

Investigation on Ash Slag from Combustion of Medium-Density Fiberboard Production Residues

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Abstract. Medium-Density Fiberboard (MDF) is made by breaking down of wood as conifer wood thinnings and wood processing industry residues including sawdust, which is glued and pressed together, and is widely used as a building material. Woody residues from production of MDF (MDFres) is a large and available amount and can be combusted for heat and energy production. In this study, MDFres fuel properties and ash melting behavior were investigated. The ash slag from combustion of MDFres in a residential combustion appliance was collected and analyzed with scanning electron microscopy–energy-dispersive X-ray spectrometry (SEM–EDX). The results show that MDFres ash contains considerably high content of calcium, silicon, potassium and sodium. The ash has a very low fusion temperature, of about 878 °C in oxidizing atmosphere. The ash slag collected from combustion of the MDFres has dense and intact structure and glass-like morphology, indicating that the ash experienced intensive melting. EDX spot analyses on the chemical composition of the slag reveal that Ca, Si, Al, Mg, K and Na are the main elements contained in the slag. Together with the spot analysis, EDX mapping analyses results indicate strong correlations between the elements Ca, Si and K and indicates formation of alkali silicates that have low melting temperatures during combustion of MDFres. Formation and presence of these low temperature melting compounds are the main reason for ash sintering and slagging at a sufficiently high combustion temperature.

Introduction

Ash sintering and slagging are more than occasionally occurring in biomass fired plants and especially in residential combustion appliances [1]. The ash related operational problems can interfere with the combustion process and reduce energy conversion efficiency as well as performance of the combustion appliances. There are large variations in both total content and relative concentration of ash forming elements in biomass fuels. During combustion of a biomass fuel, the ash forming elements mainly remain in the bottom section of the combustor as solid residues, known as residue ash. The ash forming elements will react with each other during and after conversion of the biomass fuel to form different solid chemical compounds. Some of these compounds have low melting temperatures and will fuse at typical combustion temperatures, causing sintering and aggregating of ash particles. Along the progressive accumulation and sintering, the ash residues will form large size slag that cannot be transported out of the burner and/or furnace. Some melted and sintered ash might also stick to and deposit on burner and/or furnace surfaces, resulting in corrosion and loss of refractory materials [2]. Ash sintering and slagging are especially critical issues for introducing new fuels in the combustion market, which have high ash content and high concentration of problematic ash forming elements. Detailed studies on ash residues from combustion of new fuels are required to understand sintering and slagging mechanisms and proposing anti-sintering/slagging measures.

The present work was performed with the aims to (1) characterize properties and sintering behaviors of residues from production of MDF, and (2) investigate structure and chemistry of slag from combustion of the residues. The results obtained in this study can provide a better understanding

of the sintering behavior of the studied residue as a solid fuel and valuable information for preventing sintering and slagging of residues in combustion applications.

Experiment Section

Characterization of Residue from MDF production

Residue from the MDF production process was collected from a local wood processing plant in powder form. The residue was submitted for ash content, ultimate analysis, heating value and bulk ash composition analysis. Ash from the residue was prepared for conducting fusion test in an ash melting microscope and determining fusion points in oxidizing atmosphere.

SEM-EDX Analysis

The MDFres is currently burned as fuel in a powder fired burner combined with a boiler (4MW, Bio Swirl burner, Sweden) in Arendal heating center in Norway, operated by Agder Energi Varne AS. The boiler is normally burning fine wood wastes (sawdust) originating from wood processing industry. The fine fuel particles are mixed with primary air and injected tangentially into the cylindrical furnace muffle to establish a rotational vortex flow [1]. Normally with well mixing of air and fine fuel particles, high energy density at the furnace walls and high combustion temperature can be realized, and the furnace is water-cooled. After the outlet of the primary combustion chamber, secondary air is introduced to achieve good mixing and combustion of remaining combustible gases. Ash from the furnace can be carried out by high speed flue gas and partly precipitate in the post combustion chamber. Along the combustion process, more ash can accumulate at the inlet of the post combustion chamber at high temperature, with progressive sintering and melting. With long enough combustion operation, the melted ash covers the bottom section of the post combustion chamber and stick on the surface of the refractory material and cannot be cleaned. In this work, the ash slag samples were collected directly from the inlet of the post combustion chamber. The collected slag samples were then cut, ground, mounted in resin and polished to obtain cross-sections with smooth surfaces. The cross-sections were then analyzed by a scanning electron microscopy (SEM) combined with energy-dispersive X-ray spectrometry (EDX) to study their morphology and microchemistry. Semi-quantitative spot analyses were performed using EDX, to obtain element compositions of representative scanned areas. Element maps were also obtained to show the distribution of important elements in the sample structure.

