ASPECTS OF HPGR IN IRON ORE PELLET FEED PREPARATION *

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Abstract

High Pressure Grinding is applied in iron ore pellet feed preparation to generate a specific surface area increase. The technology is applied for final grinding of fine concentrates or pre-grinding (ahead of conventional milling) of particles. The process assumes inter-particle breakage and inter-particle abrasion as a major factor in generation of fines which contribute to an effective increase in Blaine specific surface area. Process parameters and material conditions such as moisture and particle size composition can be critical, especially at higher Blaine values of the concentrate. As alternative to classification, a multi-pass system or closed circuit operation for HPGR can be established by product recycling, where a proportion of the HPGR discharge is recirculated (or the full throughput is recirculated is certain number of times) to achieve a finer final discharge product for subsequent pelletizing. In the scope of this paper, effects of parameters and conditions in HPGR feed on efficiency of the compression are highlighted. Sample preparation for Blaine analysis is discussed in view of standardizing and exchange of process results, especially in view of breaking of fine particle agglomerates and HPGR flakes.

Keywords: HPGR; Pellet Feed; Blaine; De-agglomeration.

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1 INTRODUCTION

Initially developed for the cement industry in the realms of the energy crisis in the 80's of the last century, high pressure grinding is an accepted technology, also in the mining and minerals industry for many years now. It has been successfully applied in an expanding field of applications throughout the minerals industry, with applications in base and precious metals, but also in industrial minerals processing.

The comminution process mainly relies on size reduction through high pressure compression and inter-particle crushing in a particle bed in the operating gap between two counter-rotating rolls. The equipment typically has a high unit capacity and low specific energy consumption, and is increasingly used as alternative application for conventional tertiary and quaternary crushing and grinding, in particle size ranges reaching from 100 mm down to 25 microns. It can be applied to moist ores and dry material, in open circuit arrangement or in a closed circuit with dry or wet classification (screening, air classification).

For iron ore pellet feed preparation from fine iron ore concentrates, at sizes below 1 mm and generally at a high moisture content ranging between 7 % and 12 %, HPGR has proven to be successful in increasing the specific surface area [8, 9, 11]. Research has confirmed that for samples having equal Blaine specific surface areas numbers, the amount of fine particles produced in HPGR was higher than that produced in a ball mill [1, 2, 6, 7]. A higher surface area was observed from HPGR treatment, associated with a higher porosity, more micro-cracks, a higher roughness and new surfaces. It was also observed that HPGR produced particles that were more elongated, less circular and rougher than those processed by the ball mill. These are all essential characteristics to produce high integrity pellets.

Worldwide over 40 applications are in operation in pellet feed preparation, with about 50 % of these from Weir Enduron.

For fine materials such as iron ore beneficiation concentrates, the process assumes inter-particle breakage and inter-particle abrasion as a major factor in generation of fines which contribute to an effective increase in Blaine specific surface area. Process parameters and material conditions such as moisture and particle size composition can be critical, especially at higher Blaine values of the concentrate.

As alternative to classification, a multi-pass system or closed circuit operation for HPGR can be established by product recycling, where a proportion or the full throughput of the HPGR discharge is recirculated or re-ground by HPGR to achieve a finer final discharge product for subsequent pelletizing.

2 GRINDING CIRCUIT ARRANGEMENTS

A number of circuit arrangements are used for the increase of the specific surface area ("SSA" as defined for instance by Blaine method) for different purposes. Depending on the specific surface area required for a particular pelletizing process, and depending on the material used (hematite, magnetite, or other), circuits in use include:

- open circuit (single pass)
- closed circuit with partial product recycle
- closed circuit with dry grinding

The open circuit variant is applied both as stand-alone option, to grind self-produced or purchased iron ore concentrates to a final SSA, as pre-grinding ahead of a final ball milling, or as post-grinding after an installed ball mill.

