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Quality properties of pelletised sawdust, logging residues and bark

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Abstract

The dominant raw material for wood pellet production in Sweden is sawdust, planer shavings and dry chips. However, other types of biomass, such as bark and logging residues, are also interesting raw materials due to the large volumes available. These alternative raw materials differ from stemwood with regard to physical characteristics and chemical composition. In order to produce high-quality pellets of such materials, it is necessary to understand the role of these variations. Nine pellet assortments, made of fresh and stored sawdust, bark and logging residues (a mixture of Norway spruce and Scots pine) were tested for moisture content, heating value and contents of ash, sulphur, chlorine and Klason lignin. Dimensions, bulk density, density of individual pellets, durability and sintering risk were also determined. The heating value was highest in logging residue pellets. The ash content was highest in the bark and logging residue pellets, implying higher sintering risk compared with sawdust pellets. The results showed that bark pellets had the highest durability, whereas sawdust pellets had the lowest. Pellet density had no effect on durability, unlike lignin content which was positively correlated. It is concluded that bark and logging residues are suitable raw materials for pellets production, especially if the ash content is controlled.

Keywords: Biomass; Wood fuel; Pellet; Quality; Sawdust; Bark; Logging residue

1. Introduction

The pellets market has increased during recent years in Sweden, today being about 720 000 ton, including 250 000 ton of imported pellets. About 13% of the pellets are utilised in small-scale boilers (< 500 kW) during 1998 [1]. Sawdust, planer shavings and dry chips are the dominant raw materials. Only one of the over 20 Swedish pellet factories produces bark pellets. Such a base means a high sensitivity for possible changes in the supply of raw material. Only a few studies dealing with wood pellets have been published and our knowledge of the effects on pellet quality of raw material properties is very limited.

Stemwood, bark, branches and needles differ with respect to fibre structure and chemical composition, e.g., contents of lignin, hemicelluloses, pectin and extractives. Processes such as hydrolysis, autoxidation or microbial degradation change raw material properties during storage [2,3]. Back et al. [4] reported that storing the wood made it more suitable for

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particleboard manufacturing. Due to the relatively high content of amorphous compounds, lignin and extractives, the bark is expected to be more sensitive to temperature and pressure than wood [5]. Several factors may affect milling properties and the agglomerating character of the raw materials.

The quality of pellets is determined by the end-user's requirements on the heating system and the handling properties. As a guideline for both producers and end-users, a Swedish standard has been developed for classifying the pellets into different quality groups [6]. The dimensions of the pellets, both diameter and length, are important factors with respect to combustion. Experience has shown that thinner pellets allow a more uniform combustion rate than thicker ones, especially in small furnaces. The length of the pellets affects the fuel feeding properties, the shorter the pellets the easier the continuous flow can be arranged. Transport efficiency is dependent on the bulk density of pellets. Mechanical strength of the pellets is a very important quality factor at many levels. Organic dust may constitute a health risk for those who handle the fuel. Dust explosion is another problem connected with handling and transporting of fuel. Strength properties can be defined by two distinct parameters, i.e., hardness, which describes the force necessary to crush a pellet, or durability, which describes the amount of fines returning from pellets after being subjected to mechanical or pneumatic agitation [7]. In this study, the strength properties were determined as a durability of pellets. The density of individual pellets as well as the lignin content are parameters that may have an influence on durability. The end parts of the pellets are the biggest source for fines and therefore the durability can be connected to the number of pellets per kg. Several studies have shown that the finer the grind, the better the pellet quality will be [7–9]. High surface area/volume ratio in each particle allows better penetration of moisture and heat, and consequently improves strength properties. The lignin largely controls the viscoelastic properties of the wood [10] and may therefore have an influence on the durability of pellets.

