



## Removal of mica from crushed sand by high pressure washing

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### ABSTRACT

Sand and gravel are the second and third largest minerals in production in Brazil, and this is increasing noticeably. The extraction of natural sand from river beds is increasingly restricted and most of the sand used in large cities comes in from more than 150 km away, resulting in high transportation costs. As a result, it has become more common to use crushed rock as artificial sand. The main difficulties in this process are controlling the shape of the particles and the content of deleterious materials, such as mica.

Within this situation, this paper presents an alternative to using artificial sand for concrete use. Our procedure involves the following steps: a) sampling sand from different production days, b) characterizing the bulk sample by particle size and shape distribution, chemical composition by X ray fluorescence and mineralogical composition by X ray diffraction, c) removing fine grains by air classifier, d) performing intensive attrition with high pressure washing and e) characterizing products.

The results demonstrated that this sample contains a huge proportion of fine grains and a notable content of mica, which is distributed along all sieve fractions. The presence of mica makes the use of sand in concrete unfeasible, moreover scanning electron microscopy analysis demonstrated that this phyllosilicate is finely grained and associated with coarse fractions. Thus, the removal of fine fractions made possible a partial reduction in mica content. Furthermore, intensive attrition demonstrated that the procedure was efficient to remove most of the mica while also reducing sharp edges, which improved the shape of these particles.



## INTRODUCTION

Sand and gravel are respectively the second and third highest produced mineral commodities in Brazil (DNPM, 2012), and it has increased notably in the last few years. The mining of aggregates features high volume production, simple mineral processing operations, low value and high cost of transportation - 1/3 the price of sand and 2/3 the price of gravel (La Serna & Rezende, 2009). The Brazilian production of sand and gravel exceeds 500 million tons/year (DNPM, 2012).

Restrictions on sand mining close to urban centers and large consumer markets have worried the mineral sector. The blocking of deposits due to the expansion of urban areas and environmental restrictions has a direct impact on the prospects of cost and supply of these minerals (La Serna & Rezende, 2009). The price of sand in Sao Paulo, the largest Brazilian city with about 20 million people, raised 100% in the last few years and costs from 30 to 40 USD/m<sup>3</sup> (DNPM, 2012).

In this scenario, in the late 90s there was a big push for cheaper alternative sources of sand; at that moment the production of artificial sand by crushing gravel became the most promising market and remains to this day (Almeida, 2005).

Artificial sand is in most quarries a byproduct of coarse aggregates production; the fine fraction not intentionally generated from crushing of limestone, basalt and granite make up the artificial sand. As a by-product, artificial sand has irregular shape and rough texture. The shortage of sand is so critical, that many quarries have dedicated part of their operation to produce sand as the main product. In this case, mineral processing was fundamental to enhance sand properties, such as the use of vertical impact crushers (VSI) (Almeida, 2005) or sand mills (BHS Rotor Impact Mill) for the improvement of roundness and sphericity of particles and classifiers (air classifiers or cyclones/spirals) to remove fine fractions (below 0.074 mm).

The use of artificial sand for mortar and concrete should be carried out with prudence. The rheological behavior of mixtures depends on packing particles with less amount of voids, so particles size distribution and morphology have to be controlled and optimized through mineral processing (Cincotto & Carneiro, 1999). Besides, the presence of some minerals, such as mica presents a deleterious effect as the reduction in compressive, tension, flexural and split strengths, decrease of workability, and loss increase of abrasion (De Jain, 1977) or increase the rate of concrete expansion due to alkali-aggregate reaction (Grattan-Bellew & Beaudoin, 1980. Yujiang & Wang, 2008).

Therefore, this paper presents an alternative to suit artificial sand for concrete use by removing mica and improving aggregates shape.

## EXPERIMENTAL

This paper presents a summary of the main properties of the artificial sand produced from crushed rock by tertiary crushing in a vertical shaft impact crusher (VSI) and its composition after air classification and high pressure washing removed mica and fragile phases through intensive scrubbing. The main properties of the attained products were characterized and compared to the previous sand.

The experimental procedure is shown in Figure 1 and described below.