Results and Discussions

The characteristics of the studied MDFres and its ash are shown in Table 1 and Table 2, respectively. It can be seen that the residue has relatively low ash content and a heating value comparable with normal woody biomass.

Table 1. Characteristics of the studied MDFres.

	Moisture (wt%)	Ash content (wt%)	Heating value (MJ/kg)	Carbon (wt% d.b.)	Hydrogen (wt% d.b.)	Nitrogen (wt% d.b.)	Oxygen (wt% d.b.)	Sulphur (wt% d.b.)
MDF production residue	4.4	0.46	19.28	49.5	6.2	3.44	40.4	0.071

Table 2. Characteristics of studied MDFres ash.

Ash fusion characteristic temperature (°C)								
Initial Deformation Temperature (IDT)	Softening Temperature (ST)	Hemisphere Temperature (HT)	Fluid Temperature (FT)	Si (mg/kg)	Ca (mg/kg)	Al (mg/kg)	K (mg/kg)	Na (mg/kg)
878	1326	1378	1428	103	721	30.3	41.1	115

The ultimate analysis reveals a high nitrogen content, originating mainly from glue used in the MDF production. Hence, the major part of the MDFres originates likely from the MDF-glue mix used in the production process itself. However, the MDFres ash contains a significantly high content of potassium and sodium. The MDFres ash has a very low initial deformation temperature, 878 °C. The initial deformation temperature (IDT) of a biomass fuel is of concern because ashes from solid fuels usually become sticky and easily sinter at this temperature, which will cause further aggregation and fusion of a large amount of ash along the combustion process [2]. The combustion temperature in the current furnace is typically around 1100-1200 °C, which is much higher than the IDT of the MDFres ash. Therefore, sintering and fusion of the MDFres ash is likely to occur. With initial sintering of the ash, more ash grains or particles can bound on the melted fraction, which is followed by intensive fusion and slag formation [3,4].

Figure 1 below shows one refractory material (Fig 1a) and one slag sample (Fig 1b) collected after shutdown of the combustion appliance in the Arendal heating center. The ash slag is quite dense and hard, and difficult to remove from the refractory material surface. One needs to use a hammer to crush the slag into pieces and a metal bar with a sharp tip to disconnect the slag from the refractory material. As a result of this, large pieces of refractory material often become damaged and need to be replaced. Therefore, new costly refractory material needs to be installed after each maintenance shutdown.



Figure 1. Refractory material (Fig 1 a) and slag (Fig 1 b) collected after shutdown of the combustion appliance.

Figure 2 below shows treated slag samples that have dense and intact structure, indicating completed melting of the ash during combustion. The two slag samples are collected from different locations with different distance to the furnace wall surface. Sample A is from a position closer to the furnace wall and sample B is from a position closer to the center of the burner. There are holes or openings that can be seen easily, which is caused by formation and release of gases or volatiles from the melted ash. Along continuous accumulation and reaction of the melted ash, the structure of the ash will be further densified and homogenized with elimination of voids.

