DEVELOPMENT OF METHOD AND CRITERIA FOR EVALUATION OF DRY-WASHING EFFICIENCY WITH RE-CON ZERO EVO

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Abstract

Society recognises the need for the preservation of nature and the need for better resource utilisation. Integration of good practice in the building industry is mainly targeted at reducing or completely eliminating waste. One of the waste sources in the concrete industry is created in washing facilities and consists of returned concrete, washing water and cement slurry. Concrete trucks are washed with a large amount of water, and the most common treatment of washing water is sedimentation in several interconnected sedimentation pools. Recycled water from the cleaning facility is commonly used again for cleaning or disposed into nature. The sedimented slurry is collected several times a year and disposed at a landfill. Re-Con Zero EVO (RCZ) is a product introduced by Mapei to transform fresh returned concrete into a dry, granular material. Re-Con dry-washing is a subsequent process that was developed to reduce waste, cement slurry, in concrete trucks by using the dry granular material from the RCZ process as an absorbing material for the slurry in the trucks. Its efficiency and benefits are the main subjects of this study.

Parameters for dry-washing efficiency evaluation are based on the amount of fine particles left in the truck after Re-Con dry-washing and properties of the Re-Con dry-washing aggregates (Re-Con DWA), especially particle size distribution and water absorption. Two different approaches were developed, and results were compared. The first approach focused on cleaning cement slurry exclusively, and the second approach assumes that there is still concrete in the concrete truck before cleaning. Dry-washing of a slurry was performed with 10, 15 and 20 kg of Re-Con DWA and testing showed the best washing effect at the highest dosage of 20 kg of Re-Con DWA. The second test setup determined the amount of Re-Con DWA differently for washing of concrete, and obtained better particle size distribution with lower content of grains over 22.4 mm. The efficiency of dry-washing with Recon Zero EVO was around 70% in both test setups and showed promising results, which needs further investigations.

Keyword

Dry-washing, Dry-washing efficiency, Re-Con Zero EVO (RCZ), cement slurry, dry-washing aggregates (DWA), Re-Con dry-washing aggregates (Re-Con DWA)

INTRODUCTION

In recent years, individuals and also industry sector acknowledged the need for resource optimisation, waste reduction/recovery and mitigation of global warming connected to greenhouse gas (GHG) emissions. The concrete industry operates commonly on local bases, which means using local aggregates, water, and in best practice, also a local supply of cement and supplementary cementitious materials (SCM). Their product, ready mixed concrete, is distributed in a fresh state by concrete trucks or within the facility if it is used for precast production. Most of the time, the requested concrete amount is produced and delivered with volume margin to prevent uncompleted work or lack of materials for precast elements. An estimation of the global annual production of concrete is approximately 4 billion metric tons, out of which 1 to 4% is waste in the form of return concrete [1, 2]. Furthermore, fresh concrete has high adhesion to all materials and remains attached to all surfaces, and if it is not correctly cleaned, it can damage or completely destroy equipment and machinery used for its handling.

The current practice is cleaning with water, which is, or becoming a scarce resource in some regions. Water for cleaning shall be non-contaminated and without organic residuals, which might remain attached to washed surfaces. The amount of water needed for cleaning of a concrete truck is about 500 to 800 liters (0,5 – 0,8 m^3), so as for washing of the concrete pump. This water can be reused several times, if the cement particles and aggregates are sedimented and form so-called slurry. Due to washing, water pH increases to pH 11.5 or higher [3], which is not favourable to dispose back into nature. The safe pH ranges for aquatic life habitats are between 6.5 and 9 for freshwater and 6.5 to 8.5 for saltwater [4].

The other type of waste created during the washing of concrete equipment and machinery is slurry consisting of dissolved cement paste and aggregates. In many cases, this slurry is collected several times a year, and disposed in a landfill or in the worst-case scenario into nature or the sea. In cases of better practice, aggregates can be sieved apart and reused for other purposes, and slurry with only fine particles below 0,125 mm (cement slurry) used as return water in a concrete mixer. Properties of slurry, particularly mineralogy composition and particle size distribution, are essential as they can positively contribute to the new concrete mix. This slurry is hard to handle due to its consistency and its disposal is usually costly. To summarise: cleaning by water, concrete plants are left with wastewater of high pH, and slurry. Based on attempts to align with UN´s sustainable development goals, the concrete industry started to search for other ways to clean their equipment and machinery. Based on expressed need of concrete producers, Mapei introduced a product Re-Con Zero EVO (RCZ) in 2014 [5], that is predominantly meant for the reduction of water in fresh return concrete, and formation of granulates. Thanks to such an agent, most of the returned concrete is consumed, granulates which can be further utilised as aggregates are formed, and a smaller amount of water can be used for cleaning of concrete trucks.

