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Dustiness of Various Carbon Materials for Metallurgical Industries

G. Jahrsengene[1], A.A. Lindholm[2], I. Opstad[2], and S. Jayakumari[2]
[1]SINTEF, Norway, goril.jahrsengene@sintef.no
[2]SINTEF, Norway

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Abstract – Due to the fragility of traditional biocarbon materials, high amount of dust and fines may be generated during transport and handling when replacing fossil carbon with biocarbon in metallurgical industries as part of their decarbonization strategies. Although carbon losses and effect on furnace performance are important, the health and safety of workers are of the highest importance. Inhalable and respirable dust is a direct safety concern, and the increased risk of dust explosions are also present. As such, being able to easily predict the airborne dust formed under typical conditions is necessary. In this work, the aim is to compare one of the most common strength tests, the tumble abrasion test, to a standardized dustiness evaluation called the Heubach Dustmeter Type I analysis, which has previously not been used on these types of materials.

1. INTRODUCTION

Utilizing renewable carbon reductants in metallurgical industries as a replacement of fossil carbon is a goal for industries spanning silicon, ferromanganese and other ferroalloys, steel, as well as for aluminium production. For charcoal, the main challenge is the fragility of the material, producing significant amounts of fines and dust during transport, storage and handling. This results in mass losses, affects furnace performance, and raises health and safety concerns due to the airborne dust (Jahrsengene et al., 2023; Jayakumari and Ksiazek, 2023). Related to health and safety, being able to predict the presence of airborne dust is an important step for choosing materials, and strategies related to agglomeration techniques which typically makes the biocarbon stronger.

Figure 1: Example of what occurs when dropping a fragile charcoal material after tumbling.

Tumble abrasion strength method, where a sample of known particle size distribution is tumbled in a drum for a set speed and time before sieving, is the main method used to estimate the mechanical strength as it attempts to replicate the mechanical degradation that occurs when the material is transported and charged into the furnace. The results are often reported as the tumble index and the abrasion index after sieving after the test. ISO 3271 (Iron ores for blast furnace and direct reduction feedstocks — Determination of the tumble and abrasion indices (ISO Standard, 2015)) defines these as amount over wt% >6.3 mm and wt%<0.5 mm respectively.

To evaluate if a specific material is likely to generate a lot of airborne dust, it has been suggested to further analyse the smallest fraction after the abrasion test. By including smaller sieves than 0.5 mm during the analysis, the airborne dust generated in the strength test could possibly be better identified. For this approach, representative sieves must be included in the analysis.

Airborne particles are most often defined as particular matter (PM) with an aerodynamic diameter (considering the combined effect of shape, density, porosity, surface roughness) rather than the actual diameter of the particles. The resulting aerodynamic diameter is equivalent to how a smooth, spherical particle with 1 g/cm^3 density would behave. Although airborne particles often are defined as having an aerodynamic diameter of 100 µm or less (PM_{100}), a 100 µm sieve will likely not capture the airborne dust due to the particles possibly having a higher measured diameter. Also, losses can be expected during transfer of materials to sieves and during sieving due to the aerodynamic properties. Small carbon dust is typically also electrostatic and can get stuck to other particles or equipment. In addition, the properties of the material have an influence on the sieving process; is the material fragile the sieving process itself may give rise to more dust and possible different fractions than what was initially produced by the drum.

Heubach Dustmeter is a standardized instrument designed to measure the dustiness of bulk solid materials, particularly powders and granulates (Delft Solids Solutions, 2025). It is used in various industries to assess how much dust a material release during handling by use of a rotating drum, a coarse particle separator, a well-controlled air stream and a filter. As such, the method follows the principle of the gravimetric filter method in a standardized, closed lab environment, reporting total airborne dust (in mg/kg) under certain conditions of material, drum speed and airflow, drawing airborne particles onto the filter. The result reported reflects the dust present in the bulk material, and those formed during the tumbling. The method is extensively used on seeds (Euroseeds, 2026) and powders (Bach and Schmidt, 2008) with well, pre-defined parameters for the standard test.

Heubach dustmeter measurements have currently not been reported for evaluating dustiness on materials for metallurgical industries. The methodology is similar as the abrasion tumble strength test but will avoid losses and influence of sieving due to the closed environment, and capture of dust using an airstream. Finding appropriate parameters and standardizing the method would be crucial for this to be a developed method for the metallurgical industries. Initial investigations are necessary to understand the major limitations of the equipment and identify important parameter effects when using these types of materials in this type of test.

In this work, metallurgical coke, coal, charcoals, and agglomerated biocarbon in the form of pellets have been assessed by rotating drum tests to determine the smallest airborne fractions. Heubach Dustmeter Type I measurements were done with standardized parameters for drum speed, time and airflow. One charcoal was investigated in more detail related to the effect of

drying, as well as variation in drum speed and time. The results were compared to more conventional tumble abrasion strength analysis using a Hanover drum followed by sieving. To investigate the airborne dust fractions further, particle size distribution analysis was performed on the airborne materials collected by the filter during the Heubach Dustmeter measurements.

2. EXPERIMENTAL

2.1 Materials

In this work, three different industrial charcoals (Charcoal 1, 2 and 3) were considered and included for different parts of the work. Reference materials of metallurgical coke and coal was included in most of the study. Two biocarbon pellets (Pellet 1 and 2, no further details on production available due to confidentiality) were also investigated to show how this important step of biocarbon agglomeration affects the strength and airborne dust generation. Pictures of the materials is given in Figure 2.

Charcoal 3 was investigated in more detail after drying for 24 h at 110 °C, to see how this would affect the results (as a possible pre-treatment to normalize the material before the test) and briefly evaluate the effect of moisture.