Increasing ash content lowers the heating value and implies the risk for sintering as well as negatively affects milling and pelleting equipment. High moisture content in the raw material will obviously increase the drying costs of the material. Moisture acts as one of the binding agents in the pelleting process. However, too much moisture makes the feedstock slippery and it slides through the holes too easily, thereby reducing pellet quality. Materials that are too dry may plug the holes in the die if the resistance from the holes exceeds the roller force [11]. The opinions vary regarding optimum moisture content. Pellets normally contain 8–15% water wet basis (wb), but according to Gunnerman [12], who worked with high pelletising temperatures (up to 180°C), the optimum moisture content for the pellets was 17–20% wb. Biomass fuels contain varying amounts of elements, such as sulphur and chlorine, which can reduce the melting point of the ash. This may cause operational problems in combustion, such as formation of deposits (slagging) in the furnace [13]. Being corrosive components, sulphur and chlorine can reduce the protective oxide layer in the furnace. Chlorine can induce, e.g., formation of extremely toxic dioxins. However, sulphur and chlorine are present in low concentrations in wood fuels.

The purpose of this study was to test and compare pellets made out of sawdust, bark and logging residues, fresh and stored, in respect to quality and to raw material properties. Possible relationships between the various parameters were also investigated.

2. Materials and methods

2.1. Raw materials

Sawdust, bark and logging residues from final cuttings, consisting of a mixture of 60% Norway spruce (*Picea abies* (L.) Karst.) and 40% Scots pine (*Pinus sylvestris* L.), were used for pelleting (Table 1). The raw materials were delivered from Östergötland province in southern Sweden. The material, which is referred to as "fresh", was felled and chipped 1–5 days before being pelletised in December 1998. The stored materials were prepared 3 and 6 months earlier and placed in 6–7 m high piles. The uncomminuted logging residues were stored in a 3–4 m high and 4–5 m wide windrow and chipped one day before pelletising. Fresh bark contained about 20% of stemwood due to the debarking of the logs in frozen condition.

Table 1
Symbols for and explanations of different assortments

Symbol	Explanation
S0	Sawdust, fresh
S6	Sawdust, stored for 6 months
B0	Bark, fresh
B3	Bark, stored for 3 months
B6	Bark, stored for 6 months
W0	Logging residues, fresh
W6	Logging residues, uncomminuted, stored for 6 months in windrow
C3	Logging residues, chipped, stored for 3 months in pile
C6	Logging residues, chipped, stored for 6 months in pile

2.2. The manufacturing process

All the assortments were produced in the same plant under conditions as similar as possible in order to minimise the sources of process variations. The raw material volumes of each assortment varied between 10 and 20 m^3 loose. The drying temperature in the rotary drier varied mostly between 120 and 150°C. Magnets and screens were used to remove undesired particles before the material reached the hammermill. The particles passed through a screen of 3 mm circular openings. The pellets, 6 mm in diameter, were produced with a Sprout Matador 12 press without any additives. The length of the straight part of the aperture was 55 mm and the conical part (where the pellets will break off) was 15 mm long. The newly pressed, hot and soft pellets were cooled in a vertical cooler by ambient air of about 0°C.

2.3. Laboratory procedures

- Moisture content (% wb): Six 1 kg samples from raw material and four samples from the cooled pellets were oven-dried at 103 ± 2°C to a constant weight.
- Ash content (% dry wt): The SS187171 [14] test procedures were applied (six samples).
- Heating value ($MJ\,kg^{-1}$ dry wt): The calorific heating value (W_c) was determined (four samples) according to SS-ISO1928 [15] by using a bomb calorimeter (LecoAC-300). The effective heating value (W_{ea}) was calculated by correcting W_c by the heat energy required to vaporise water due to hydrogen released during combustion:

