilled today. According to the obtained results, bio ashes produced at pulp and paper industries have a considerably consistent chemical composition and exhibit a satisfactory pozzolanic behaviour. Nevertheless, according to the conclusions of this study, the pozzolanicity of these alternative binders is not reflected equally with respect to the most known reactivity tests for common SCMs. The results imply that although "R3" tests method infers the pozzolanic characteristics of the bio ashes in focus of this study, the "activity index test" as well as "calcium consumption test" indicate otherwise.

Key words: Cement, Supplementary Cementitious Materials (SCM), Bio ashes, Pozzolanicity test

1. INTRODUCTION

Our developed societies require a built environment that is unimaginable without the widespread use of cement-based materials that allow cheap construction anywhere with complex and massive shapes. However, cement production is associated with 6% of the total global anthropogenic CO_2 emissions [1] which has created a lot of challenges in construction sector to deal with. This is because statistical data reveal that approximately 50% of built structures around the world are made by concrete. Limited availability of some construction materials like timber or the questionable durability and costs attributed to steel has caused concrete to be the most demanded construction material around the world. These facts have attributed a great attention to the sustainability issues of concrete industry in order to reduce the high CO_2 footprints assigned to this building material (650-900 kg CO_2 per ton of binder OPC). It is known that 40% of the emissions are attributed to the production process which has caused much effort in recent decades to adjust the cement kilns or to find alternative fuels. However, the other 60% portion of emissions is only due to a chemical reaction known as calcination process that happens during cement production. To reduce these parts of emissions the most viable solution has been to reduce the amount of Portland cement in clinker and replace it with supplementary cementitious materials (SCMs). SCMs are reactive industrial by-products such as fly ash and blast furnace slag or, if available, natural reactive materials such as volcanic ash. This leads to blended cements or blended binder systems with a lower CO_2 footprint [2] due to a reduced amount of calcined limestone within the material flow of cement production.

Although this solution has helped the matter of sustainability and helped to reduce the amount of clinker to an acceptable level, however, in recent years worldwide increased concern of the CO_2 emissions has led to progressive minimization of coal combustion. This would cause the scarcity of fly ash, one of the most well-known SCMs in near future.

Nevertheless, among available resources for energy production, biomass has found to exert an important role, since it is considered a renewable and CO_2 neutral energy resource, once the

consumption rate is lower than the growth rate, and can potentially provide energy for heat, power and transports from the same installation. Therefore, biomass has obtained worldwide value in recent years as an alternative fuel and therefore large amounts of ash are produced. Currently, most of the biomass ash produced in thermal power plants is either disposed in landfills or recycled on agricultural fields or forest. Utilization of biomass ashes in producing construction materials can consequently also enhance the circular economy as industrial wastes are being used in production of more sustainable materials.

Consequently, there has been some investigations done on evaluation of possibilities for using bio ashes as alternative construction materials [3-13]. It is reported that flexural strength and compressive strength in mortars and concrete specimens using biomass ash is comparable to the reference material [3, 9]. Moreover, durability related factors such as frost resistance and alkali silica expansions were reported to either be comparable to the reference materials or even improved with application of biomass ash [4, 5, 9].

However, as biomass is obtained from a relatively vast number of sources, e.g., scrap lumber, forest debris, crops and certain types of waste residues, the variations in chemical composition of the biomass ash have been the major concern reported in literature. As an example in some studies [3], the sum of the contents of silicon dioxide, aluminium oxide and iron oxide is higher than 70% and the content of calcium oxide is lower than 10%, while others [6, 7] reported the same values being lower than 50% and the content of CaO being higher than 20%. Another reported major problem has been the high chloride content in some types of analysed biomass ashes which is a hindrance for further use of such wastes in construction materials. Chloride enters biomass from a variety of sources, including irrigation water, rain, fertilizers, and air pollution. The concerns with the chloride content in the bio ash are attributed towards further durability problems with chloride corrosion of the reinforcements.

Hence, bio ashes have shown good performance when blended in cementitious systems as reported in literature [4, 5, 9]. However, the noted prohibiting factors such as mainly inconsistent chemical composition of the ash which is due to variable sources of biofuel or some reports of high chloride contents (the accepted chloride content is lower than 0.1% according to EN-196-2) has caused the construction sector to have a negative judgment about this source of SCM. Therefore, for the time being, biomass fly ash is excluded from addition in concrete according to the standards because of its non-coal origin.

Eventually, there have not been many studies to investigate the efficiency of the available test methods to properly examine pozzolanic characteristics of the bio ashes.
This is while the large variations documented in chemical composition of biomass ashes will be considerably less if instead of focusing on all different types of bio ashes only one type with consistent flow of biomass feed is focused on. For example, the pulp and paper industry as of being one of the major industries in Sweden, produces considerable amounts of biomass ash. The biomass feed is basically tree barks and therefore the chemical composition of produced bio ash is relatively constant. Moreover, large amounts of bio ashes do have very low chloride content and the rest with higher contents are to a large extent possible to be re-conditioned with simple leaching methods or batch type water washing systems [6, 14, 15].

According to statistics received from Södra Cell Värö, in 2016, 1050 tons of ash has been produced at Värö while predicted production in 2017 is around 1500 tons. This is while there are much more pulp and paper industries in Sweden with more or less similar production amounts.

These materials, if proven to be beneficial, can to a very good extent support the construction sector, instead of being land filled.

Additionally, energy production is also performed mainly using biomass feed which consists of wood and agricultural waste. According to Energifosrk (Askprogrammet), every year about 1.7 million-ton bio ashes are produced in Swedish energy production industry. Bottom ash being a large portion of the total produced ash (700,000 ton a year) is a priority to be used in other industries, while most of the studies so far have been only focused on proving the potentials of bio fly ashes.
Therefore, in this study bio ashes from pulp and paper as well as energy production industries (a wooden based biomass feed) are focused on, where:

- Variations in chemical composition of both bottom and fly ashes over a period of 6 month is investigated
- The effectivity of simple washing methods on minimizing chloride content of the bio ashes is accounted for.
- Pozzolanicity of the bio ashes and the proper test methods for this investigation is examined.
- Hydration properties of binary blends of cement and bio ashes considering replacement levels of 10, 20 and 30% of cement content with bio ashes.

