Modelling of HPGR Edge recycling with progressive grinding data

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Abstract

During the past 35 years HPGR technology has seen continues advancements. Following the success story in the cement industry HPGR technology has now advanced into the mining industry. Especially the continuous development of wear resistant grinding tools made HPGRs technology a good fit for the mining industry. With more than 300 HPGR applications in ore grinding it has proven their benefits as compared to conventional comminution circuits.

However, it is still possible to increase the HPGR advantages by applying the right flowsheet. Concepts like screen recycling versus edge recycling and progressive grinding are options for optimization of HPGR application for an individual ore. Therefore intensive test work has to be performed to support the sizing of the HPGR.

This paper takes a view on modelling work with HPGR to predict throughput, specific energy and fineness of the product for edge recycling circuits. The aim is to reduce test work efforts and show options for optimizing industrial operations.

Key words

HPGR, Edge Recycling, Material Fineness

Introduction

During recent years a worldwide trend towards comminution installations using High Pressure Grinding Rolls (HPGR) has been established [1]. This comminution practice was made famous in the 1980s by the research work of the German Professor Schönert. The technology has its foundations much deeper in the past [2]. Köppern, as one supplier of HPGR, has worked for almost 120 years on roller presses, starting with the formation of coal briquettes between two rollers. Subsequently, other fields of application, e.g. for fertilizer compaction, emerged. The first HPGR grinding solutions were used in the cement industry where the advantage of energy savings was very welcome on this medium cost product.

Nevertheless, it was a difficult step to transfer this grinding principle to minerals applications due to the much higher wear caused by the abrasive materials. The first applications started in iron ore concentrate grinding and have been established for hard rock with the optimization of the roller surfaces. The preferred roll surface system for ore applications is the stud system which is commonly being used today.

HPGR are available in a wide size range. Depending upon the required plant throughput, grinding tests are necessary to predict the operational behavior of the machine for a certain material. The most important parameters are the specific throughput and specific energy consumption what enables to size the HPGR for the required product fineness. It is defined by the transfer size to the downstream application such as flotation, magnetic separation or pelletizing and will vary with the ore characteristics. Depending on the complexity of the resulting flowsheet (single pass, multiple pass or edge recycling) the HPGR scale-up tests suffer from the remarkable need of test material. The quantity of test material may be decreased by using simulation models.

Once installed in industry the flowsheet and size is fixed but optimizations might be required since the ore body of the mine usually will change over the lifetime. Again models can be used to predict the operation and decrease the time for practical improvement steps.

Sizing

Figure 1 shows a state-of-the art Köppern type HPGR. As every HPGR application has its own characteristics regarding throughput, energy and fineness production a set of normalized scaling values is used. These values are very ore dependent. Therefore, lab scale tests are done at suppliers' facilities. The sizing calculations using such test results are given below:

Figure 1 – Picture of a state of the art HPGR by KÖPPERN

Specific throughput:

The specific throughput mdot in units of (t*s)/(h*m³) is defined as:

$$mdot = \frac{\dot{M}}{(L \cdot D \cdot v)} \tag{1}$$

Where:	$\dot{M}$ [t/h]	-	throughput rate
	D [m]	-	roller diameter
	L [m]	-	roller width
	v [m/s]	-	roller circumferential speed

The specific throughput describes the HPGR throughput at a given specific pressing force, feed material and type of roller surface. This normalized value gives the throughput of a machine with 1 m roller diameter and 1 m roller width at a circumferential speed of 1 m/s. Scale-up factors are then used for sizing the machines from lab scale to industrial size.

Specific Energy Consumption:

The specific energy consumption $E_{Sp,net}$, in units of kWh/t, is a mass rate normalized value to describe the amount of energy transferred to the material in one single pass pressing.

$$E_{Sp,net} = \frac{(P_t - P_i)}{\dot{M}} \tag{3}$$

Where:	P_t [kW]	total power draw under load
	P_i [kW] -	idle power draw (without feed)
	$\dot{M}$ [t/h] -	HPGR total throughput

The specific power consumption is used for sizing the drive system for industrial size machines. It is also a parameter for the required energy input into the material to achieve a certain comminution result. The specific energy consumption typically correlates well with the specific pressing force. Figure 2 shows one example from a test series with granodiorite.