$$W_{ea} = W_c - 2.45 \times 9 \times H_2 \times 0.01.$$

The hydrogen content values (H_2) used in these calculations are based on the literature data [16–18]: S0, S6: 6.38% dry wt, B0, B3, B6: 5.72%, W0: 6.11% and W6, C3, C6: 6.14%, for symbols, see Table 1.
- Particle size distribution (% wt): 20 kg of the milled material was screened through 1 and 2 mm circular holes and the distribution for classes < 1 mm, 1–2 mm and > 2 mm was calculated (moisture content: 8–12%).
- Sulphur and chlorine (ppm): Total sulphur content was determined by measuring sulphur content in emissions during combustion (LecoCHN932). The total chlorine content was determined by using Tecator application not.63-01/83. The results are an average of two samples per assortment.
- Klason lignin (% dry wt), residue after sulphuric acid hydrolysis of the polysaccharides, was determined (two samples) according to Theander and Westerlund [19]. Corrections for ash content or extractives were not made.
- Length (mm): The average of 40 randomly chosen pellets.
- Number of pellets/100 g was counted (two samples, MC: 8–12%).
- Density ($kg\,m^{-3}$ solid): 20 randomly chosen pellets were weighed and their dimensions measured for calculation of density (MC: 8–12%).
- Bulk density ($kg\,m^{-3}$ loose): The weight of a 12.5 l bucket (two samples) filled with cooled pellets.
- Durability: 2–7 days old pellets (four samples) were rotated in an eight-sided tumbler (50 l, 14 $r\,min^{-1}$). The method followed SS187180 [20], except for the sample weight, which was 6 kg instead of 1 kg. The results were expressed as the percentage of fine fractions (< 3 mm) of the total weight.
- Ash sintering tendency: 10 g milled pellets, mixed with 10 g quartz sand (> 98% SiO_2, 0.25–0.75 mm) were combusted for 12 h at three temperature levels: 650, 800 and 950°C. Light microscopy was used for visual determination of the agglomeration degree.

Table 2
Quality parameters of raw material before pelleting

Sample	Moisture content (% wb)		Ash content (% dry wt)		Cal. heating value (MJ kg^{-1} dry wt)		Particle size distribution (% wt)
	Avg	SD	Avg	SD	Avg	SD	< 1/1–2/ > 2 mm
S0	53.9	0.4	0.26	0.03	20.15	0.03	43/45/12
S6	57.1	5.2	0.20	0.02	20.09	0.08	50/44/6
B0	60.4	0.8	2.65	0.18	20.14	0.03	62/31/7
B3	55.2	1.9	3.00	0.15	20.43	0.11	62/29/9
B6	61.6	1.0	6.94	1.27	19.92	0.43	64/28/8
W0	49.1	1.3	2.36	0.24	21.00	0.01	60/36/4
W6	36.4	1.6	1.92	0.27	20.90	0.05	49/41/10
C3	60.4	8.9[a]	3.81	1.23	20.36	0.05	46/30/24
C6	35.5	3.8	5.66	3.24	19.65	0.34	64/31/5

[a]Including a deviating value of 45%.

3. Results and discussion

3.1. Moisture content

The logging residues stored in a windrow and as chips, both of which being harvested in June, had the lowest moisture contents (Table 2). The other raw materials had a moisture content between 50 and 60%. The moisture content of different pellet assortments varied between 7.3 (C6) and 21.3% (B3) (Table 3). The average moisture content of commercially produced pellets is about 10–12%.

The time as well as the amount of energy required for drying is dependent on the initial moisture content of the raw materials. Since the logging residues are easy to dry in windrows, they may have an advantage over the comminuted material with regard to drying economy. Possible effects of drying time or temperature on the quality of pellets were not considered.

3.2. Ash content

The ash content in stored bark and chips was considerably higher (Table 2) than the natural ash content values given in the literature [21]. The high values can be explained primarily by mineral impurities, but even the substance losses during storage can contribute to increasing ash contents. The material stored in a windrow showed lower ash content than fresh logging residues, which is mainly due to partial needle fall. Dry matter losses are usually small during the windrow storage of logging residues [22].