2. MATERIALS AND METHODS

2.1 Sample uptake

The bio ash samples analysed in this study were taken from:

I. Three different pulp and paper plants for 3 months. The time interval between the sample uptakes is between 1 day and 3 weeks depending on the possibilities onsite and changes in the biomass sources, corresponding to 60 samples. The samples were collected as fly ash, bottom ash and mix of both. The biomass feed has been a constant flow of tree bark mixed with up to 10% addition of wood chips.
II. Several energy production companies with a biomass feed consisting of wood, saw dust, and agricultural waste. 15 bio ashes were sampled over a period of 3 months.

A complete sample list of obtained bio ashes in this study is provided in the appendix.

2.2 Chemical composition

The chemical composition of the bio ashes was measured by LAS Scandinavia by inductively coupled plasma mass spectrometry (ICP-MS).

2.3 Mineralogy

The characterization of crystalline phases was performed by X-Ray Diffraction (XRD) measurements with a Rigaku Miniflex 600 with a fast 1d solid-state detector. The scan was performed between 2 and 42° 2Θ with an increment of 0.02 and a scanning speed of 1°/min.

2.4 Washing/immersion

The produced bio ashes at the pulp and paper plants before being stored, are immersed in a water pool to get cooled down. This water pool is located on site at one of the pulp and paper production facilities which delivered the samples for this study. In this study the effect of this immersion method on washing the chlorides from the bio ashes is studied, however, it should be noted that as this process is only aimed for cooling the bio ashes on site, there is not a major control on precise solid (ash)/liquid (water) ratio in the pool. Therefore, to account for the effect of this method on chemical composition of the bio ashes, the mix ashes were sampled both before and after immersed in the cooling pool and in different dates.

2.5 Pozzolanicity

Calcium hydroxide consumption
The calcium hydroxide consumption test was performed according to the Standard SS-EN_196-5 [16]. In this standard the pozzolanicity is assessed by comparing the quantity of calcium hydroxide present in the aqueous solution in contact with the hydrated cement after a fixed period of time with the quantity of calcium hydroxide capable of saturating a solution of the same alkalinity. The test is considered positive if the concentration of calcium hydroxide in the solution is lower than the saturation concentration.

Activity index
The activity index test was performed on randomly selected bio fly ashes according to the ASTM C311 Standard [17]. In this method, six prisms ($4\times4\times16$ cm^3) of standard mortar are produced as the control mixture. Further, six more prisms were prepared from a batch of test mixtures with 20% replacement of cement content with the bio ashes. The mix proportions are presented in Table 1. The prisms were cured for 7 and 28 days after which their compressive strength was measured according to EN 196-1 [18]. Tests were performed on a standard mortar press for cement mortars (load cell 300 kN, Tony Technik). The strength activity index is then calculated according to Eq.1, where A is the average compressive strength of the test mixtures (MPa) and B is the average compressive strength of the control mixes (MPa). The sample passes the test if the activity index is superior than 70%.

$$\text{Activity index} = (A/B)\times100 \quad (1)$$

Table 1. Mix Proportion for control and test mixes in activity index test

	Cement (g)	Graded standard sand (g)	Bio ash (g)	Water (g)
Control mix	500	1375	-	242
Test mix	400	1375	100	Required for flow ±5 of control mix = 225 ml in this study

R3 method
The "R3" Rilem method [19], consists of an isothermal calorimetry study carried out on model mixes at 40°C. Those mixes are composed of clay, portlandite and gypsum, with the following proportions: portlandite-to-ash ratio is 3:1 and the addition of gypsum is calculated to have a SO_3/Al_2O_3 molar ratio of 1. Finally, the powder is mixed with a 0.5 mol/l KOH solution to reach a water-to-solid ratio of 1. The heat flow was recorded at 40°C up to 7 days of hydration. The R3

test allows to rank the pozzolanicity of SCMs in time frame much shorter than other methods. The repeatability is also better [19].

2.6 Hydration

The early heat development was measured by isothermal calorimetry in form of time vs. cumulative heat and time vs. heat flow curves over 7 days. The analyses were performed with a TAM Air isothermal calorimeter. The description of the method application on cement hydration can be found in the literature [20, 21]. The heat release was measured during the hydration of the paste.

After 7 days, the samples were retrieved, dried, powdered and analysed by XRD.
Drying of the sample were performed by submerged them in isopropanol (2-propanol ≥ 98 % technical, VWR chemicals) for 7 days. During that time, the isopropanol was renewed two times the first day, and one time after during the 2nd, 3rd and 5th day. The samples were then dried in an oven at 35°C for 24 h and stored in a desiccator with silica gel and soda lime as CO_2 trap prior to analysis.

3. RESULTS AND DISSCUSSIONS

3.1 Chemical composition

Table 2 presents a summary of the chemical composition (wt.% of the different oxides) of all the bio ashes that has been retrieved. Only an average of the data recovered over time and the associated standard deviation are presented in this table. In the case of the bio ashes reciveed from pulp and paper industry the presented average results are categorized with respect to the location the samples are obtained from. However, the chemical composition of all the bio ashes recieved from energy production industries are presented as a single average value

Table 2. Summary of the chemical composition in wt.% of the ashes retrieved from the different locations.

