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Demolished concretes recycling by the use of pneumatic jigs

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Abstract

Large quantities of construction and demolition waste is generated annually around the world. Part of this material is processed in recycling plants. After removing metals, fines and lights, the construction and demolition waste is crushed and sized and can be used as aggregates for low resistance concrete, for road sub-base, city landfill and other low value-added applications. For their use as coarse aggregate in structural concretes, construction and demolition waste must exhibit high densities and regularity of the material. This material usually is presented in demolished concretes. About 20% of the particles from demolished concretes can be used as coarse aggregates substituting part of natural aggregates in structural concretes. This article presents studies of demolished concretes recycling by the use of a pneumatic jig. All jigging tests were carried out with three different concretes produced in three strength classes: C16/20, ordinary concrete; C50/60, high strength concrete; and C70/85, very high strength concrete. Based on density distribution of the three concretes, there are reasonable masses with densities over 2.7 g cm^{-3}, particle density considered appropriate to the used as coarse aggregate for structural concretes. The concretes present different mass recoveries of the denser particles (different liberation). Coarse aggregates can be recovered with reasonable masses by the use of air jigs: About 65% for high strength concretes and about 75% for the low strength concrete. The jigging concentration efficiency depends on the concrete liberation, density and size distribution.

Keywords

Concrete recycling, waste recycling, construction and demolition waste, pneumatic separation, air jigging

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Introduction

Large quantities of construction and demolition waste (CDW) is generated annually around the world: Between 310 and 700 million tonnes in the European Union (Eurpean Commission, 2011).

There are hundreds of CDW recycling plants around the world (Cazacliu et al., 2014; Coelho and Brito, 2013). Most of the plants crush CDW in different top sizes, remove the fine particles (usually discharged), the low-density material (like paper, plastics, wood, etc.) and the metal particles. The remaining material is known as inert CDW and consists basically of bricks, tiles, plaster, concrete, mortar and aggregate (Hua et al., 2019; Tam and Tam, 2006; Wu et al., 2014).

Inert CDW is used as aggregates for low resistance concrete, for road sub-base, city landfill and other low value-added applications (Contreras et al., 2016; Tam, 2009; Wong et al., 2018). This material is not used as aggregate in structural concretes (Behera et al., 2014; Silva et al., 2014; Xuan et al., 2018; Zega et al., 2010) where its commercial value would be several times higher.

For the use of inert CDW as coarse aggregate in structural concretes, CDW must exhibit high densities and regularity of the material (Behera et al., 2014). It is estimated that about 20% of inert CDW (denser material) can be used as a substitute for natural aggregates (Behera et al., 2014; Mueller et al., 2008). These

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20% consist of the denser part of the demolished concretes, which are basically old natural aggregates liberated by crushing.

A part of the natural aggregates produced can be replaced by the denser fractions of the inert CDW generated in recycling plants around the world. However, it is necessary to concentrate the dense fraction of inert CDW through some usual technique used in mineral processing (Cazacliu et al., 2014; Sampaio et al., 2016).

Jigs are the most commonly used equipment in gravity concentration (concentration based on the density of the particles) (Sampaio and Tavares, 2005). They are one of the oldest known processes in mineral processing. Their use in the process of particle separation was already known in Ancient Egypt (Lyman, 1992).

Jigs are the main equipment used in the mineral processing industry in terms of processed tonnes, mainly because of their low costs. Also, they are robust, have high processing capacity, are easy to operate and can process relatively large particle size ranges, which simplifies flowsheets in mineral processing (Sampaio and Tavares, 2005).

As a separation medium used in jigging cycle (expansion and compaction of the particle bed), the jigs can use water or air. Equipment that uses air is known as pneumatic jigs, dry jigs or simply air jigs.

Jigging concentration

Stratification in a pulsating bed of particles can be explained by the theory of Mayer (1950, 1964). A particle bed formed by spheres of the same size and different densities presents lower potential energy in the stratified bed (increase density from the top to the base) than in the bed of fully mixed particles. The stratification allows a lowering of the centre of gravity of the bed and consequently reduces its potential energy. Thus, stratification can be faced as a thermodynamic problem. The expansion and compaction of the particle bed (jigging cycle) does not promote stratification, but creates the conditions for the bed to stratify and thereby decrease its potential energy.