The calculations showed that the relationship between the ash content of raw materials and the pellets (Table 3) was obvious, the coefficient of correlation was $r = 0.982^{***}$. It was, however, noticeable that the ash content of pellets was consistently higher (p-values varied from 0.00 to 0.05), unlike from the pellets, which were produced of chips stored for 6 months (C6). This indicates that the proportion of organic material had decreased during the pelleting process. It is well known that thermal treatments cause a reduction of the extractives [23–25], which indirectly leads to an increasing ash content of the material. Terpenes, which constitute the largest part of the easily volatile extractives, are emitted readily at relatively low temperatures. Visual observations showed that stored chips (C6) contained a high amount of relatively large mineral particles. Screening them out during production may be an explanation of lower values in pellets than in the raw material.

Seasonal variations in nutrient concentrations theoretically imply higher ash contents of materials harvested during the dormancy period in winter [26,27], i.e., fresh assortments in this study. However, the contamination of the material with impurities during storage and handling may normally be so high — as was the case in this study — that seasonal fluctuations are of minor importance for high mineral content of the fuel.

3.3. Heating value

Logging residues had the highest calorific heating value of all the raw materials (Table 2). Sawdust as

Table 3
Quality parameters of pellets

Sample		Moisture content (% wt)	Ash content (% dry wt)	W_c (MJ kg^{-1} dry wt)	W_{ea} (MJ kg^{-1} dry wt)	Cl (ppm)	S (ppm)	Klason lignin (% wt)	Number (pieces/100 g)	Length (mm)	Density of pellets (kg m^{-3} solid)	Bulk density (kg m^{-3} loose)	Durability (< 3 mm % wt)
S0	Avg	13.7	0.45	20.08	18.67	40	155	28.6	427	9.4	1234	606	1.1
	SD	1.3	0.02	0.02		0	7	0.1	5	5.9	63	19	0.2
S6	Avg	14.8	0.53	20.34	18.94	75	95	29.7	326	8.4	1228	641	0.8
	SD	0.8	0.04	0.06		7	7	0.3	4	3.6	47	7	0.5
B0	Avg	10.3	3.71	20.06	18.80	265	335	37.4	324	18.0	1248	676	0.4
	SD	0.4	1.00	0.09		7	78	0.1	4	9.6	60	0	0.1
B3	Avg	21.3	3.45	20.16	18.90	200	410	40.9	227	17.0	1146	653	0.4
	SD	2.5	0.12	0.10		14	113	0.3	3	6.6	17	2	0.1
B6	Avg	7.9	8.29	19.51	18.25	190	390	48.3	790	5.1	1350	747	0.3
	SD	1.8	0.98	0.22		0	14	0.4	6	4.4	97	4	0.1
W0	Avg	8.1	2.63	20.79	19.44	350	525	37.7	347	9.8	1193	552	0.6
	SD	0.2	0.09	0.04		0	21	0.1	5	4.9	35	0	0.1
W6	Avg	11.8	2.39	20.78	19.43	170	445	38.7	478	9.2	1251	592	0.5
	SD	0.9	0.09	0.00		28	7	0.3	5	4.1	56	6	0.1
C3	Avg	14.8	3.84	20.40	19.05	170	450	39.2	336	12.0	1194	683	0.2
	SD	2.7	0.07	0.06		14	0	0.2	4	7.7	67	7	0.1
C6	Avg	7.3	5.50	20.05	18.69	150	435	40.0	503	6.4	1282	665	1.0
	SD	0.6	0.15	0.08		14	177	0.1	6	3.8	71	8	0.7

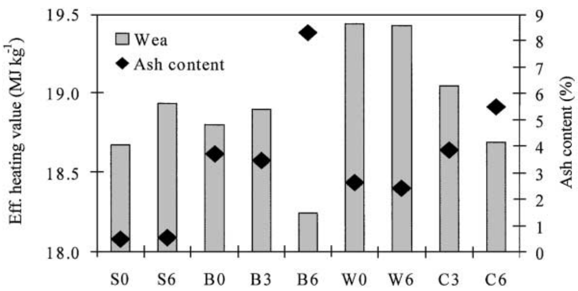

Fig. 1. The effective heating value and the ash content in different pellet assortments.

a pure stemwood component gave the lowest heating values. Stored materials, especially bark and chips (B6, C6) were contaminated with sand which may account for the relatively low heating values in these assortments (Table 2). The extractive content decreases with increasing storage time [28] and thus there is a decrease in heating value due to their higher heating value compared with other chemical constituents [29]. On the other hand, the selective biological degradation, the microbes prefer low molecular weight sugars to more energy-rich lignin [30], can compensate the losses of the heating value. According to White [31], there is a high linear correlation between the effective heating value of the extractive-free wood and lignin content. Due to the complexity of the processes it is difficult to make a forecast of how a certain material will be affected in certain storage situations.