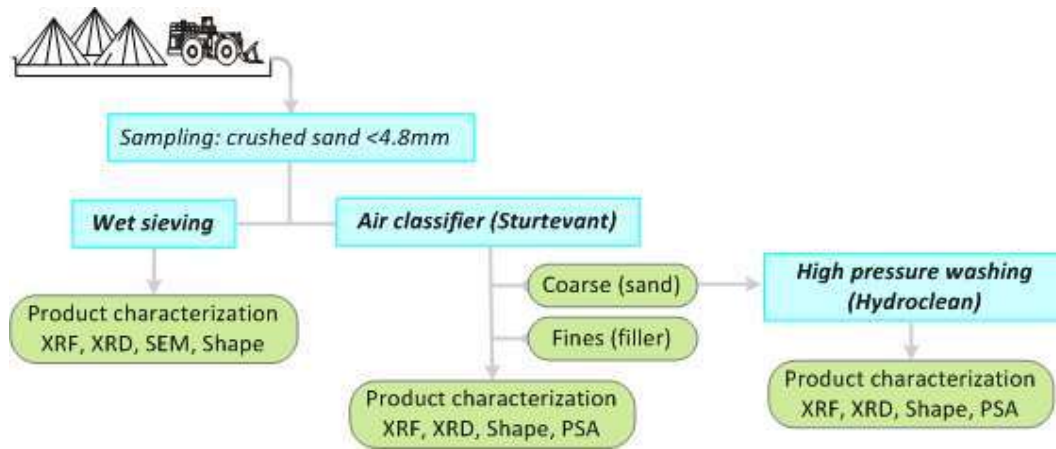


Figure 1 Experimental procedure

**Sampling:** crushed sand directly from the plant was sampled for one week. The total sample was homogenized and sampled again to obtain a representative sample for laboratory studies.

**Wet sieving and mica associations:** the sample was wet sieved in different size fractions. The attained products were characterized according to their chemical and mineralogical composition, particle shape and mica associations by scanning electron microscopy (SEM; Quanta 600 FEG, FEI) coupled with an energy disperse spectrometer (EDS; Quantax, Bruker) and mapping of the main elements.

**Air classification:** this step was carried out to remove the maximum amount of fine fractions (filler), so different fan blade rotations and feed rates were tested. The process was conducted with the Sturtevant Whirlwind air classifier 3 FT 7.5 HP. The selected operational condition was 800 rpm rotation, 1,500 kg/h feed rate and no selector blades. The products (coarse and fine) were sieved at 0.074 mm to assess the efficiency of the separation.

**High pressure washing:** this step aimed to promote an intensive attrition to assess the possibility of removing the mica adhered to particles surface (coarse product from air classification) according to the following procedure: high pressure washing in a Hydroclean® labor unit (Haver & Boecker equipment) at 120 bars and 2 cycles of 30 s each followed by wet sieving of the attained products.

**Product characterization:** the chemical analyses were carried out by quantitative X-ray fluorescence with an Axios spectrometer (PANalytical) in fused beads for the quantification of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, K<sub>2</sub>O, Na<sub>2</sub>O, CaO, MgO, Fe<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, MnO e P<sub>2</sub>O<sub>5</sub>; loss on ignition was assayed at 1,050°C for 1 h.

**Mineralogical composition:** X-ray diffraction (XRD) of each product was assessed by the powder method with X'Pert PRO X-ray diffractometer with CuK $\alpha$  radiation and X'Celerator detector (PANalytical); the identification of crystalline phases was obtained by comparing the XRD patterns to the ICDD (International Centre for Diffraction Data) database.