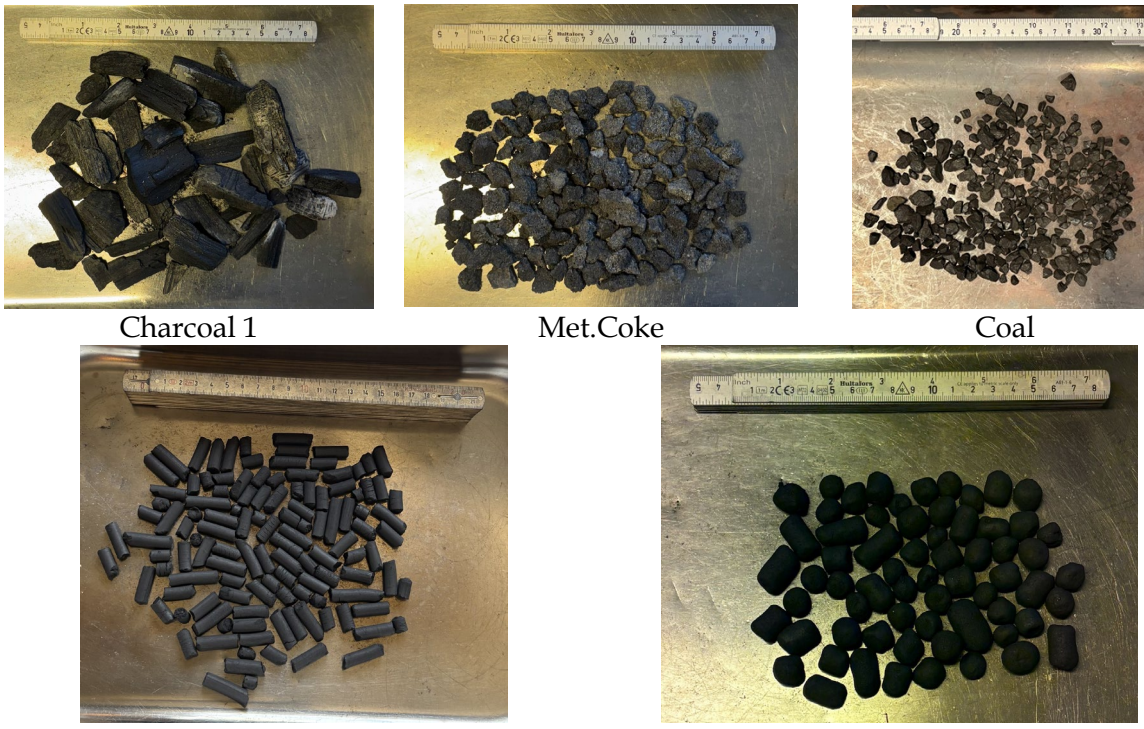

Figure 2: Materials used in the study (except charcoals 2 and 3).

2.2 Cold strength tumble test

Tumble abrasion strength was evaluated for the carbon materials in a lab setting using a Hanover drum. The carbon material was placed in the steel drum measuring 30 cm in diameter that contained 4 raisers spaced 90 degrees apart. The standard test was run with 100 g samples; however, some tests with Charcoal 3 also utilized 200 g (to see difference in the weight). The sample was tumbled 5-30 minutes at 30 or 40 rpm. For all samples, materials of size smaller than 1.25 mm was removed before start, and for the charcoal, coal and metallurgical coke

samples, 90-100 % of the material was above 6.7 mm (the rest above 4.75 mm). The pellets were used in the shape they were produced.

After the test, the material was sieved in 9 different fractions (+10 mm, +6.7 mm, +4.75 mm, +3.35 mm, +1.25 mm, +0.5 mm, +0.25 mm, +0.125 mm, and -0.125 mm). The expectation is that the fraction smaller than 0.125 mm is close to the airborne dust fraction and is the focus of this work, while there are also losses present that could be lost e.g. in the ventilation in the workspace. Only one parallel was done for each material.

2.3 Dustiness - Heubach Dustmeter type I measurements

The standard Heubach Dustmeter type I was used for the dustiness measurements; the standard settings utilize a rotary speed of 30 rpm for 5 minutes with an airflow of 20 L/min (DIN 55992-1). During the first campaign, the reference materials, pellets and Charcoal 1 were run as received and already generated dust is included in the analysis. Each material was run in triplicate. A second campaign, run with duplicate measurements, used Charcoal 3; both 30 and 40 rpm was used as rotation speed, and the time was increased to 10 minutes with the filter being changed and weighed at several points during the tumbling. This was partly done due to the generation of large amounts of dust for this sample; the dust blocks the filter, and the well-controlled air flow will be affected as a result of which the measurement clearly will lose accuracy. Charcoal 3 was also run at 30 rpm after drying overnight.

2.4 Particle size distribution

Laser diffraction (LD) is an instrumental method for the characterization of particle size distributions (PSD) of dry powders, suspensions and emulsions. The dust of the filters from the Heubach Dustmeter measurements was collected, split in two parallels (except for the least dusty material where all was combined to one parallel), and was placed in the sample unit of the laser diffraction instrument. A Malvern Mastersizer 3000 was used in combination with the Aero S sample dispersion unit for measuring in air. This configuration has a measuring range from 0.1 µm up to 3500 µm. The used optical model is Lorentz-Mie taking into account the optical characteristics of the particles, all in accordance with ISO 13320-1:2020. The applied optical model has a Particle Refractive Index [n] of 1.52, which is a commonly used value and among the range given for charcoal like materials. The validity of the optical characteristics is verified by the quality of the fit. The fit is a comparison of the actual measured diffraction pattern and the calculated deconvoluted diffraction pattern.

The principal result of the LD technique is a volume-based PSD for a collective of *spheres* having defined optical properties, for which the calculated scattering behaviour gives an optimum match with the measured pattern. As such, with non-spherical dust, the model may be less accurate. The definitions of the key numbers are given below.

- D_0: The minimum particle size.
- D_{10}: Distribution Percentile, 10% of the particle volume is smaller than the value.
- D_{50}: Distribution Percentile, median particle size.
- D_{90}: Distribution Percentile, 90% of the particle volume is smaller than the value.
- D_{100}: Distribution Percentile, 100% of the particle volume is smaller than the value, the end of the distribution.
- D [4,3]: Volume weighted mean diameter $(\Sigma n_i D_i^4)/(\Sigma n_i D_i^3)$.
- Span: Distribution width, calculated as $(D_{90} - D_{10})/ D_{50}$.
- Mode: Modal size, particle diameter present with the highest frequency

3. RESULTS AND DISCUSSION

3.1 Cold strength tumble test

The results of the smallest fractions of the cold strength tumble test after running the 100 g samples for the majority of the materials in the study is presented in Figure 3. The results show that when evaluating the more traditional abrasion index, the fraction below 0.5 mm, the trend between the different materials is slightly different than when evaluating the fraction only below 0.125 mm. Especially when evaluating the three charcoals this is evident; Charcoal 2, which had 14 wt% of material under 0.5 mm, had less than 2 wt% being below 0.125 mm. When evaluating Pellet 2, all the material below 0.5 mm is also below 0.125 mm, but in the other cases there is usually a difference (although much less than for Charcoal 2). These results show that the abrasion index is not sufficient to compare material trends related to the airborne dust, since the distribution within this fraction varies greatly between different materials.

