INFLUENCE OF THE RAW MATERIALS ON THE COLD AGGLOMERATION IN HPS (HYBRID PELLETIZED SINTER) PROCESS[1]

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Abstract
ArcelorMittal Monlevade Steel works was motivated to study the HPS (Hybrid Pelletized Sinter) process due the natural fine iron ore from Andrade Mine. The study began in the year 2000. Different characteristics in raw-materials have introduced distortions in the HPS technology accord Sakamoto (1), in the Monlevade sinter plant. The fuel coating step of the original HPS could not be achieved in the Monlevade plant. This study is based on the raw materials effects on the cold agglomeration phenomena. The burnt lime properties and its contribution to cold agglomeration were studied, reaching an increase in average size of the quasi-particles and in the sinter machine productivity. The other raw materials such as limestone, serpentine and manganese ore were studied and changes in size distribution (to increase the proportion of smaller fractions) were implemented, aiming to improve the agglomeration performance. Laboratory and industrial scale tests carried out in the Monlevade sinter plant yielded results showing that the changes made in the raw materials caused a positive and relevant outcome.
Key words: HPS; Cold agglomeration; Raw materials; Sintering process.

INFLUÊNCIA DAS MATÉRIAS-PRIMAS NA AGLOMERAÇÃO A FRIO NO PROCESSO HPS (HYBRID PELLETIZED SINTER)

Resumo
A ArcelorMittal Usina de Monlevade foi motivada a estudar o processo de aglomeração a frio HPS a partir do ano de 2000 devido ao minério da Mina Andrade ser naturalmente fino. Diferenças nas características das matérias-primas levaram a uma distorção do processo HPS na ArcelorMittal Monlevade em relação ao processo da NKK Co descrito por Sakamoto(1), chegando a não ser possível em Monlevade a realização da etapa de recobrimento de combustível conforme previsto no projeto original. Neste trabalho elaborou-se um minucioso estudo sobre a contribuição das matérias-primas na aglomeração a frio nas etapas do tambor de mistura e do disco de pelotização do HPS. Assim, foi possível observar a importância da cal virgem na aglomeração a frio, permitindo, após a adequação granulométrica desta, um ganho expressivo no tamanho médio da quase-partícula e na produtividade da sinterização. Outras mudanças executadas foram na distribuição granulométrica das matérias-primas: calcário, serpentinito e minério de manganês aumentando a quantidade das frações mais finas, mas mantendo-se as mesmas características do minério de ferro sinter-feed Andrade (SFAN). Os ensaios em laboratório e testes industriais demonstraram a relevância dos resultados obtidos, causando impacto positivo na performance do processo HPS na Usina de Monlevade.
Palavras-chave: HPS; Aglomeração a frio; Matérias-primas; Sinterização.

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1 INTRODUCTION

The HPS process was designed by NKK Co (current JFE Steel) in the early 80´s, as a form of taking advantage of iron ores with a large size distribution (pellet-feed). In a general view a conventional sinter plant consists of a single stage of cold agglomeration routinely called mixing drum, and the product of this process step is known as "microparticles" or micropellets.

The sintering with HPS (Table 1) incorporates a second stage of the cold agglomeration performed in pelletizing discs performed shortly after the mixing drum, whose product is called "quasi-particles" Saito.(2)

Associated to the second stage of cold agglomeration, there is a step of fuel coating of the particles performed within a covering drum or coating mixer, Oyama.(3)

Table 1 - Comparisons between the sintering process - HPS - pelletizing.

Item	***Sintering***		***Pelletizing***
	Conventional	***With HPS***	
Size distribution of iron ore	Sinter-feed (Astier distribution - <0,125mm <20%)	Sinter-feed + pellet-feed with large distribution (<0,125mm ~50%)	Pellet-feed (< 0,044mm > 85%)
Cold agglomeration step	Drum mixer	Drum mixer + pelletizing disc	Disks or drum of pelletizing
Size range size of the agglomerates	Microparticles 3mm to 5mm	Quasi-particles 3mm to 10mm	Green pellets 8mm to 16mm
Fuel	Fine coke and/or anthracite among the mixture	Coating with fine coke (fines < 1,0mm)	Fine coke or petroleum coke within the mixture (pulverized) plus oil.