In most of the assortments, the calorific heating value of pellets was significantly lower than that of the raw materials (Table 3), probably due to the loss of volatile extractive compounds during drying. However, the pellets made out of chips stored for 6 months and out of sawdust showed the opposite ($p = 0.04$ and 0.004, respectively). The higher value in pellets could be explained by the removal of coarse sand particles during screening. The temperature during drying of stored sawdust was 70°C compared to 120–150°C for all the other assortments. This factor might explain the smaller losses of volatiles compared with fresh sawdust. It cannot, however, be a complete explanation for the differences. The effect of the ash content can be seen in Fig. 1.

3.4. Particle size distribution of the milled raw materials

More than 90% of the grind used for bark pellets consisted of fractions smaller than 2 mm (Table 2). The pellets made out of stored chips and sawdust consisted of a finer grind than the fresh ones. This might be due to deterioration during storage, that means easier milling. The fresh logging residues, however, contained more fine fractions than the stored ones. Fresh logging residues contain a higher percentage of needles than material stored in a windrow. The degradation of logging residues is minimal in windrows [22]. There was a significant negative correlation ($r = -0.901^{**}$) between the percentage of the finest particles (< 1 mm) in the raw materials and the moisture content of pellets, when an extremely moist sample (B3: 21.3%) was not included. This may be a consequence of faster drying of the finest particles. The observation deserves attention, since the strength properties may be lowered due to excessively dry raw materials.

3.5. Total chlorine and sulphur

The total chlorine contents were lowest in sawdust pellets (40 ppm = 0.004%) and highest (350 ppm) in fresh logging residues (Table 3). The same tendency was found in the sulphur content with values ranging from 100 to 530 ppm. The sulphur concentration was generally slightly higher in logging residues than in bark. These values were close to the values reported in the literature [21,32]. Both chlorine [33] and sulphur depositions [34] are dependent on the level of air pollution and therefore are highest during wintertime and lowest during the summer [34]. This might be an explanation for the highest values in fresh logging residues. However, the variations between and within trees may be large, depending on the form of the crown, the number of the needles, the roughness of the bark, the direction of the dominating winds, etc., and more fundamental conclusions cannot be drawn.

3.6. Klason lignin

The lignin contents in pellets made of bark and logging residues were considerably higher than that of sawdust pellets (Table 3), which are similar to values

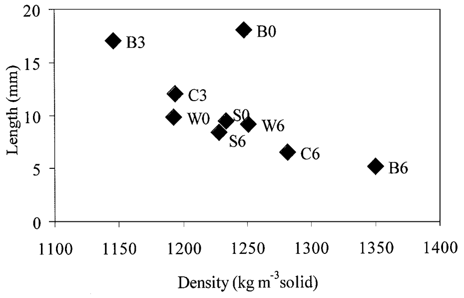

Fig. 2. Relation between density and length of the individual pellets.