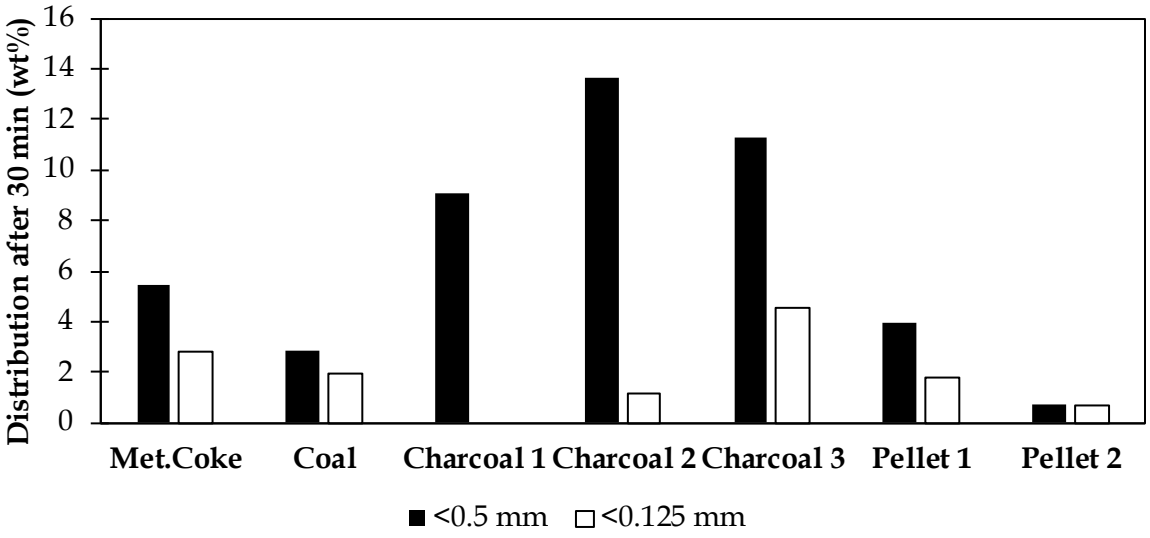

Figure 3: The weight distribution of the smallest fractions after 30 minutes tumbling at 40 rpm with the Hanover drum.

In these types of experiments, the final distribution most often disregards the material losses. 100 % typically sums up what is measured in the different fractions but depending on the properties of the material there are some carbon not found when weighing the resulting separated fractions. For the above materials, after 30 minutes, the charcoal materials had ca. 2.7-2.8 wt% loss, the metallurgical coke and coal about half at 1.4 wt%, while the pellets had only about 0.7 wt%.

It is observed that the losses are mainly due to the smaller particles, which is observed during the experiment to more easily get stuck to the smallest sieves as well as the tumbler, or small material that vanish into the ventilation when opening the drum, transferring from drum to the sieves, or from the sieves to the scale. Some of the carbon was also shown to be more electrostatic than others, and may both get stuck to other larger carbon particles, agglomerate together, and get stuck in the sieve. The small, airborne particles that ends up dispersed for longer time air during transfer between equipment may easily get removed with a normal lab ventilation suction, which is necessary to use for safety and could otherwise also spread out over the working area. As such, it can be assumed that large part of the losses is airborne dust, and the 0.125 mm fraction is not an exact measure of this fraction.

Charcoal 3 was investigated in more detail to get a better understanding of the losses, as well as some further information about moisture and rotation speed during the tumble test. After

drying the material overnight, it had lost 7 wt% which can be attributed to moisture. 200 g of the charcoal, both dried and as stored, was tumbled at 30 and 40 rpm, while the 100 g sample as presented above is also evaluated to see the effect of the sample amount.

The results related to the losses are presented in Figure 4. For the 100 g sample run at 40 rpm, it can be observed in Figure 4a that after 5 and 10 minutes, the material loss is of the range of what is measured in the 0.125 mm fraction. After an additional 20 minutes (the previously separated fine fractions below 0.5 mm was not re-introduced to the tumbler after mid-sieving), the total loss does not continue in a linear fashion. This indicates that some of the small dust could more easily attach to larger particles over time, or that the material itself is reaching a type of steady state.

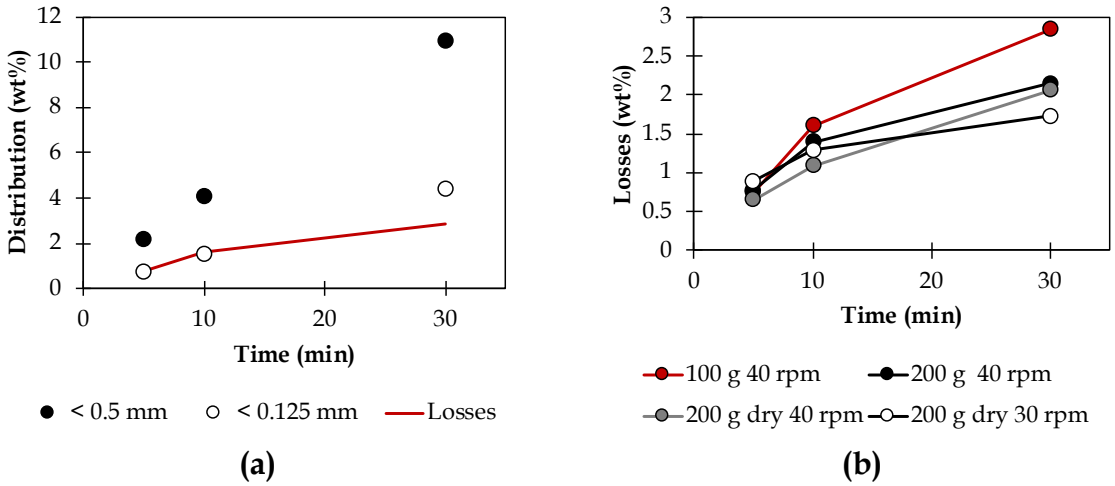

Figure 4: The distribution of the smallest fractions with the losses included after 5, 10 and 30 minutes tumbling. (a) 100 g, 40 rpm, and (b) variations specified for losses only.

Comparing only the losses in Figure 4b including most of the 200 g samples, the exact same trend is observed as for the 100 g loss in Figure 4a. In addition, the mass loss seems independent of the amount, moisture and rotation speed for the first five minutes. The three examples of 200 g samples are otherwise very similar after all three times, while the 100 g sample had significantly more losses after the full 30 minutes. This shows the importance of comparing same sample sizes; a possible explanation could be that more of the dust is able to settle on larger charcoal pieces when more are present.

