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Alternative Sands as Substitute for Natural Sand for the Construction Sector

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Abstract. While the need for sand in the construction sector is increasing, natural sand becomes scarce. On the other hand, several sand-like fractions out of industrial residues become available. This paper focusses on the potential use of these “alternative sands” as substitute for natural sand in the construction sector. The investigation included the study of the properties of alternative sands and a market research. In order to determine the properties, standard tests were performed such as the determination of the particle size distribution, the fineness modulus, the methylene blue test, determination of the density and the water-absorption. The particle size distribution of several fine recycled aggregates and of other fine fractions, derived from different producers, were compared to each other and to natural sand. This was to how alternative sands relate to natural sand and more specifically if they can be compared to natural sand and if they match the requirements of use of sand in constructional applications set by the standards and the standard specifications for road construction SB250. As a result, an overview table is made with the potential applications for each type of sand.

1. Need for sand

Natural sand that can be used in the construction sector becomes scarce. In the meantime, the demand for sand is increasing year by year. To be able to meet this demand for sand in the future and to reduce the pressure on nature, it would be an advantage if ‘alternative sands’ could be used as a substitute for natural sand. In this study, the properties of alternative sands derived from several sources, are examined to see whether they can meet the requirements set in the standards for use of sand in constructional applications. This was done by selecting a series of standard testing methods to determine the quality of sand to be used in construction applications. These tests include sieve analysis to determine the particle size distribution, determination of the fineness modulus, the methylene blue test, the determination of the density and the water-absorption. In addition is market survey was held to gain some insight into the market offer and demand of alternative sands.

2. Performed tests and survey

2.1. Selection of testing methods for sands

It is commonly known that the particle size distribution of the fine and coarse aggregates used in concrete, influences the workability of concrete. [1] Therefore, it is necessary to perform a sieve analysis to determine the particle size distribution of the sand. From the sieve analysis the fineness modulus and the filler content can also be determined. The particle size distribution of 693 samples of alternative sands from different producers are plotted to check the mutual differences between the producers. Next to this, a mutual comparison is made between natural sand and alternative sand and respectively between the alternative sands among each other.

To estimate the quality of the filler particles, the methylene blue test was performed on 59 samples. A high content of clay particles in the sand has a negatively influence the concrete quality.

Many researchers proved that recycled concrete aggregates have a higher water-absorption due to the attached mortar which influences the water demand and the workability of the concrete mixes. [2] [3] This is also the fact for fine recycled aggregates. [4] [5] [6] Next to this, recycled fine and coarse aggregates have a lower density which should be considered when designing a proper concrete mixture. Therefore, the density and the water-absorption of the alternative sands used in this study was also determined on 62 samples.

Once these properties are determined, the test results can be compared to the requirements for use of sand in construction applications mentioned in several standards and in the Standard Specifications for Road Construction SB250. [7] From this, potential applications can be determined for each type of alternative sand.

2.2. Market survey

The market survey was send to 95 producers. The analysis was made based on 26 completed surveys. The market survey consisted of various parts: information about the type of activities of the companies, the origin of the alternative sands, the acceptance policy, the recycling process, the certification of their products, the annual production, the cost and their commitment to valorise alternative sands as substitute for sand in the construction sector. This analysis provided a clear overview of the production and processing of alternative sands.