The RCZ consists of two components, a super absorbing polymer (SAP) and an accelerator. Both components are in powder form and are typically added to the fresh returned concrete that remains in the concrete truck upon arrival at the concrete batching plant. After a few minutes of mixing, the SAP will bind the water in the concrete mix causing it to lose its flowability. The cement paste, together with fines from the aggregates will start to form lumps, typically as a shell around the larger aggregate particles in the concrete mix, but also agglomerates on its own in different sizes. The accelerator component will help to stabilise the process and avoid a reversal of the water-binding achieved by the SAP.

Methods of Recon Zero EVO use and related benefits

Since the product Re-Con Zero EVO was introduced, various applications have been developed, each with a slightly different focus and positive impact on nature and climate. The first two applications or methods are closely connected, production of granulates usable as aggregates and dry-washing that generates those granulates. The third method of RCZ utilisation, granulated porous concrete production, was developed in Japan. The terminology and abbreviations used henceforth:

- **Re-Con Zero EVO aggregates (RCZA)** are granulates formed during the blending of concrete or cement slurry with Re-Con Zero EVO.
- **Dry-washing** is process where granulate material is used instead of water for collection and removal of concrete and cement slurry from concrete truck.
- **Dry-washing aggregates (DWA)** are aggregates formed during the dry-washing process.
- **Re-con dry-washing** is a method in which particularly RCZA is used as an absorber for cement slurry in trucks without returned concrete.
- **Re-Con dry-washing aggregates (Re-Con DWA)** are aggregates formed during dry-washing with use of Re-Con Zero EVO product in at least one cycle.

Production of RCZA

There is a slight difference between RCZA and Re-Con WDA which is connected to their production. RCZA are produced by blending fresh concrete with RCZ in a concrete truck, the original idea behind RCZ. This principle is utilised when there is a large amount of return concrete, and it has no other purpose of use. Individual grains of RCZA have a core, grain of coarse aggregates, and a single layer of cement mortar of varying thicknesses. RCZA are discharged from a concrete truck on a pile and let to hardened between 24 to 48 hours. The strength gain is similar to the strength development of concrete used to produce of those RCZA.

The other type of aggregates produced during dry-washing is Re-Con WDA with the use of RCZA as a “core” for the individual grains. Thanks to higher water absorption of RCZA, between 4 and 8.5% cement slurry is forming layers on already formed grains of RCZA. The dry-washing process will be explained in the following section. Rc-Con WDA can undergo several dry-washing cycles and, therefore, can be composed of grains made of multiple cement slurry layers on a single core. Visual demonstration of RCZA and Re-Con DWA is given in Figure 1. Individual grains might also be formed by merging more grains together, but for simplification, the main principle is explained.

Figure 1- (a)RCZA – one layer of mortar around core grain; (b) Microscopic picture of a Re-Con DWA after 4 dry-washing cycles – visible individual layers of paste, where one was coloured in red to distinguish them.

A study of the RCZA and Re-Con DWA has shown that it contains 15-18% acid-soluble material. This is due to the absorption of cementitious sludge that forms the shell of RCZA and Re-Con DWA. It is in principle a concrete mortar and therefore, it has the potential to absorb CO_2 over time through carbonisation. Current research conducted in project RECONC [7] is trying to establish the total potential and rate of carbonation. It is an interesting concept to explore. If RCZA and Re-Con DWA have a high enough and fast enough rate of carbonisation, it could be used in the Life cycle assessment (LCA) and environmental product declaration (EPD) processes and set off the CO_2 emissions from other sources. For example, by using the RCZA and Re-Con DWA as a recycled concrete aggregate replacing natural aggregates, it would eliminate those CO_2 emissions stemming from natural aggregates production and transport, thus reducing the total CO_2 footprint from each cubic meter of concrete.

Dry-washing

As a further development of the Re-Con Zero EVO product, Mapei also invented a method for cleaning concrete trucks which have delivered all of its load and thus does not contain any returned concrete. A practical study showed that even an apparently empty truck can contain several hundred litres of cement slurry that is typically washed out with large amounts of water, ending up in sedimentation pools.