Source/Location		Type	SiO_2		Al_2O_3		CaO		Na_2O		K_2O		LOI	
			Avrg	*Std.*	Avrg	*Std.*	Avrg	*Std.*	Avrg	*Std.*	Avrg	*Std.*	Avrg	*Std.*
Pulp and paper industry	Värö	BFA[1]	17.7	*5.7*	4.0	*1.0*	29	*4*	2.0	*0.3*	11.5	*3.8*	15.5	*2.7*
		Mix	20.9	*5.9*	4.9	*0.9*	30	*5*	1.2	*0.3*	4.5	*0.9*	23.8	*7.7*
		BBA[2]	13.5	*2.9*	4.1	*0.6*	35	*4*	1.2	*0.1*	3.9	*1.2*	25.1	*3.5*
	Mönsterås	BFA	41.7	*5.0*	9.3	*1.6*	27	*4*	2.0	*0.2*	5.0	*0.7*	2.4	*2.0*
		BBA	17.8	*2.9*	7.4	*2.6*	31	*2*	1.7	*0.2*	5.9	*0.7*	14.4	*1.7*
	Mörrum	Mix	71.2	*2.3*	7.6	*1.5*	10	*1*	2.2	*0.4*	5.3	*0.8*	0.6	*0.1*
Energy production		BFA	15.7	*3*	4	*0.4*	29	*3.1*	2	*0.3*	3	*0.7*	8	*4*
		BBA	64.3	*7.4*	8.3	*2.6*	10.3	*1.7*	1.8	*0.5*	4.6	*0.5*	1.19	*1*

1. BFA: Bio Fly Ash
2. BBF: Bio Bottom Ash

The type of ash indicated as “mix” in the table represents samples where both fly ash and bottom ash are present. From Table 2, it can be noticed that, for each oxide and ash type, the standard

deviation is relatively low compared to the average value. This indicates a rather small variation of the composition over time. However, it should be noted that in the case of SiO_2 content the bottom ashes with the origin from fluidized bed combustion, do have considerably higher SiO_2 content compared to other bio ashes. This is because the sand utilized in fludized bed is mixed with the bottom ashes in these cases. The presented sodium and potassium contents appear to cause the equivalent alkali content to exceed the requirements for coal fly ash according to EN 450-1:2012. This needs to be taken into consideration in relation to the effect of alkali content on eventual alkali silica reactions.

The main oxides interesting for the cement industries (SiO_2, CaO and Al_2O_3) are all present in these bio ashes, although the Al_2O_3 content seems quite low (between 4 % and 9.3% for the different ashes). The general evolution of compositions of the bio ashes with respect to SiO_2, Al_2O_3 as well as CaO contents, , are also presented in Figure 1.

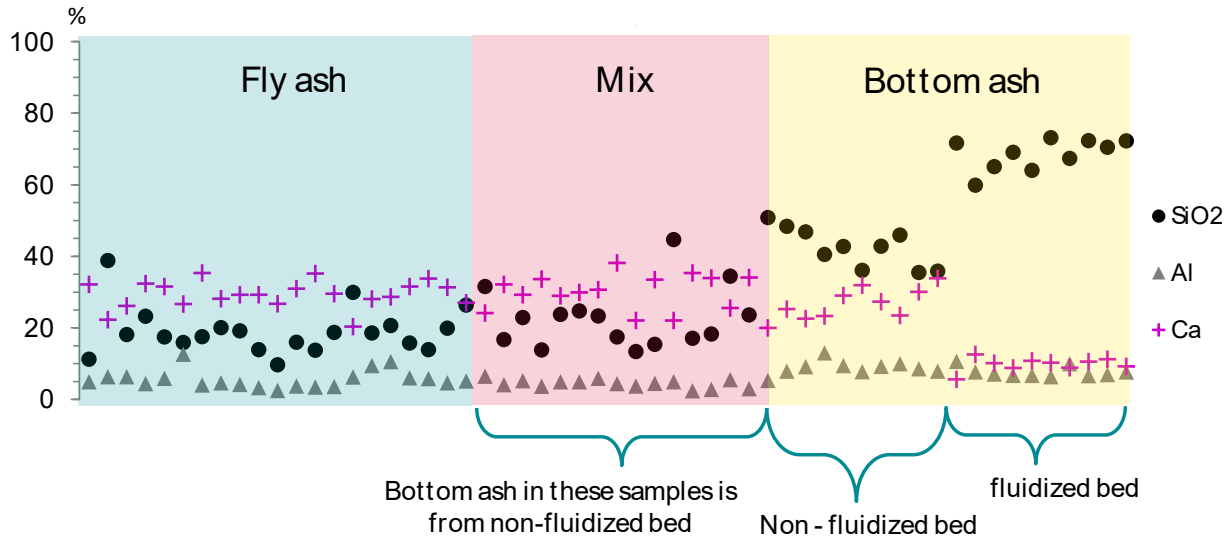

Figure 1. Chemical composition of the retrieved ashes, from different locations and at different dates.

As expected, the type of ash and the plant of origin slightly affect the chemical composition of the bio ashes. SiO2 and CaO are the oxides that show the more important variation. Those oxides also present the main differences when comparing bio fly ashes and bottom ashes: there is less SiO_2 and more CaO in the bio fly ashes than in the bottom ashes. This is even more noticeable for bottom ashes mixed with sand in the case of fluidized bed combustion, as noted earlier.

The loss on ignition (LOI) which is an indication of carbon content seems to be higher than the values that are required according to EN 450 for an ordinary commercial coal fly ash class C (9%). This can partially affect the rheological properties of the mixes as well as causing a reduction in the air content in air-entrained concrete, which will be cast with these bio ashes [23].

Figure 2 illustrates the evolution of the chloride content of the bio ashes over time. The vertical scale is a logarithmic scale. The content of chloride is one of the key parameters to know if the ash can be used in reinforced concrete. According to standard SS-EN 450-1:2012 [22] (requirement for fly ash), the chlorine content should not excess 0.1% by mass. This limit is represented in Figure 2 by a horizontal red bar. As shown, a clear decrease of the chlorine content is measured after immersion in water. The average values of the chloride content of the bio ash

samples as well as the obtained standard deviation are presented in Table 3. As presented, the chlorine content goes down from 1.2 wt% for the unwashed mix to 0.1% for the mix after washing. This indicates that a simple immersion of the bio ashes in water is enough to remove most of the chloride present in the sample.