Finally, the measured <0.125 mm fraction (excluding the losses) for all these are compared in Figure 5. As expected, the same sample run at 40 rpm gave more of the smallest fraction than 30 rpm, although, in the case of the dried material, the difference was minimal until reaching 30 minutes (Figure 5a and 5b). However, when observing the difference between the dried and not dried material run with the same rotation speed in Figure 5c and 5d, the expectant behaviour of the dried giving more fines is not observed. At 40 rpm the dry material is always marginally lower than the not dried, while at 30 rpm the materials shift, also ending with the dried material giving less of the smallest fraction.

The behaviour related to the dried materials observed in Figure 5c and 5d was surprising and could not be explained by including the losses. Although not done in repeat, both rotation speeds gave the same trend and is an indication of the effect that the moisture in the charcoal when it is at these levels (7 wt% and below) have little effect on the smallest dust.

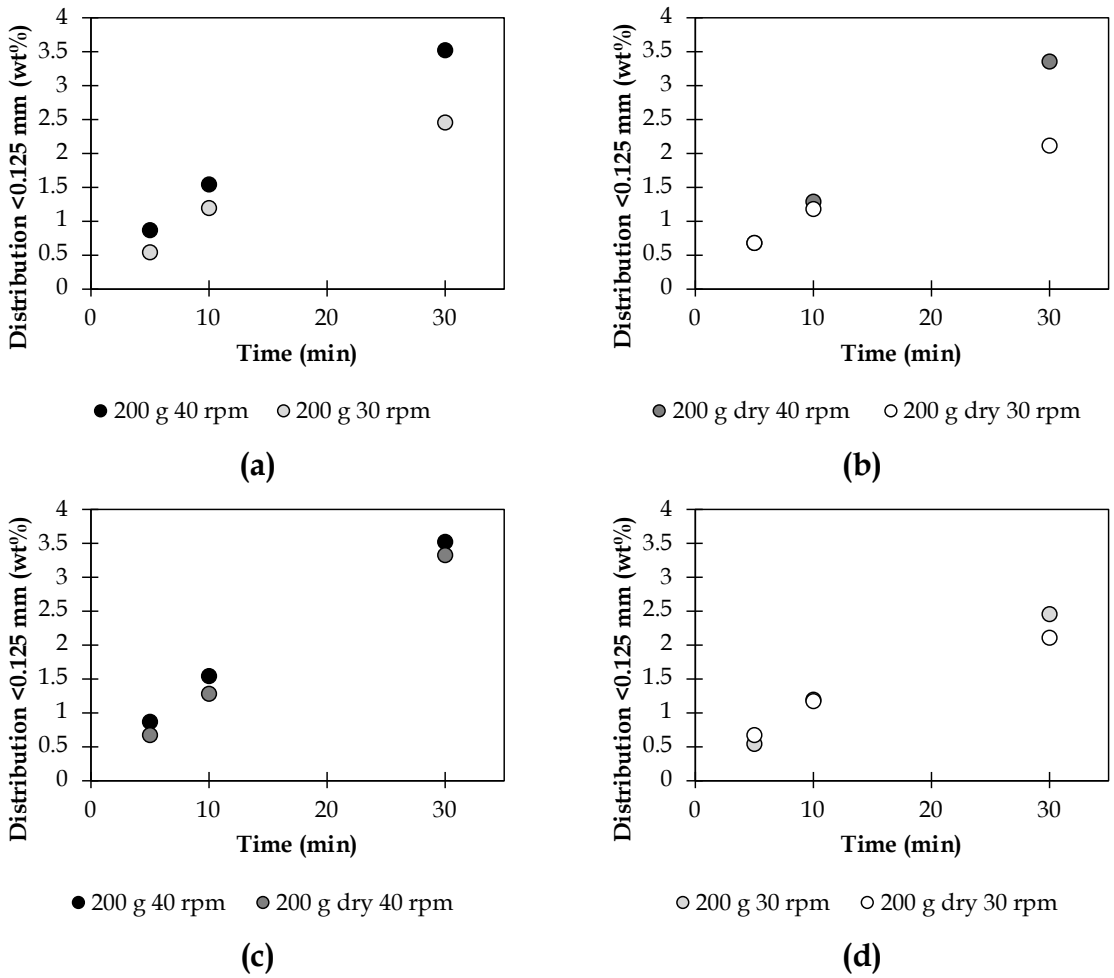

Figure 5: Comparison of the measured <0.125 mm fraction (excluding the losses) between the different parameters.

3.2 Heubach Dustmeter results

By use of the standard settings of the Heubach Dustmeter type I (DIN 55992-1: 30 rpm, 5 minutes, airflow 20 L/min), the average dustiness is reported as mg/kg (ppm, based on the weight loaded for the test) and is presented in Figure 6 (2 duplicates of Charcoal 3, 3 duplicates for all other samples). The relative standard deviation (RSD) is 5-13 % (well within the 17 % found by Round Robin testing). The dustiness is in the range of 400-2500 mg/kg for all but the charcoals, which have the highest dustiness potential, with Charcoal 3 (5600 mg/kg) more so than Charcoal 1 (4200 mg/kg).

The removal of moisture of Charcoal 3 by drying overnight, resulting in 8 wt% loss, have an expected increase in dustiness and ends up with the highest measured dustiness potential of 6800 mg/kg. By adjusting for the moisture initially included in the dried sample, the dustiness is estimated to 6300 mg/kg, which is closer to the non-dried material. When evaluating the uncertainties the adjusted number is within the uncertainty of the non-dried material. As the other samples does not have the final moisture level at time of measurement, it is not possible to compare them on dry basis, as the transport and storage have an effect (likely what is resulting in 8 wt% compared to the 7 wt% moisture loss before the Hanover drum test). The numbers reported from the test cannot be compared to previously reported numbers for other types of materials because they often investigate powders themselves more importantly their inherent dustiness, not dust that is formed during the test due to being a fragile material.

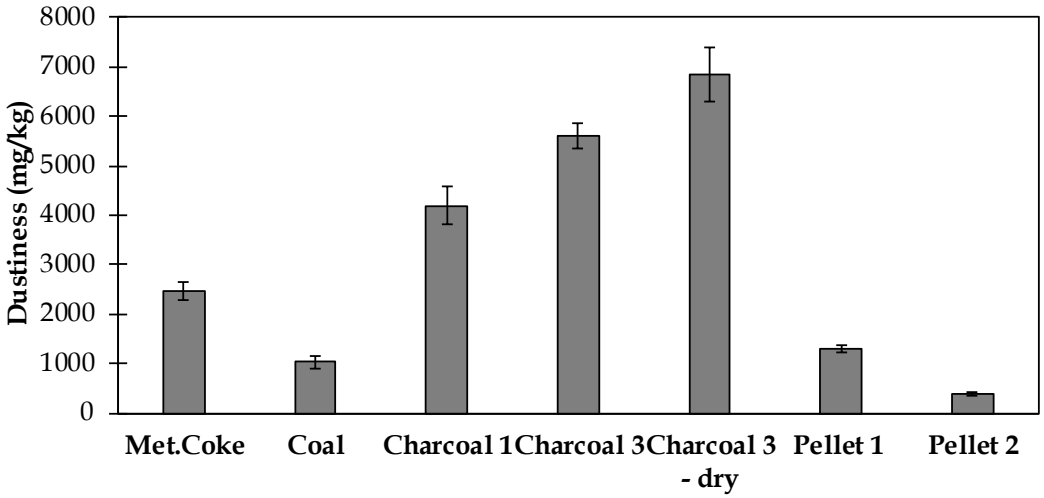

Figure 6. The dustiness as reported by standardized Heubach Dustmeter Type I for the different materials.