To address this problem, Mapei developed the method called Re-Con dry-washing, in which the dried and hardened granulates formed by the Re-Con Zero Evo process, are added into the concrete truck mixing drum to absorb the cement slurry. Tests of the method in full scale have shown that approximately 70% of the cementitious residue inside the truck is absorbed by the RCZA in the dry washing process. A light washing is still sometimes necessary after dry-washing to rinse out remaining aggregates and formations of fine particles in tight corners inside the concrete mixing drum. This washing requires much less water than a standard washing process for empty, dirty trucks.

There are two main potentials of dry-washing. Firstly, the reduction of water used for cleaning concrete trucks and secondly, less waste material, cement slurry dispersed in water. From the laboratory testing it was also observed that the water sedimentation process is faster, and therefore, its reuse can be accelerated.

Granulated porous concrete production in Japan

Another application of the Mapei product Re-Con Zero EVO evolved during the handling of formed granulates. As described before, granulates from returned concrete are discharged from the concrete mixer and let harden for approximately 24 hours or more and then crushed into RCZA. Japanese concrete plant Nr-mix produces “Owacon”, granulated porous concrete made with Re-Con Zero technology [6]. Owacon started from the thought of processing the concrete left in the concrete truck that came back from the site. Owacon is made of 125 kg of cement, 2000 kg of aggregates (fine and coarse), approx. 125 kg of water and Recon Zero EVO. Everything is blended in the concrete truck on its way to the placement location. Granulated porous concrete is finished by compacting and among the other properties, dispone by high permeability. The idea of reduction of waste from concrete plants evolved even further and developed granZ concrete, granulated porous concrete with zero cement concrete, and slag aggregates in cooperation with Yokohama National University. The grandZ concrete is currently being tested on a large scale after robust testing and development in the laboratory. New Owacon concrete has a high surface area composed exclusively of cement paste which has the potential to bind atmospheric CO_2. The principle which was described earlier for RCZA and Re-Con DWA, is also applicable for Owacon.

Figure 2 - Owacon concrete (a) fresh concrete before placement, (b) surface of placed Owacon after compaction.

Positive potentials, reduction of washing water, reduction of waste in the form of slurry and accelerated carbonisation rate, are in synergy for all Recon Zero EVO utilisation methods. Despite all the known positive potentials of Recon Zero EVO, its utilisation shell be optimised to obtain valuable outcomes not only from dry-washing but also the quality of RCZ.

Within this study, the focus is targeted on the evaluation of two listed “methods of use”:

- Dry-washing: development of a method for efficiency assessment tested on 2 different dry-washing methodologies.
- Production of RCZA: properties evolution due to 2 different dry-washing methodologies and number of cycles

The efficiency of dry-washing was assessed based on solid particle mass collected from a test drum after dry-washing. In addition, the quality of Re-Con DWA produced after individual cycles was assessed based on their density, water absorption and particle size distribution.

DRY-WASHING APPROACHES

The first dry-washing approach consideres that only cement slurry has to be washed/remains in concrete truck, and the second dry-washing approach assumes that there are also aggregates in the returned concrete/concrete truck drum. The other parameter which is different between the two studied methods is the amount of Re-Con DWA used for dry-washing. In the first case, Re-Con DWA doses for individual cycles were 10, 15 and 20 kg, while the second method was based on the maximum needed dose of Re-Con DWA for efficient dry-washing evaluated visually. Re-Con DWA was added continuously until there was no visible colour change/attachment of paste from fresh concrete.

Slurry based approach

To study the efficiency of the Re-Con dry-washing process and the properties of the Re-Con DWA, a series of laboratory experiments were designed and performed at the University of Lund, department of building materials.

Design of experiment
A base concrete at W/C of 0,5 was produced and directly transformed into RCZA by mixing in the Re-Con Zero EVO product. The RCZA were produced in a volume of approximately 50 litres, and left to dry and harden for 48 hours. Dry-washing tests were made by adding different dosages of the aggregates, 10, 15 and 20 kg, into a lab mixer that had been prepared with a fixed quantity of a simulated cementitious residue in the form of water, cement and fine sand. After the dry washing test, the drum was emptied through tilting and rotating discharge on the floor, where the dry washing aggregates were collected and left to dry for minimum 24 hours before the process was repeated. In order to simulate the method, the DWA are emptied from the concrete truck in a production environment, the discharge of dry washing material was not forced or aided in any way.