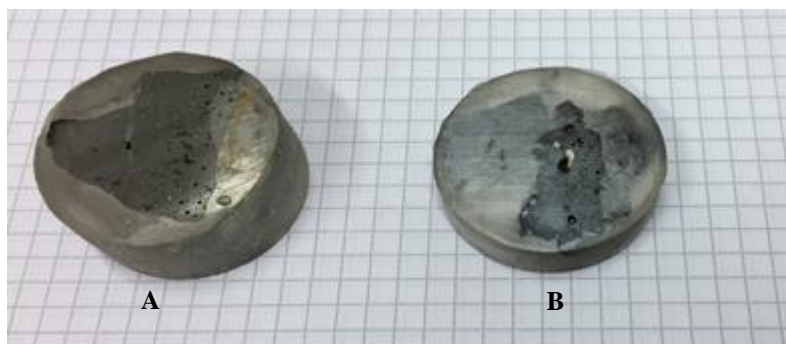


Figure 2. Cross-sectioned samples in the resin after grinding and polishing treatment.

Figure 3a shows a SEM image of slag sample A that melted into a continuous phase. The rectangular area marked in Figure 3a, enlarged in Figure 3b, was selected for micromorphology and microchemistry analyses. In general, the Si and Ca concentrations for all detected spots are quite high. Notably high concentrations of K were detected in the light gray zones with irregular shapes (Figure 3b, sampling spots 3-4). In addition, in the rest of the area, with dark gray color, the concentrations of

K are also relatively high. Figure 4 shows EDX mapping of element Si, K and Ca for sample A. The high brightness of the Ca element map indicates general enrichment of this element in sample A. Figure 5a shows a SEM image of slag sample B that also melted into a continuous phase. The rectangular area marked in Figure 5a, enlarged in Figure 5b, was selected for micromorphology and microchemistry analyses. In Figure 5c (sampling spots 4-6), the SEM-EDX analysis results clearly identify zones with high content of K (> 25 wt%), Si and Al, but with considerably lower content of Ca compared to sample A. It indicates formation and presence of potassium aluminum silicates in sample B. Figure 6 shows EDX mapping of element Si, K and Ca for sample B. The low brightness of the Ca element map indicates the lower enrichment of this element in sample B compared to sample A.

In general, the overall compositional distributions of the slag samples are limited to various $K_2O-CaO-SiO_2$ and $K_2O-Al_2O_3-SiO_2$ ternary systems. It is possible to extract the melting temperatures of the detected sampling points from $K_2O-CaO-SiO_2$ and $K_2O-Al_2O_3-SiO_2$ phase diagrams. The extraction results indicate that the melting temperatures of K-Ca-silicates with similar elemental distributions as detected in Figure 3b (sampling spots 3-4) for sample A and of K-Al-silicates with similar elemental distributions as detected in in Figure 5b (sampling spots 4-6) for sample B, are less than 1000 °C.

The SEM-EDX analysis results imply that the slag contains mainly K-Ca-silicates and K-Al-silicates, and the results from the current work agree with previous studies [2-4]. The results also show that the two slag samples, collected from two different locations with different reaction conditions, results in different slags with respect to elemental composition. However, considering the low ash content of the studied residue, it indicates that the slag formation tendency and chemistry additionally depends on the non-ash chemical composition of MDFres, likely related to its high glue content and its composition. Further work is needed to assess this.

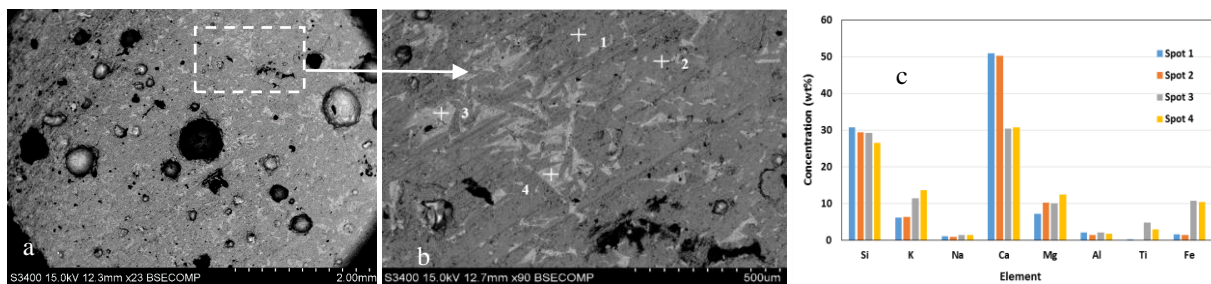


Figure 3. (a) and (b) SEM image of studied slag sample a, (c) SEM-EDX analyses of the area selected in panel (a).