In stand-alone, the feed material generally is of high quality (high Blaine specific surface area), and requires only a final upgrade to meet pelletizing demands. Pre-grinding ahead of ball milling can be applied to benefit from an increased fines proportion and improved grindability ahead of an existing ball mill, in which the latter also serves to reduce the proportion of remaining oversize particles (> 100 µm). Post-grinding is used to generate a high Blaine SSA for the final product from the filter cake following an existing ball mill, also in view of possible (ultra-) fines lost in the process of classification, sedimentation and filtration.

Closed circuit grinding with partial product recycling ("PPR") is used for producing a final pellet feed qualities without the need for ball milling [8]. This technique effectively simulates a multiple pass of material [10], by recycling a split fraction of the HPGR discharge, and recycling this to the head of the HPGR circuit. Alternatively, a multi-pass circuit consisting of several HPGRs in series could be applied for the same purpose.

An example of progress of Blaine specific surface area increase and decrease of product particle size with progressing HPGR stages is shown in Figure 1.

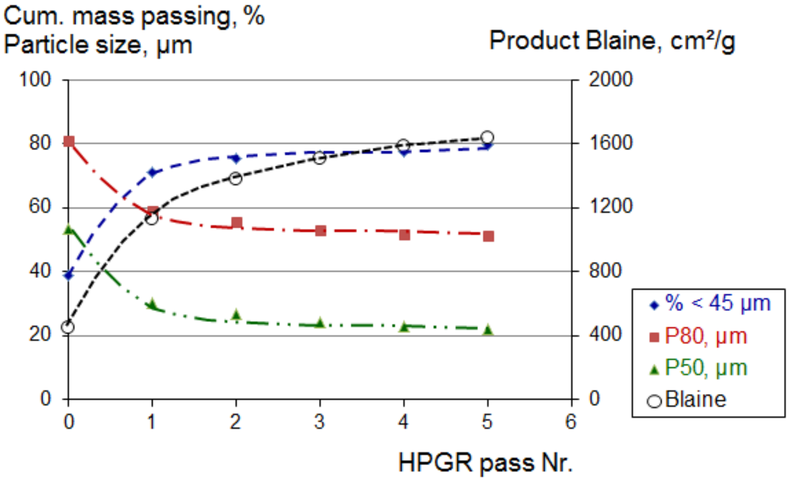


Figure 1. SSA increase and product size decrease with progressing HPGR stages

Advantage of the PPR would be that one can chose the proportion of recycling, thereby balancing the operation to optimize HPGR size for a given product particle size and SSA, and only one single (larger) HPGR would be required.

Closed circuit grinding with air classification involves HPGR grinding followed by a static (cross-flow) separator for a coarse scalping at a 200-2,000 microns range and/or a dynamic (cage wheel of equivalent) separator for fine product generation at

80 % passing 25-125 µm [10, 12].. Air classification requires a dry feed of below about 2 % moisture, and requires a dedicated fines recovery and dust extraction system in form of gas cyclones, electrostatic separation or a bag house. Depending on the circuit and classifiers applied, products can be obtained for further processing and final upgrading e.g. magnetic separation or flotation or shipment.

3 HPGR PARAMETERS

Main parameters for HPGR are the applied pressure and roll speed, and conditions such as feed moisture content applied in HPGR can be of major influence on the product quality. Several investigations [1, 2, 3, 6] deduced that increasing the specific pressure and decreasing the roll speed would result in reduction of the 80 % passing particle size, and would increase the Blaine number. It was observed that particles tended to be angular, with elongated shape due to the inter-particle and compression breakage mechanism in the HPGR.

3.1 Pressure

As for particle size reduction, the Blaine SSA is directly affected by the pressure applied. A higher pressure generates a higher specific surface area, but can also increase the (specific) energy consumption and reduce the specific throughput. In general, a trade-off is to be sought to balance these effects in HPGR sizing and operation. Examples of trends of specific energy, throughput and SSA are shown in Figure 2.