Mayer (1950, 1964) also describes in his theory that a bed of particles of different sizes, shapes and densities will be packed in such a way that the largest possible lowering of its centre of gravity occurs and consequently the lowest possible potential energy.

The variation of the potential energy (difference of the mixed and stratified bed) is also a function of the process kinetics. Thus, the greater the density difference between the particles, the greater is the separation kinetics.

The particle bed, however, never reaches its maximum stratification. The process of expansion and compaction (jigging cycle), which releases potential energy to lower levels, requires bed movement, which generates re-mixing of the particles (Tavares, 1999; Tavares and King, 1995). This instability occurs until the bed reaches a balance, with the potential energy tending to stratify the bed and the jigging cycle promoting re-mixing.

In mineral processing, one way of estimating whether a particle bed can be stratified is the concentration criterion (CC) (Taggart, 1945), which is a relation between the densities of two particles to be separated, discounting the buoyancy force. If the CC is a large number, the density difference between the particles is large. Thus, there will be a greater decrease of the potential energy, facilitating stratification. Particles with densities closer will be more difficult to be stratified than particles with bigger density differences.

Materials and methods

Concrete samples

All tests were carried out with three different concretes produced in three strength classes defined by the EN206 European standard): C16/20 ('ordinary concrete' – denominated in the paper *Concrete 16 MPa*), C50/60 ('high strength concrete' – denominated *Concrete 54 MPa*) and C70/85 ('very high strength concrete' – denominated *Concrete 85 MPa*).

The concrete samples were crushed in a jaw crusher at top size of 20 mm and sized in the following size ranges: 4.75/19.1 mm, 4.75/8.0 mm, 8.0/12.7 mm and 12.7/19.1 mm. The concrete samples were submitted to sink–float tests in the densities 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7 and 2.8 g cm^{-3}, in the same size ranges.

Mixtures of the following heavy liquids were used to reach the different separation densities: Bromoform ($CHBr3$ – Trimethyl bromide) with a density of 2.81 g cm^{-3}, and Perchloroethylene (Tetrachloroethylene), with density of 1.62 g cm^{-3}.

The concrete samples were separated in the following density ranges: $\delta < 2.1$ g cm^{-3}, $2.1 < \delta < 2.2$ g cm^{-3}, $2.2 < \delta < 2.3$ g cm^{-3}, $2.3 < \delta < 2.4$ g cm^{-3}, $2.4 < \delta < 2.5$ g cm^{-3}, $2.5 < \delta < 2.6$ g cm^{-3}, $2.6 < \delta < 2.7$ g cm^{-3}, $2.7 < \delta < 2.8$ g cm^{-3} and $\delta > 2.8$ g cm^{-3}.

Particles with a density over 2.7 g cm^{-3} were considered as liberated coarse aggregate (Linss and Mueller, 2004; Park et al., 2018; Ulsen et al., in press) that can be recycled in Civil Industry as a mixture with natural coarse aggregate to produce structural concretes.

Jigging tests

The jigging tests were carried out in a batch pilot-scale air jig model AllAir® S-500 of the company AllMineral (Figure 1). The jigging chamber is assembled with different rectangular sections of Plexiglas (500 × 500 × 50/25 mm), here referred to as 'separate sections' (Figure 1), fitted one over the other on a perforated plate (Ø = 1 mm) for the air passage. The set of separation sections made possible the extraction of the particle beds layer by layer.

In order to increase separation efficiency, three separation sections were used: Two with 50-mm high and one with 25-mm high (Figure 1). The separation sections present, from the bottom to the top of the jig, the following particle layers: 'Bottom layer' with height of 50 mm, where dense particles were