Source: Januzzi (4)

In order to optimize the use of the SFAN iron ore (SFAN: Andrade sinter-feed), ArcelorMittal studied and implemented from 2002 on, the HPS process at the Monlevade Plant, thus enabling the use of 100% of the ore from the Andrade Mine which is located 11km from the Monlevade Plant, linked by a railroad owned by the Company, which makes it extremely strategic in face of the current price of iron ore.

Differences in characteristics of the ores used by NKK Co and SFAN led to a distortion in the HPS at Monlevade Plant in relation to the originally designed HPS process.

The central idea of this work was to study the degree of influence of each raw material on the HPS cold agglomeration process at Monlevade plant, keeping up the current characteristics of the SFAN. The study aimed at:

- characterize the various raw materials involved in the HPS process;
- study the contribution of each raw material on the cold agglomeration effect;
- observe the microstructure of the quasi-particle with the use of optical and electron scanning microscopes;
- adjust the specification parameters of the raw materials aimed at improving the performance of the agglomeration process;
- Validate the adequacy of the changes with an industrial test.

2 MATERIALS AND METHODS

2.1 Characterization of Raw Materials

The samples of all raw materials used in the Monlevade sintering plant were collected in the sampling points near the proportioning scales, in a 24-hour period. Table 2 presents the tests to which the samples were submitted.

Table 2 – Analyses and tests performed for the technological characterization of the raw materials.

MÉTHOD	MATERIAL	SFAN	Burnt lime	Serpentine	Limestone	Mn ore	Quasi-particle
Mineralogy, texture and microstructure	XRD	X	X	X	X	X	X
	SEM-BSE and SE	X	X	X	X	X	X
	Optical microscopy						X
Chemistry	XRF	X	X	X	X	X	
	Wet analysis	X	X	X	X	X	
Reactivity	WHÜRER		X				
S.S.A.	BET		X				
Size distribution	Screening separation	X	X	X	X	X	X

Source: Januzzi [4]

2.2 Study of the Cold Agglomeration

This step was used to study the cold agglomeration phenomenon in the drum mixer, in HPS pelletizing discs and in the coating mixer. A special technique was developed for sample impregnation using an epoxi resin.

2.3 Adequacy of Raw Materials

Tests were conducted in pilot scale according to Table 3.

Table 3 – Tests on pilot scale

Material	**Test 1**	**Test 2**	**Test 3**
SFAN	65% SFAN e 35% natural PF	65% SFAN e 35% ground PF	50% SFAN e 50% ground PF
Burnt lime	Burnt lime A	Burnt lime B	Burnt lime C

2.4 Process Validation

Industrial tests were carried out with the already suitable raw materials and the already studied process parameters.

3 RESULTS AND DISCUSSION

3.1 Characterization of Raw Materials

The results of the quantitative chemical composition of the raw materials examined by wet analyses are presented in Table 4.

Table 4 – Global chemical composition of raw materials sampled in the sintering plant.

Sample	Results in weight (%)									
	Fe total	SiO_2	Al_2O_3	Mn	CaO	MgO	P	Cr	S	PPC
SFAN	64.68	4.29	1.28	0.12	0.062	0.108	0.041	-	-	0.81
Serpent.	-	40.0	4.34	0.11	2.67	31.83	0.020	0.133	-	12.46
Burnt lime	-	1.52	0.24	-	94.32	0.53	0.085	-	0.126	4.82
Limestone	-	0.96	0.32	-	54.69	0.36	0.078	-	0.074	41.62
Mn Ore	47.77	5.52	1.57	14.93	-	-	0.064	0.044	-	6.58

Source: Januzzi [4]

The mineralogical characterization was carried out by X-ray diffraction analysis and the results are presented in Table 5.

Table 5 – Minerals and minerals phases present in the samples (analyses by XRD).