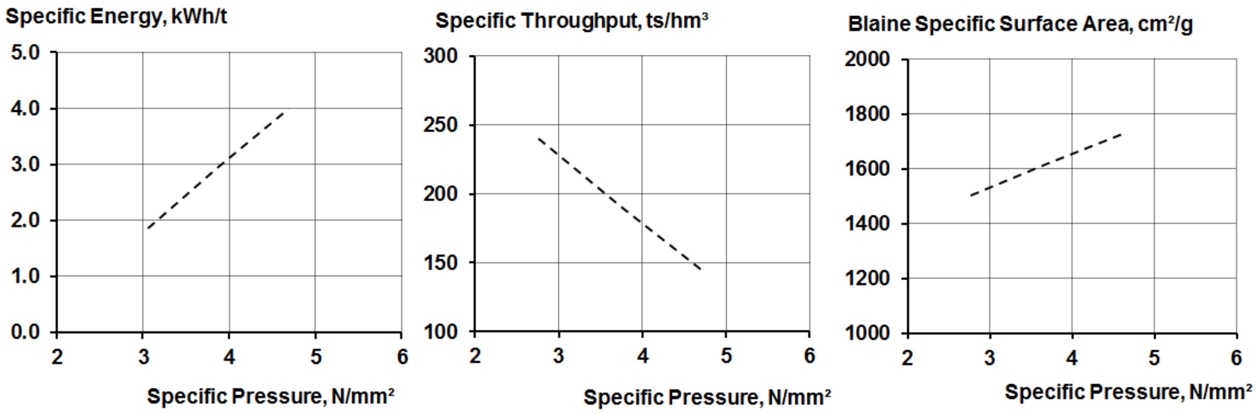


Figure 2. Effect of specific pressure on process parameters.

3.2 Roll Speed

At a higher roll speed, the specific throughput in a HPGR generally tends to drop, due to increased material slippage. In most cases, the size reduction is hardly affected, and energy consumption tends to increase as consequence of a lower throughput against a maintained pressure and energy input [13]. In pellet feed applications, similar trends do appear, although a reducing speed was indicated to benefit the SSA [6]. In a series of multi-pass tests, these effects were confirmed, but a tendency of decreasing Blaine with increasing roll speed was also observed, as shown in Figure 3.

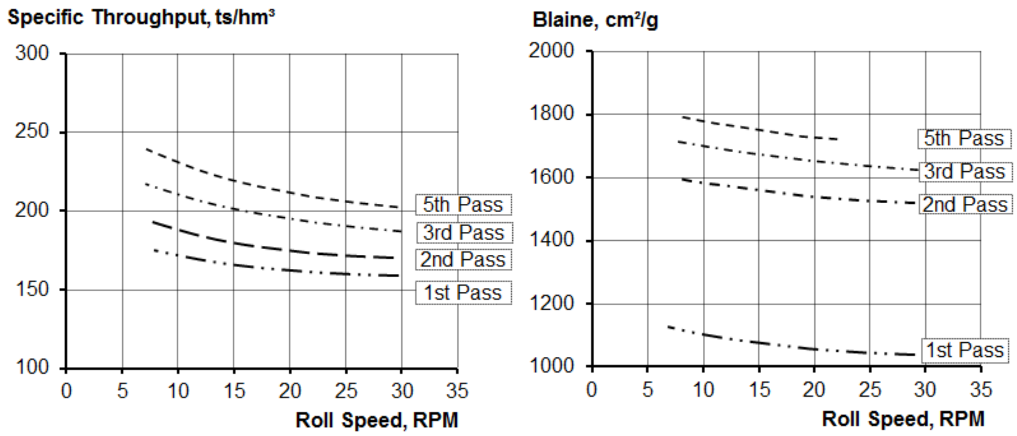


Figure 3. Effect of roll speed on process parameters.

3.3 Moisture

Moisture is a most critical parameter in the grinding of pellet feed. In general, it might be postulated that grinding a filter cakes takes place at the moisture content that can practically and economically be reached by the filtration process.

The effects of moisture content on pellet feed grinding by roller press may follow the below described general tendencies:

At a relatively dry feed material (e.g. 5 % moisture), where the water contained is either inside the pores of the ore grains, and further only (partially) covers the particle surfaces, and only partially fills the inter-particle voids, a relatively competent (strong) particle bed can be formed when compressed between the rolls. The resistance of this particle bed to withstand the pressure exerted by the rolls is relatively high, and therefore the applicable pressure (and thus grinding force) to the material can be high, resulting in a relatively high size reduction and a relatively high Blaine specific surface area increase. A relatively high (specific) throughput and power consumption will be achieved.