3. Results and discussion

3.1. Sieve analysis

All sieve analysis was performed according to the Belgian standard NBN EN 933-1: Tests for geometrical properties of aggregates – Part 1: Determination of particle size distribution – Sieving method. (2012) By plotting the particle size distribution of all alternative sand samples, differences in the particle size distribution of the samples can be determined. Moreover, differences between several types of recycled sands can be shown and these differences can also be related to the producers and/or production process. From the evaluation can be concluded that the sand fractions 0–2 mm and 0–4 mm always have a finer distribution than the sand fractions 0–6,3 mm. This is obviously the fact for the high-quality fine recycled concrete aggregates (fine RCA) as can be noticed in figure 1. The fraction 0–2 mm (producer F) obtains a cumulative passing of 98,0 % on the sieve 2,5 mm mesh. For the fraction 0–4 mm of the same producer (producer J) the cumulative passing is the first time 90,8 % and the second time 80,8 %. For the fraction 0–6,3 mm of high-quality fine RCA from producer A, the mean value for the cumulative passing on the sieve 2,5 mm mesh is 59,8 %. For the high-quality fine RCA from recycling porphyry concrete, the cumulative passing on the sieve 2,5 mm mesh is 62,6 % while for the same fraction of high-quality fine RCA from recycled gravel concrete this is 68,2 %. From this observation can be concluded that the smaller the cumulative passing, the rougher the sand is.

Figure 2 shows that ‘sieve sand’ from recycling broken up road construction is much finer than the sieve sand of mixed rubble and sieve sand from unspecified origin, compared to fine recycled concrete aggregates fraction 0–6,3 mm in figure 1. When comparing the average values of the curves on sieve of 0,5 mm mesh, the cumulative passing of the sieve sands from recycling road constructions is 85,66 %. For sieve sand of mixed rubble from producer B this is 56.18 %, respectively 52,28 % for producer F. In the case of sieve sand from unspecified origin, the cumulative passing on sieve 0,5 mm mesh this is 52,04 %.

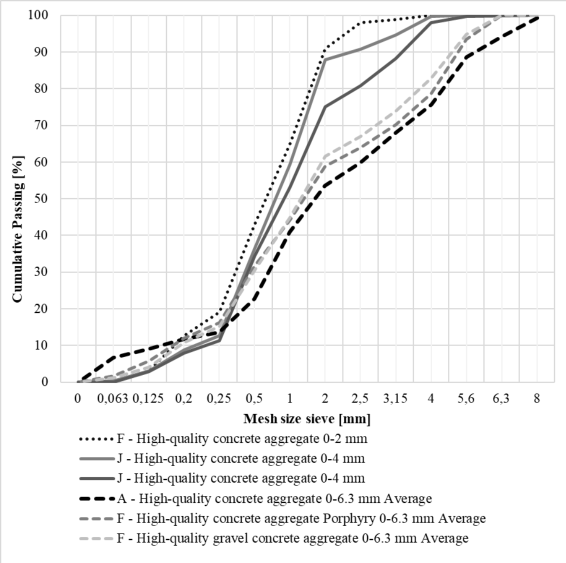

Figure 1. Particle size distributions high-quality concrete aggregate – Mean values

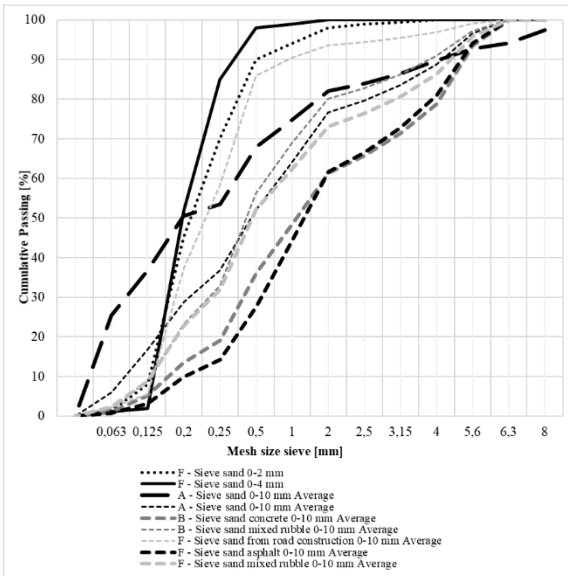

Figure 2. Particle size distributions sieve sand – Mean values

Sieve sands from concrete rubble and broken up asphalt are coarser. On the same sieve of 0,5 mm mesh the curves of the average values for fractions 0–6,3 mm have a cumulative passing of 36,14 % for concrete sieve sand at producer B, respectively 27,54 % for asphalt sieve sand at producer F.