Sample	The concentration of minerals (phases) in the sample			
	Abundant	Middle range	Low	Traces
SFAN	hematite	talc	kaolinite quartz	goethite gibbsite
Serpentine	clinochrysotile	talc nimite (Ni-chlorite) tremolite	goethite chromite	
Limestone	magnesium calcite		quartz	
Burnt lime	calcium oxide		portlandite	
Mn ore	hematite quartz	pyrolusite		goethite gibbsite magnetite kaolinite

Source: Januzzi [4]

The study of size distribution of raw materials showed the need for adequacy of some materials depending on the stage of pelletizing in the pelletizing discs. Table 6 shows the results.

Table 6 - Summary of the observations in the size distribution analysis of raw materials.

	Coarse fraction	Intermediary fraction	Fine fraction
SFAN	high percentage, reaching >10%	major percentage	low percentage of <0.044mm
Serpentine	high percentage, reaching >35%	low to average	low percentage
Limestone	high percentage, reaching >60%	low to average	practically inexistent
Mn ore	high percentage, reaching >15%	major percentage	low percentage
Burnt lime	high percentage, reaching >11%	major percentage	low percentage

Source: Januzzi [4]

The analysis of specific surface area (SSA) by the B.E.T. method (Lowell & Shields[5]) showed that the burnt lime had low specific surface area, thus contributing to a low reactivity performance. The measured SSA was 1.45m^2/g, while the measured reactivity in 3 minutes was 312 ml HCl.
The study of the shape and texture of the grain was essential in characterizing the materials and knowledge of the properties that contribute positively and negatively to the cold agglomeration. The images of MEV were analyzed for the several particle sizes of grains of raw materials. Table 7 shows the results.

Table 7 – Key features observed in the form of raw materials (SEM analysis).

Material	Coarse fraction	Intermediary fraction	Fine fraction
Sinter-feed	specularite grains, smooth surface, low porosity, with foliation	specularite grains, smooth surface, without pores	specularite grains, smooth surface, low porosity
Serpentine	fibrous crystals, highly porosity, highly wrinkle, agglomerated aspect	fibrous crystals, high porosity, highly wrinkled, agglomerated aspect, presence of magnetite	fibrous crystals, high porosity, highly wrinkled surface, agglomerated aspect
Limestone	microporous in the surface of the grains, microwrinkled, agglomeration of fine grains	microporous in the surface of the grains, microwrinkled, agglomeration of fine grains, coarse grain coated by fines	irregular grains, some with planar shape, microporosity, coated by very fine grains
Mn ore	grains with soil aspect, high porosity, corroded, with fine grains agglomerated	grains with soil aspect, high porosity, corroded, with fine grains agglomerated	grains with soil aspect, high porosity, corroded, fine grains agglomerated
Burnt lime	porous grains with high wrinkled surface	sintered grains due to excessive heat	sintered grains due to excessive heat

Source: Januzzi [4]

3.2 Study of HPS Cold Agglomeration

Granulation is the process whereby very fine particles are joined together for making up a coarse particle, as shown in Figure 1.
We can understand by “granulation”, the process where very fine particles are joined together for the structuring of a coarse particle as shown in Figure 1.