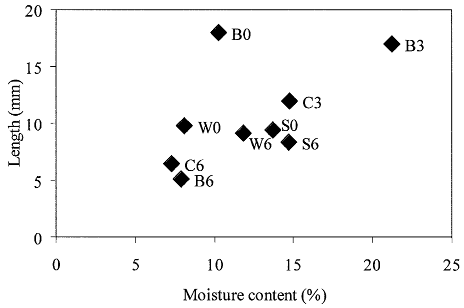

Fig. 3. Effect of moisture content on average length of the pellets.

that are reported earlier [18,35–37]. The lignin content increased with storage time, especially in bark assortments. Similar results have been reported [37] and a positive correlation between temperature during storage and lignin content was observed. Selective microbial degradation of wood carbohydrates increases the proportion of lignin after storage. Lignin composition varies between tree species and tree components, e.g., between wood and bark [38]. Compression wood has a higher softening temperature than normal wood [39] as well as the proportion of compression wood being higher in logging residues than in sawdust [40]. The carbohydrates can, especially at high temperatures, be transformed via dehydration into furans, phenols, acids and other non-carbohydrate products, and can be determined as Klason lignin [41]. Knowledge of lignins and other compounds of bark or needles is limited and the changes in raw material properties during pelleting are difficult to predict.

3.7. Number, length and density

Visual observations showed that the pellets were more compacted, and broke down readily in the die, when the residence time during pressing was prolonged. These observations were confirmed when correlation analyses showed clear relationships between the parameters (number/density: $r = 0.920^{***}$, number/length: $r = -0.742^{*}$ and density/length: $r = -0.648^{*}$). The pellets made of fresh bark were long despite the relatively high density (Fig. 2). The pellets made of bark stored for 3 months showed low density compared with the other assortments. These pellets had a high moisture content after cooling (Table 3) but dried down to about 10% before the density measurements were taken. Drying resulted in cavities filled with air and lowered the density as a consequence. The particle size distribution had no effect on the density of the pellets. A clear relationship between the moisture content and the length of the pellets was observed (Fig. 3), which might indicate that moisture was functioning as a binding factor.

3.8. Bulk density

The bulk density of the pellets is an important factor for the transport and storage capacity. In general, the bark and chips pellets had the highest bulk density (Table 3). The results showed that the length of the pellets had no influence on bulk density, while the density of individual pellets had a positive effect on the bulk density. As mentioned earlier, the bulk density was measured using a bucket, which means that the actual values may not be directly comparable with values measured, for example, in a container.

3.9. Durability

High durability of pellets is advantageous when transporting pellets either at the production plant or to the end-user. Fines may accumulate under transport conveyors and result in dust explosion. Fines are also formed when pellets are dropped from the conveyor down to the pile. The high tendency for moisture absorption of fines and susceptibility for fungal attack imply a risk for temperature development. Screening the pellets before delivery to the end-user will reduce the dust problems to some extent. High-risk zones at the heating plant and during combustion are fuel silos, mills, cyclones and filters. In small-scale handling, the dust is problematic, mainly due to health risks.

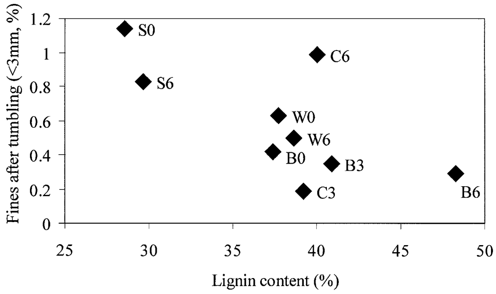

Fig. 4. The relationship between the percentage of fines and Klason lignin content of the pellets.

The highest durability, i.e. lowest amount of fines, was measured in pellets produced using logging residue chips stored for 3 months and of bark. The pellets made of logging residue chips that had been stored for 6 months and those made of fresh sawdust were most fragile (Table 3). The percentage of fines after tumbling decreased with increasing lignin content ($r = -0.683^*$, Fig. 4). Strength properties of wood are dependent on the amorphous components, such as lignin and hemicelluloses, to an extent determined by their concentrations and structural arrangements [42]. Various steps during pellet production, e.g., drying at high temperatures, milling and pressing, may affect the material properties. According to Goring [43], the softening temperature of lignins and hemicelluloses affects the bonding properties of wood and, on the other hand, the sorption of water decreases the softening temperature by plasticising the molecule chains. The glass transition temperature (the main softening point) was 195°C in dry spruce periodate lignin and stabilised to 90°C in lignin containing 27% or more water [43]. Pellets normally contain 8–15% water, which means lignin softening temperatures are about 110–135°C. The low moisture content and drying temperature (70°C) of the pellets made of logging residue chips stored for 6 months may not have been high enough for softening. A minor fire appeared in the cooler when the fresh sawdust pellets were processed, indicating that the pellets might have been insufficiently cooled when leaving the cooler. Pellets can have a reduced durability due to cracks caused by the temperature gradient between the outer and inner layers [44], meaning that fines may have been already formed before the testing of the durability.