By comparing the sieve sands of the different producers can be concluded that there isn't a large difference in particle size distributions between the sieve sand of mixed rubble from producer B and that from producer F. However, regarding the unspecified sieve sand from producer A, a wide spread in the particle size distribution is detected. This spread is at its maximum on the sieve of 0,2 mm mesh having a standard deviation of 7,20 %.

Fine RCA of the same fraction all have a similar particle size distribution for that particular fraction as seen in figure 3. From comparing the sieve analysis between the different producers can be concluded that the fine RCA of producers B and I show a finer gradient than those of the other producers. The values of Producer A show a larger spread between the minimum and the maximum values. The spread is maximum on the sieve of 1 mm mesh. The standard deviation there is 6,55 %. The average particle size distribution follows the most common curves of fine RCA.

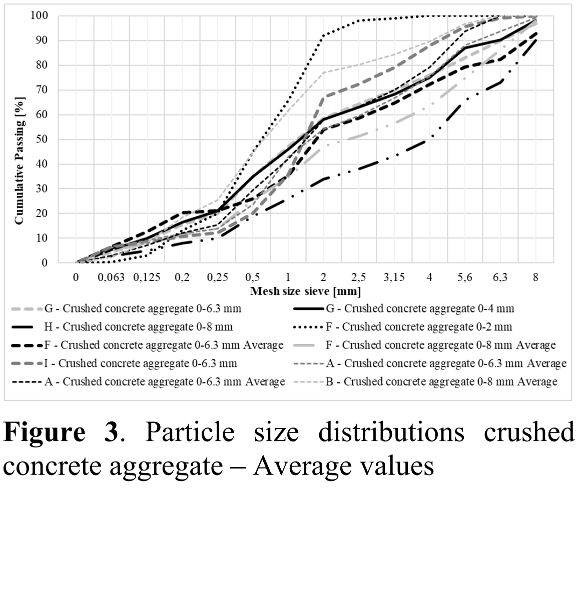

Figure 3. Particle size distributions crushed concrete aggregate – Average values

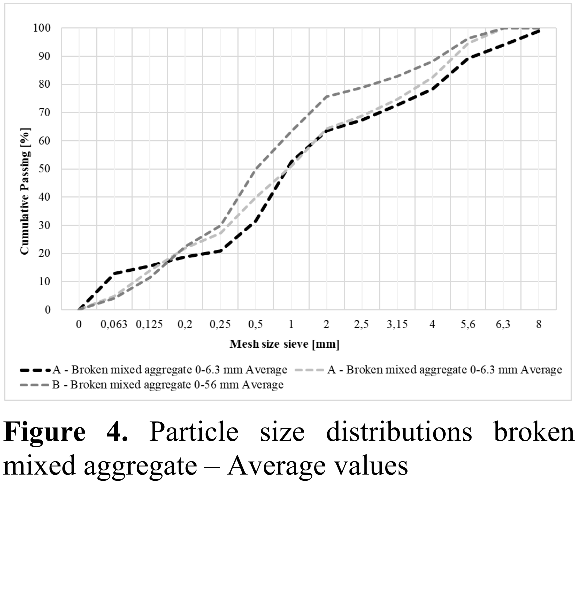

Figure 4. Particle size distributions broken mixed aggregate – Average values

Regarding the curves of high-quality fine RCA, almost always the same gradient is noted for the same fraction. There is a larger fine particle content detected for producer A. See figure 1.

For the particle size distribution of broken mixed aggregates, the same gradient is detected. This can be seen in figure 4. The particle size distribution of producer B are always higher than those of producer A. From the extended data given by producer A, also a larger quantity of fine particles is recorded.