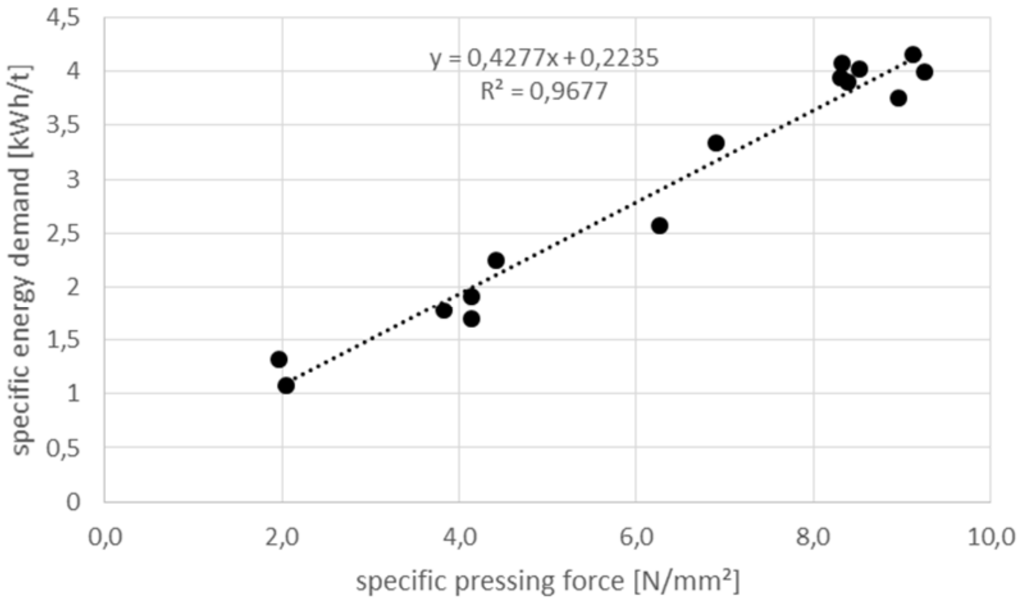

Figure 2 – Correlation of specific pressing force and specific energy demand from a test series with Granodiorite

Fineness:

There are multiple options to define the fineness of the feed and product. According to the Bond theory [3] the P80 (80% of the product mass passing a certain screen size) can be used for describing a particle size distribution with one single reference point. This value can be measured with wet [5] or dry screen analysis [6] for standard minerals applications with a top feed size of up to 80 mm. For finer grinding aims < 0.300 mm the use of laser diffractometer [4] has been established but also integral values as the measurement of the specific surface according to Blaine method [7] are used.

It is important to mention that the particle size distribution (PSD) of HPGR products varies from a ball mill ground product. The PSD is not only shifted along the horizontal axis of the size distribution diagram but also twist towards more fines. Figure 3 presents two examples for HPGR grinding of Granodiorite in the top size range of 22 mm and 2 mm.