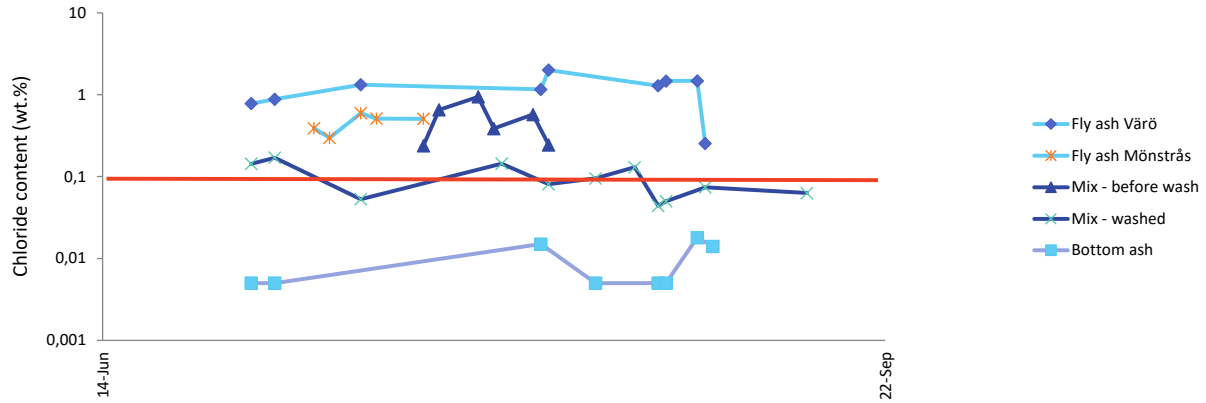

Figure 2. The chlorine content as a function of time for the different types of bio ashes obtained from different plants. The red line represent the maximum chloride content according to the standard EN 450-1[22].

Table 3. Chloride content in function of time for the different type of bio ashes obtained in different plants (Värö, Mönsterås and Mörrum)

Location	**Type**	**Cl (wt. %)**	
		Average	*std dev*
Värö	Fly ash	1.2	*0.5*
	Mix - washed	0.10	*0.04*
	Bottom ash	0.01	*0.006*
Mönsterås	Fly ash	0.5	*0.1*
	Bottom ash	0.02	*0.003*
Mörrum	Mix - Unwashed	0.5	*0.3*

3.2 Mineralogical properties

Figure 3 presents the diffractograms obtained on bio ashes. All samples have been analysed but only a selection is shown here. The ashes are separated in three categories: fly ashes, mix ashes, bottom ashes. Calcium hydroxide, orthoclase (silicate phase), albite, calcite, anhydrite lime and quartz are found in most of the samples. Hematite is present in some of them. As expected, the presence of quartz is also confirmed in bottom ashes.

3.3 Pozzolanic behaviour

The calcium hydroxide consumption test results for randomly selected bio fly ashes are presented in Figure 4. The vertical axis represents the calcium ion concentration, and the horizontal axis is the concentration of hydroxyl ions. The blue curve represents a border under which all the concentration infer presence of a pozzolanicity (pass region) while the region above the curve regards lack of pozzolanic potential (fail region). To better compare the results, a randomly

selected cement samples is also tested alongside randomly selected bio fly ashes obtained from different plants. As shown, the bio fly ashes, although very close to the border of acceptance, are either on the blue curve or above it, indicating poor or lack of pozzolanic behaviour.

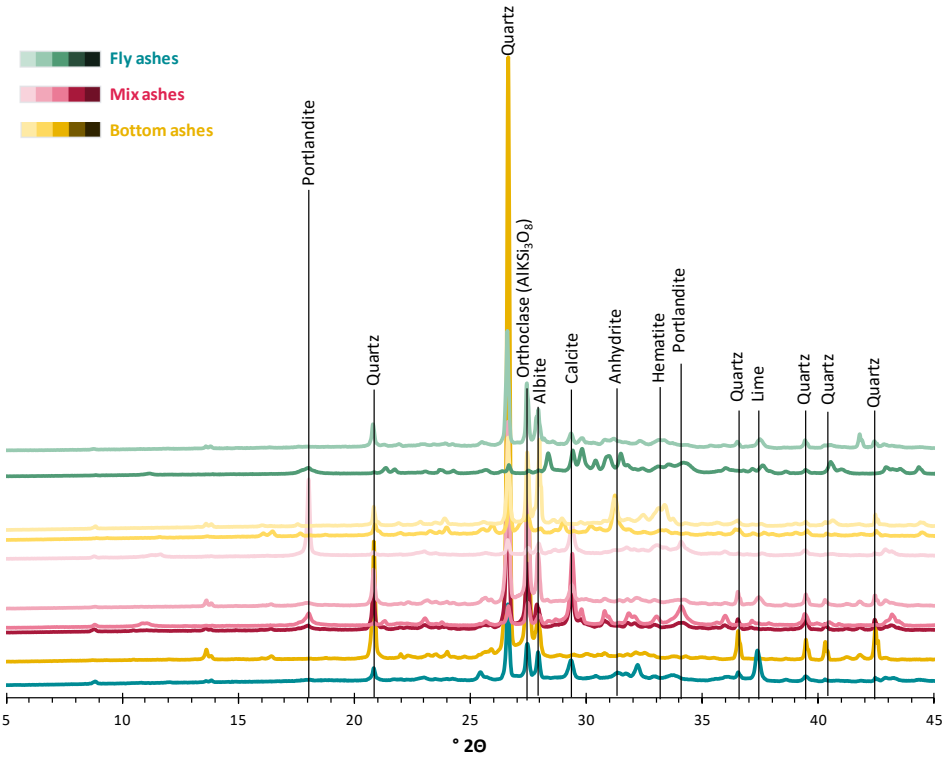

Figure 3. Diffractograms of a selection of bio fly, bottom, and mix ashes.