Particles shape was characterized by dynamic image analyses according to the procedure described by the international standard ISO 13322-2/ 2006. The assays were carried out on the Retsch Camsizer® L (30  $\mu$ m



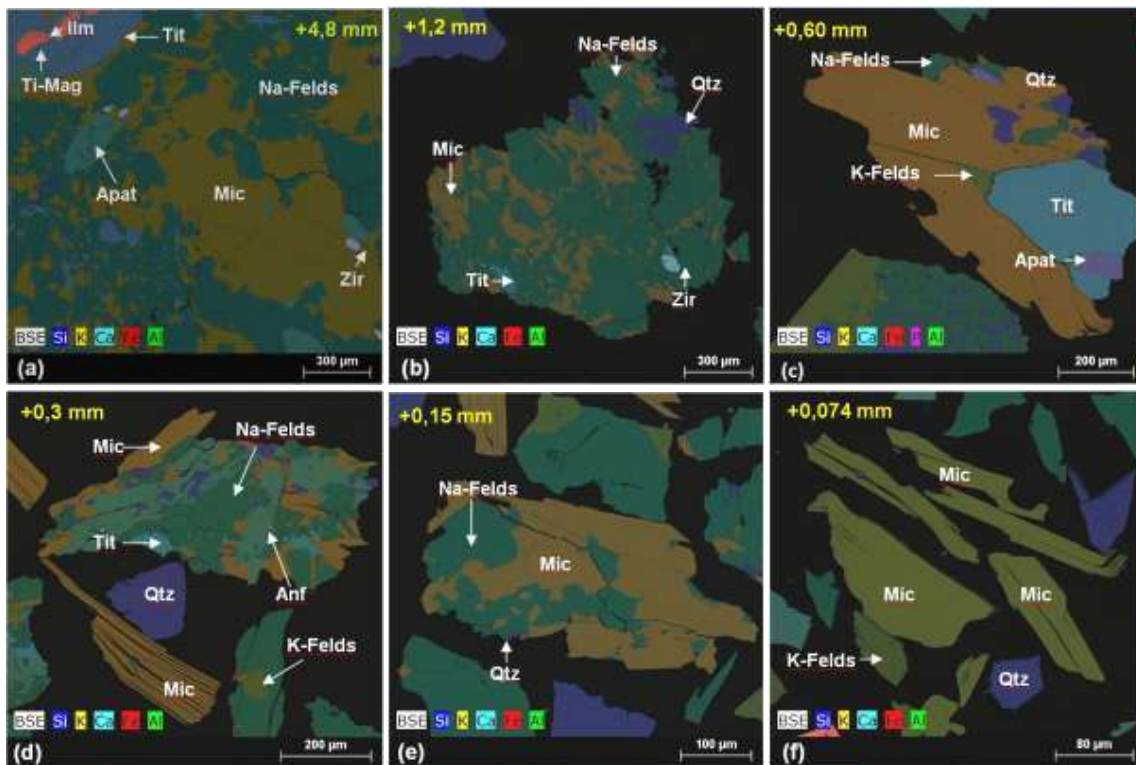
a 30 mm) and Camsizer® XT (1 µm a 3 mm).

## RESULTS AND DISCUSSIONS

Representative images of scanning electron microscopy with mapping of the main chemical elements (Figure 2 and Figure 3) demonstrate that mica (colored in brown) is associated with other minerals in all size fractions. The occurrence of free mica is observed only in the finest fraction (Figure 2 f), which means that the removal of fine fractions by air classification (or hydrocyclones) eliminates only part of the mica.

The complex texture observed during mica's association with other minerals justified the high pressure washing tests to evaluate the possibility of removing mica from the surface of coarse particles.

The chemical composition, weight and elemental distribution of all products is shown in Table 1, the mass balance of all attained product is better explained in Figure 4, and the diffractograms of products from air classification and high pressure washing are compared in Figure 5.



Obs: Mic: Mica; Qtz: quartz; Na-Felds: sodium feldspar; K-Felds: potassium feldspar; Tit: titanite; Ti-Mag: titanium magnetite, Ilm: ilmenite; Zr: zircon; Ox-Fe: iron oxide, Apat: apatite; Anf: amphibole.