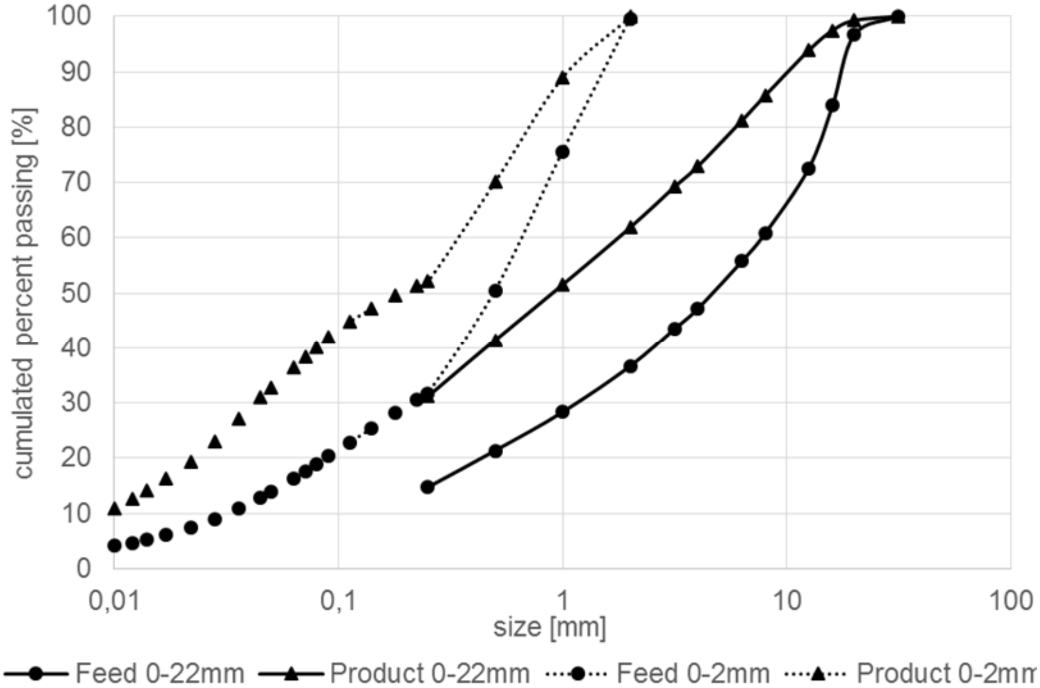

Figure 3 – Feed and product of a single pass HPGR pressing for 22 and 2 mm top size

Flowsheets

Various publications regarding the several flow sheet options with the use of HPGRs were published in the last decades [some examples 8-12]. This paper details the following simple flow sheet options:

Single Pass:

The single pass is the most simplified flowsheet using the HPGR. The material enters the top and is compressed and ground in the machine. The material is transferred directly to downstream applications such as ball milling in case of pregrinding, or balling in case of iron ore pellet feed regrinding.

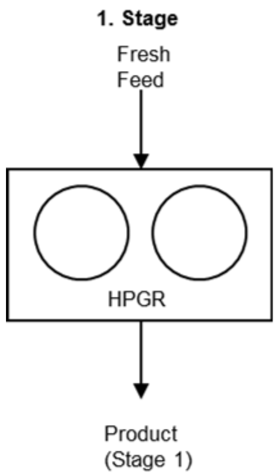

Figure 4 – Block diagram of a single pass HPGR pressing

During single pass grinding the HPGR is able to influence the product fineness by changing the pressing force. Figure 5 shows the effect of the specific pressing force on the product fineness.

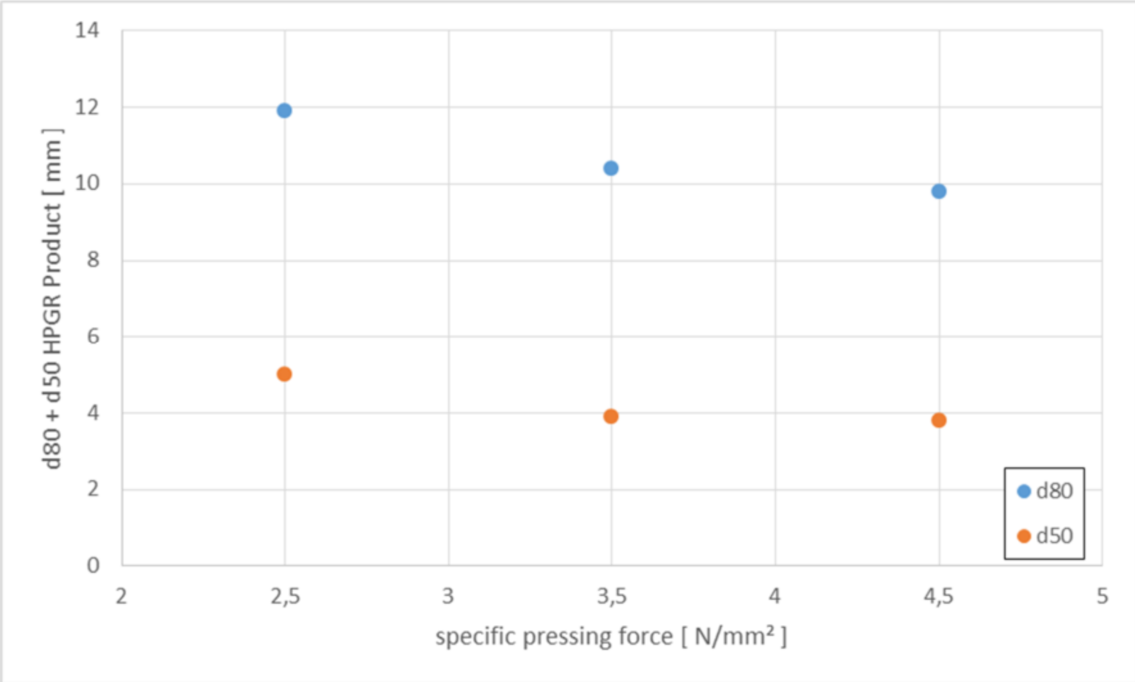

Figure 5 – Specific pressing force against product fineness for a coarse iron ore