For the 'secondary sands', is it established that 'blast furnace sand', 'bottom ash' and 'ferro aggregated slag' all have a similar particle size distribution. This is shown in figure 5. In the case of 'foundry sand', a particle size distribution with more finer grains is noted. The 'physico-chemically cleaned sand' prepared by producer E is slightly finer than that of producer D. The largest difference is seen on the sieve of 2 mm mesh. The average cumulative passing is 98,07 % for producer E, respectively 89,85 % for producer D. The particle size distributions are almost the same for the sieves less than 0,5 mm mesh.

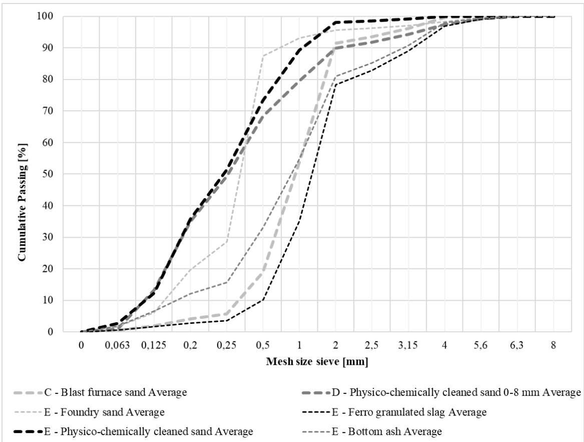

Figure 5. Particle size distributions secondary sand – Average

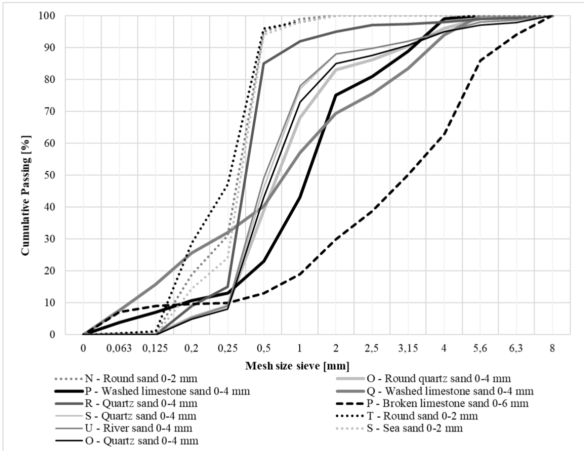

Figure 6. Particle size distributions of natural sands

3.2. Comparing the particle size distributions

The particle size distribution of secondary sand, blast furnace sand, aggregated ferro-slag, bottom ash and foundry sand, as seen in figure 5, match fairy well with the particle size distribution of natural sands as shown in figure 6. Physico-chemically cleaned sand has a too large cumulative passing on the sieves 0,125 mm; 0,2 mm and 0,25 mm. To match the particle size distribution of quartz sand, the cumulative passing of physico-chemically cleaned sand should decrease with 13 % on the sieve of 0,125 mm, and respectively 28 % on the sieve of 0,2 mm mesh and 40 % on the sieve of 0,25 mm mesh.

The gradient of the particle size distributions of the recycled sands start too flat to match properly with the natural sands. In general, according to the particle size distribution of the average values of all supplied data and own measurements, recycled sands have a higher cumulative passing on the sieves with larger mesh opening – so they are coarser than natural sand – but on the sieves with smaller mesh there is a smaller cumulative passing – so there they are finer than natural sands.

In the fraction 0–6,3 mm of recycled sands, it can be noticed that sieve sands generally have a higher position in the particle size distribution curve, thus they are finer than other recycled sands, except for sieve sand from crushed asphalt or concrete. This can also be noticed in the calculated values of the fineness modulus. The smaller the fineness modulus, the finer the sand. The fineness modulus of the average particle size distribution of sieve sand from asphalt or from concrete are 3,7 respectively 3,4. The fineness modulus of the unspecified sieve sand is 2,7. For sieve sand from recycled road constructions this is 1,7. Sieve sand from mixed rubble obtained from producer B and producer F has a fineness modulus of 2,7 and respectively 2,8.

The particle size distributions of broken mixed aggregate have a lower course on the graph than those of sieve sands, which indicates that sand from broken mixed aggregates are coarser than sieve sands. The particle size distributions of high-quality crushed concrete are the lowest and are therefore the coarsest.