The results in Figure 6 also show that the agglomeration technique of pelletization is an effective way to improve biocarbon dustiness. The two pellets can be seen in Figure 2 to be different from each other, and the Hanover drum experiments also indicated a large difference (they are from different producers and as such not produced in the same way). Pellet 2 is the least dusty material, better than also the reference metallurgical coke and coal samples. Within the RSD, it is not possible to discern if Pellet 1 is any different than the coal, indicating this has not as good properties as Pellet 2, however, a large improvement from the typical charcoals can still be observed.

Charcoal 3 was investigated in more detail, running also at 40 rpm and for longer times. Although initially planned to go up to 30 minutes, to best compare with the Hanover drum test results, the high dustiness of the material made it necessary to either change the filter every few minutes or reduce the amount of material drastically. For this reason, the test was stopped after 10 minutes, keeping the initial amount around 100 g and the use of 3-6 filters per experiment. The results are presented in Figure 7, which summarize all filter measurements of the 2 parallel runs done for each set of parameters.

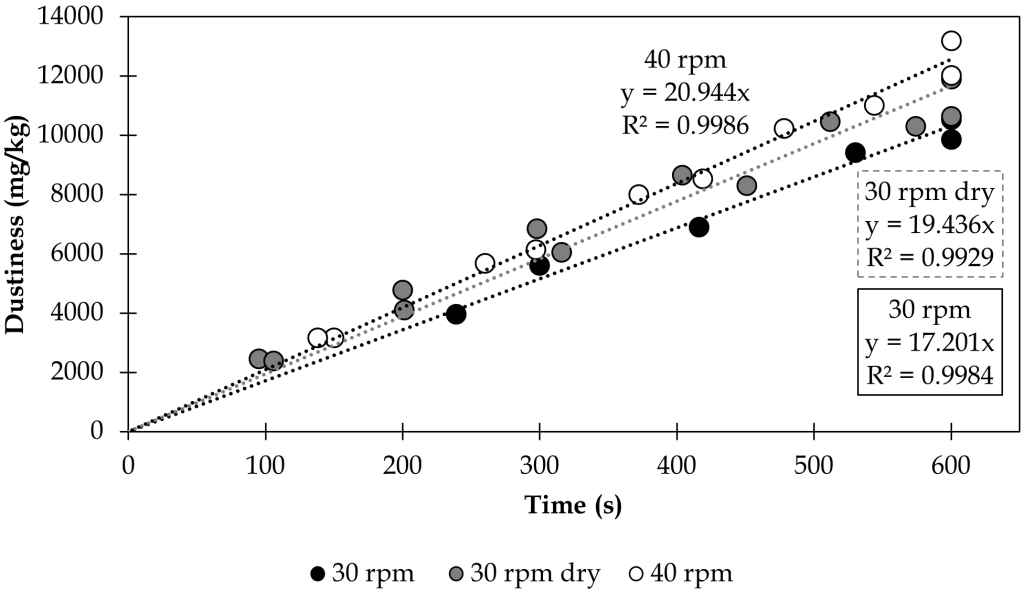

Figure 7: Dustiness behaviour of Charcoal 3 during 10 minutes of tumbling.

As expected, a linear increase with time is observed. The slope is higher for the higher rotation speed of 40 rpm, which is explained by the larger number of interactions with walls and other material that the material experience at higher rotation speed. The dry material also has an increased slope compared to the not dry material at 30 rpm. With more moisture in the sample, there is a possibility that this cause cohesive effects which prevent dust from becoming airborne, possibly by sticking it to larger particles. However, this change could also be explained by the lower sample mass when dried, as the sampling to 100 g was done before drying. Where the non-dried sample still has 8% weight in volatiles, these are not solids that can be caught by the filter. The dried sample did not contain these volatiles meaning a relatively higher possible dusting potential. The mass loss of 8% is also comparable to the relative difference of dusting potential between the samples of ~10% further strengthening this possibility; when adjusting for the 8 wt% the slope for the dried material is almost identical to the not dried material (17.88 mg/kg/s).

3.3 Particle size distribution of captured dust

The dust captured in the standardized Heubach Dustmeter type I measurements (except the Charcoal 3 variants), where collected from the different parallels and split into two for the LD analysis (for the least dusty material, Pellet 2, all the dust collected was used for one parallel LD measurement due to the low amount of dust for this sample). The results, in form of differential and cumulative volume, are presented in Figure 8, and the key numbers are presented in Table I.

In theory, for the Heubach type I method airborne particles with an aerodynamic diameter below 100 µm are caught on the filter as dust and larger particles settle in the coarse particle separator. For the samples, 97-99% of the volume of particles is below 100 µm in the LD analysis. The small volume of particles detected above 100 µm is likely due to the differences in equivalent sphere volume reported by laser diffraction and the aerodynamic diameter. In the latter also density, porosity, shape and potential surface roughness are considered.

Table I: The laser diffraction analysis key numbers.

	D_0 (µm)	D_{10} (µm)	D_{50} (µm)	D_{90} (µm)	D_{100} (µm)	D[4,3] (µm)	Span	Mode (µm)
Met.Coke	0.1	3.2	15.3	45.7	160.8	21.0	2.8	18.7
Coal	0.1	4.9	16.9	48.2	162.9	22.9	2.6	17.0
Charcoal 1	0.5	5.5	17.4	55.9	238.3	25.7	2.9	17.0
Pellet 1	0.2	5.5	13.5	32.5	183.0	17.7	2.0	13.6
Pellet 2	0.2	3.5	14.4	46.5	209.3	21.2	3.0	16.0

The results in Figure 8 show that the dust samples have similar particle size distributions with only nuanced differences. For all samples the particle size distribution of the dust is monomodal. The median particle size (D_{50}) was 13.5-17.4 µm, while the frequency that occurred the most (mode) was a bit higher, 13.6-18.7 µm. For the coal and Pellet 1 no difference is observed between these two values; metallurgical coke and Pellet 2 increased from median to modal while the charcoal was slightly lower. The volume weighted mean diameter was higher in all cases, 17.7-25.7 µm.