Altogether 600 – 800 kg of test material is required to characterize this typical influence of the specific pressing force on the product fineness.

Multiple Pass:

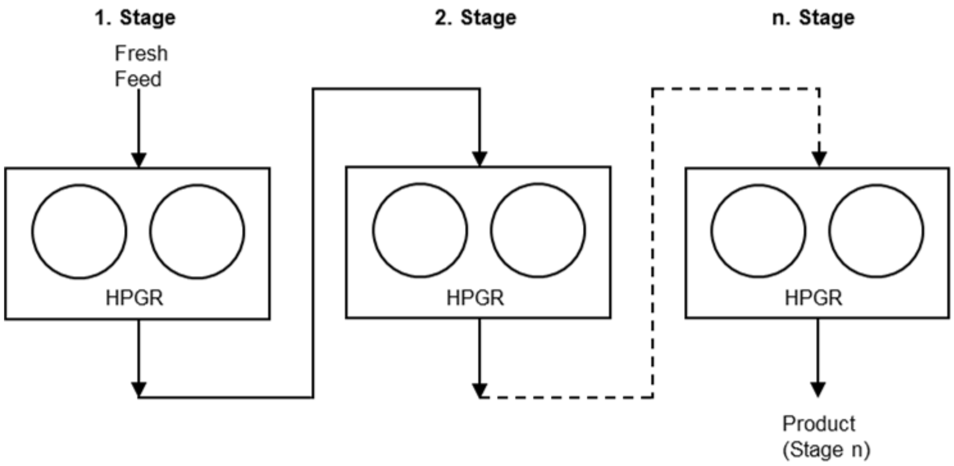

Figure 6 – Block diagram of a multiple pass HPGR pressing

If for example a D50 of 2 mm would be needed for the material according to figure 5 the specific pressing force effect on the fineness is too low to achieve this required fineness of the HPGR product. Higher forces are technical possible but will increase the OPEX of the machine strongly. It is possible to add more machines in series in the flowsheet (Figure 6). Thereby the biggest influence on the fineness is to be seen in between the first and second HPGR in series (Figure 7).

