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Citation for published version (APA):
van de Wouw, P. M. F., Florea, M. V. A., & Brouwers, H. J. H. (2017). Liberation of original natural aggregates from recycled concrete by abrasion comminution. In V. Bílek, Z. Keršner, & H. Šimonová (Eds.), *6th International Conference on Non-Traditional Cement & Concrete* (Vol. 6, pp. 316-323). NOVPRESS.

Document status and date:
Published: 01/01/2017

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Download date: 08. Feb. 2024

6th International Conference on Non-Traditional Cement and Concrete, June 19–22, 2017
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LIBERATION OF ORIGINAL NATURAL AGGREGATES FROM RECYCLED CONCRETE BY ABRASION COMMINUTION

P.M.F. van de Wouw, M.V.A. Florea, H.J.H. Brouwers

Abstract

Recycling of concrete waste into structural concrete reduces the consumption of raw materials, decreases transport and production energy costs, and saves the use of limited landfill space. Since attached mortar is known for lowering the performance of recycled concrete aggregates (RCA) in concrete applications, current recycling involves the use of RCA as a road base material or in non-structural concrete with low strength requirements. Therefore, the application in structural concrete is limited. In general, the applicability of RCA is improved by comminution through various crushing methods. Hereby, the parent particles are cleaved or shattered into a minimum of two particles with a comparable size and a number of much smaller particles. Through this technique, both mortar and aggregates fracture alike, resulting solely in a size reduction. However, to minimise undesirable effects, original natural aggregates (ONA) have to be cleared from attached mortar. Through the use of attrition and shear instead of pressure or impact, surface layers, edges and corners are removed, producing particles both slightly smaller and much smaller than the initial. In this study, ONA liberation through abrasion was investigated.

Keywords: Recycled Concrete Aggregates, Crushing, Aggregate Liberation, Abrasion

1 Introduction

Deteriorated and obsolete constructions generate large amounts of demolition waste (Chandra, 2004). Reutilizing recycled concrete fines (RCF) and recycled concrete aggregates (RCA) into new concrete reduces the need for natural aggregates (NA) and cement, and decreases the use of landfill areas, while simultaneously providing a high quality recycling of construction and demolition waste. The main difference between NA and RCA is the attached (residual) mortar. This is the key factor and main concern causing impaired quality when applied into new concrete. Additionally, the fines generated with the production of RCA are considered to have a negative influence on the quality of the new concrete (Hansen, 1992; Shui et al., 2009). Their presence is, therefore, considered to be undesirable and is to be avoided in production.

Several experimental concrete recycling techniques were developed recently with the aim of separating aggregates from hardened cement paste (HCP). These techniques comprise smart crushing (Florea et al., 2014; Florea and Brouwers, 2013a; Schenk, 2011), electrodynamic fragmentation (Sakai, 2009), microwave fragmentation (Akbarnezhad et al., 2011), and heating and rubbing (Sakai, 2009; Shima et al., 2005). This study is part of a larger study into upscaling the Smart Crushing technique and is carried out on a modified jaw crusher with a typical capacity of up to 15 t/h.

Preceding studies investigated the properties (PSD, density, oxide and mineralogical composition) of a number of recycled concrete fractions, obtained through both conventional jaw crushing and optimized crushing. Results showed that, when the optimized technique is applied, the generated RCA can have a significantly lower amount of residual attached mortar (Florea et al., 2014; Florea and Brouwers, 2013a; Schenk, 2011). Furthermore, the application of such RCA, practically free of attached cement paste, completely replacing river aggregates in mortars, has shown to be without loss of mechanical properties. Especially for short curing times, the mechanical properties of the recycled concrete sand mortars proved to be promising, achieving higher strengths than the reference samples. In contrast to the fines generated through regular crushing, the fines generated primarily consist of HCP and can be thermally activated to replace cement (Florea et al., 2014; Florea and Brouwers, 2013a).