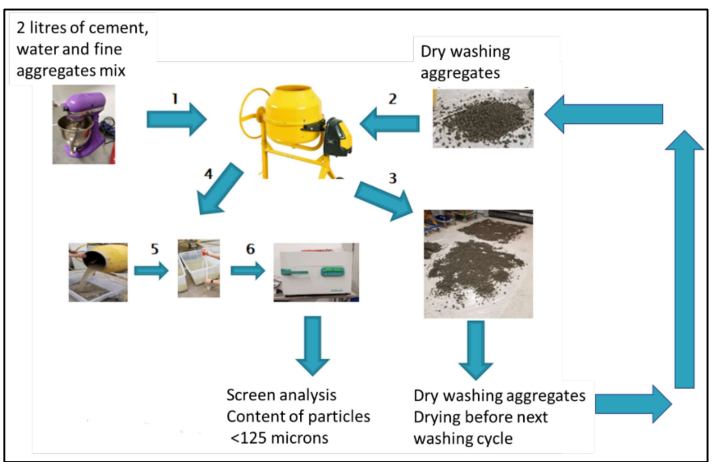

Figure 3 - Workflow of the slurry based approach of dry-washing testing.

The remaining material in the drum that had not been discharged was thoroughly washed out with water and collected in a tub. After sedimentation, all particles were collected, dried and screened at a sieve of 0.125 mm. By weighing the particles passing 0.125 mm left in the drum after dry washing and comparing that weight to the known weight of 0-0.125 mm particles added to the drum before dry washing, a relation of efficiency can be established. A sample of Re-Con DWA was taken out after every cycle (randomly mixed from the 3 different dosages in each cycle) and analysed for particle size distribution. water absorption and density.

Dry-washing efficiency
Dry-washing efficiency didn't show any significant pattern over 8 test cycles. A significant increase of dry-washing effect was recorded in cycle 5 after using Re-Con DWA from cycle 4, which were dried for 4 weeks instead of 24 hours as for other cycles. The overall efficiency of dry-washing ranges between 73 and 97% according to the slurry-based approach's method.

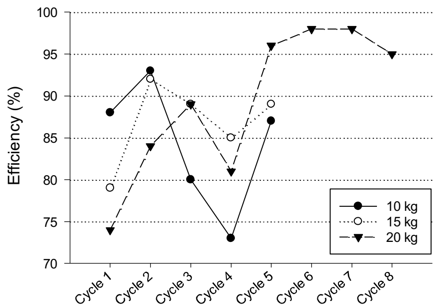

Figure 4 - Efficiency of dry-washing (Absorption of particles <125 microns at different dosages over 8 washing cycles).

1.1.1 Properties of Re-Con DWA

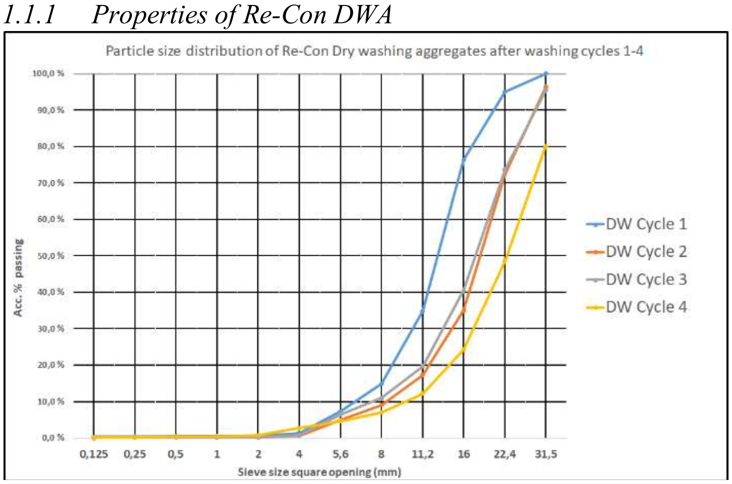

Figure 5 - Particle size distribution of Re-Con DWA after dry-washing cycles. X-axis scale is non-logarithmic for enhancement purposes.