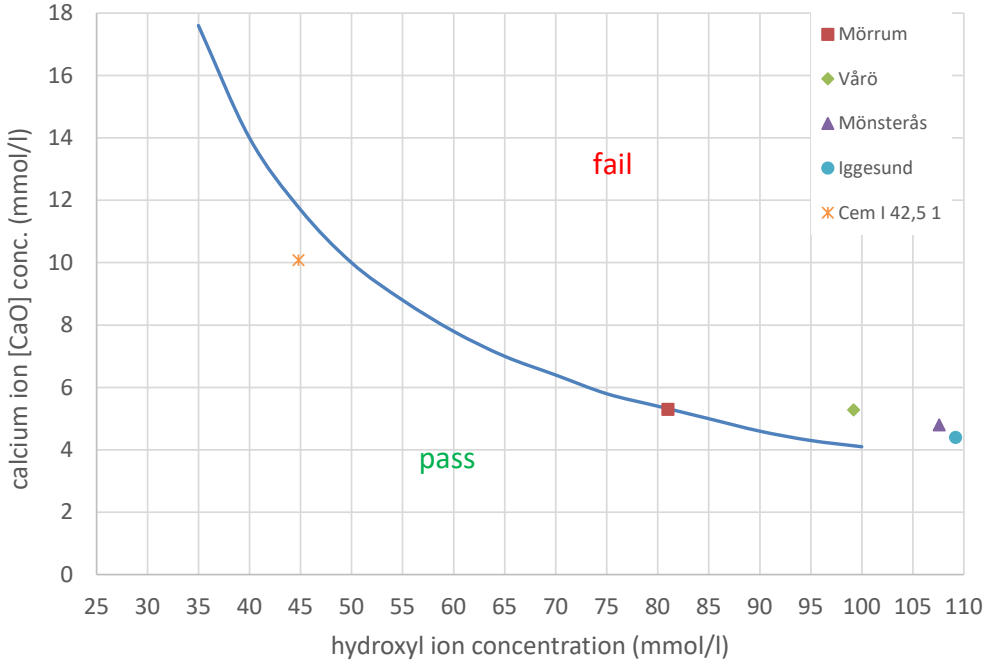

Figure 4. Calcium hydroxide consumption test results for randomly selected bio fly ashes

The results of the activity index test performed on randomly selected bio fly ashes are presented in Figure 5. A 70% activity index shown as a red line is considered as the border separating the region with poor pozzolanic behaviour (fail) from the pass region in which higher pozzolanic behaviour can be expected. The sample from Mönsterås is slightly above the line while the other two samples, although close to the border, are laying under the curve inferring poor pozzolanic behaviour. It should however be noted that the difference in w/b-ratio between the control and test mix could also affect the strength properties. The decision of choosing standard ASTM C311 Standard [17] to be followd in this test which requires similar flow properties resulting in differences in w/b-ratio is to account for the effect of application of bio ashes on wokability of the mix alongside the strength properties. A propoer further investigation in continuation of this work would be to follow stregth properties of the mortar prisms according to SS-EN 450 [22] as well, which requires a similar w/b-ratio instead.

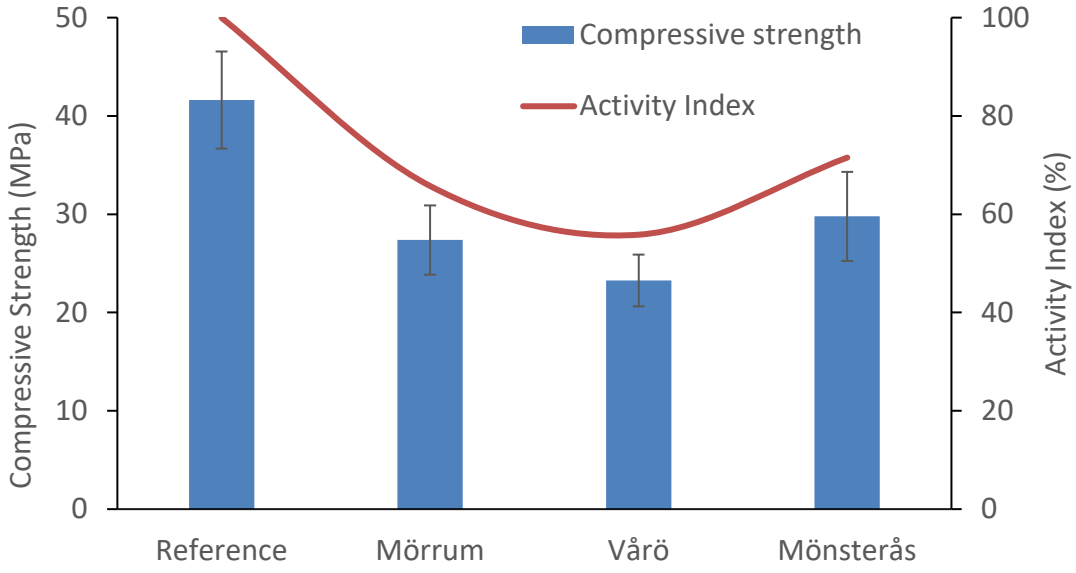

Figure 5. Compressive strength and Activity index test results

The pozzolanic potential of the bio ashes measured with the R3 test is illustrated in Figure 6. The sample called “industrial mix” represents a homogeneous mix of all the blend ashes originating from the Värö plant. The results are compared to a commercial coal fly ash to better reflect the pozzolanicity of the ashes. As shown, bio fly ashes exhibit higher pozzolanicity followed by mix ashes (bottom and fly ashes) and bottom ashes. Only one fly ash and one mix ash present a rather low pozzolanicity. Most of the bio fly ashes exhibit a significantly higher pozzolanicity than the reference commercial coal fly ash. The industrial mix seems also slightly better. It must be pointed out that the two bio ashes with the highest pozzolanicity are obtained from energy production industries.