The mechanism at the root of shaping natural river gravel is abrasion (Alexander and Mindess, 2005). Due to this, flaws in the material which could succumb under abrasion forces were tried long before the gravel is extracted, forming each particle to be resilient against these forces. Consequently, abrasion can be a suitable method to liberate the ONA from RCA without fracturing it.
In general, the applicability of RCA is improved by size reduction, making use of various crushing methods. Here, the main method of size reduction is the fracturing of particles under pressure or impact, whereby, the parent particles are broken into a minimum of two particles with a comparable size and a number of much smaller particles. When this occurs, both mortar and aggregates fracture alike, hence the generated fractions possess a composition close to that of the original concrete. With the intention of applying the recycled concrete aggregates into concrete, undesirable properties have to be minimised. One approach to guarantee this, is by liberating the original natural aggregates (ONA) and clearing them from attached mortar. Because of this, the properties of the RCA will be close to those of the ONA, and will, therefore, show a similar applicability.

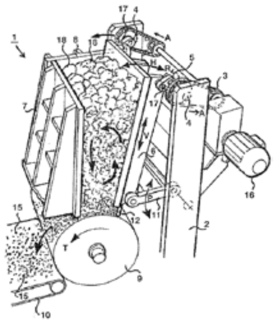

Figure 1: Principle of Smart Crushing (Schenk, 2011)

In this study, based on the concept of Smart Crushing (Figure 1), a jaw crusher-based crusher explicitly designed for concrete recycling was used with the aim of producing RCA with a high degree of liberated ONA. The removal of HCP, from both fine and coarse RCA, has been proven to be possible with the use of this technique (Florea et al., 2014; Florea and Brouwers, 2013a). The produced RCA were found to have enhanced separation into the original constituents, namely gravel, sand, and HCP. The design of the prototype crusher used in the tests deviates from the drawing in Figure 1 by containing material between the jaws by means of a plate pivotally attached to the stationary crushing plate. The goal of this technique is to disperse the recycled concrete (RC) into its composing materials without damaging the components themselves. In order to achieve this, the occurring (indirect tensile) forces have to be intermediate between the yield strength of the HCP and that of the aggregates. Hereby, the aggregates stay intact while the HCP succumbs under the applied stress.

Comminution through impaction is associated with high internal stresses, whereby particles are scattered; this type of loading is therefore avoided by keeping the eccentric speed of the jaws low. Additionally, direct compression or pinching, being the operational mechanism of a typical jaw crusher, also introduces yield stresses surpassing those of the aggregates and leads to subsequent cleavage of both HCP and aggregates. This type of loading is therefore to be avoided and is prevented by applying a jaw distance which is large in comparison with the maximum particle size. In this test setup the shape of the crusher box together with the distinct movement of the single-toggle type jaw crusher, an eccentrically gyrating cycle, creates a condition in which a combination of pressure, shear, and attrition is present. When applying these conditions instead of pressure or impact to produce the RCA, surface layers, edges and corners are removed, producing particles both slightly smaller and much smaller than the initial. Herewith, the interlocking of angular pre-fractured concrete particles is beneficial for the abrasion process during the comminution. To aid this and maintain these conditions during the entire process, the removal of the finer fractions, created during the initial fracturing, was found to be beneficial for comminution through abrasion (Florea and Brouwers, 2013a).

2 Methodology

2.1 Materials

The RC investigated in this study is released during the evacuation and renovation project of the AVF-cyclotron building at the campus of the Eindhoven University of Technology (TU/e) where it has been used in a structural application since 1967. As a first step in the recycling of this concrete, the rebar of the elements was removed by fracturing the concrete by means of a hydraulic jaw pulveriser. In preparation to a direct application of the material on the TU/e campus as a road base material, the pulverised material was crushed using an excavator-operated bucket jaw crusher before transferring the material to a flexible intermediate bulk container (FIBC). Prior to using the RC for the research, the prepacked material was exposed to outdoor weather conditions for several months. Prior to studying fracturing characteristics of the RC, the initial material was sieved making use of a Mogensen sizer (type 0554) equipped with effective mesh sizes of 16 mm, 10 mm, 4 mm, 1 mm and 150 µm. Only the two largest fractions out of the produced ones were used as input material for this study.