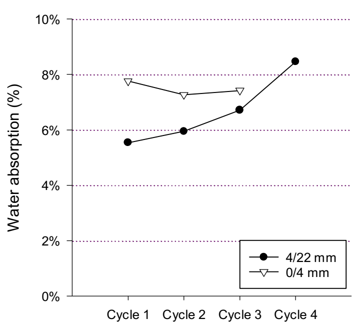

Figure 6 - Water absorption of coarse and fine Rc-Con DWA from different cycles.

Concrete based approach

Design of experiment

This experiment aimed to study the efficiency of the Re-Con Zero dry-washing process on concrete trucks with returned concrete (3-5%) of truck drum volume. The process of dry-washing was carried out in a concrete mixer of 200 litres capacity. Four different cycles of dry-washing were carried out in the experiment. On the first cycle, C30/37 concrete was prepared in the mixture and Re-Con Zero EVO was added to produce Re-Con DWA. The Re-Con DWA was cured for 48 hours between individual cycles. The aggregates produced from cycle 1 was named Re-Con DWA-1.

On the next dry washing cycle, 6-10 litres of C30/37 concrete were prepared in the concrete mixture. This volume of concrete is (3-5%) of the volume of concrete mixture, simulating 3-5% of the returned concrete in a concrete truck. A colour pigment was added in the concrete to separate the different layers formed on the Re-Con DWA at different cycles of dry washing. Re-Con DWA-1 was added in the concrete mixture and was rotated for about 3 minutes. The aggregates produced from the second cycle were named Re-Con DWA-2. This process was repeated two more times to produce Re-Con DWA-3 and Re-Con DWA-4. A schematic representation of the experiment is presented in Figure 7.

At the end of each cycle, the concrete mixture is washed with water with the same volume of water. The water was collected after washing, and the dry weight of the slurry was measured. The aggregates from all the cycles were left to cure for 28 days and sieve analysis, water absorption and density test were carried out.

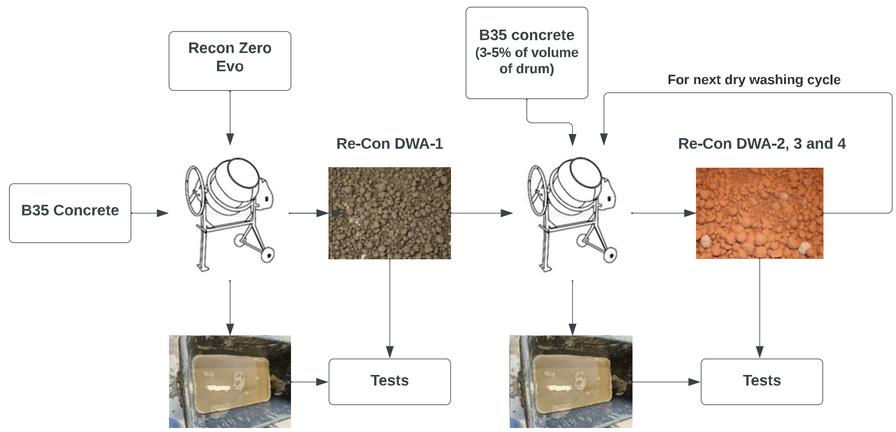

Figure 7 - Workflow of the concrete based approach of dry-washing testing.

Dry-washing efficiency

It was observed that the Re-Con Zero dry-washing process was effective. The drum was clean and almost no residue was left except at places where lumps of concrete were attached as patches in the drum or the mixer blade. The lumps tend to form at the earlier cycles of dry-washing and reduce with the number of cycles of dry-washing. They were prominent, especially on the first cycle where RCZA were produced with RCZ and concrete. Figure 9 shows the inside of drums in different dry washing cycles.

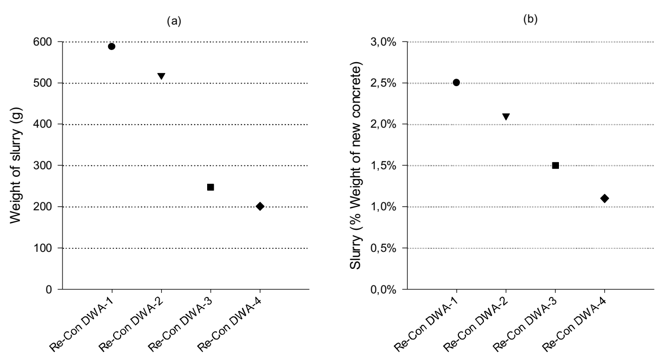

Figure 8 - (a) Weight of dry slurry in each cycle of dry washing (b) slurry as % of weight of new concrete prepared in the mixture

The dosage of DWA aggregate used for dry washing was 6 kg/litres, 7 kg/litres and 7.5 kg/ litres of fresh concrete prepared in the mixer in cycles 2, 3 and 4 respectively. The weight of dry sludge obtained from washing water as described in section 0 is presented in Figure 8. The weight of sludge decreases with the number of cycles. In the 4th cycle, the weight of dry sludge is about 1% by the weight of the new concrete made (Figure 8 (b)).