The compaction of the feed before and during the grinding action maximizes, to a point where the particle bed density in the operating gap increases to near or even higher than about 85 % of the true material density.

As the moisture increases, the material becomes saturated with water: the water covers all particle surfaces and fills most of the inter-particle voids in the feed. The wet material may approach a clayey, greasy character, and nipping conditions for entrance of the rolls gap will deteriorate. A lower (specific) throughput will result due to material slippage, and a smaller operating gap will be achieved.

When compressed during the roller press grinding action, part of the water is purged from the particle bed. This purging may cause an increased moisture content in the edge material. A weaker particle bed will result from these wet conditions, and the specific pressure aimed for may not any longer be reached. Specific power consumption may reach a maximum plateau level, depending on the achieved resultant press force (as net power input varies about linearly with press force) and the achieved material throughput. Due to the combination of press force and an increased particle mobility, an increased abrasive inter-particle friction and action is promoted. As a result of this, the Blaine value of the achieved product may still increase, be it at a lower throughput and high power input.

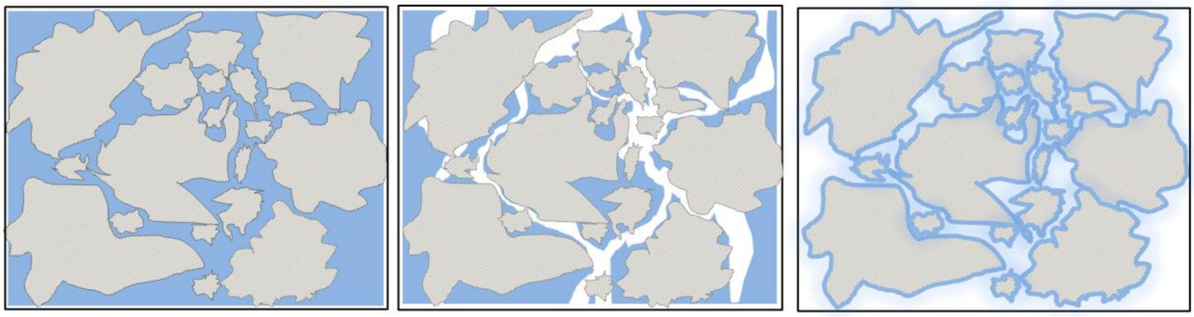
At very high moisture content, the increased material mobility on the roll surface will add to the abrasive wear, and may markedly shorten the wear life of the rolls. Also, the purging of water to the edge, and the material handling a very high moisture feed and products may affect the envisaged operation.

At any higher moisture level, the (specific) throughput tends to drop dramatically, as the material will not be able to build-up any resistance and compactness against the applied press force. Power consumption will drop, and product fineness (Blaine) will deteriorate. Effectively, a further increase in moisture will render the roller press feed and product to act as a wet pulp slurry.

Given the above tendencies, it may very well be assumed that a higher specific power requirement and lower specific throughput may prevail at a maximum moisture level as would result from incomplete filtration or the wetting of filter cake by weather conditions. The exact levels of these parameters are different for most every ore type, and have to be determined by dedicated testing.

HPGR of fine iron ore filter cake is sensitive to the moisture content of the material. By virtue of the process, moisture control for both process stages are in competition.

Obviously, the objective for vacuum filtration or pressure filtration is to reduce moisture content as much as possible, aiming at levels required for downstream processing (for pelletizing or handling). Consider starting with a sample where the material is suspended as slurry of water and solid particle. (Figure 4a)



4a **4b** **4c**

Figure 4. States of moisture level in particle groups
4a mineral grains in slurry
4b mineral grains with water at filtration's end
4c moist material with surface coating

Sedimentation will densify the sample by removing free water up to a point where particles are close to being in physical contact (Figure 4a)

When fed to a filtration stage, where the wet sludge is deposited as a layer of a certain thickness in-between filter plates or upon a cloth surface (filter cake), more water will be drawn from the material by the pressure difference over the filter cake, either through suction in case of vacuum filtration or as pressure as in the case of pressure filtration. However, as the material gets dryer, more channels open-up in the filter cake. With progressing filtration and drying, this channeling ultimately results in the pressure drop over the filter cake to diminish and the filtration process comes to an end (Figure 4b).