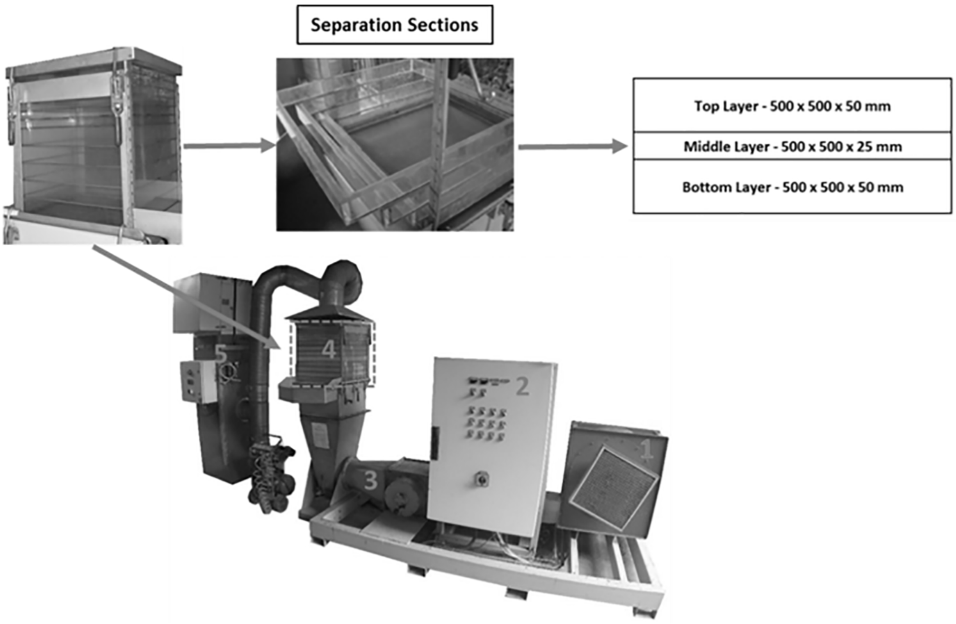

Figure 1. Some views of the air jig AllMineral AllAir® S-500.

concentrated, called here '*HEAVIES*'; 'middle layer', with height of 25 mm, layer of middle density particles, called here '*MIDDLINGS*'; and 'top layer', with height of 50 mm, where light particles are concentrated, called here '*LIGHTS*'. The middle layer was used specifically to increase jig efficiency. In a continuous industrial process, the lighter particles can be concentrated in the top layer, denser particles in the bottom layer and all particles retained in the middle layer can be recycled in the same jig (return to the feed).

All the jigging tests were carried out with a particle range of 4.75 to 19.1 mm, a similar size range of natural coarse aggregate (natural rocks) used in civil engineering construction.

For each test, the three separation sections were completely filled with concrete particles. The mass used in each jigging test was about 50 kg. After jigging stratification, the three layers were separated. The top layer (with light particles) and the bottom layer (with heavy particles) were submitted to dense and size characterisation, and the middle layer was discharged.

The following jigging parameters (optimised in previous tests) were used: Frequency of 140 r min; percentage of air generated by the jig fan: 80% of the total jig fan capacity for 60 s, 60 s more with 70% fan capacity and finally another 60 s with 60%. Total jigging time was 180 s. The jig airflow is provided by a 15-kW blower (Combimac, 49,631/B1Y1), which was adjusted in the control panel in function of the percentage of the blower power (0% to 100%). The blower could produce an airflow of up to 73 $m^3 min^{-1}$.

Results and discussion

Size distribution

The concrete particles present the following size distribution (size ranges: <4.75 mm, 4.75/8 mm, 8/12.7 mm and 12.7/19.1 mm):

- Concrete 16 MPa: 25.98%, 10.04%, 30.86% and 33.12%, respectively.
- Concrete 54 MPa: 24.65%, 10.84%, 32.60% and 31.91%, respectively.
- Concrete 85 MPa: 22.19%, 11.70%, 33.77% and 32.34%, respectively.

Concretes with a smaller strength produce a higher liberation during comminution of the cement paste, owing to the different strength of the materials (cement paste and coarse aggregate). The higher the concrete strength, the smaller the material amount in small sizes. On the other hand, in the coarser size range (>8 mm), the concrete with higher strength presents a higher mass of particles.

This behaviour can be explained by the coarse aggregate liberation from cement paste during crushing. Concretes with higher strengths tend to be comminuted randomly and the particles accumulate in coarser sizes. Concretes with smaller strengths tend to liberate the coarse aggregates during comminution, owing to the strength difference of the coarse aggregate and the cement paste.