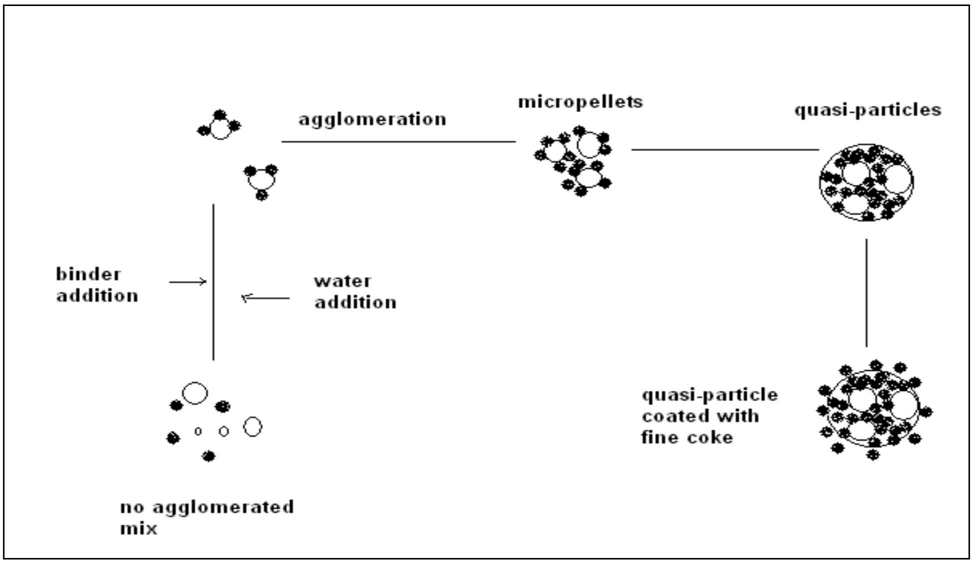

Figure 1 – Granulation process following the addition of water. Source: Vasconcelos.[6]

3.2.1 Formation of the micropellets in the drum mixer

During the formation of the micropellets in the drum mixer, strong relationship of dependency of the grain shape which is positioned in the pellet’s core with the binding agent was observed. In the SFAN case, since the ore particle which is positioned at the core is very smooth and has low porosity, the binding agent needs to be very effective so that the fine particles contact with the nucleus is not damaged in following handlings. Figure 2 shows a picture of the contact of the thin layer with the core particle, showing a detachment surface caused by the lack of small pores.

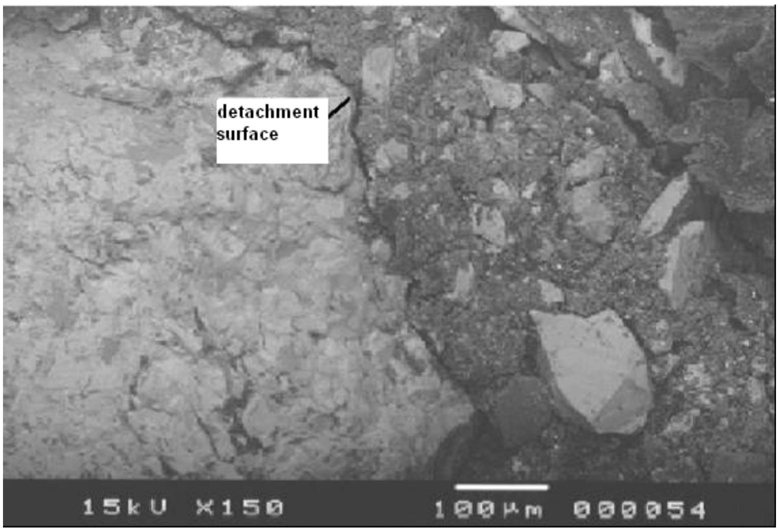

Figure 2 – Microstructure of a quasi-particle showing the detachment surface of the thin layer in the core due to low intra granulate porosity of the Andrade ore. Scanning electron microscope, backscattered electrons image (SEM-BSE)

3.2.2 Formation of quasi-particles in the pelletizing discs

During the growth of quasi-particles in the pelletizing discs, the formation of a second thin layer was observed, containing finer particles than the first film formed in the mixing drum (Figure 3). Thus, it was possible to conclude that the pelletizing disks are able to add finer particles to the micropellets, optimizing the cold agglomeration and enabling the growth of quasi-particles until they reach the average size of 4.5mm to 5.0mm.