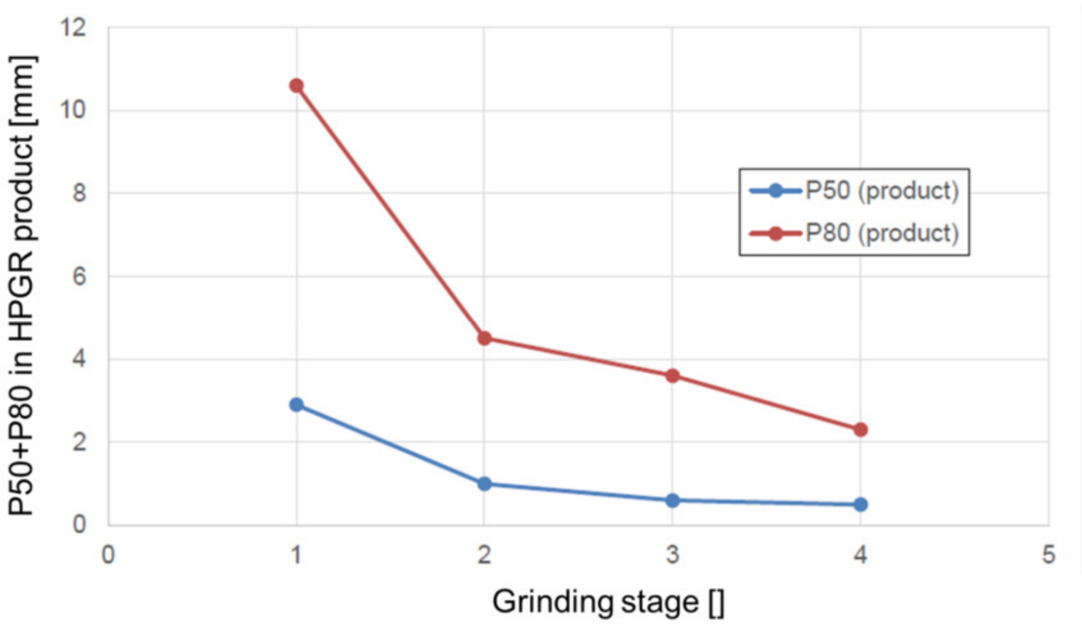

Figure 7 – Product fineness versus grinding stage for a coarse iron ore

The amount of test material for the above shown step-wise grinding is around 250 kg as the product can be used as new feed for the next grinding step while only the amount of samples is excluded.

Edge Recycle:

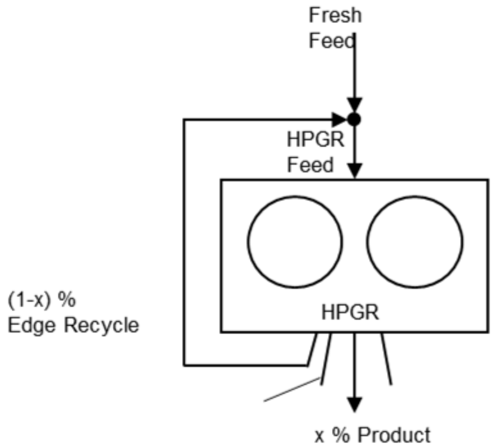

Figure 8 – Block diagram of an edge recycling HPGR pressing

As the installation of several machines for the multiple pass option results in a higher CAPEX the system of edge recycling is established as well (Figure 8). Thereby a part of the material is recycled and fed to the same HPGR together with the fresh feed. Then, the fineness of HPGR feed increases and hence, results in a finer product. Because the total throughput of the grinding systems remains equal the size of the HPGR has to be increased to be able to handle both fresh feed and recycle.

The fineness along the roll axis follows a certain gradient according to Figure 9. Reasons for this are linked to the physical compression of the material in the pressing zone of the HPGR and the limited transport of material at the edge of the rollers [13]. Thereby it is useful to recycle the coarser edge product as the center will contain the highest amount of fineness then. This effect is higher for small than for wide rollers.

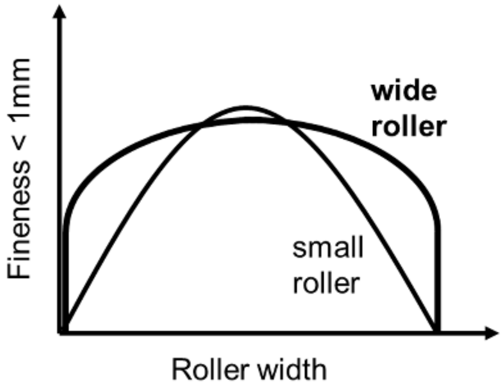

Figure 9 – Schematic fineness over the roller width

The amount of test material for such a test series is about 1000 kg as a certain stabilization of a linked series of batch and mixing tests is needed. This is a remarkable amount for green field applications where the material might have to be supplied with drill core efforts. One aim of the modelling approach is the reduction of the above mentioned test quantities.

Modelling and Results

The fineness result of edge recycling is placed along the row of multiple HPGR grinding. As example a typical edge recycle result from industry for material after figure 7 would be around a P50 of 2 mm which would be in between the first and second grinding step. As the multiple HPGR test series is not consuming a lot of material it shall be used to predict the throughput, specific energy and fineness of the product for the mass consuming edge recycle test. The basic idea is to determine which volume percentage of the feed is transported through the grinding zone during an edge recycle (Figure 10 for a 50 % split).