Density distribution

Table 1 presents the density distribution of the three concretes in size ranges: 4.75/19.1 mm (jigging feed), 4.75/8 mm, 8/12.5 mm and 12.5/19.1 mm. Each density fraction of the size range 4.75/19.1 mm is the sum of the material in the same density range of the fractions 4.75/8 mm, 8/12.5 mm and 12.5/19.1 mm. The size distribution 4.75/19.1 mm of the three concretes is the jig feed. All the jigging tests were carried out with these densities and size distribution.

The 16 MPa concrete particles in size range 4.75/19.1 mm present 29.05% by mass in the density lower than 2.3 $g\,cm^{-3}$; and

Table 1. Concretes density distribution of the three strength classes (16 MPa, 54 MPa and 85 MPA) and different size distribution (4.75/19.1 mm, 4.75/8 mm, 8/12.5 mm and 12.5/19.1 mm).

Density range (g cm⁻³)	Size range 4.75/19.1 mm			Size range 4.75/8.0 mm			Size range 8.0/12.5 mm			Size range 12.5/19.1 mm		
	16 MPa	45 MPa	85 MPa	16 MPa	45 MPa	85 MPa	16 MPa	45 MPa	85 MPa	16 MPa	45 MPa	85 MPa
	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)	Mass (%)
$\delta < 2.2$	2.7	7.0	0.0	1.2	14.4	0.0	3.5	9.6	0.0	2.5	2.5	0.0
$2.2 < \delta < 2.3$	26.4	13.8	1.2	66.5	35.4	1.7	40.8	16.8	1.7	9.0	4.2	0.3
$2.3 < \delta < 2.4$	2.5	5.0	23.8	11.8	9.6	47.5	2.4	4.7	25.9	0.6	3.7	7.6
$2.4 < \delta < 2.5$	1.4	6.3	7.1	2.6	3.4	14.4	0.2	5.2	6.5	1.9	8.2	3.7
$2.5 < \delta < 2.6$	2.7	7.0	4.3	0.4	2.3	2.0	1.4	5.1	3.5	4.1	9.9	6.6
$2.6 < \delta < 2.7$	3.2	13.7	10.6	0.5	4.6	3.6	1.2	10.5	14.7	5.1	19.2	9.7
$2.7 < \delta < 2.8$	8.7	14.7	15.1	0.7	5.8	4.7	4.7	13.4	11.6	12.9	18.6	25.3
$\delta > 2.8$	52.4	32.6	37.8	16.3	24.5	26.1	45.8	34.7	36.1	63.9	33.7	46.8
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

61.10% in the density range higher than 2.7 g cm⁻³. Most of the coarse aggregates (in the case natural rocks) are partially or totally liberated and accumulates at densities over 2.7 g cm⁻³. On the other hand, most of the liberated cement paste accumulates in densities lower than 2.3 g cm⁻³.

In general, after comminution, particles of the three comminuted concretes tend to cumulate preferentially in lower and higher densities with different masses, owing to different particle liberation that is a function of the concrete strength. During comminution, there are preferential plans of rupture in the coarse aggregate/cement paste interface, which propitiate the breakage along the interface. In higher densities, there is a concentration of coarser particles, which are the coarse aggregates partially liberated by crushing (see Table 1). The higher the strength of the concrete, the smaller is the coarse aggregate liberation.

The same behaviour can be observed for light particles, which commonly are the liberated cement paste and accumulate in lower densities and in the finest size ranges. The cement paste presents lower density and strength than the coarse aggregates. During crushing, the cement paste tends to be liberated and to be comminuted in smaller particles.

Concretes with high strengths present higher strength cement paste and, consequently, when crushed, high amounts of particles in middle densities (in the case from 2.3 or 2.4 to 2.7 g cm⁻³). As defined, these particles are called middlings and are formed partially by particles of coarse aggregate and cement paste.

It is important to emphasise that the 85 MPa concrete cumulates light particles in density range 2.3 to 2.4 g cm⁻³. On the other hand, concrete with 54 MPa cumulates light particles in density range 2.2 to 2.3 g cm⁻³. Owing to the high strength of the paste in the concrete, 85 MPa, even light particles are not completely liberated.

The three concretes (size range 4.75/19.1 mm) present the following masses of the particles with density over 2.7 g cm⁻³: Concrete 16 MPa – 61.10%; concrete 54 MPa – 47.25%; and concrete 85 MPa – 52.89%. Particles with density over 2.7 g cm⁻³ are considered appropriate to the used as a coarse aggregate for structural concretes.