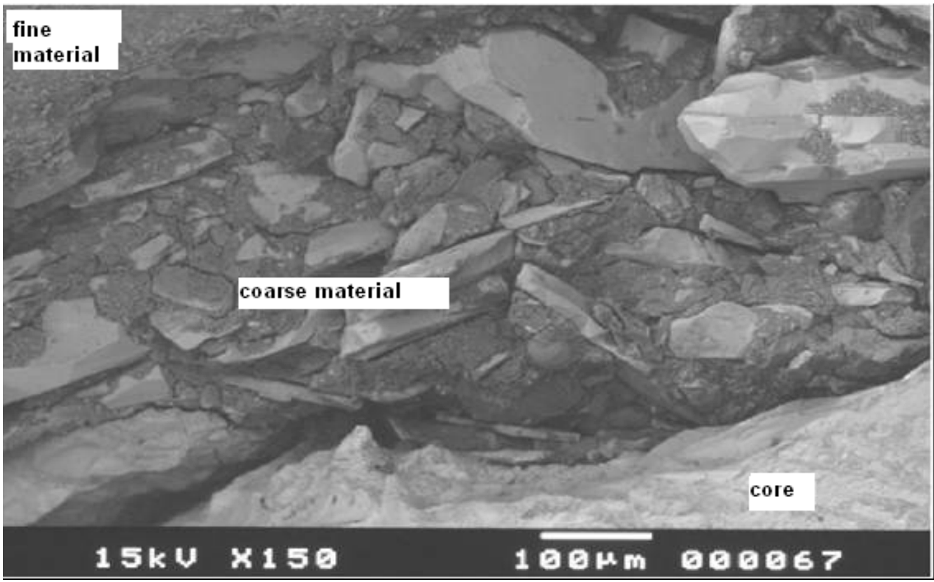

Figure 3 – Details of the two thin layers formed on the quasi-particle after the exit from the pelletizing disk. Image SEM - BSE.

3.3 Adequacy of the Raw Materials

The characterization of raw materials showed the need to change the size distribution of limestone, serpentine and manganese ore, making these raw materials finer and with a lower percentage of coarser fractions.

Tests carried out with the SFAN grinding plant showed the importance of the fraction below 0.044mm in the cold agglomeration, as shown in Figure 4.

As the percentage of the fraction <0.044mm increased in the SFAN material, an improvement in the agglomeration in the pelletizing discs was observed.

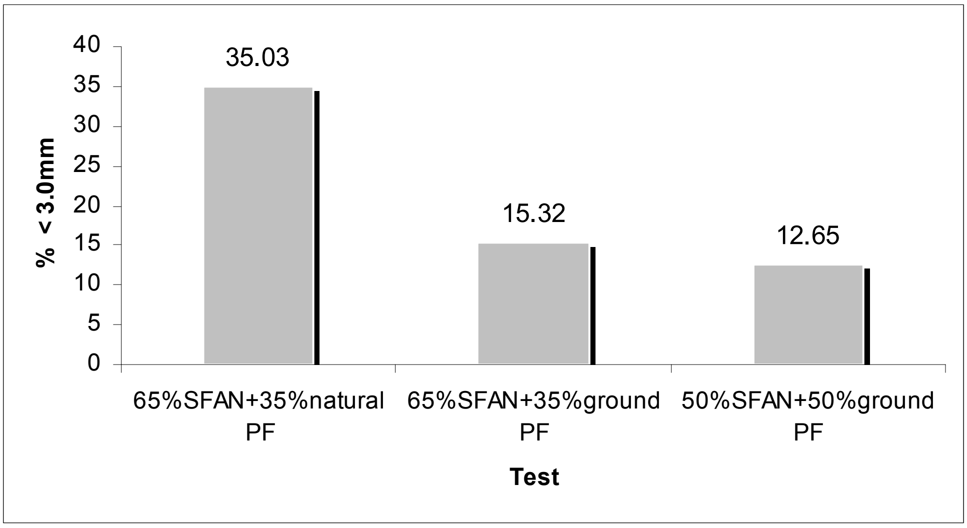

Figure 4 – Tests with SFAN adjoined with ground pellet-feed (Source: Januzzi [(4)]).

Another important variable studied was the reactivity of burnt lime; as verified earlier the quality of burnt lime is directly linked to the effectiveness of agglomeration in the stages of the drum mixer and the pelletizing disc.
A more reactive burnt lime means a very fine grained lime, ground, showing internal grain porosity, without the sintered appearance. At this point the control parameter designed for the burnt lime was the specific surface area.
After the necessary changes implemented by the supplier, the specific surface area of lime grew from a level of $1.45m^2/g$ to $7.75m^2/g$. The percentage of the fine fraction <0.105mm increased from 30% to over 60% and the reactivity from 312ml of HCl to 370ml of HCl, improving the efficiency of this raw material to cold agglomeration.