This signals the end point of the filtration stage. Thus filtration reached an end-point where still some moisture is included in the filter cake, and the filtered material is sub-saturated at, for instance, 8%-9%. In optimal circumstances, the moisture of the filter cake can drop to e.g. 7 %, but process considerations (maximizing throughput and minimizing cycle time for filtration) may result in filter cake that can be significantly wetter. So filtration can reach a minimum moisture of between 7 and 9 %, determined by economics and operator actions. If the material is transported (e.g. in open rail wagons) conditions from surroundings (rain, dampness) can further influence the condition of the material

HPGR process could be considered to be optimal with a material having a moisture content well below the saturation moisture. A certain proportion of water, as surface coating on the particles, is considered to be beneficial in transferring the pressure applied into the particle bed, and acting as binding agent for material compressibility (Figure 4c).

A higher moisture will cause the material to behave as a paste; the compressibility resistance of the material will be low (Figure 5).

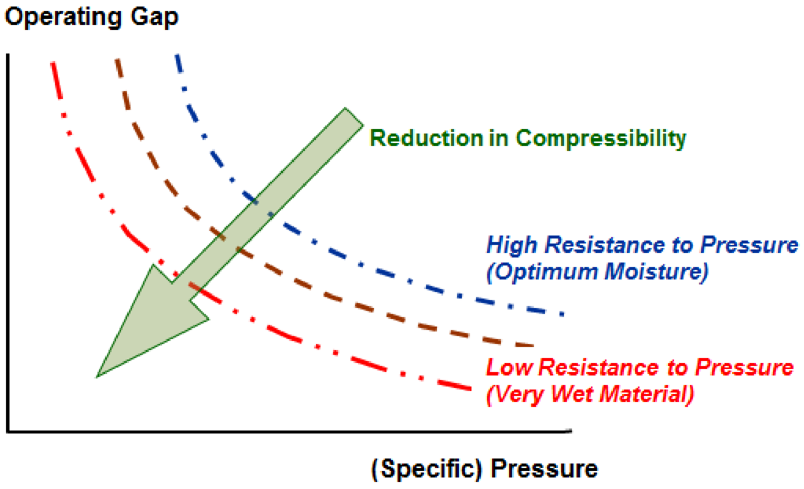


Figure 5. Shift in compressibility relationship at changing moisture content.

The low pressure resistance results in a low size reduction or an only moderate to low increase in Blaine specific surface area. Any force on the material bed will purge out any remaining air in the voids, and subsequently purge water from fissures, voids and channels in the bed. The moisture acts as a smearing or lubrication in-between the particles, and promotes the movement or transport of particles, following the pressure gradient out of the high pressure zone. This results in a material slip over the rolls, and even extrusion. A moisture content over or near the saturation level will also result in water being pressed towards the edges of the rolls; in testing, it is frequently observed that the center material is relatively dry (e.g. 2 % lower than the feed), and the edge material becomes significantly wetter, having taken-up the water purged from the center. The edge product can form a paste or sludge mass that sticks to the rolls and the inside of the equipment.

In summary, little or no sufficient compression force can be exerted on a high moisture pellet feed material bed, and thus little or no size reduction can take place.

The operating gap will reduce, and so will the (specific) throughput of the HPGR unit, with the (specific) energy initially increasing as a result of the proportion of mass put through at maintained energy input, or ultimately reduce as result of low pressure conditions for the wet material (Figure 6).