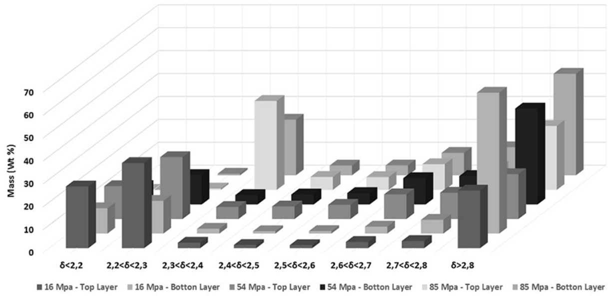

Figure 2. Density distribution of the jig products, top layer and bottom layer, with three strength concretes (16 MPa, 54 MPa and 85 MPa). Size range 4.75/19.1 mm.

Jigging tests

Figure 2 presents the density distribution of the jigging tests products. The density distribution is presented for the light particles (top layer) and for the heavy particles (bottom layer). As commented, the middle layers were not used in this work and were discharged.

The jigging test with the concrete 54 MPa, to exemplify the figure, presents two concentrates: Light particles (lights) in top layer and heavy particles (heavies) in the bottom layer. The heavies present the following density distribution: 8% in mass in density under 2.2 g cm⁻³, 12.8% in density range 2.2 to 2.3 g cm⁻³, etc. The total mass distribution is equal to 100%.

It is possible to see in Figure 2 that the higher the concrete strength, the higher the amount of middling (in this case particles with densities between 2.3–2.4 g cm⁻³ up to 2.7 g cm⁻³) in the jigging products (top and bottom layers).

Figure 2 also presents a higher liberation of the coarse aggregate and the cement paste in the concrete 16 MPa. Owing to the strength difference of the coarse aggregates and the cement paste, there are preferential plans of rupture in the aggregate/paste interface. This phenomenon propitiates a higher liberation of the coarse aggregates and the cement paste. In high-strength concretes (54 MPa and 85 MPa), the ruptures are not preferentially in the interface coarse aggregate/cement paste, but randomly, owing to the similar strength presented by the materials.

In a perfect separation, if all particles were liberated and there was no presence of middlings, the liberated coarse aggregates should be concentrated in the density over 2.7 $g\,cm^{-3}$, and the lights in densities under 2.3 $g\,cm^{-3}$.

Real concretes, when comminuted, present different density distributions, depending on their strengths that propitiate different particle liberation. The liberation study of the three concretes are presented in Table 1, which are the jigging feed. This table presents different amounts of middlings (particles with intermediary densities), lights and heavies for the three concretes studied. As described in the introduction, the expansion and compaction of the particles layer propitiate particle density stratification. It means, the particle density decreases direction to the layer top. In a simplified way, it is possible to say that in the top layer should be basically the lights, in the bottom layer the heavies and in the middle layer the middlings (not considered in this work). On the other hand, heavy particles should not be in top layer and light particles should not be in bottom layer. These particles are called misplaced material and represent the separation imperfection or cut imperfection.

Based on the Mayer theory (Mayer, 1950, 1964), not only the particle density is taken into account for stratification. The bulk density of the particle layers should also be considered. It means the packing of the particles with different sizes. Theoretical stratified particle layers should present the lowest potential energy of the particle mixture, and consequently the lowest centre of masses. There should be a density particle stratification (density increase from the top to the bottom) and small particles with the same density stratification in between the coarse particles (space available between coarse particles). The particle mixture should present the highest possible bulk density, as well as the lowest centre of masses.

In a real stratification system, this theoretical system is never reached. In order to stratify a particle bed, the particle layer should be expanded and compacted to liberate potential energy. In jigging, an expansion/compaction cycle is used to stratify the particle bed. The energy used to make the particle bed movement (jigging cycle) tends to be a re-mixture the partial stratified layer. After some jigging cycles, a balance is reached (Mayer, 1950, 1964) and induces a jigging separation imperfection, with dense particles with the lights and light particles with the heavies.