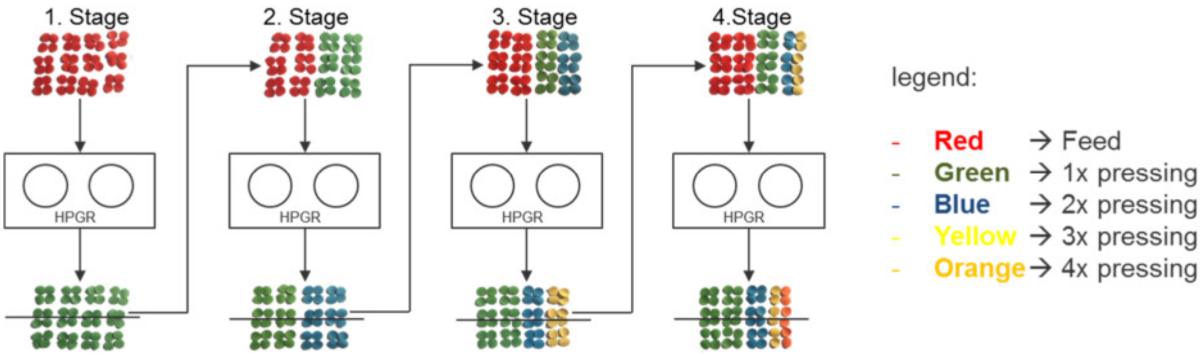

Figure 10 – Abstract model philosophy for 50 % Edge recycle [14]

For a split of the edge product of 50% the volumes after the second stage would result as following:

50 % 1x pressing,
50 % 2x pressing,

whereas 50 % of both fractions will be extracted as product and the rest will be recycled. The model is based on the assumption that an ideal mixture is applied when fresh feed and recycle are combined. This results in the same statistical chance that every particle can fall all along the roll axis independently of the former amount of roller press circuits.

After the fourth stage this would result as following:

50 % 1x pressing,
25 % 2x pressing,
12,5 % 3x pressing,
12,5 % 4x pressing.

This leads for all amounts of center/edge ratios (the amount of mass/volume to be recycled) to the following mathematical row:

$$X_{Edge} = X_{1;Center} \cdot q + \sum_{i=2}^{n} X_{i,Edge} \cdot q \cdot (1-q)^{i-1} \quad (3)$$

Where: X the characteristic value as mdot, $E_{SP,net}$, P80, P50, Blaine value, grinding step
q volume amount of the center material (e.g. 0,5)
i number of the grinding stage
n number of total multiple grinding steps

The definition of the grinding steps (number of theoretical passes through machine) is then calculated for a 60/40 % center/edge split as following:

$$GS = 1 \cdot 0{,}6 + 2 \cdot 0{,}6 \cdot 0{,}4 + 3 \cdot 0{,}6 \cdot 0{,}4^2 + 4 \cdot 0{,}6 \cdot 0{,}4^3 + \cdots + GS_i \cdot 0{,}6 \cdot 0{,}4^{n-1} \quad (3)$$

Where: GS grinding step

As a result of practical limitations during the test work the progressive grinding steps have been aborted after four steps. Thereby the mathematical balance was closed to 100% after the forth step for the model also. The following table shows the resulting impact on the grinding stages (Table 1):

Table 1: impact factors of the grinding stages

Grinding step	Proportion of Center/Edge 70/30	Proportion of Center/Edge 60/40	Proportion of Center/Edge 30/70
1	70,0 %	60,0 %	30, 0 %
2	21,0 %	24,0 %	21,0 %
3	6,3 %	9,6 %	14,7 %
4	2,7 %	6,4 %	34,3 %

The theoretical grinding step calculation according to formula (3) for the center/edge rations is summarized as follows:

70/30 -> grinding step 1,4 ,
60/40 -> grinding step 1,6 ,
30/70 -> grinding step 2,5 .

Figure 11 shows the results of a progressive grinding row with Granodiorite and the measured values of the fineness at the calculated grinding steps. The multiple grinding rows show very good correlations with quadratic formulas in the considered range. These formulas have been used to interpolate and foresee the fineness for edge recycling. Table 2 shows the results of measured and calculated values for several center/edge ratios as well as different feed fineness.