3.4 Process Validation

The most important step of all this work was the certification in the industrial process in which the implemented adjustments in raw materials were validated and had a positive response on the performance of the HPS cold agglomeration process.
For this certification, a plan of industrial test was designed with entirely suitable raw materials, excluding changes in the Andrade sinter-feed. The results of this industrial test were compared with the average routine data in 2007 for validation.
The industrial planning consisted of actions aimed at ensuring the experiment representativeness and the information gathering able to bear further examination. The following actions were carried out:

- assurance that the raw materials – limestone, manganese ore and serpentine were within the suggested specifications;
- ensure the specification of the lime reactivity was obeyed by the supplier;
- ensure that the operating parameters of the agglomeration equipment were within the working limits;
- assure that the mixture moisture was under control and within a previously established limit.

3.4.1 Validation of the process in the mixing drum

As seen in item 3.2.1; the agglomeration stage in the mixing drum, also known as the first stage of cold agglomeration, is extremely important for both following aspects:

- It is in this stage that occurs, in the first quarter of the mixer, the homogenization of the mixture of ore and other raw materials with the binding agent without water addition;
- It is also in this stage, after the homogenization that occur the first addition of water for the micropellets formation.

The challenge in the industrial test was to raise the average size of these micropellets, what will certainly be translated by the growth of the wrapping thin layer around the core thicker grains.

After the adjustment of raw materials and the use of a more reactive burnt lime there was a significant gain in the average size of the micropellets, from a size of 3.0mm to 3.3mm and in the percentage of the fraction over 3.0mm, from 36% to 42%.

Therefore, it was concluded that there was a significant change in the distribution of grain mixture after the stage of agglomeration in the drum mixer or the first stage of agglomeration.

This is a confirmation of the established premise that the finer raw materials are better suited to the HPS cold agglomeration.

3.4.2 Process Validation in the pelletizing discs

The other studied stage of agglomeration during the industrial test was the agglomeration in the pelletizing discs, which represents the essence of the HPS process. By keeping the basic parameters of rotation, tilting and mixture moisture in discs following the same ones used during 2007, the studied variable started to be the granulation of the quasi-particles, after the adequacy of raw materials and more reactive lime.

There was a considerable increase in the percentage of the > 3.0mm fraction, from 56% to 71%, which means that there was an improvement in the agglomeration performance in the pelletizing discs. This improvement is attributed to the best performance of the burnt lime that, in the pelletizing discs, performs an important role as binding agent for the micropellets from the drum mixer.

Even the average size presented a growing progress, going from 4.07mm to 4.36mm denoting a certain steadiness of the process after the adequacy of the raw materials.

3.4.3 Process Validation in the sinter machine

During the industrial test, other analyzed and followed parameter was the depression of the exhauster fan that relates itself to the suction pressure exerted for the air percolation in the mixture layer inside the sinter machine.

In the case of a low-permeability layer, it will imply in a high suction pressure, while a permeable mixture will implicate in a low pressure.

What was observed was a non-stop increase in permeability of the layer as the average size of the quasi-particle increased and a consequent reduction in the values of the suction pressure (depression). This fact led to the increase in the layer height in 20mm, which means a rise in levels of production and productivity and a reduction in energy consumption measured in kWh/t of sinter.

4 CONCLUSION

The characterization of the main raw materials used at the Monlevade sinter plant indicated several improvements which proved to be worth while.

Thus, the serpentine, limestone, manganese ore and limestone have their size distribution graphs changed, aiming at increasing the finer fraction percentage and the reduction of the coarser fractions.

The burnt lime was also changed in size distribution, having the fraction <0.105mm increased from 30% to 60% on the average, aiming at enhancing the specific surface area, as well as reactivity.

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The average size of the quasi-particles increased from 4.07mm to 4.36mm and the fraction percentage of >3.0mm increased from 56% to 71%, originating an improvement in the permeability of the sinter machine, which allowed a rise in productivity and increasing the layer height.

Thus, it was found that in the HPS it is important to explore the synergy between raw materials, mainly when iron ore presents low power of cold agglomeration.

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