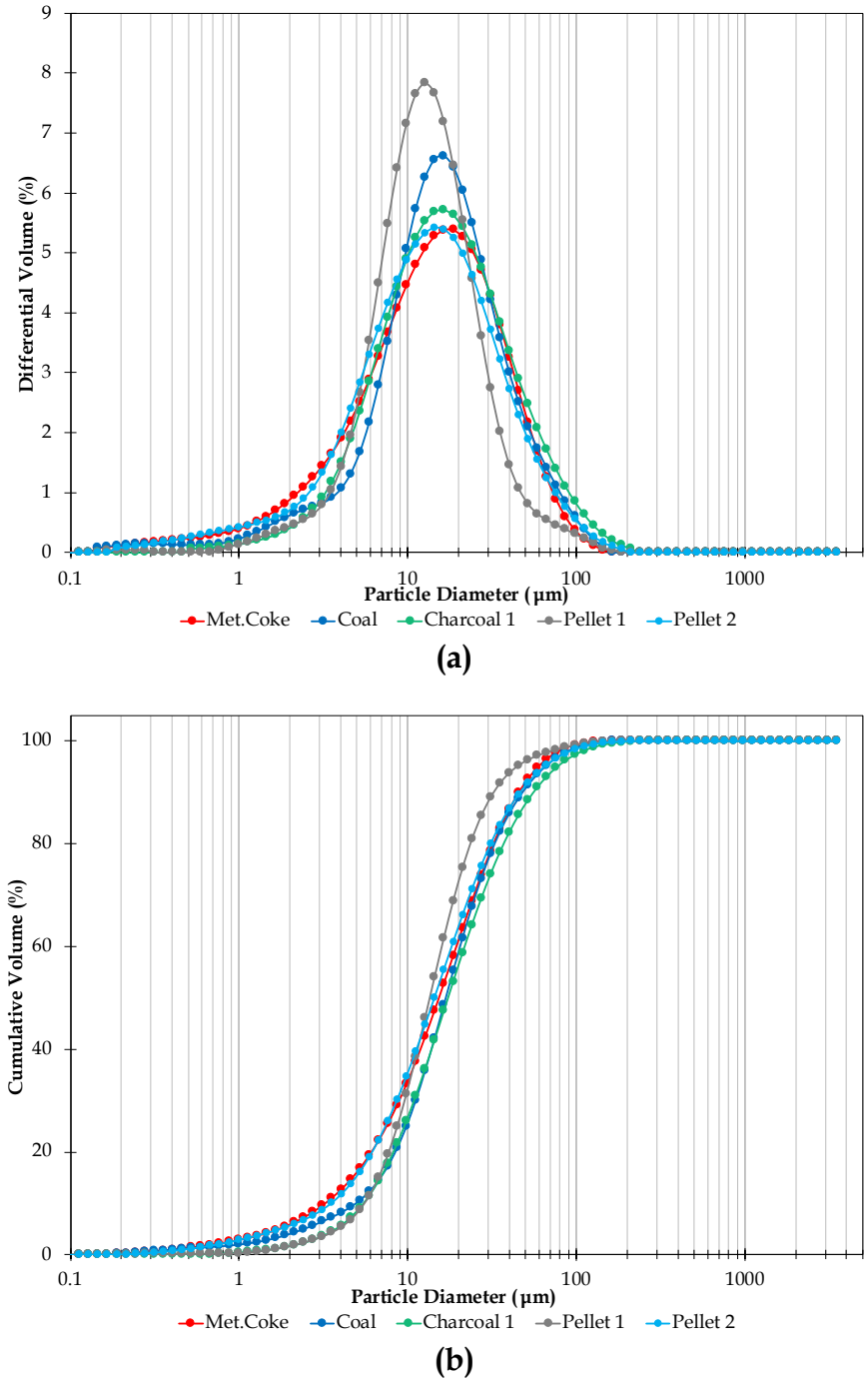

Figure 8. The particle size distribution of the captured dust in (a) differential and (b) cumulative volume.

Looking at the D_{90} values, metallurgical coke, coal and pellet 2 were all of similar values around 46-48 µm, but the charcoal was significantly higher with 56 µm and pellet 1 significantly lower, with 33 µm. Despite the difference, this mean that most of the dust captured is quite small. The test targets PM_{100} and as such 100 µm as the aerodynamic diameter, but small amounts of particles (1-3 vol%) were detected to have the spherical diameter above this value. The larger values detected can be due to the actual shape and the use of equivalent sphere volume used for the calculations. The largest particles captured by the test was close to 250 µm for charcoal, indicating that some dust of this size may still be airborne and as such with an aerodynamic diameter still below 100 µm, as previously mentioned likely due to density, porosity, shape and surface roughness of the particles.

4. HEALTH AND SAFETY

PM_{100} (dust with aerodynamic diameter of 100 µm or less) is expected to be airborne and cover both inhalable and respirable fractions upon handling scenarios (Heyder and Svartengren, 1999). Inhalable dust is often considered to only affect the upper respiratory system and is irritating for nose, mouth, eyes etc. Typically, one may sneeze, cough, or cry when subjected to this dust. This dust typically does not have the longest travel distance, and relatively quickly end up on surfaces (where it can be further disturbed and briefly be airborne again). However, the smaller dust, most typically defined as 10 µm and smaller (PM_{10}), can be airborne for a much longer time, and is defined as the respirable (or thoracic, or suspended) dust. This dust may penetrate the lungs and as such potentially cause very serious health issues.

The Heubach Dustmeter type I test aims to capture PM_{100}, but it is not possible to say if some of this is so small it is also respirable and PM_{10}. The LD results cannot be viewed as aerodynamic diameters and as such cannot properly differentiate between the amounts that is likely PM_{10}. However, the LD results may be presented as volume percentages in or below a certain size, similar as to how we divide different fractions in sieving tests, and as such give an indication if some can be expected to be in the PM_{10}. These results are presented in Figure 9 for the total fraction below 10 µm, 50 µm or 100 µm. It can be observed most of the material is below 50 µm, as indicated by the D_{90} value. However, the volume below 10 µm varies from 26-27 % for the coal and charcoal, to 32-34 % for the metallurgical coke and pellets, and this is the smallest dust most important to the respirable health issues. This may indicate that despite the pellet's good behaviour with total amount of fines, what little is produced could possibly be in a size fraction more prone to personal health.