Figure 2 SEM images with detailed associations of mica

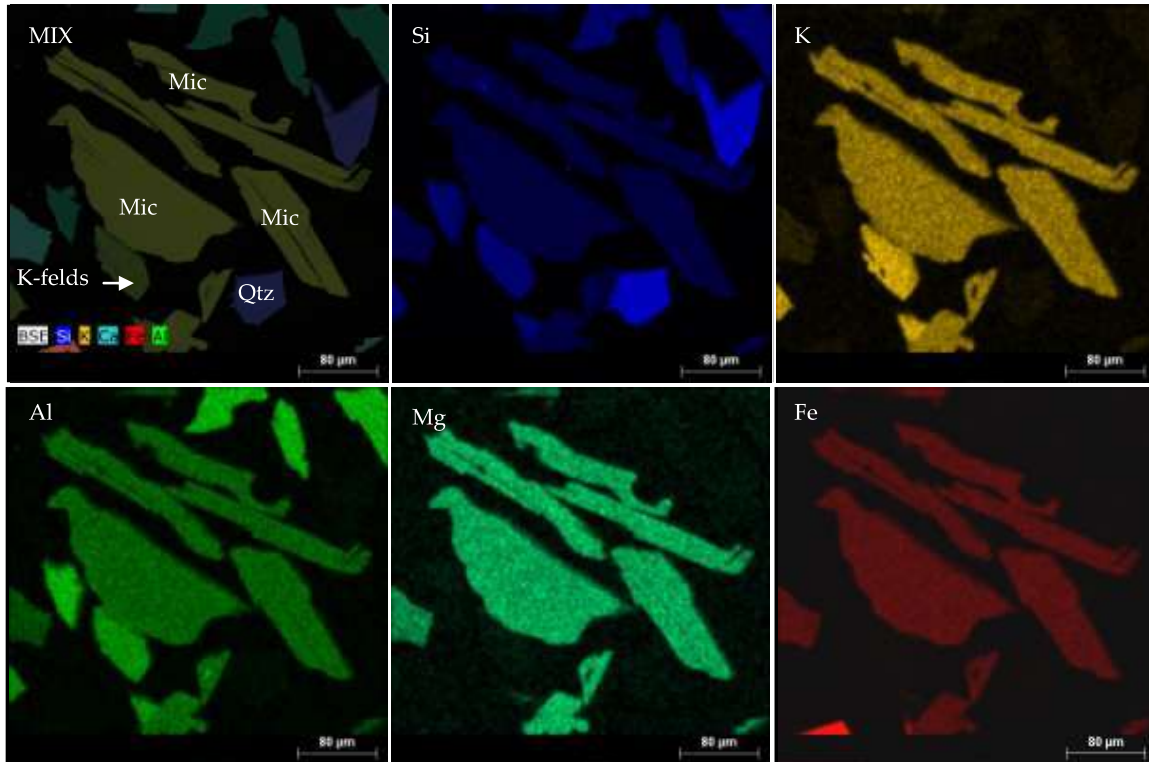


Figure 3 Mapping of the main chemical elements presents in mica - responsible for the Mg and secondarily Fe (also associated with the amphibole) contents in the sample



Table 1 Chemical composition, weight and elemental distribution of products from sieving, air classification and from Hydroclean high pressure washing

Products	Weight (%)		Grades (%)								Sample distribution (%)							
	assay	sample	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>
Feed	100.0	100.0	60.6	15.5	6.29	2.40	4.25	3.50	4.39	1.06	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
<b>Sieving</b>																		
>0.15 mm	75.1	75.1	61.6	15.8	5.49	2.10	4.04	3.59	4.56	0.99	76.3	76.5	65.6	66.0	71.4	77.2	78.0	70.2
0.15-0.074 mm	10.1	10.1	57.9	13.6	9.35	3.46	5.06	2.82	3.80	1.39	9.7	8.9	15.0	14.6	12.1	8.2	8.8	13.3
<0.074 mm	14.8	14.8	57.2	15.3	8.25	3.14	4.75	3.46	3.91	1.18	14.0	14.6	19.4	19.4	16.5	14.7	13.2	16.5
<b>Air classifier</b>																		
Coarse	80.9	80.9	61.4	15.6	5.86	2.13	4.20	3.55	4.44	1.04	82.0	81.3	75.3	71.9	79.9	82.0	82.0	79.6
Fine	19.1	19.1	57.0	15.2	8.13	3.52	4.46	3.28	4.14	1.13	18.0	18.7	24.7	28.1	20.1	18.0	18.0	20.4
<b>Hydroclean</b>																		
>0.15mm	72.4	58.6	62.6	16.1	4.75	1.76	3.88	3.67	4.73	0.94	60.6	60.8	44.3	43.1	53.5	61.6	63.2	51.7
0.15-0.074mm	18.3	14.8	59.3	13.8	8.62	3.00	5.05	3.11	3.58	1.37	14.5	13.1	20.3	18.5	17.6	13.2	12.1	19.1
<0.074mm	9.3	7.5	56.2	15.2	9.03	3.27	5.03	3.42	3.89	1.23	6.9	7.3	10.7	10.2	8.9	7.3	6.6	8.7