Upon visual assessment of the concretes fractured surface, only non-angular course aggregates could be distinguished. In turn, this suggests that the origin of the course aggregates used in the production of this concrete can be found in natural gravel which is deposited by rivers. In contrast to other countries, the use of this type of aggregates in concrete is common practice in the Netherlands and in all probability accordingly the case. However, the exact origin of the aggregates and the original recipe could not be retrieved.

2.2 Methods

The capacity of the crusher was regulated by the size of the outlet opening of the crusher box. In this study, the minimum distance between the containment plate and the moving jaw (hereinafter called aperture) was set at 30 mm.

The sampling of both the initial and the processed material was done in accordance with DIN EN 932-1 (DIN EN 932-1, 1996) from respectively 1 m^3 FIBCs and a conveyer. Contrary to a typical continuous process, the experiments were carried out by means of a batch process.

Hereby, the phase of filling and emptying the crushers cavity deviates and could potentially influence the properties of the produced materials. To exclude these influences, samples were only taken after an initial purge with the material and prior to discharging the crusher's cavity. To avoid agglomeration when sieving the material, all materials investigated were pre-dried to an oven-dry state at 105 °C until constant mass was reached (S., Mindness, Young J F, Darwin D., 2003). Particle size analysis was performed in accordance with EN 933-1 and EN 933-2 (CEN, 1997, 1995) whereby additional sieves were added to increase the detail of the study (45 mm, 22.4 mm, 11.2 mm, 5.6 mm, 2.8 mm, 1.4 mm, 710 µm, 355 µm, 180 µm, 91 µm). Consecutively, the material was split into corresponding fractions for further analysis.

The elements in the materials (computed as oxides) were determined by energy-dispersive X-ray fluorescence (EDXRF) using a PANalytical Epsilon 3 instrument (a 9 W / 50 kV rhodium X-ray tube, a silicon drift detector) equipped with Omnian software 1.0.E (PANalytical). The samples for EDXRF were 40-mm fused beads prepared from pre-dried powdered samples, 0.95 g, with a 67.00% $Li_2B_4O_7$ – 33.00% $LiBO_2$ flux, 9.50 g; and 0.32 mL of a 4 M LiBr solution as a non-wetting agent using a LeNeo fluxer (Claisse) at 1065 °C.

The loss on ignition (LOI) of the materials was determined according to EN 196-2:2005 (CEN, 2013), by measuring the mass loss of samples at 950 °C to a constant mass. Additional thermal analysis was performed by differential scanning calorimetry (DSC) to determine the quartz content of the various size fractions. At about 570 ºC the endothermal crystalline phase change process from α-quartz to β-quartz takes place without loss of mass (Shui et al., 2008). The thermal analysis was performed in Pt crucibles in inert atmosphere (N_2) using a Netzsch STA 449 F1 Jupiter up to a maximum temperature of 640 °C. The peak area on the DSC curve of both the heating and the cooling step was analysed and correlated to measurements of samples containing a known amount of α-quartz, quantifying the quartz content of the measured samples. In contrast to prior studies, pure quartz is used for the calibration since the quartz content of the original aggregates used is unknown (Florea et al., 2014; Florea and Brouwers, 2013a, 2013b, 2012).

3 Results and discussion

During the abrasion comminution process, a perceptible amount of heat is generated in comparison with typical size reduction methods (e.g. jaw or impact crushing). This can be related to the quantity of fractures needed to produce the comparably large amount of a finer material. Specifically, in a process with a limited throughput, in addition to the comminution, liberated aggregates remain present in the process and continue to rub over one another generating heat through friction. Generally, additional heat generated in comminution is considered as a waste of energy since it serves no purpose. In this process though, the initial concrete can have a varying moisture level; the present water can cause the agglomeration of the fines, potentially complicating further extraction processes through clogging or smearing. Hereto, the heat generated while particles are being both fractured and continuously mixed, can be utilised for the (pre)drying of the material. Hence, in addition to dry screening and potential refeeding of the larger size fractions, this enables further dry removal of fines through air separation and subsequent storage in silos prior to further treatments.