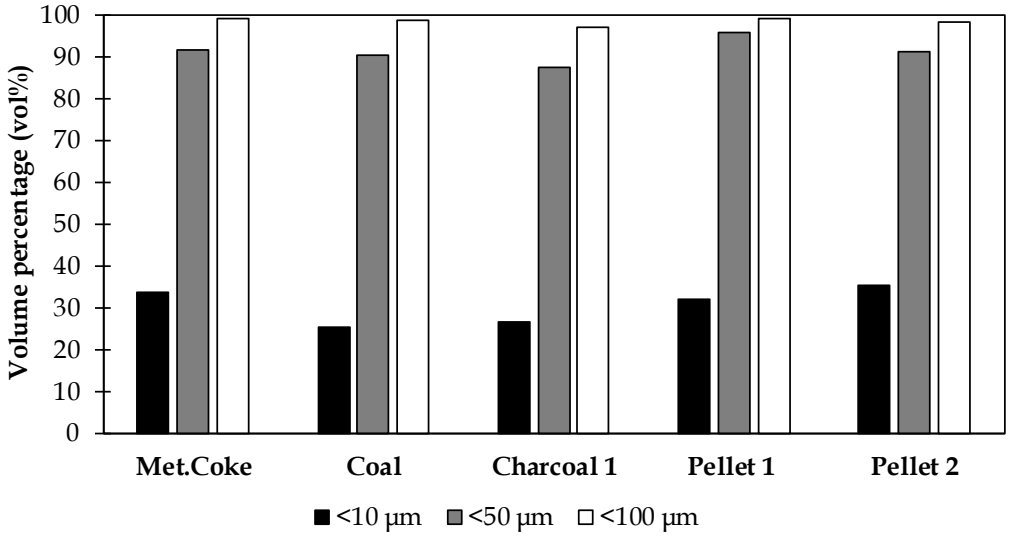

Figure 9. Volume percentages of differently chosen diameters of the dust captured in the filter during the Heubach Dustmeter type I measurements.

Different types of Heubach Dustmeters than the type I used in this study is further optimized to differentiate between inhalable and respirable dust. However, an exploratory exercise was done on the results, using the volume percentages obtained in the LD analysis to further normalize the total dust (in mg/kg) to attempt to get more information on the potential smallest <10 µm fraction (Figure 10). The trend is mainly kept with respect to the full dustiness in Figure 6, but when removing one and one fraction, the trend changes. For example, when only evaluating the fraction below 1 µm, the metallurgical coke appears to have the highest amount of this dust produced, while the charcoal has almost no dust below 1 µm despite

having the most under 10. As it is not known which carbon and biocarbon particle sizes that is of most importance related to especially the respirable dust, any of these might cause serious health issues. This exercise also demonstrates the need of more precise measurements to differentiate between the smallest fractions.

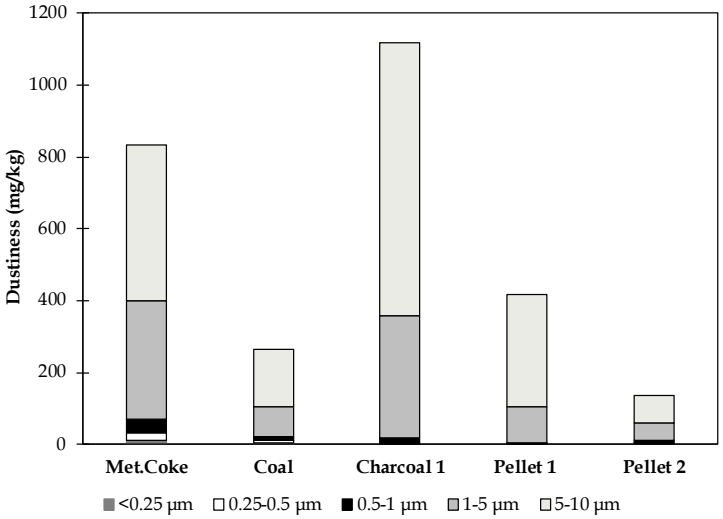

Figure 10: "Corrected" captured dustiness with the particle size analysis.

The risks related to dust explosions were not assessed as part of this study.

5. METHOD COMPARISONS AND LIMITATIONS

The study was conducted to investigate if a closed system like the Heubach Dustmeter type I could be used to better investigate airborne dust than adapting the already established tumble abrasion test. The relevant values from the tumble abrasion test, evaluating the <0.5 mm fraction after 30 minutes tumbling at 40 rpm, compared to the dustiness under standard conditions of 30 rpm, is presented in Figure 11. The numbers are not comparable in value, but the same linear trends related were observed in both tests over time (Figures 5 and 7), and now also when they are compared to each other. By further optimization and investigations of a larger number of samples it may be possible to predict the dustiness values of a material based on the tumble abrasion test without adjustments.

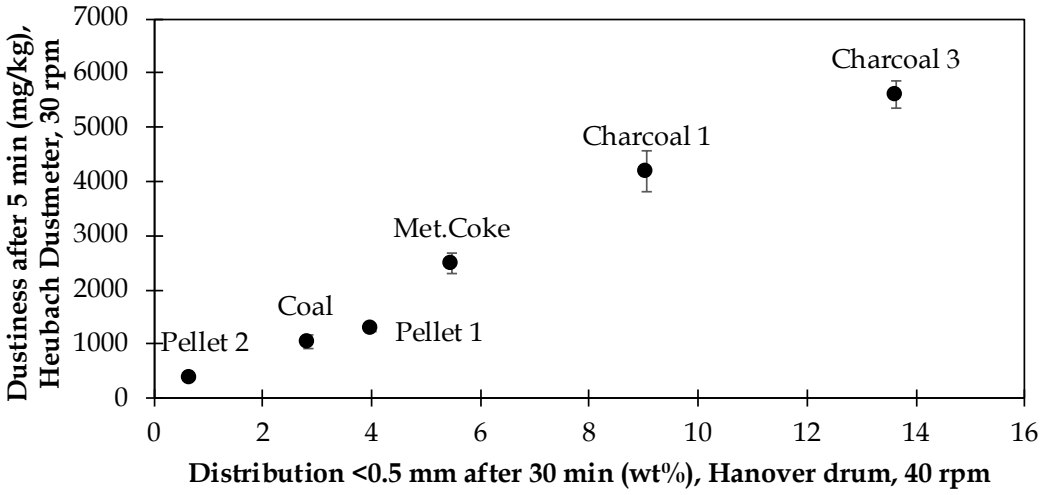

Figure 11: Comparison between the traditionally run <0.5 mm fraction after 30 minutes in the Hanover drum and the Heubach Dustmeter type I measurements.