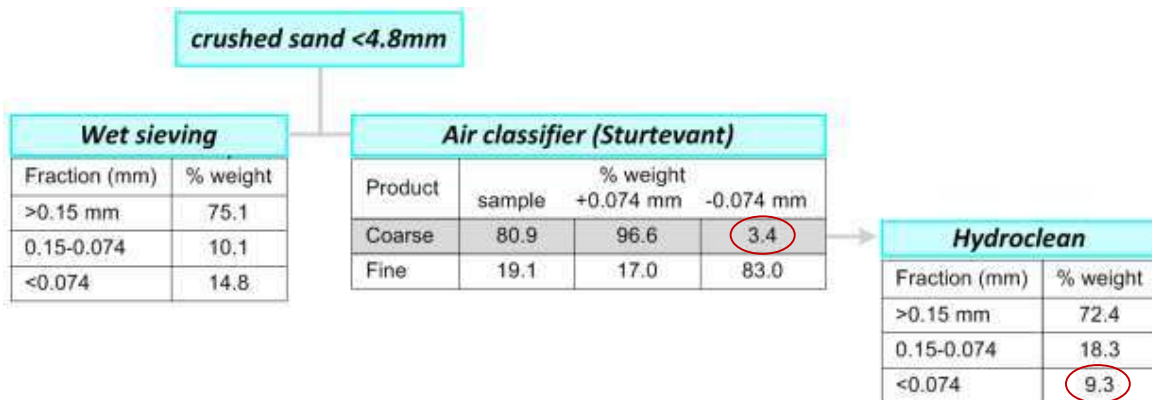
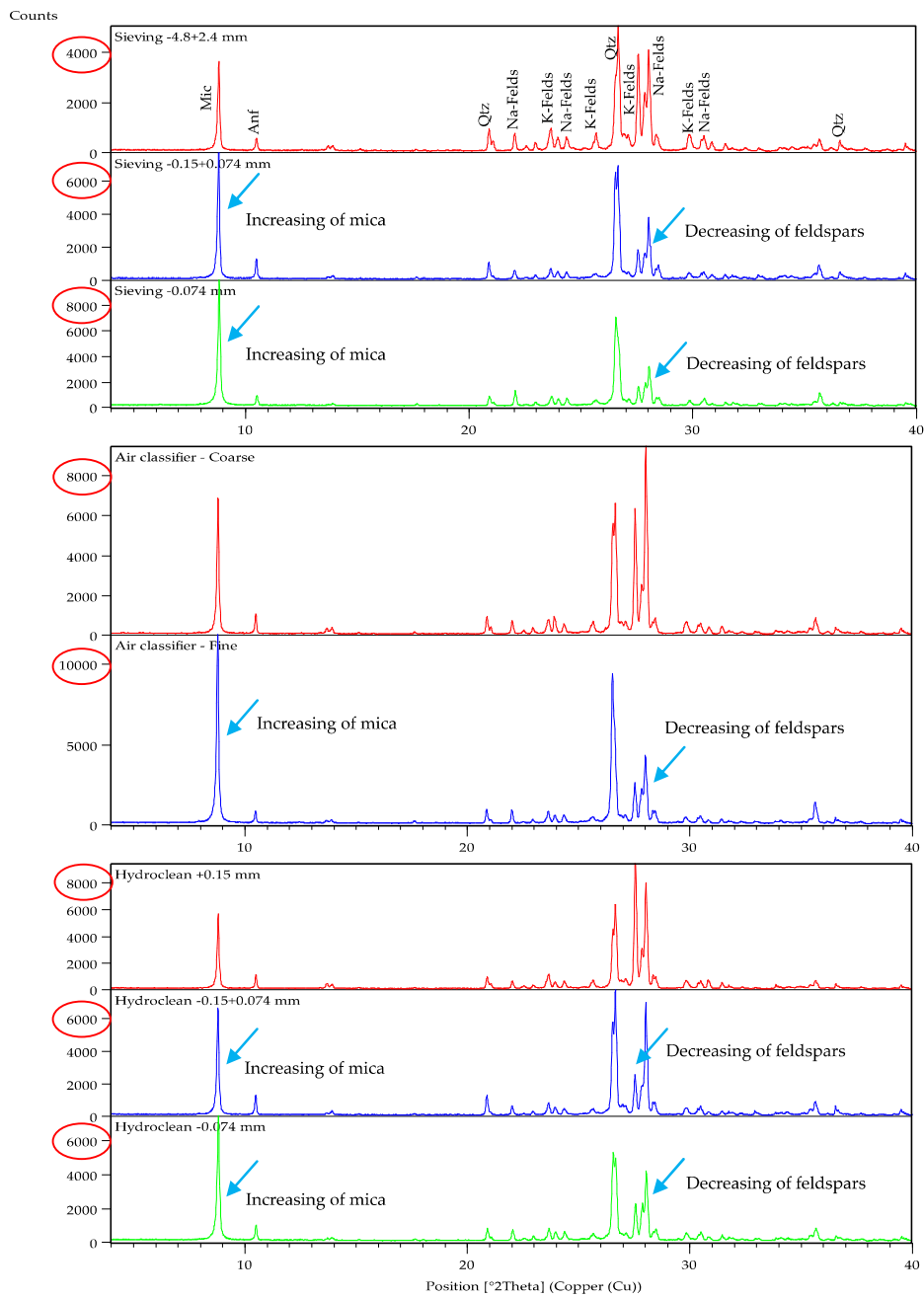