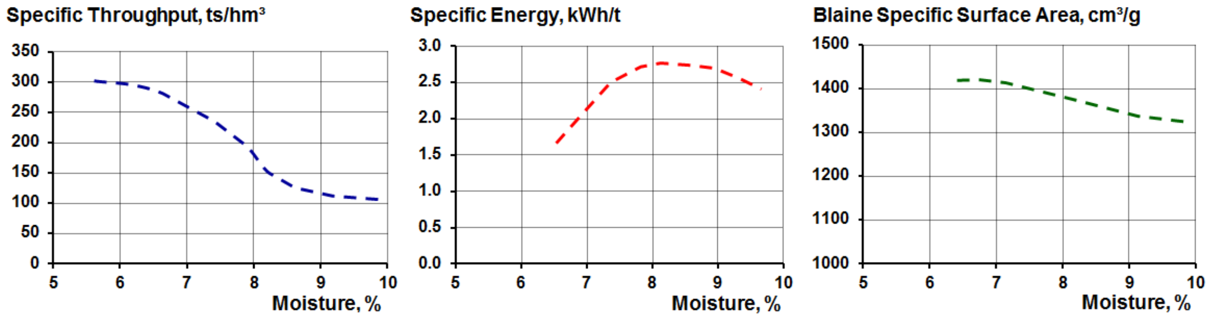


Figure 6. Examples of changed HPGR results with changing moisture content.

Thus all HPGR parameters and results may suffer from a too high moisture content. In addition, material handling through conveyors and bins may pose increasing difficulties at elevated moisture contents.

These effects take place even more at higher SSA material from HPGR, where the finer particle size distribution and the presumed high proportion of ultra-fines together with a high moisture content do appear to generate a particle bed that behaves as a sort of paste, and with little pressure resistance. The operating gap decreases, and size reduction or SSA increase reduces significantly. An example is shown in Figure 7.

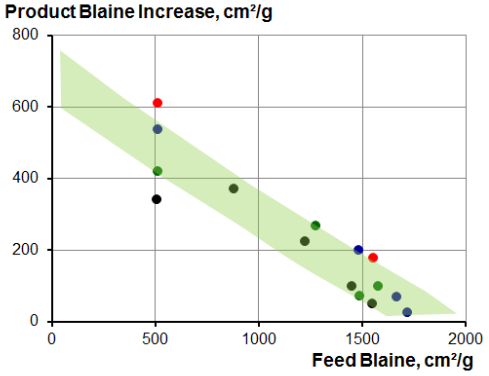


Figure 7. Example of product SSA increase as function of Feed SSA

So HPGR can achieve an optimum at a moisture that is preferably well below saturation.

Together, moisture content that filtration can deliver and that HPGR can process only have a very small overlapping range. Optimizing conditions for both thus is of essence for a well performing operation.

To optimize the HPGR operation a close control over the moisture fed to the HPGR is required. It may well advisable to adapt a firmer control over filtration and stockpile management, and possibly evaluate drying possibilities for the HPGR feed. In this, a complete drying is not required, and for the driving-off of a few % to meet optimum moisture, low quality excess heat from nearby pelletizing plant may be adequate.

3.0 Sample Preparation for Pellet Feed Analysis

As indicator of product quality and for providing a basic empirical criterion for assuring pellet quality in the balling and burning to pellets with a high drop strength and adequate porosity and reducibility, a careful determination of the specific surface area (+/- 30-50 cm²/g) is generally carried out. This is done by determining of the Blaine number. This number is an indication of an empirically calculated specific surface area based on measurement of air flow resistance through a packed bed sample of dried pellet feed concentrate [3, 4, 5]. The required Blaine number for different operations and different materials does differ, but generally ranges between 1,300 and 1,800 cm²/g.

Obviously, even though standardized, procedures for Blaine measurement do differ from place to place, as well as the equipment used. Both manual and automated Blaine measurement devices are in use.