With the increase of the concrete particle liberation, related to concrete strengths, there is a higher amount of liberated coarse aggregates (density over 2.7 $g\,cm^{-3}$) and liberated cement paste (density under 2.3 $g\,cm^{-3}$). It propitiates a higher concentration criterion, a higher centre of mass lowering (difference of the centre of mass position before and after stratification) and a higher lowering of the potential energy (related to centre of mass lowering). These factors have influence in a better jigging separation efficiency.

Figure 3 presents a mass balance of the lights (concretes 16 MPa and 54 MPa $\delta < 2.3\,g\,cm^{-3}$, and concrete 85 MPa $\delta < 2.4\,g\,cm^{-3}$), middlings (concretes 16 MPa and 54 MPa $2.3 < \delta < 2.7\,g\,cm^{-3}$, and concrete 85 MPa $2.4 < \delta < 2.7\,g\,cm^{-3}$) and heavies ($\delta > 2.7\,g\,cm^{-3}$) for the three concretes concentrated in the air jig.

As an example, it is possible to say that the concrete particles 54 MPa, after stratification in the air jig, present the following products (Figure 3): Bottom layer presents 20.8% lights ($\delta < 2.3\,g\,cm^{-3}$), 24.9% middlings ($2.3 < \delta < 2.7\,g\,cm^{-3}$) and 54.3% heavies ($\delta > 2.7\,g\,cm^{-3}$); middle layer was not considered (discharged); and top layer presents 41.3% lights ($\delta < 2.3\,g\,cm^{-3}$), 27.7% middlings ($2.3 < \delta < 2.7\,g\,cm^{-3}$) and 31.0% heavies ($\delta > 2.7\,g\,cm^{-3}$).

The amount of heavies in the bottom layer increases with concrete strength. The higher is the concrete strength, the smaller is the coarse aggregate liberation, owing to the higher cement paste strength (Figure 3). Coarse aggregate mass recovery in the bottom layer is associated with the particle liberation and for sure the separation efficiency of the jig (Figure 2). In a completely liberated particles bed, concentrated in an air jig with very high efficiency, the most part of the heavies should be allocated in the bottom layer. The same behaviour is expected in the top layer, therefore with the cement paste liberation, the amount of lights increases.

It is important to emphasise the amount of middlings in the products (bottom and top layers). They should be concentrated in the middle layer, which is not considered in the work. In industrial processes, these particles can be submitted to a new comminution and feed the beginning of the circuit, or simply discharged. Figure 2 presents a smaller amount of middling in the concrete 16 MPa (higher liberation). This material should be concentrated in the middle layer, but owing to the jigging efficiency part of the material is allocated in the bottom and top layers.

Considering only the material of the top layer and bottom layer, and not considering the particles of the middle layer, a mass balance of the coarse aggregate (size: 4.75/19.1 mm and $\delta > 2.7\,g\,cm^{-3}$) is presented in Table 2.

It is possible to see in Table 2 that, after the jigging process, 73.57% of the heavies ($\delta > 2.7\,g\,cm^{-3}$) are reported to the bottom layer of the concrete 16 MPa, 64.92% of the concrete 54 MPa and 64.52% of the concrete 85 MPa. It can be seen clearly that jigging efficiency is higher for the concrete with low strength and the coarse aggregate recoveries are about 65% for high strength concretes and about 75% for the low strength concrete.

Reasonable mass recoveries of the coarse aggregate (heavies in the bottom layer) can be reached in a jigging process, about 75% in the concrete 16 MPa, and about 64% in concretes 54 MPa and 85 MPa.

Figure 4 presents the density distribution of the jigging products (bottom and top layer) of the three strength concretes