The difference between the results obtained by this R3 test and the previous one can be explained by the slow kinetic reaction of the bio ashes which is not possible to be captured by ordinary pozzolanicity tests utilized on common SCMs but enhanced and captured by R3 method. Indeed, the R3 test method has “boosted up” the reaction of bio ashes by the high temperature (40°C), the high pH provided by the KOH solution, the high content of gypsum and the additional sulphate. All this might make the bio ashes to react quicker than during the time frame of the other tests. It

should, however, be noted that as reported in the literature the "R3" test results correlates well to the strength development results [24-25], which is not the case in this study. This can be explained as the sulphate and alkali content of the mixes prepared for strength tests in this study, were not adjusted unlike the "R3" test. Moreover, as noted, due to the requirement of the ASTM C311 Standard [17], the water-binder ratio in the mortar samples containing bio fly ashes were not similar to the reference mortar samples which may have affected the strength results.

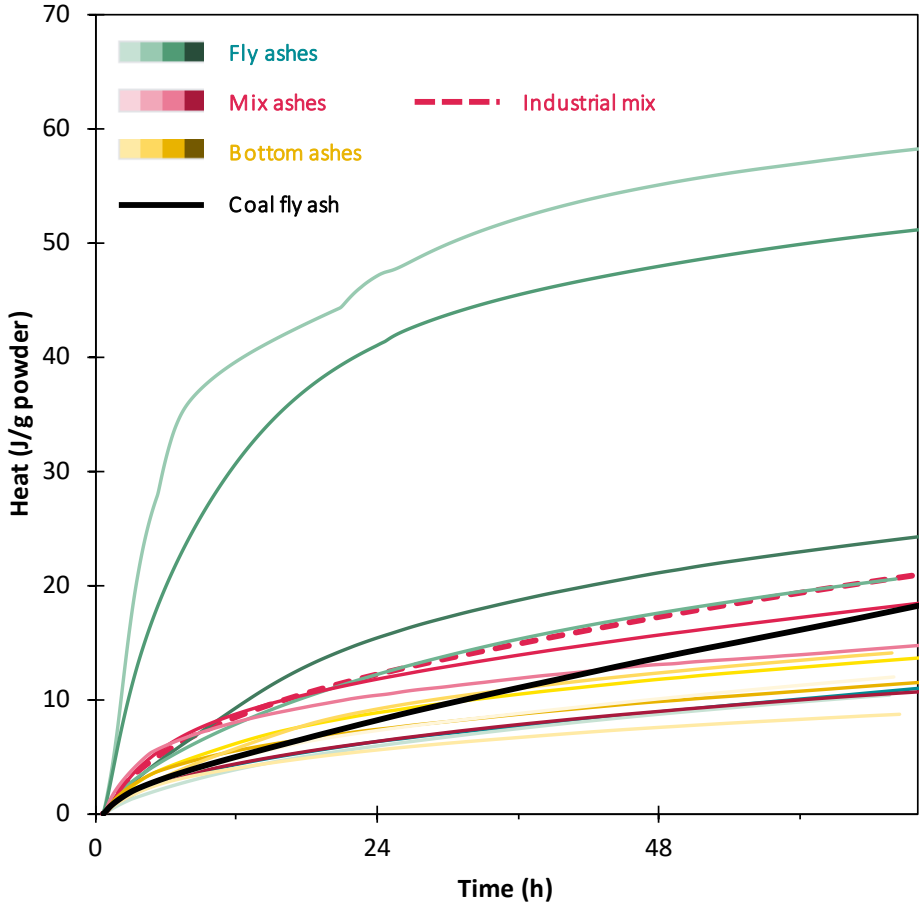

Figure 6. R3 test results of the bio ashes and a commercial coal fly ash as a reference.

3.4. Hydration properties

Figure 7 presents the heat of hydration of binders with four replacement degrees from 0 to 30% of cement with bio ashes. The bio ashes exhibiting highest pozzolanic properties according to R3 test were selected to be utilized for hydration analysis. The fly ash 1 refers to the fly ash having the best pozzolanicity according to Figure 76 The results are normalized to the mass of total powder (cement + bio ash) in the paste. As shown, the cumulative heat (lower part of Figure 8) decreases with increasing replacement level. This is due to the dilution effect, the sample contains less cement leading the intensity of the chemical reaction to decrease due to the reduction of highly reactive component. This is more pronounced for the fly ash 1 with 20 and 30% replacement. In addition, the heat flow (upper part of Figure 7) also shows that the hydration reaction is different when bio ashes are added. For the reference sample (100% cement), the two main hydration peaks are visible, i.e., the silicate (C_3S, C_2S) peak followed by the aluminate (C_3A) peak. When the fly ash 1 is present, only one peak for C_3S and C_2S is visible, indicating that either both reactions

happen at the same time or that the reactions are probably distributed on wider area, not allowing detection of the single peaks. For the fly ash 2, the two peaks for C_3S and C_2S are still separated, and the aluminate peak is more and more delayed when more fly ash is present.