3.1 Comminution

The smart crushing technique (in a laboratory-scale tests on purposely designed concrete) was found to be most effective with three passings through the crusher, with the finer material sieved out in between passings (Florea and Brouwers, 2013a). Since the characteristics of the materials are altered when the finer fraction is sieved out prior to further processing, in this study, only a single passing through the crusher is tested. Figure 3 shows the PSDs for the initial material and the resulting PSD of a single crusher passing at an aperture of 30 mm.

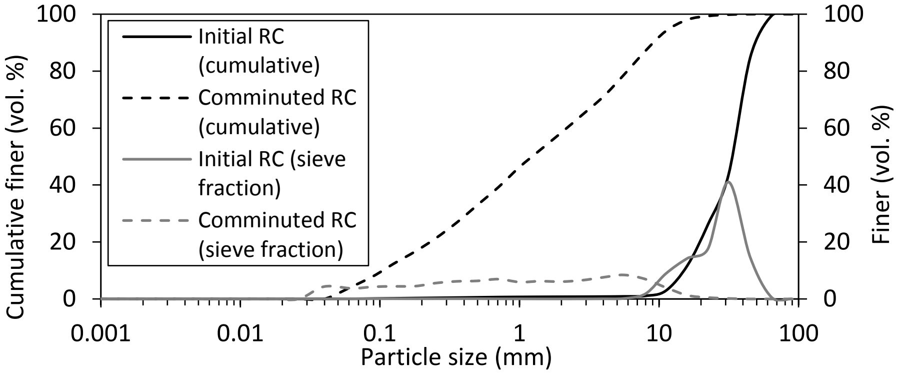

Figure 2: PSD of initial RC and comminuted RC

Overall, it can be seen that all particles are substantially influenced by the abrasion comminution process whereby both PSDs have a significant amount of material in common between 5.6 mm and 22.4 mm only. The formed particles show an even distribution over the newly formed size range, only 0.2% being larger than 31.5 mm, and, in turn, making a refeed for further size reduction unnecessary.

3.2 Composition

Figure 3 shows oxide compositions of the comminuted RC for the main oxides (Al_2O_3, SiO_2, CaO, and Fe_2O_3) obtained through XRF analysis.