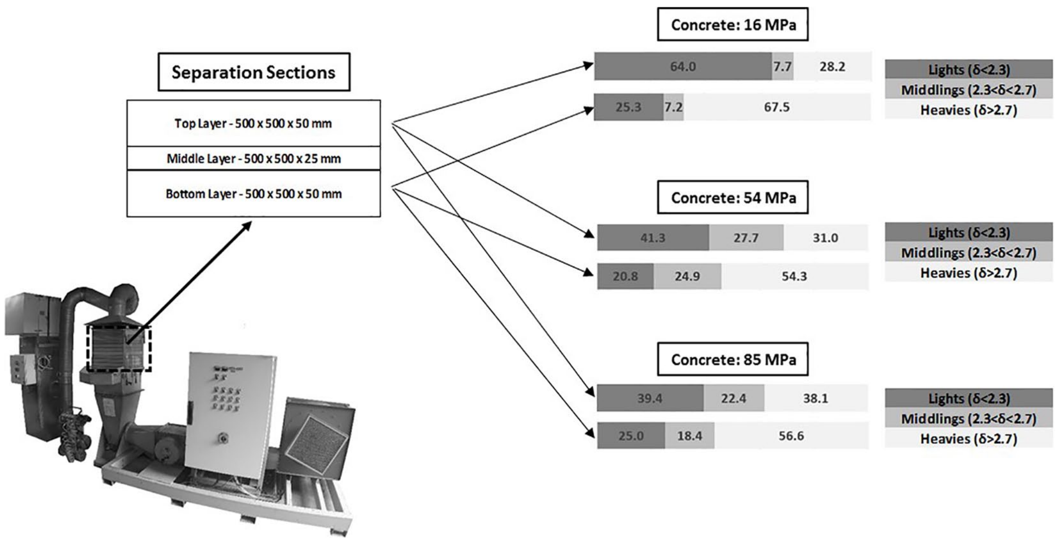

Figure 3. Mass balance of the stratified particles (heavies, middlings and lights).

Table 2. Mass balance, after jigging, of the total particles and total heavies in top layer and bottom layer.

16 MPa	Mass (Wt%)	Heavies (Wt%)
Top layer	46.20	26.43
Bottom layer	53.80	73.57
		100.00
54 MPa	**Mass (Wt%)**	**Heavies (Wt%)**
Top layer	48.60	35.08
Bottom layer	51.40	64.92
		100.00
85 MPa	**Mass (Wt%)**	**Heavies (Wt%)**
Top layer	44.96	35.48
Bottom layer	55.04	64.52
		100.00

(16 MPa, 54 MPa and 85 MPa) in three different size ranges (4.75/8 mm, 8/12.5 mm and 12.5/19.1 mm). The sum of the masses in all density ranges is 100%. For instance, the concrete 16 MPa presents for the top layer, size range 4.75/8 mm, 82% in mass in the density range $2.2 < \delta < 2.3\,g\,cm^{-3}$; 27.7% in mass in top layer, size range 8/12.5 mm and density range $2.2 < \delta < 2.3\,g\,cm^{-3}$; and 2.1% in mass in top layer, size range 12.5/19.1 mm and density range $2.2 < \delta < 2.3\,g\,cm^{-3}$.

Figure 4 shows higher amounts of middlings ($2.3 < \delta < 2.7\,g\,cm^{-3}$) in concretes 54 MPa and 85 MPa, and for coarser size ranges. The higher the concrete strength and the size range, the higher is the amount of middling. The particle liberation depends on the size range.

This behaviour interferes directly with the jigging efficiency of the coarser particles, owing to the density distribution (presence of middling). As commented, the jigging efficiency depends on particle liberation, which increases the concentration criterion. It is worthwhile to say that liberated fine particles can be located in the spaces in-between coarse particles, increasing bulk densities in the heaviest layers and consequently increasing the jigging efficiency.

Figure 5 presents the amount of lights in the top layer and heavies in the bottom layer for different size ranges and concrete strengths. For instance, the concrete 16 MPa, after stratification in the air jig, in the top layer, 91.5% in mass of the particles in the size range 4.75/8 mm presents $\delta < 2.3\,g\,cm^{-3}$. In a perfect jigging separation, this number should be 100%. The concrete 54 MPa, after stratification in the air jig, in the bottom layer, 50.3% in mass of the particles in the size range 4.75/8 mm presents $\delta > 2.8\,g\,cm^{-3}$.

Figure 5 presents a simple way to express the separation efficiency function of the particle size. Small numbers mean low separation efficiency and high numbers high separation efficiency. In this case, there is a clear tendency that finer particles present a higher separation efficiency.

This phenomenon can be explained by different positions. Coarser particles present a lower liberation that influence stratification in jigs (Figure 4). Owing to the higher liberation of finer size ranges, the separation efficiency is higher in finer size ranges. Another way to explain this phenomenon is based on Mayer's theory (Mayer, 1950, 1964). Mayer theory is based not only on particle densities distribution, but also based in bulk densities of particle beds, as explained above. A particle bed with different size promotes a better packing of the particles. Small particles occupy empty spaces in between coarse particles. In fact, the better efficiency of finer particles should be a sum of both effects. The same behaviour was described by Ambrós et al. (2019).