Validating and correlating Blaine numbers from test work or processes carried out by others not seldomly shows relatively large discrepancies. Apart from the above differences in Blaine determination, the most likely cause may lie in the method of sample preparation, especially where HPGR products are concerned. Especially HPGR samples, which in effect stem from compressed material, do show formation of flakes on a macro-scale, but also do result in fine aggregates or agglomerates on a micro-scale, through capillary, van der Waals, magnetic or other forces. Without a proper desagglomeration, a determination approaching the assumed free particle bed in Blaine determination in a reproducible way is difficult to achieve. Differences in Blaine results of 300 cm²/g or more in the range of a 1500 cm²/g sample are frequently encountered between different parties.

It therefore would be a valuable tool, when a common procedure for sample preparation between research institutes, iron ore producers and equipment manufacturers could be agreed upon.

An example of one of the procedures used by WEIR for generating samples for moisture determination, particle size analysis, density determination and Blaine analysis is described below.

4.1 Sample Preparation Method Example

A representative sample from a process stream is taken from a larger representative sample off the process stream (either a blend of smaller incremental samples or a single large volume), and a sub-sample of at least 1.0 kg is obtained by coning and quartering, or by automated (rotary) sample splitter.

A further sample volume reduction is done by coning & quartering and coarse riffling (Figure 8) or by certified rotary sampler.

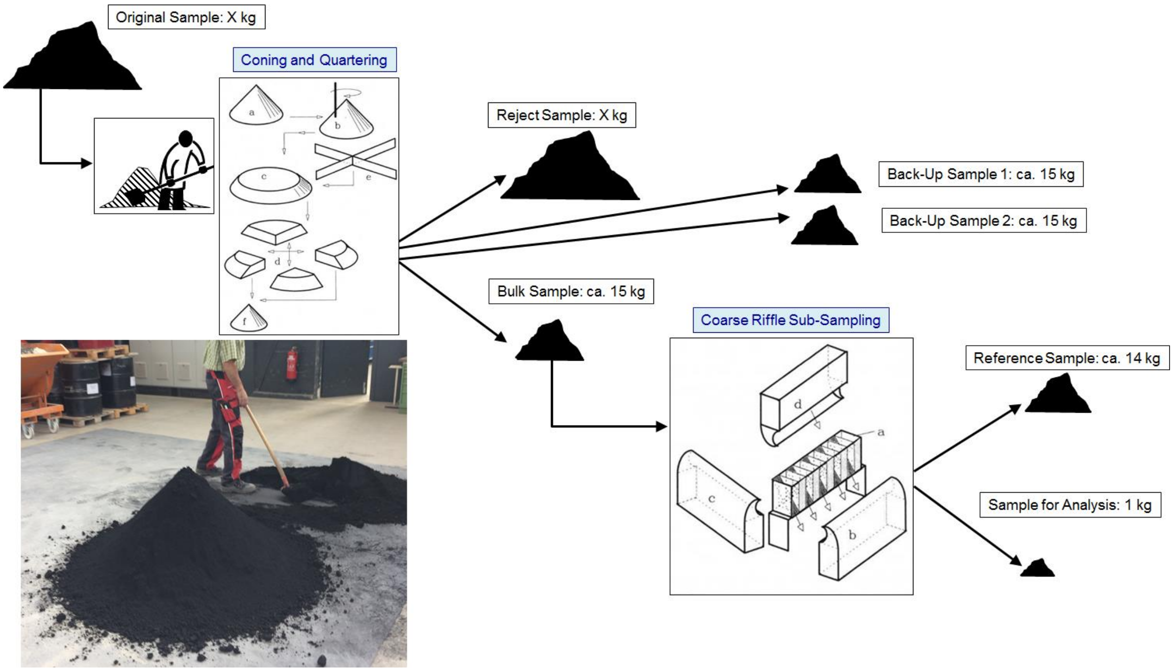


Figure 8. Bulk Sampling Sequence Procedure by Coning & Quartering and Riffling

The wet sample of approximately 1 kg is weighed, and then put in a drying oven (stove) at 105°C for 24 hours. After that the dried sample is weighed, and the original moisture content of the wet material calculated using the differences in wet and dry weighed mass.

The dried 1 kg sample is placed in a flat metal tray of sufficient dimensions (A3 size or larger)

To destroy coarse agglomerates or caked lumps, the sample is rolled with a metal cylinder (type dough-roller) to break-up coarse agglomerates until visual inspection indicates all material to be near or below approximately 2 mm in diameter.