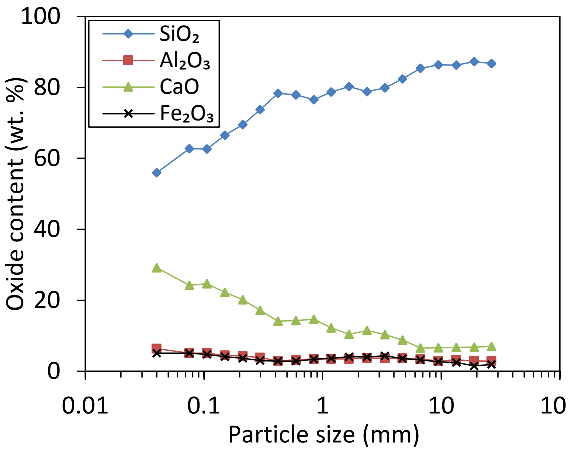

Figure 3: XRF-obtained Al_2O_3, SiO_2, CaO, and Fe_2O_3 content of comminuted RC

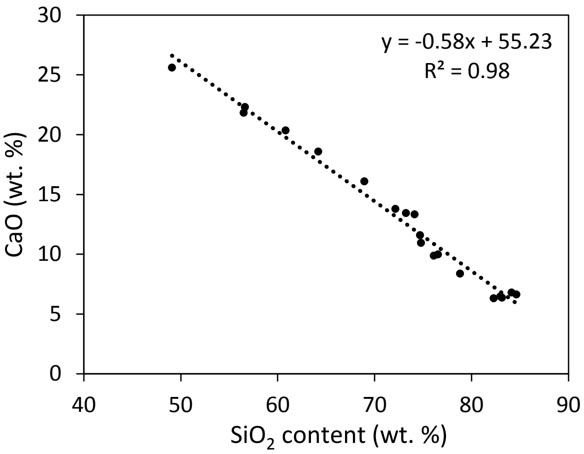

Figure 4: CaO vs. SiO_2 content

CaO shows a relatively constant decrease in content with an increase in particle size until it reaches a near stable value of 6.5% on average in particles larger than 5.6 mm. SiO_2 shows an opposite trend with a declining increase until it approaches a limit in particles larger than 5.6 mm with a maximum value of 84.6%. Additionally, it can be seen that for all fractions Al_2O_3 and Fe_2O_3 show an average concentration of 3.6% and 3.3% respectively. The CaO to SiO_2 ratio over the various size fractions shows a good linear correlation with an R^2 value of 0.98 (Figure 4).

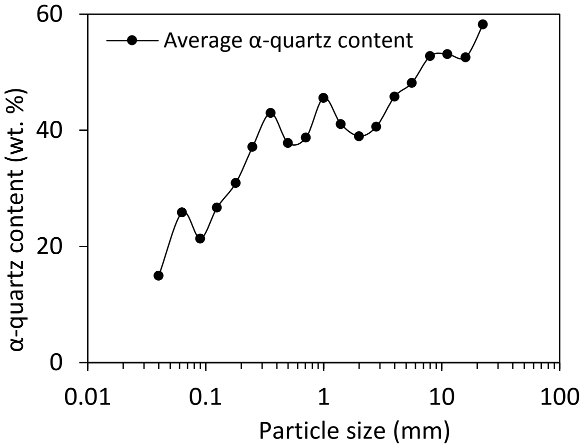

Figure 5: α-quartz content vs. particle size

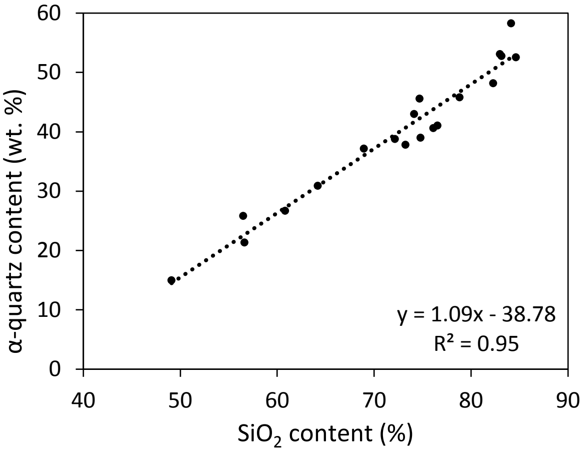

Figure 6: α-quartz vs. SiO_2 content

The α-quartz content determined through thermal analysis (DSC) for different fractions generated is shown in Figure 5. Except for some outlying values, an increasing α-quartz content with increasing particle size can be seen. In contrast to prior research the largest fractions do not show a reduction in quartz content which was related to a composite material (Florea and Brouwers, 2013a). The α-quartz content is related to the SiO_2 content in Figure 6. When the trend line is extrapolated it indicates 35.6% residual non-quartz silicates. With an assumed 1:2:3 concrete mix design ratio of respectively cement, sand, gravel, in the region of 1/6 of the material has its origin in cement. In 1967 it was highly likely that ENCI was the supplier of the cement used. Their Portland cement from that time showed to contain 21.4% (m/m) of SiO_2, in all likelihood present as C_2S and C_3S. Of the total 35.6% of non-quartz silicates, 3.6% can thereby be contributed to the cement. The remaining 32.0% of silicates, therefore, has to be attributed to non-quartz siliceous coarse or fine aggregates or fillers (e.g. feldspar, clays, mica, flint, coal-combustion fly ash, ground granulated blast-furnace slag, etc.). Remarkably, the slope of the trend line is close to 1, indicating that the amount of non-quartz silicates is nearly constant in all produced fractions.