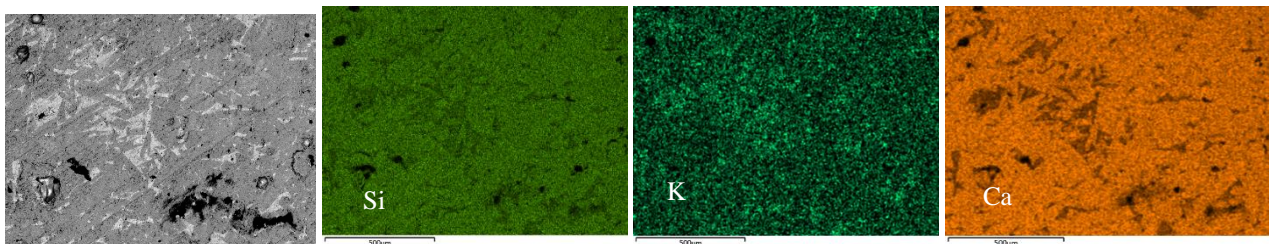


Figure 4. Mapping of selected area in Figure 3(b).

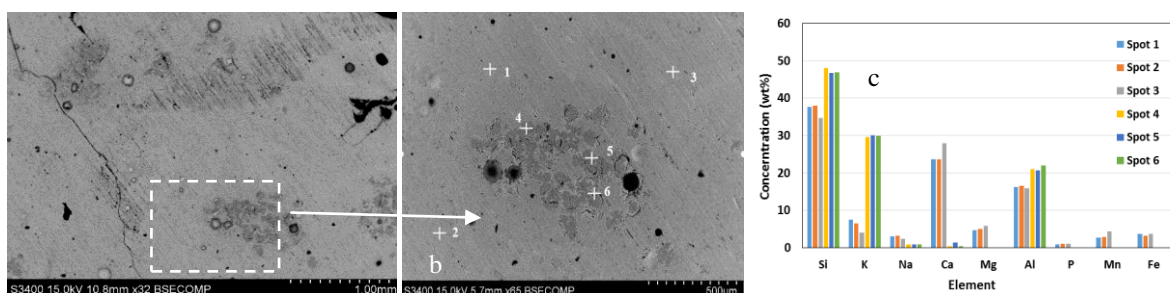


Figure 5. (a) and (b) SEM image of studied slag sample b, (c) SEM-EDX analyses of the area selected in panel (a).

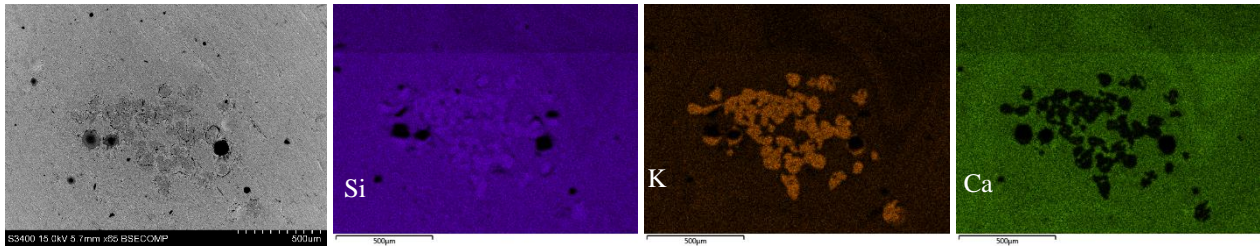


Figure 6. Mapping of selected area in Figure 5(b).

Conclusion

In this work, residue from the MDF production process was studied in terms of fuel properties and ash melting behavior. The ash from the studied residue has low initial fusion temperature and can melt during the combustion process and initiate sintering and slag formation. SEM-EDX analyses were conducted for slag samples collected from combustion of the residues in a residential combustor. Analysis results revealed that the slag formed because of the formation of low temperature melting potassium aluminum silicates and potassium calcium silicates during the combustion process. With further accumulation and fusion of ash, slag with continuous and dense structure can form.

Acknowledgement

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