The durability of the pellets correlated positively with moisture content when each raw material group (S, W or C) was separately evaluated. The bark pellets had a high durability independent of moisture content. A positive correlation between the ash content and durability of pellets was shown. The ash content correlated positively also with lignin content, which indicates that the effect on the durability was indirect. Moreover, the temperatures used were probably too low for agglomeration of minerals.

The major part of the fine fractions comes from the end parts of the pellets implying that longer pellets produce fewer fines as long as they do not break. A slight tendency of shorter pellets to give more fines after tumbling was observed. Large particles in pellets means inhomogeneous shrinking, which may cause cracks [45]. It is known that, e.g., a large extractive content affects gluability and contributes to the reduction of shrinkage [5,46]. The bark pellets showed good durability independent of length, probably due to the high extractive content. In general, it is concluded that all the tested assortments had good durability.

The durability of pellets is dependent on the chemical and physical properties of the raw materials and on the process variables. Thomas and van der Poel [7] concluded that binding in animal feed pellets is most probably due to solubilisation and subsequent crystallisation of raw material components or due to surface tension of water in a system of air, water and particles to maintain structural integrity of the pellet. Particles may also be folded due to the pelleting process and thus plied around each other [47]. According to Chow and Pickles [5] the thermal softening of moistened wood and bark at temperatures below 180°C is more physical than chemical in nature. Exact mechanisms with regard to wood pellets are still poorly understood.

3.10. Sintering tendency

The unstored bark, bark and chips stored for 6 months before pelleting showed a clear agglomeration tendency at 650°C. Ash particles were, however, still visible in the agglomerate (Table 4). According to the risk prognoses, the sawdust pellets constituted a low risk for agglomeration and pellets made out of bark or logging residue chips stored for 6 months (B6, C6) showed a high risk level. In the present study,

Table 4
The sintering tendency of pellets made of different raw materials[a]

Sample	Combustion temperature 650°C	800°C	950°C	Risk level[b]
S0	(A)	A	A(B)	L
S6	(A)	A	A(B)	L
B0	A(B)	A	AB	M
B3	(A)	A	AB	M
B6	A(B)	A(B)	AB	H
W0	(A)	A(B)	A(B)	M
W6	(A)	A(B)	A(B)	M
C3	(A)	A(B)	AB	M
C6	A(B)	A(B)	AB	H

[a]A: The sand particles are agglomerated by ash particles; B: the sand particles are agglomerated, ash particles are not visible; ( ): the evaluation is unreliable or the effect is weak; L: low; M: medium; H: high.
[b]Determined after combustion at 900°C.

the risk for agglomeration increased with higher ash contents.

4. Conclusions

- Bark and logging residues were suitable raw materials for pellets production compared with sawdust, especially with regard to durability.
- The durability of pellets was significantly influenced by the lignin content and the positive effect of moisture was observed. Bark pellets always had good durability irrespective of moisture contents.
- The mineral impurities in the raw materials have to be minimised due to their negative effects on the heating value.
- The pellets had higher ash content and lower calorific heating value than the raw materials, probably due to loss of volatiles during drying.

It is not clear, how the measured quality parameters influence each other or the quality of the pellets. The effect of the manufacturing process itself is also unclear. The study showed that improving pellet quality is possible by increasing the knowledge of the raw materials used. More research is needed on the effects of seasonal variations and storage, to facilitate a steering of production in the desired direction and to produce more homogeneous pellets all round the year.

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