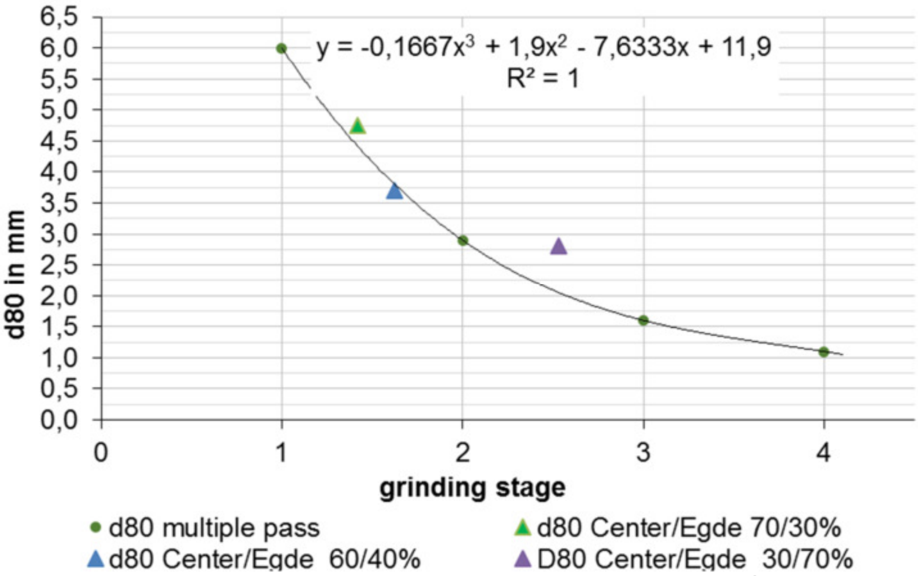

Figure 11 – Product fineness versus grinding stage for Granodiorite

Table 2: measured and calculated values for fineness

Feed fineness [mm]	Center/Edge ratio	$d_{80,measured}$	$d_{80,calculated}$	difference in %
0/22	70/30	4,8 mm	4,4 mm	7
	60/40	3,7 mm	3,8 mm	3
	30/70	2,8 mm	2,0 mm	27
0/2	60/40	0,75 mm	0,71 mm	4
0/0,2	70/30	98 µm	95 µm	3
	60/40	93 µm	92 µm	1
	30/70	94 µm	86 µm	9

Table 3 and Table 4 give the results for specific throughput and specific energy.

Table 3: measured and calculated values for specific energy

Feed fineness [mm]	Center/Edge ratio	$W_{Sp,net,measured}$ [kWh/t]	$W_{SP,net,calculated}$ [kWh/t]	difference in %
0/22	70/30	2,39	2,49	4
	60/40	2,83	2,85	1
	30/70	5,43	4,47	17
0/2	60/40	2,77	2,68	3

Table 4: measured and calculated values for specific throughput

Feed fineness [mm]	Center/Edge ratio	$\dot{m}_{spez.,measured}$ [ts/hm³]	$\dot{m}_{spez.,calculated}$ [ts/hm³]	difference in %
0/22	70/30	275	248	10
	60/40	264	241	9
	30/70	256	214	16
0/2	60/40	214	223	4
0/0,2	70/30	105	107	2
	60/40	115	120	5
	30/70	135	155	15

The model is predicting the operation behavior of specific throughput, fineness and specific energy in good range for high amount of center but intends to mislead if the edge amount is very high (E.g. 27% difference of 30/70% split). One reason might be that the supposed ideal mixing of feed and product is not given for this high edge ratio. Further investigations have to be ventured for this theme.

The prediction of the fineness of the product is more accurate than the specific throughput and specific energy. Nevertheless it has to be stated that the inaccuracy of >10% could easily result in a bigger machine during sizing. Therefore this method of saving test material can only be used during prefeasibility stage and should be confirmed by real edge recycling test work later on.

Once installed in industry the size of a machine is fixed. A certain center/edge ratio is chosen then and mechanically installed. After measurement the change of the fineness a forecast for other edge results can be given before time consuming rebuilding modifications are set in progress. Also the model offers an interesting new possibility to check data for accuracy as it provides an independent fineness result to measured edge recycling value.

Conclusions:

This paper takes a view on modelling work with HPGR to predict throughput, specific energy and fineness of the product for edge recycling circuits. After definition of the needed parameters the model can estimate the fineness of the product of edge recycle circuits in an acceptable range using multiple pass results as a basis. Specific throughput and specific energy are less accurate. Due to the difference to one-hundred percent accuracy the model still needs an engineer's control while using it in sizing . However, this is not in contradiction with the basic functionality of this model.

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