Figure 4 Bass balance of all attained products



Obs: Mic: Mica; Qtz: quartz; Na-Felds: sodium feldspar; K-Felds: potassium feldspar; Anf: amphibole.

Figure 5 Comparative diffractograms of products from air classification and Hydroclean high pressure washing



According to the chemical and mineralogical assays, finer fractions show an increasing mica content (demonstrated by the increase in Mg and Fe grades on the X ray diffractograms and SEM images) and a notable reduction in feldspar percentages (which is better seen in the decrease of feldspar peaks intensity in XRD patterns).

Air classification was carried out to remove as many fine fractions as possible; therefore the coarse product represents 80.9% wt of the total sample. The efficiency was very high, since coarse product has just 3.4% of particles below 0.074 mm (assessed by wet sieving). On the other hand, the fine fraction represents 19.1% of the sample and has 17% of particles above 0.074 mm. So, it is possible to conclude that the set conditions optimized the recovery of the coarse fraction with high efficiency but part of coarse particles were diverted to the fine product.

However, as shown by SEM images, most of the mica is associated with other minerals in coarse size fractions and cannot be removed by air classification alone, so Hydroclean proved to be an effective option. First of all, on coarse product, the weight proportion of the fraction over 0.074 mm increased from 3.4% to 9.3% wt, demonstrating that high pressure intensive washing generates attrition and particle breakage. Moreover, the fine fractions produced by the Hydroclean operation present a higher content of Mg, which indicates an increase in mica, which is also confirmed by the XRD patterns.

Regarding full mica removal, it can be pointed out that free mica particles are present in fine fractions and can be removed by air classification, while another percentage of mica is attached to coarse particles and can be partially removed by Hydroclean washing.