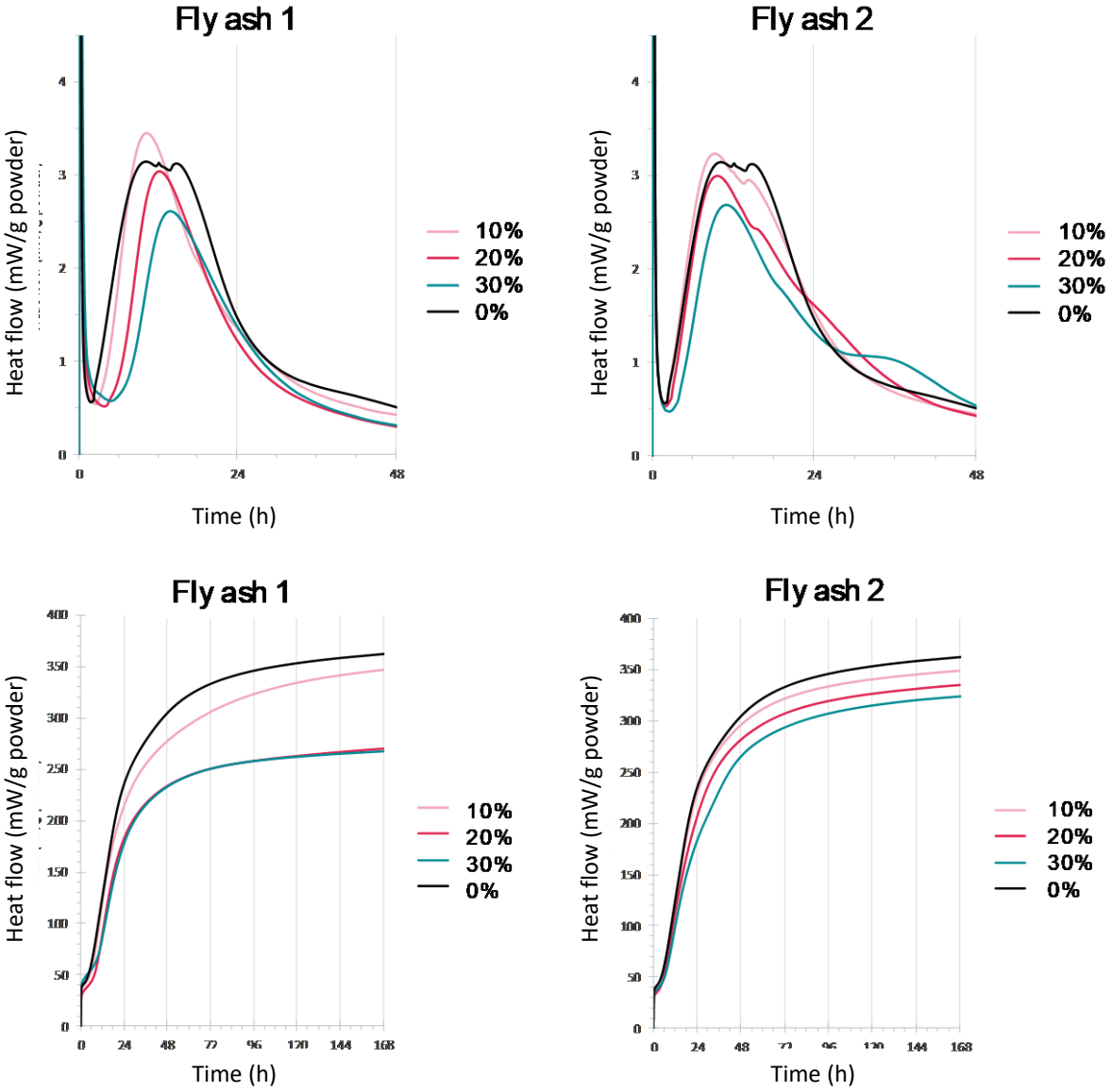

Figure 7. Isothermal calorimetry results within 7 days of hydration of binders with different clinker replacement levels with two bio ashes coming from energy producer. Heat flow on the top and cumulative heat at the bottom.

After the 7 days calorimetry, the samples were retrieved and analysed by XRD. The results are presented in Figure 8. For the fly ash 2, similar hydrates are formed at all replacement level, with the presence of AFm/AFt (mono and hemicarbonates, ettringite). It seems that more ettringite is formed for higher replacement rate. For the fly ash 1, the formation of AFm is more limited, there is no mono and hemicarbonates. Those results might be in contradiction with the R3 test, whereas the fly ash 1 seems to have the best reactivity, the calorimetry study shows a hight decrease of released heat after 7 days (compare to the fly ash 2) coupled with the presence of less hydrates

revealed by XRD. This can be explained by the fact that the fly ash 1 needs more time to react than the fly ash 2, as most parameters are being boosted up during the R3 test to fasten the reaction. Nevertheless, production of the hydration phases is an indication of obvious presence of bio ashes in hydration reactions for both investigated bio ashes.

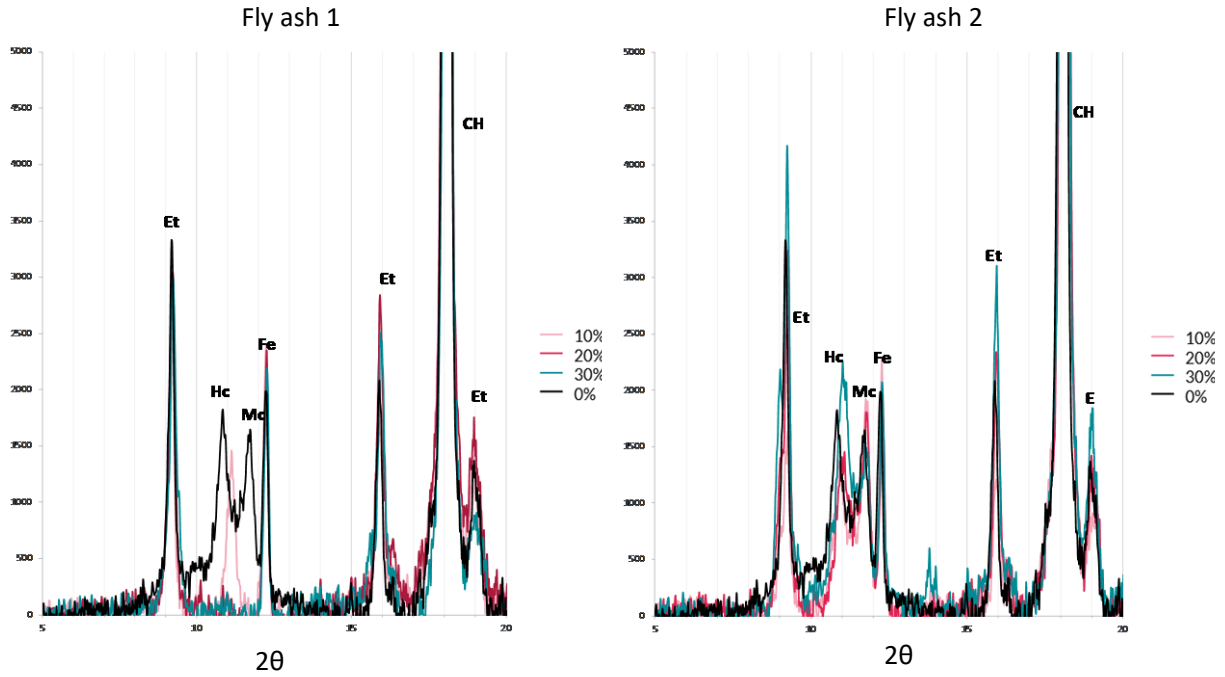

Figure 8. Diffractograms of the samples retrieved after calorimetry (7 days old)