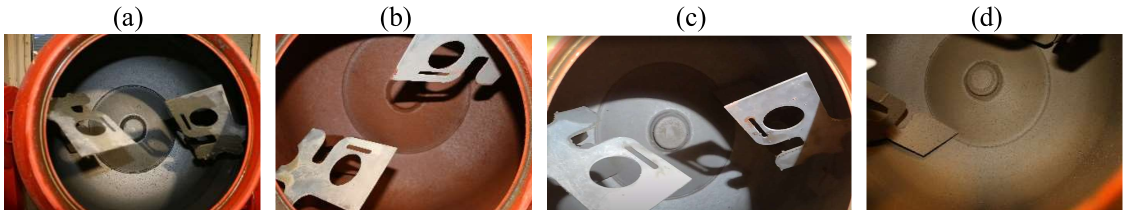

Figure 9 - Inside of the drum after dry-washing (a) Re-Con DWA-1 (b) Re-Con DWA-2 (c) Re-Con DWA-3 (d) Re-Con DWA-4

Properties of Re-Con DWA

The results of sieve analysis and water absorption of the Re-Con DWA formed in the four cycles are presented in Figure 10 and Figure 11 respectively. The results are compared with each other and with the properties of natural aggregate used in the test.

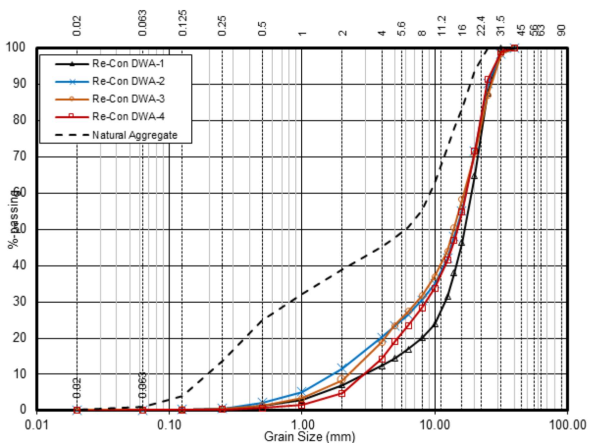

Figure 10 - Particle size distribution of Re-Con DWA in different cycles.

The size of the granules formed after dry-washing is significantly larger than the natural aggregate used in the concrete (see Figure 10). Microscopic analysis of an aggregate after 4 dry-washing cycles showed that the size of the aggregate is determined in the first cycle when the RCZA were produced. About 0.2-0.3 mm of cement paste layer was added on every cycle of dry-washing (Figure 1 (b)). The water absorption of Re-Con DWA in all four cycles is about 5% which is significantly higher than that of natural aggregates. Furthermore, the water absorption slightly decreases with the number of cycles. A saturated surface dry density of about 2.5 g/cm^3 was obtained for Re-Con DWA irrespective of the number of cycles.

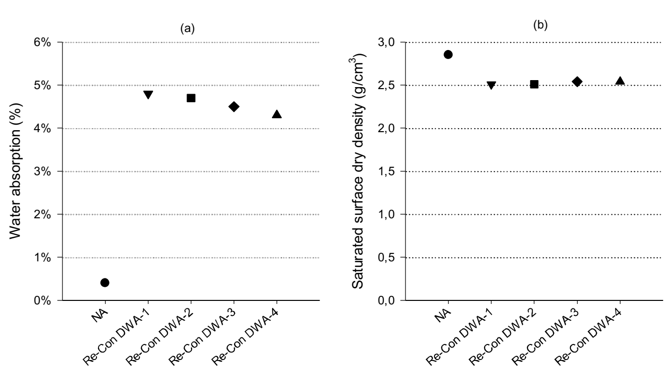

Figure 11 - Properties of Re-Con DWA (a) Water absorption (b) Saturated surface dry density.