Sand from crushed concrete aggregate is coarser than most sieved sands, as expected. The fractions 0–8 mm and 0–6,3 mm are always coarser than the coarsest sieve sand. In the graphs of the particle size distributions, crushed concrete aggregates are situated in the same area as crushed mixed aggregate sand and high-quality crushed concrete.

When comparing the secondary sands, it can be concluded that physico-chemically cleaned sand is finer than foundry sand. Sand from bottom ashes contains more fine material than blast furnace sand. Sand from ferro aggregated slag is the coarsest.

3.3. The methylene blue test

All methylene blue tests were performed according to the Belgian Standard NBN EN 933-9 NBN EN 933-9 Tests for geometrical properties of aggregates – Part 9: Assessment of fines – Methylene blue test. (2013) From figure 7 can be seen that the filler content of recycled sand is usually higher is than 3 %. Especially fine recycled concrete aggregates (FRCA) have a high filler content. However, this type of sand has a low methylene blue value which indicates a good quality of the fine particles. In each case, the methylene blue value is situated between 1,7 and 7,5. This is always lower compared to the methylene blue value of crushed mixed rubble where the methylene blue value is situated between 7,5 and 9,5.

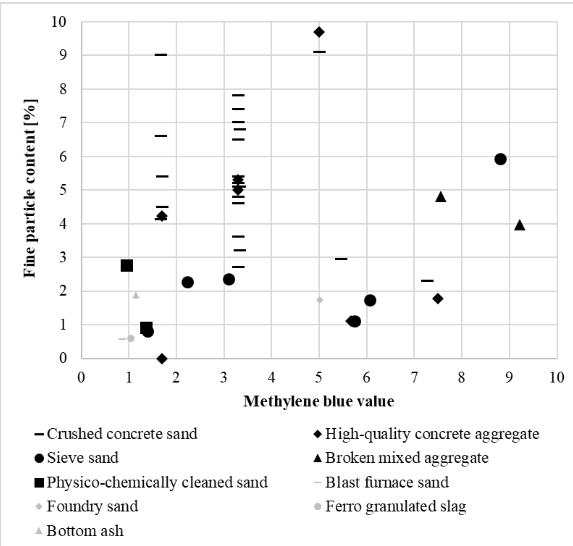

Figure 7. Methylene blue value relative to the fine particle content

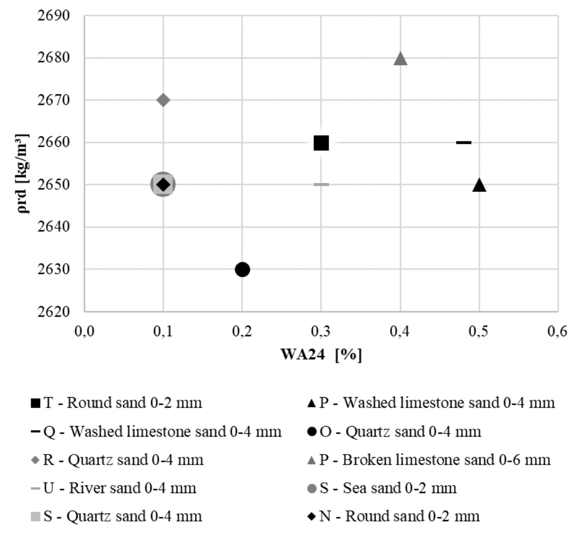

Figure 8. Natural sand: Water-absorption relative to dry density ρ_{rd}

Sand of secondary aggregates always shows a low methylene blue value between 0,86 and 1,36, except for foundry sand which has a higher methylene blue value of 5,01. All sands of secondary aggregates have a fine particle content less than 3 %.

3.4. Density and water-absorption

All tests for the determination of the density and the water-absorption were performed according to the Belgian Standard NBN EN 1097-6 Tests for mechanical and physical properties of aggregates – Part 6: Determination of particle density and water-absorption. 2013.