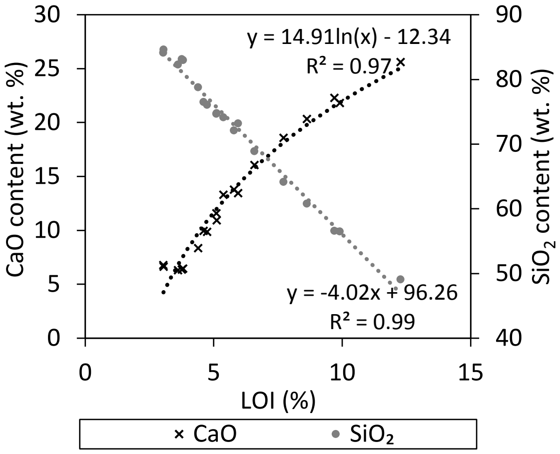

Figure 7: CaO and SiO_2 vs. LOI

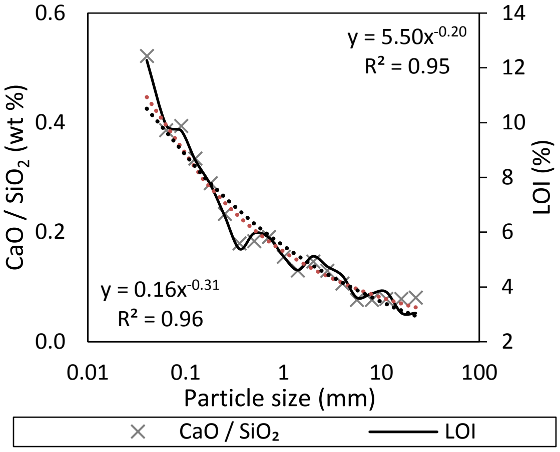

Figure 8: CaO/SiO_2 and LOI vs. particle size

The CaO/SiO_2 ratio can be an indication of the HCP to aggregate ratio. Figure 7 shows a power law correlation between the LOI and the CaO content; the correlation between the LOI and SiO_2 present can be expressed linearly. When both CaO/SiO_2 ratio and LOI are plotted against the particle size, both graphs show a good correlation which can both be captured by corresponding power laws (Figure 8).

4 Conclusion

In conclusion, it is shown that the investigated method is able to produce reclaimed gravel and sand fractions which are optically rather clean of cement paste out of RC; this is supported by the quartz content of the different fractions. Next to that, correlations have been found between LOI, quartz content, CaO and SiO_2 content, and particle size.

Further analysis is required on the composition of the original aggregates so that the quality of liberation can be validated through LOI, quartz content, or CaO / SiO_2 ratio. To substantiate how the presence of finer particles in the input material influences the output material (e.g. by cushioning, energy absorption, or the prevention of interlocking), additional studies are required. Subsequently, this data can then be used to validate whether a relatively high throughput together with the sequential removal of produced fines and a refeed of larger particles is beneficial for the output quality, quantity, and overall energy consumption compared to a single passing at a lower throughput.

Acknowledgements
The authors wish to express their gratitude to the STW-foundation (project 13318, Development of eco-concretes by using industrial by-products), the EU project S(P)EEDKITS (S(P)EEDKITS has received funding from the European Union’s Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 284931), Van Gansewinkel Minerals, Attero, ENCI, v.d. Bosch Beton, Struyk Verwo, and CRH Europe Sustainable Concrete Centre for their provision of material, knowledge and financial support in this project, as well as to the Cement-Concrete-Immobilisates sponsor group at TU Eindhoven: Rijkswaterstaat Grote Projecten en Onderhoud, Graniet-Import Benelux, Kijlstra Betonmortel, Rijkswaterstaat Zee en Delta - District Noord, BTE, Selor, GMB, Geochem Research, Icopal, BN International, Eltomation, Knauf Gips, Hess AAC Systems, Kronos, Joma, Cement&BetonCentrum, Heros, Inashco (chronological order of joining).