Following this, the sample is split down to 3 smaller samples; two of each approximately 125 grams and a third one of approximately 750 grams by fine riffle sampler.

The larger sample is set aside, bagged, sealed and labeled with origin, date and name of product as reference back-up sample.

One sample of approximately 125 grams is used for particle size analysis and density determination.

The other sample of approximately 125 grams is split in two and used for duplicate Blaine analysis.

Particle size analysis is preferably done on a 125 gram sample by analytical dry jet sieving or alternatively by wet analytical screen analysis. Determination by laser diffraction can be used as well, provided sufficient care is taken for effective dispersion of the material.

Particle size range for the analytical screens to be used should include the anticipated product top size and a further series down to at least 20 micron screen aperture opening.

To obtain a sieve cut from 10 µm to 4 mm an air jet sieving can be applied. In this, only one sieve at a time is used instead of a stack of sieves. The sieve itself is not put into motion. An industrial vacuum cleaner generates low pressure inside the sieve chamber through an exit hole at the bottom. Air is sucked-in through a rotating slit nozzle which is located at close distance underneath the sieve deck, and ejects upward with high speed from the rotating slit nozzle through the screen mesh.

This air jet fluidizes and disperses the particles on the screen mesh. The suspended particles are then drawn-in with the air flow towards and (for the particles finer than the screen aperture) through the screen mesh. In this process they are not only redirected but also de-agglomerated. The particles which are small enough are then transported through the sieve mesh and sucked into the vacuum cleaner dust compartment. Sieve diameters of 203 mm (8”) can normally be used.

4.2 Sample Preparation for Blaine Specific Surface Area Measurement

Sample preparation for Blaine analysis is carried out on a sample of approximately 50 grams. The 50 grams are weighed and placed on a 200 microns analytical screen. Using a fine brush and gentle tapping, the material is screened until all visible agglomerates are dissipated and only residual coarse grains remain on the screen deck. The > 200 microns oversize grains are weighed and set aside.

The < 200 micron fine product is place in a ceramic bowl with 7 soft rubber balls (Figure 9). The bowl is then closed and clamped on a vibration stand of the analytical screening device, after which it is set to vibrate for 5 minutes at a frequency of 200 RPM for destruction of fine material agglomerates (Figure 10).

Figure 9. 200 µm Sieve and Desagglomeration bowl.

Figure 10. Desagglomeration Bowl and Stand with Timer

After 5 minutes, the bowl is emptied and cleaned with a soft brush to collect all material. Control particle size analysis by wet screen analysis, which included stirred preconditioning with sodium hexametaphosphate or sodium silicate and ultra-sonics, a CILAS laser diffraction and a Malvern Mastersizer

Two representative sub-samples of material sufficient for use in the available Blaine measurement apparatus is then taken for a duplicate specific surface area determination.

5.0 Summary of Discussion and Conclusions

Control of process parameters and material conditions such as moisture and particle size composition does show to be of significant importance, especially at higher Blaine values of the concentrate. Each does have an impact on the performance of HPGR in terms of operating gap and throughput, and energy consumption. Especially the combination of a high moisture content at a fine feed of increased specific surface area can lead to a low compressibility of the material in the HPGR gap, and therefore a reduced incremental raise in specific surface area. Control of feed quality to maintain a low moisture content in the feed could be of significant benefit.

HPGR products, which in effect stem from compressed material, do show formation of flakes on a macro-scale, but also do result in fine aggregates or agglomerates on a micro-scale. Without a proper desagglomeration, a specification of specific surface area in a reproducible way is difficult to achieve, and correlation in results and exchange of process results, especially in view of breaking of fine particle agglomerates and HPGR flakes between different parties, is difficult.

The definition of product quality in terms of specific surface area, as specified by Blaine method, would benefit from using a standardized sample preparation procedure between research institutes, iron ore producers and equipment manufacturers. A sample preparation procedure for Blaine analysis is indicated as possible starting point for standardization.

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