4. CONCLUSIONS

The potentials of Swedish bio ash sources (with origin of wooden biomass feed) to be used as alternative SCMs have been investigated. The main aim is to promote industrial application of these alternative binders as cement replacements in order to facilitate minimization of environmental footprint of cement production in Sweden.
The following conclusions can be drawn from this project:

- Chemical composition of the bio ashes over a sampling period of 6 month seems to be relatively stable with respect to calcium, aluminium, and silicon contents, although slight variations depending on the origin of the bio ashes as well as the utilized combustion method is demonstrated.
- The chloride content is lower than allowable by standards [22] in most samples. When it is not, mostly in the case of bio fly ashes, it is proved to be easily washable by simple immersion washing methods.
- Pozzolanic behaviour if investigated by common standard methods recommended for common SCMs [16, 17], seems not to capture the reactivity of bio ashes, while using new developed methods such as R3 test [19], demonstrated presence of hydration activity as well as pozzolanic behaviour in the bio ashes.
- Hydration of binders using up to 30% replacement of cement content with bio fly ashes, resulted in production of a hydrate phase assemblage containing AFm/AFt phases

demonstrating participants of bio ashes in the hydration and eventually pozzolanic reactions.

Therefore, application of bio ashes with a wooden origin in construction materials is promoted according to the conclusions of this study. However, further investigations in terms of possible removal methods to minimize the chloride and alkaline contents should be taken into consideration in continuation of this study. Moreover, application potentials of these materials in other fields of construction other than structural concrete is worth investigating.

AKNOWLEDGEMENTS

All the work in this study is performed at RISE Research Institute of Sweden. The results presented in this article are part of the study financed by Consortium for the Financing of Fundamental Concrete Research (consisting of Cementa, Thomas Betong, ABetong, Strängbetong, Betongindustri and Swerock) as well as Energimyndigheten (Re-source program). The support from Helena Sellerholm, responsible for askprogrammet, as well as Inge Johansson at RISE Research Institute of Sweden, to help us find the bio ash samples, is greatly appreciated. We are also very thankful for all the help received from Andreas Martinsson and Mehdi Arjmand at Södra cell Värö as well as Peter Ottosson at Kraftringen. All the help and support from our colleagues Monica Lundgren, Alexander Oliva Rivera, Camilla Lindström, Lovise Sjöqvist and Sandra Davidsson is also acknowledged.

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APPENDIX

Sample list of bio ashes with respect to the sampling location, type, and date of sample uptake. For the sample received from Örebro and Karlstad, the exact sampling date is not known.

Location	Type (Pulp and paper Industry)	Date
Värö	Flyash	2017-07-03
Värö	Flyash	2017-07-06
Värö	Flyash	2017-07-17
Värö	Flyash	2017-08-09
Värö	Flyash	2017-08-10
Värö	Flyash	2017-08-16
Värö	Flyash	2017-08-24
Värö	Flyash	2017-08-25
Värö	Flyash	2017-08-29
Värö	Flyash	2017-08-31
Värö	Mix	2017-07-03
Värö	Mix	2017-07-06
Värö	Mix	2017-07-17
Värö	Mix	2017-08-04
Värö	Mix	2017-08-10
Värö	Mix	2017-08-16
Värö	Mix	2017-08-21
Värö	Mix	2017-08-24
Värö	Mix	2017-08-25
Värö	Mix	2017-08-29
Värö	Mix	2017-08-31
Värö	Mix	2017-09-12
Värö	Bottom ash	2017-07-03
Värö	Bottom ash	2017-07-06
Värö	Bottom ash	2017-08-09
Värö	Bottom ash	2017-08-16
Värö	Bottom ash	2017-08-24
Värö	Bottom ash	2017-08-25
Värö	Bottom ash	2017-08-29
Värö	Bottom ash	2017-08-31
Värö	Bottom ash	2017-09-01
Mönsterås	Flyash	2017-07-11
Mönsterås	Flyash	2017-07-13
Mönsterås	Flyash	2017-07-17
Mönsterås	Flyash	2017-07-19
Mönsterås	Flyash	2017-07-25
Mönsterås	Bottom ash	2017-07-11
Mönsterås	Bottom ash	2017-07-13
Mönsterås	Bottom ash	2017-07-17
Mönsterås	Bottom ash	2017-07-19
Mönsterås	Bottom ash	2017-07-25
Mörrum	Mix	2017-07-25
Mörrum	Mix	2017-07-27
Mörrum	Mix	2017-08-01
Mörrum	Mix	2017-08-03
Mörrum	Mix	2017-08-08
Mörrum	Mix	2017-08-10

Location	Type (Energy Production)	Date
Kraftringen	Flyash	2018-01-31
Kraftringen	Flyash	2018-02-22
Kraftringen	Flyash	2018-04-03
Kraftringen	Flyash	2018-04-03
Kraftringen	Bottom ash	2018-01-31
Kraftringen	Bottom ash	2018-02-28
Kraftringen	Bottom ash	2018-04-03
Kraftringen	Bottom ash	2018-05-08
Mälarenergi	mix	2018-03-05
Mälarenergi	mix	2018-04-09
Mälarenergi	mix	2018-04-19
Örebro	Flyash	Unknown
Örebro	Bottom ash	unknown
Karlstad Energi	mix	unknown
Karlstad Energi	Flyash	unknown