References

Akbarnezhad, a., Ong, K.C.G., Zhang, M.H., Tam, C.T., Foo, T.W.J., 2011. Microwave-assisted beneficiation of recycled concrete aggregates. Constr. Build. Mater. 25, 3469–3479. doi:10.1016/j.conbuildmat.2011.03.038
Alexander, M., Mindess, S., 2005. Aggregates in Concrete. CRC Press.
CEN, 2013. NEN-EN 196-2: 2013, Method of testing cement - Part 2: Chemical analysis of cement.
CEN, 1997. DIN EN 933-1: 1997, Prüfverfahren für geometrische Eigenschaften von Gesteinskörnungen - Teil 1: Bestimmung der Korngrößenverteilung - Siebverfahren.
CEN, 1995. DIN EN 933-2: 1995, Prüfverfahren für geometrische Eigenschaften von Gesteinskörnungen - Teil 2: Bestimmung der Korngrößenverteilung; Analysensiebe, Nennmaße der Sieböffnungen.
Chandra, S., 2004. Implications of using recycled construction and demolition waste as aggregate in concrete, in: Sustainable Waste Management and Recycling: Challenges and Opportunities. Volume 2 - Construction Demolition Waste: Challenges and Opportunities: Proceedings of the International Conference Organised by the Concrete and Masonry Research Group and Held at . London, pp. 105–114.
DIN EN 932-1, 1996. Prüfverfahren für allgemeine Eigenschaften von Gesteinskörnungen -

Teil 1: Probenahmeverfahren.

Florea, M.V.A., Brouwers, H.J.H., 2013a. Properties of various size fractions of crushed concrete related to process conditions and re-use. Cem. Concr. Res. 52, 11–21. doi:10.1016/j.cemconres.2013.05.005

Florea, M.V.A., Brouwers, H.J.H., 2013b. The influence of crushing method on recycled concrete properties, in: Proceedings of the International Conference on Advances in Cement and Concrete Technology in Africa, Johannesburg (South Africa). pp. 1041–1050.

Florea, M.V.A., Brouwers, H.J.H., 2012. Recycled concrete fines and aggregates: the composition of various size fractions related to crushing history, in: Proceedings of the International Conference on Building Materials (IBAUSIL). pp. 1034–1041.

Florea, M.V.A., Ning, Z., Brouwers, H.J.H., 2014. Activation of liberated concrete fines and their application in mortars. Constr. Build. Mater. 50, 1–12. doi:10.1016/j.conbuildmat.2013.09.012

Hansen, T.C., 1992. Recycling of Demolished Concrete and Masonry. Spon, London.

S., Mindness, Young J F, Darwin D., 2003. Concrete, 2nd ed. Prentice Hall, Pearson Education, Inc. Upper Saddle River, NJ 07458.

Sakai, K., 2009. Recycling concrete -The present state and future perspective-, in: TCG-JSCE JOINT SEMINAR Nov. 20, Athens. Kagawa University, Japan, Athens.

Schenk, K.J., 2011. WO 2011/142663 A1: Separating device. WO 2011-142663.

Shima, H., Tateyashiki, H., Matsuhashi, R., Yoshida, Y., 2005. An Advanced Concrete Recycling Technology and its Applicability Assessment through Input-Output Analysis. J. Adv. Concr. Technol. 3, 53–67. doi:10.3151/jact.3.53

Shui, Z., Xuan, D., Chen, W., Yu, R., Zhang, R., 2009. Cementitious characteristics of hydrated cement paste subjected to various dehydration temperatures. Constr. Build. Mater. 23, 531–537. doi:10.1016/j.conbuildmat.2007.10.016

Shui, Z., Xuan, D., Wan, H., Cao, B., 2008. Rehydration reactivity of recycled mortar from concrete waste experienced to thermal treatment. Constr. Build. Mater. 22, 1723–1729. doi:10.1016/j.conbuildmat.2007.05.012

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