Another option to get better comparisons of actual values are by including a smaller fraction during sieving, as was done in this study. As PM_{100} is a traditionally used value for airborne particles and the goal for the Heubach Dustmeter measurements, choosing 0.125 mm as the smallest sieve was suggested as a compromise to adjust for particles with larger diameter but still airborne due to e.g. shape and density, i.e. the aerodynamic diameter. The LD analysis in this study showed that among the captured dust, expected to be the PM_{100} fraction, most of the dust was significantly smaller than 100 µm, so it seems like a reasonable value for a sieve. Making the correlating graph as Figure 11 would not change the trend; the only difference is the order of Coal and Pellet 1 sample, which has already been identified as being too similar to differentiate. The 0.125 mm sieve could as such also give more similar values as in the Heubach Dustmeter measurements if both tests were run at the same time and rotation speed.

For Charcoal 3, measurements using 40 rpm for 5 minutes tumbling resulted in very similar values for the two tests. Heubach Dustmeter measurements gave 6100 mg/kg (0.61±0.04 wt%) and what was found after tumble testing and sieving <0.125 mm was 0.7 wt%. However, due to the large amount of loss in the tumble abrasion test (also around 0.7 wt% after the first 5 minutes), it is difficult to know how close the numbers are. Some, but not all, of the losses are likely also in the smallest fraction which is not captured in the open system. The closed Heubach Dustmeter method is superior evaluating this uncertainty, as such losses should be eliminated.

Despite the LD results indicating that most of the captured dust is significantly smaller than 100 µm, there might still be some material that is below 0.125 mm but not captured by the filter during the Heubach Dustmeter measurements. In the first campaign of the five materials included for LD analysis, an additional sieving of the non-captured material was introduced. The results showed that there were no additional materials in the <0.125 mm fraction for Pellet 1 and 2, and coal. This indicates that for these samples, all the airborne dust was captured and all the <0.125 mm fraction was airborne. However, for the charcoal and metallurgical coke, significant amount of material was observed for this fraction when sieving after the test, doubling the total value of material found to be below 0.125 mm in diameter. These are the two materials with the highest dustiness (Figure 6), and as such either have some material below 0.125 mm in diameter but not airborne, or some of the airborne particles was not captured in the filter.

In the second campaign it was discovered that Charcoal 3 clogged the filter and reduced the airflow before the first 5 minutes were done; the method was adjusted by replacing the filter to maintain the airflow. Instead of running the test with significantly less material, which is more often done with bulk powder testing, the filter was replaced anytime the flow was below 19.5 L/min. Although no notice was made related to reduced airflow during the first campaign, the sieving results indicate that this could be true due to the large number of fines found below 0.125 mm in these two materials when no changes in filter occurred. Likely, the airflow was reduced making some particles not captured by the filter. These results show the need of maintaining the airflow, and also indicates that the dustiness reported for these two materials may be underestimated in this study.

The study shows that the Heubach Dustmeter method is a promising tool for screening materials with respect to dustiness, but as the method is still undeveloped for materials for metallurgical industry and no limiting values exist related to health and safety, it will be no replacement for real workplace exposure measurements. The dustiness reported using the standard parameters of Heubach Dustmeter type I closely followed the trend when comparing the abrasion strength of the material, despite the method being superior in the view of losses.

However, the standard parameters like tumbling speed and time, and airflow, may need to be adjusted to best give an indication on the dustiness potential of these types of materials, and method sampling must be defined. As-received material is the most relevant for real handling exposure, but it might be more prudent to eliminate the small dust already formed during transport, especially since charcoal is so fragile. This approach would give information more closely resembling Hanover drum tumbling, and result in an understanding of the underlying material performance. Another parameter is drying; a drying step is often included in standards to get more similar material conditions and normalised conditions. However, moisture is so important for the dustiness behaviour that removing the water beforehand can change the results and the relevance towards real exposures. A more thorough material and parameter analysis should be conducted to best select standardized parameters, including a more thorough shape analysis of the captured powder to get a better understanding of the real diameters of the airborne dust.

Heubach Dustmeter measurements are no replacement of traditional cold strength testing, but, if optimized, may give better understanding of the airborne dust fraction which is more uncertain by only using sieving after a traditional abrasion tumble test. The type I measurements do not differentiate between the inhalable and respirable fraction of the airborne dust, but other Heubach Dustmeter types could be evaluated for this purpose.

6. CONCLUSIONS

The study explored the possibility of using the Heubach Dustmeter method to quantify the dustiness of carbon materials intended to use as carbon reductant in ferroalloy industry. This method is run with similar approach as the cold strength tumble test, but targets capturing the airborne dust by use of an airflow in the closed drum, eliminating any of the losses observed when using the Hanover drum and sieving. It was found that highly dusty charcoal resulted in clogging of the filter and possibly underestimating the dustiness unless airflow was maintained by changing the filter during the test. When this was optimized and the airflow maintained, a linear dustiness response was measured depending on the tumbling time.

Six different materials were tested under standard conditions, and the results showed a linear correlation between this test and the abrasion index (<0.5 mm fraction) of the material as found by tumbling in a Hanover drum, as well as towards the 0.125 mm fraction when this additional sieve was introduced. As most material was detected by laser diffraction to be below 50 µm in diameter, the 0.125 mm sieve can be assumed to be effective, further highlighted by no additional fines below 0.125 mm in the drum after the Heubach test when the airflow was maintained. Running one of the charcoals under identical tumbling speed and time in the two tests gave almost identical results for the measured fraction, however, the losses for the Hanover drum was significant and makes the measurements less ideal to compare. Since no second or third parallel were run in the Hanover drum, the uncertainty related to these results are larger than for the Heubach Dustmeter measurements.

Further optimization related to establishing a standard methodology is clearly needed, also establishing limits related to the numerical values of the dustiness. The method seems promising as a complementary method to the traditional cold strength methods to analyse materials as part of the screening process.

7. ACKNOWLEDGEMENTS

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Gøril Jahrsengene
Research Scientist, SINTEF

The main author Gøril has a MSc (2015) and PhD (2019) degree in Materials Science from NTNU Norwegian University of Science and Technology (2019). She is currently working in metal production and recycling in SINTEF as a research scientist, focusing on electrolysis approaches. She also specializes in carbon for metallurgical processes, including the use of bio-carbon.

Amanda Andersson Lindholm
Engineer, SINTEF

The presenter Amanda holds a Master's degree in Materials Science from NTNU and has worked at SINTEF since completing her studies. She works at the intersection of laboratory experimentation and data processing, focusing on high-temperature furnace operations and parameter studies related to silicon production.