With respect to the air or wet sieving classification, two main aspects must be considered: a) the impact of using water and managing a tailings dam, and b) the flat shape of mica may make their removal by air flow easier and their removal by sieving more difficult (flat mica can be removed more easily by air flow than by sieving). In regard to this, the sphericity ( $SPHT = 4\pi \cdot \text{Área} / \text{Perímetro}^2$ ) and aspect ( $b/l = \text{breadth/length}$ ) ratios of particles from the attained products assessed by dynamic image analysis are compared in Figure 6.

For both parameters (SPHT, b/l), the frequency of particles with irregular shape is higher for the sieve products while the highest frequency of round shape particles occurs on products from air classification and from the Hydroclean. In summary, air classification improves the shape of crushed sand (removes flat mica particles from coarse fractions), and the Hydroclean washing improves the shape of air classification products (breakage of sharp and irregular particle edges).

The difference in terms of frequency of particles are remarkable (Figure 6). Products from sieving have between 60 and 70% low SPHT particles ( $<0.80$ ) and  $b/l$  ( $<0.70$ ) and just half of this total (between 30 and 40%) of high SPHT particles ( $>0.80$ ) and  $b/l$  ( $>0.70$ ). On the other hand, the coarse fractions from the Hydroclean process (HC  $>0.15$  mm) present almost 60% high SPHT particles, the coarse air classifier produces 55% and the intermediate fraction from the Hydroclean (HC 0.15-0.074 mm) reaches almost 70%.

There is a clear tendency for increasing SPHT from sieving to air classifier to Hydroclean products; the similarity between the  $b/l$  values of fine and coarse products from sieving and the notable difference between these values for the air classifier products corroborate that it is preferable to remove mica by air flow on fine products (mica has low  $b/l$  value like the fine product).

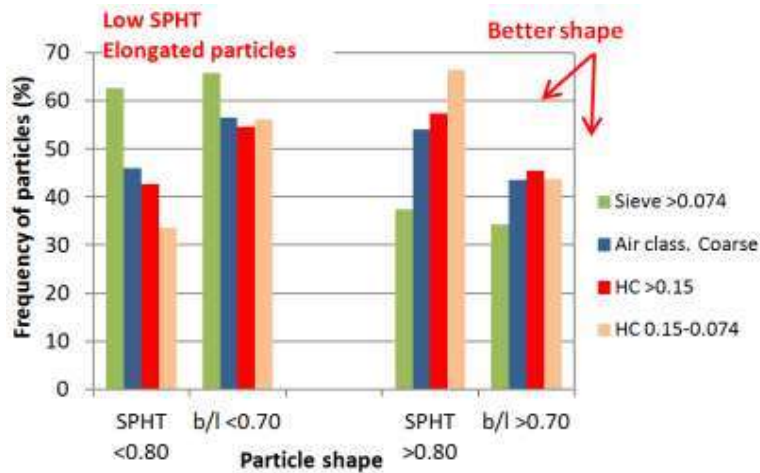


Figure 6 Frequency of particles with different shape

## CONCLUSIONS

The content of mica in crushed sand can be partially removed by air classification followed by intensive high pressure washing. In the last few years, crushed sand has become a very important raw material for concrete due to the scarcity of natural sand close to the largest Brazilian centres and growing markets. Still, mica content is limited since it reduces the concrete's mechanical strength and may increase alkali reactions with the aggregates.

In contrast to many industrial beliefs, mica is not present just in fine fractions; mica is also associated with different mineral phases at all sieve fractions, as demonstrated by the SEM studies.

Air classification proved to be very efficient at removing free and fine grained mica and also generated a product with a better sphericity and aspect ratio than wet sieving. In addition, another proportion of mica attached to coarse particles can be partially removed by Hydroclean washing, which also leads to a better shaped product since it promotes the attrition and breakage of sharp and irregular particle edges.

The content of mica in each product was estimated by the grade of Mg and the peaks intensity of XRD patterns. The precise quantification of these minerals by XRD is inaccurate because of the crystallographic complexity of each phase and could be carried out only by SEM-based automated mineralogy. Furthermore, the benefits of shape improvement and mica removal can be directly evaluated by producing concrete specimens and monitoring resistance.

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