Figure 8 shows that natural sands, such as quartz sand and sea sand, have the lowest water-absorption. This is between 0,10 and 0,20 %. This corresponds very well with the water-absorption of the alternative sands which have a water-absorption between 0,10 and 0,23 %. Washed limestone sand has a water-absorption between 0,48 and 0,50 % (producers Q & P).

Regarding recycled sands, the supplied data always show a very low water-absorption (between 0,10 and 0,23 %) compared to the data from the supplementary data (between 6,8 and 14,0 %). The determination of the water-absorption of fine aggregates (sand fraction < 4mm), is rather difficult.

The test results show that bottom ash sand has a very high water-absorption of 27,8 % compared to the other alternative sands. The loss of mass has an influence on water-absorption and density. In addition, an inverse proportional relationship is noted between density and water-absorption as seen in figure 9. The higher the water-absorption, the lower the density and vice versa.

Finally, from all the results it can concluded that the absolute density ρ_a is always higher than the saturated surface dry density ρ_{ssd}, which in turn is higher than the dry density ρ_{rd}. The difference in density value depends on the water-absorption of the sand. When the water-absorption is low, the variation of the densities is limited and vice versa.

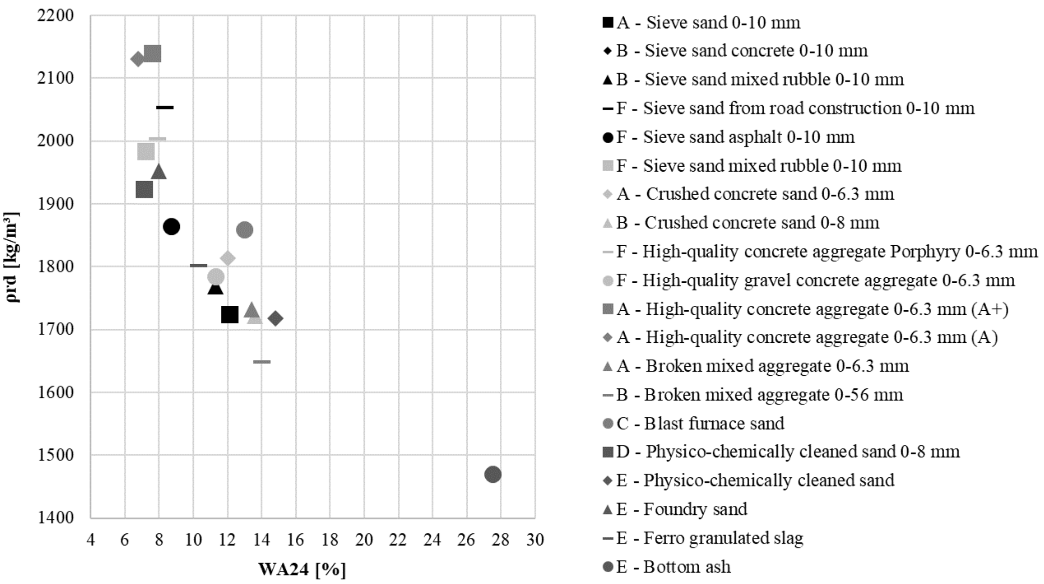

Figure 9. Alternative sands: Water-absorption relative to ρ_{rd}

4. Requirements for alternative sands in function of constructional applications

Several standards describe different requirements and testing methods for use of sand in constructional applications: *NBN EN 12620: Aggregates for concrete. 2013*, *NBN EN 13043 Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas. 2013*, *NBN EN 13139: Aggregates for mortar. 2013* and *NBN EN 13242 Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction. 2013*. For each type of sand, a sample is tested to see if it matches the requirements for grading, tolerance, fines and methylene blue value as set in the standards. Based on this evaluation and the requirements mentioned in '*The standard Specifications for Road Constructions'* [7], table 1 is drafted. Often, not all requirements can be met, and requirements can only be partially fulfilled. In table 1, applications for which a type of sand fully or partially fulfill the requirements are noted with a number within brackets. The mentioned number refers to a special attention that must be considered. The number "0" is used to indicate application for which no additional attention is required for that kind of sand.