Conclusions

When comminuted to a 20-mm top size, concretes with different strengths present different liberation of the coarse aggregate and the cement paste. The higher the concrete strength, the smaller is the phase's liberation.

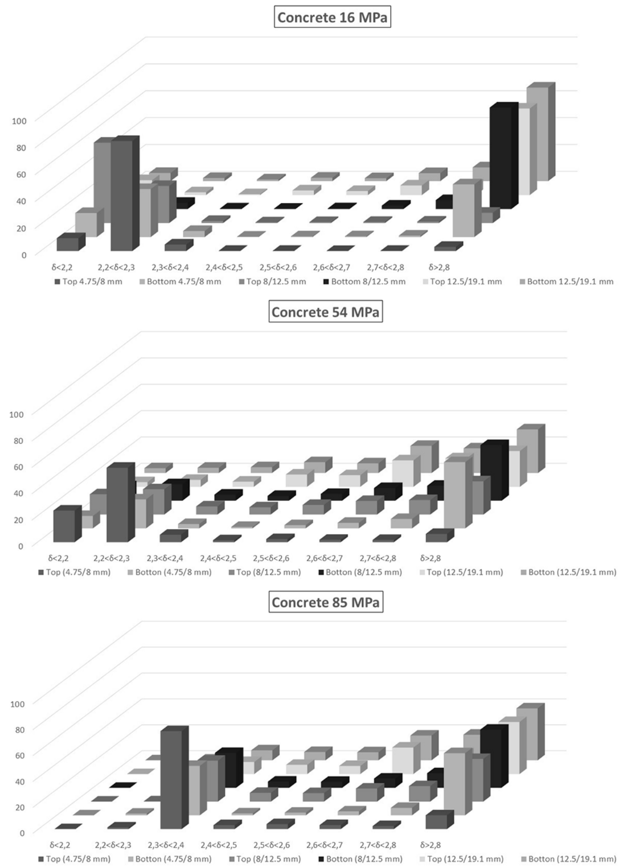

Figure 4. Density distribution of the jig products, top layer and bottom layer, with three strength concretes (16 MPa, 54 MPa and 85 MPa). Size ranges 4.75/8 mm, 8/12.5 mm and 12.5/19.1 mm.

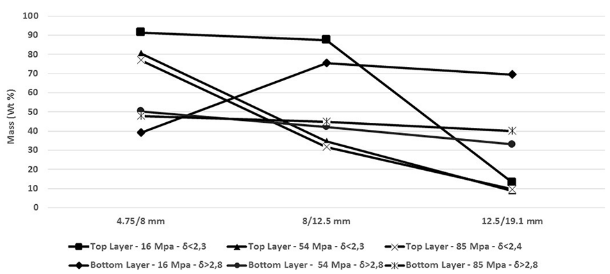

Figure 5. Lights in the top layer and heavies in the bottom layer for different size ranges and concrete strengths.

Based on density distribution of the concretes, there are reasonable masses with densities over 2.7 $g\,cm^{-3}$, the particle density considered appropriate to be used as coarse aggregate for structural concretes. The concrete 16 MPa presents 61.10% of the particles with a density over 2.7 $g\,cm^{-3}$, concrete 54 MPa 47.25% and concrete 85 MPa 52.89%.

Particle liberation, related to concrete strength, influences jigging efficiency, because of the concentration criterion and the potential energy lowering. The higher the particle liberation, the higher the jigging efficiency. The particle liberation also depends on the size range. The smaller the size range, the higher the liberation. Finer particles can be located in the spaces in-between coarse particles, increasing bulk densities in the heaviest layers and consequently increasing the jigging efficiency.

In the studied overall size range from 19.1 mm to 4.75 mm, there is a better separation efficiency for fine particles, owing to their liberation as well as their position in the particle layers (in-between coarse particles).

Coarse aggregates from demolished concretes can be recovered with reasonable masses by the use of air jigs: about 65% for high-strength concretes (54 MPa and 85 MPa) and about 75% for the low-strength concrete (16 MPa).

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