EVALUATION OF DRY-WASHING APPROACHES

Slurry based approach

The results and conclusions from the slurry based approach can be briefly summarised as follows:

1. The dosage ratio of Re-Con DWA to slurry has an effect on the efficiency over repeated cycles. Scaled up to a full concrete mixer, the lab results indicate that not less than 2 tons should be used for a normal sized concrete mixer truck carrying approx. 7 m^3 of concrete.
2. Drying time between dry-washing cycles has an effect on efficiency. The drastic increase in absorption efficiency between cycle no. 4 and no. 5 displayed in Figure 4 is most likely due to the long drying time between the cycles. In this case, 4 weeks instead of the normal 24 hours.
3. With the right dosage ratio, Re-Con DWA can maintain a high absorption efficiency over a number of dry-washing cycles.
4. The particle size analysis made after each dry-washing cycle indicates a coarsening of the particle size distribution. This indicates a significant build-up of hardened slurry around the coarser particles.
5. The water absorption of particles 4-22 mm increases for each cycle but remains more constant in the 0-4 mm fraction. A preliminary conclusion would be that as indicated by the screen analysis, there is a significant build-up of porous hardened slurry on the larger particles while the weight ratio of hardened slurry on finer aggregates changes less over the number of cycles.

Concrete based approach

The results and conclusions from the concrete based approach can be briefly summarised as follows:

1. High dry-washing efficiency was obtained during the 4 dry washing cycles tested. Cement slurry between 2.5% to 1% of the weight of return concrete should be expected in the concrete mixer truck after dry-washing.
2. The efficiency of dry-washing increases with the number of cycles. This was because lumps of concrete were not formed on the mixer wall as after an initial cycle.
3. The dosage of Re-Con DWA to be added on a concrete mixer of 7 m^3 volume with return concrete between 3% to 5% is about 2-3 tons.
4. The amount of fines 0-4 mm was significantly reduced from 50% of the natural aggregate used in concrete to less than 20% of the resulting Re-Com DWA.
5. The water absorption of dry washing aggregates is about 5% which is significantly higher than that of natural aggregates. However, the high water absorption could act positively if the aggregates are to be reused for dry-washing.

Comparison of results from slurry based and concrete based approaches

When comparing the results of the two approaches, the following can be discussed:

1. The efficiency of slurry removal is quite similar in both study methods. It was more visually evaluated in the concrete based approach and quantified in the slurry based approach. Both methods indicate a high efficiency in the removal of fine particles.
2. Water absorption of Re-Con DWA differ between the 2 approaches. Also, the water absorption does not increase after each cycle in the concrete based approach, as is the case in the slurry based approached. The reason could be that the slurry based approach adds much less particles to the complete mix inside the lab mixer than the concrete based approach. Hence, the build-up of a porous crust on a given number of particles is bigger in the slurry based approach and thereby, a more porous and water absorbing material is produced.

3. Particle size distribution of Re-Con DWA from the two approaches differ slightly in results. The slurry based approach tends to build coarser and coarser particles, like a snow-ball effect, while the concrete based approach remains relatively constant for maximum particle size but the overall gradation is coarser for each cycle. The difference is most likely explained by the same factor as point 2, that the addition of either new concrete or slurry only for each cycle affects the outcome.

CONCLUSION

- Estimated reduction of sludge in total:

  Based on theoretical and practical tests and customer interviews, Mapei estimates the waste stream of the cement slurry to be 10-90 kg for each cubic meter of concrete produced. This means a global annual waste stream of several hundred million tonnes. If the theoretical efficiency of 70% for dry-washing is be applied to that volume, a significant saving in waste stream from concrete production can be made, with both economic and environmental positive effects globally.
- Efficiency system and its assessment:

  The theoretical tests need to be followed up in a pilot plant and full scale to correctly assess the results possible to achieve in everyday concrete production.
- The efficiency of dry-washing based on the number of cycles:

  The laboratory tests give no clear indication of how many cycles can be repeated in dry-washing. Again, full-scale tests are needed to conclude on this issue.
- Properties of Re-Con DWA after a various number of cycles - optimisation of properties:

  The laboratory work indicates that further studies are needed to predict and control the properties of the Re-Con DWA so that it can be used as recycled aggregates in high quality concrete. The use of Re-Con DWA as filling material or in lower quality concrete e.g. non-frost resistant concrete is quite possible.

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