Table 1. Overview of potential applications for each type of recycled sand

	Back-fill	Drainage	Sub layer for foundations	Lean concrete / asphalt for road foundations	Sand cement mixtures	Filling material for crushed stone foundations	Lean concrete for foundations of buildings and infrastructure	pavement layers with concrete paving stones / tiles	Pervious foundation in sand cement	Ternary mixture
Sieve sand	1				2					
Recycled sand	3	4	5	6	2	7	7	7	8	
Recycled sand from crushed blast furnace slag										0
Physico-chemical washed sand			0	9	0	0	0			
Granulated ashes		9								

<u>Extra attention must be paid to:</u>

0 : Can be used without special attention
1 : Fraction III < 50 % and fractions III + IV ≥ 50 %.
2 : Methylene Blue value ≤ 8 and the category of fine particles corresponds to f16.
3 : Origin: crushing and sieving of concrete debris for concrete aggregates , non-tar-containing asphalt aggregate, mixed aggregates or masonry aggregates."
4 : Category of fine particles corresponds to f7 and attention to the particle size distribution limits.
5 : Sieve residue on 2 mm sieve ≤ 30 %.
6 : Category Gf85 and the particle size distribution limits.
8 : Category Gf85.
8 : The fineness modulus and the category of fine particles corresponds to f3.
9 : The particle size distribution limits.

5. Market survey

The market survey showed that 73 % of the participating companies are working as a recycling installation for construction and demolition waste (CDW). The products that they produce are usually certified by the independent certification organization COPRO. At recycling installations, a strict acceptancy policy is maintained, and unwanted waste streams often are refused.

The most common process to obtain a sand fraction 0–2 or 0–4 mm during the recycling process of CDW, is by crushing and sieving. For secondary sands and bottom ashes, the production process exists mainly in dry sieving and ferrous separation with electro-magnets. Slags are usually sieved and demetallized. In the case of sludge, the sand fraction is mainly separated in a sedimentation basin. Sludge, sand mixtures and foundry sand are usually cleaned by scrubbing in a washing installation, hydrocycloning and sieving.

The high costs of certification and the maintenance cost of the installation are reported as the main reasons for a too high production price.

To achieve more valorization of the alternative sands, the companies propose first to make additional investments for purification, separation and crushing technology and secondly to take an active part in additional research. The government is especially advised to adjust the standard specifications and to create more trust in the alternative sands.

In general, the producers paid a lot of attention to this question. It becomes clear that more is expected from the government. This is specifically mentioned by many producers throughout the survey. It is important that the government encourages and prescribes the use of alternative sands, if not then alternative sands will not be valorized as substitute for natural sand.

6. Conclusions

As a general conclusion of this study, from the results of the sieve analysis, methylene blue test and the determination of the density and water-absorption, can be concluded that certain secondary sands are suitable as substitutes for natural sand and can be used in structural applications. The types of sand with the best properties according to these tests are blast furnace sand and ferro aggregated slag. These types of sand match fairly well the particle size distribution of natural sand, and there is a low methylene blue value and also the water-absorption is not abnormally high compared to other alternative sands.

The particle size distribution of physico-chemically cleaned sand and recycled sands correspond less with natural sand.

Compared with earlier mentioned secondary sands, a higher methylene blue value is recorded for foundry sand making this sand less suitable for use in constructional applications. Bottom ashes are found to be unsuitable as substitutes for natural sand due to excessive water-absorption.

No ferro aggregated slag is used in the Standard Specifications for Road Construction. [7] The use of blast furnace sand is only permitted in ternary mixtures.

In the market survey the need for more research on alternative sands was prominently stated, next to more stimulation by the government of the use of suitable alternative sands to replace natural sand in structural applications.

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