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USE OF RECYCLED CONCRETE FINES IN CEMENT AND AS AGGREGATE

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Abstract.

The research project focused on investigating and optimizing the processing and use of recycled crushed sand 0/4 from concrete demolition waste, as an alternative raw material in the cement and concrete industry. Crushed sand is produced during the processing of concrete demolition waste. The goal was to identify the optimum way of using the processed material along the entire process chain so that greenhouse gas emissions, waste volumes are reduced, and natural resources are conserved. Different samples of laboratory and real crushed concrete fines were collected and examined in relation to various possible applications in accordance with the applicable standards. Results highlight, that crushed concrete fines can be used in various applications in the concrete value-chain. However, for an optimal usage, additional processing is needed.

Keywords: Cement, concrete, construction and demolition waste, LCA, recycling.

1. Introduction

More than 10 years ago, a swiss standard was introduced that regulated the use of recycled concrete demolition waste as an aggregate for structural concrete [1]. Nowadays the use of such aggregates is very common in Europe and Switzerland [2–4]. In the coming decades, the amount of construction waste in Switzerland will increase - especially concrete demolition waste from structures built in the 1950s to 1970s [5]. However, most of the processed construction waste is "down-cycled" into materials with subordinate technical requirements such as lean concrete or as road subbase material [6]. For this reason, various studies have recently been carried out to optimize the use of concrete demolition waste [7–9]. However, most studies focus on the complete concrete demolition waste. We focus on the crushed concrete fines because it has a significant impact on the possible use of the demolition material due to its less favourable properties [10]. We think, that the usage can be optimized, especially as it is assumed that recycling of concrete fine from demolition could further reduce CO_2 emissions in the concrete value chain [11–13].

We aim to optimize the usage of concrete demolition waste, especially the crushed concrete fines as a by-product. The economic efficiency of concrete recycling will be significantly improved if this crushed sand can be used profitably in cement and concrete production. We evaluate three economically viable uses of recycled crushed sand 0/4 according to sustainability criteria such as climate protection, resource conservation and waste avoidance. Possible applications would be (i) use as a low-CO_2 substitute in cement kiln, (ii) use as an additive in cement mill or concrete production, or (iii) use as an aggregate in concrete production (Figure 1). The aim is to identify the optimum place of use, the quality of the crushed sand required and the requirements for processing methods. In this way, crushed sand is to be optimally returned to the material cycle, natural raw materials are conserved, and CO_2 is saved.

2. Methodology

We estimate the potential for the use of crushed concrete fines by using various test methods and calculations to determine the properties of real and laboratory specimens. Three samples of crushed sands (BS-L) were produced in the laboratory with different cement paste contents. Another three samples (BS-R) were taken from recycling plants and a sample of sand from natural resources was used as a reference. Based on chemical analyses of the samples, the use of ground crushed fines in clinker production is evaluated in simulations and the possible degree of substitution as a raw material substitute is estimated. Subsequently, mortar samples produced with the ground crushed fines as an admixture are tested according to SN EN 196. The results are then compared with the current standards and allow predictions on the possible use of the crushed sand as an additive and the possible amount to be added. In a further step, crushed fines samples are used as a substitute for primary sand in the production of concrete. The concretes produced are then subjected to extensive testing according to SN EN 206. A comparison with the standards will allow us to estimate the maximum degree of substitution of the primary sand. Finally, the results will be evaluated and discussed.

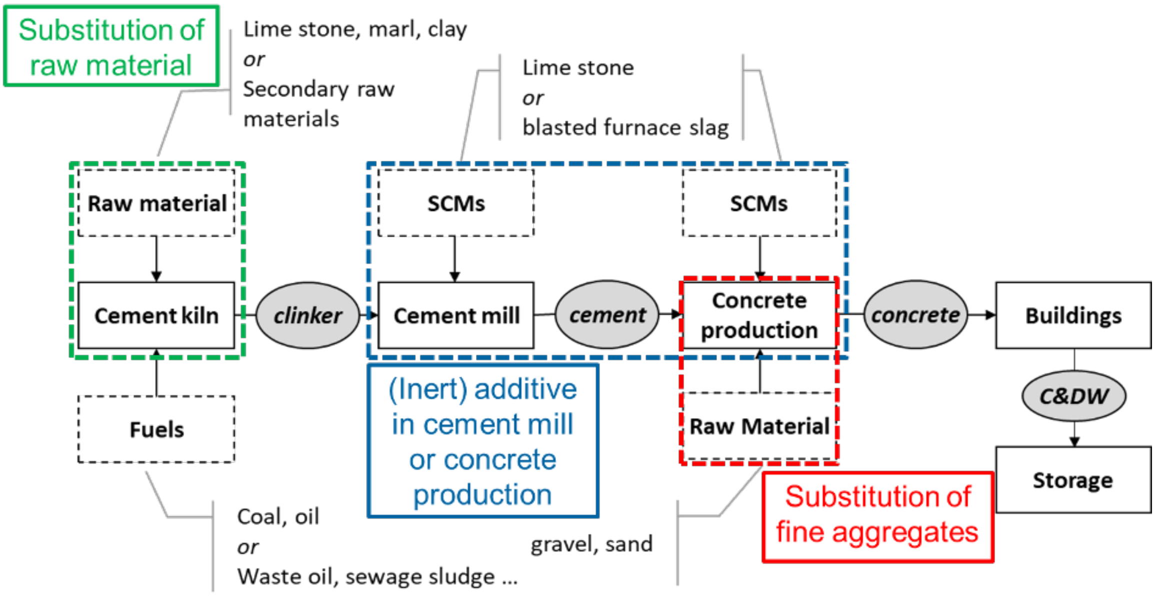

Figure 1. In the process chain, raw materials are used at various processes: in the cement kiln (green), in the cement mill/concrete production (blue) and in concrete production (red).

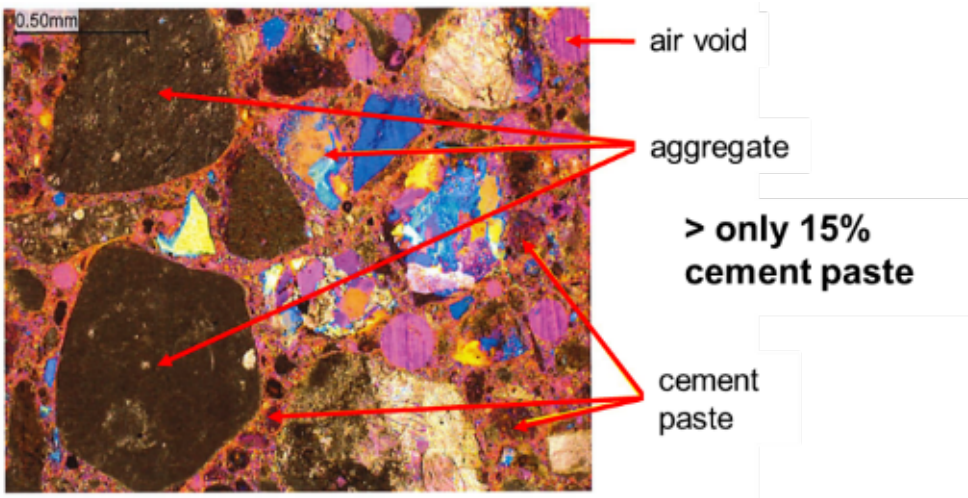

Figure 2. Thin section to determine the content of cement paste.

3. Results

3.1. Substitution of Raw Material in Cement Production

Recycled crushed fines contains sand and hardened cement paste and can be used as an alternative raw material in cement production [6, 10]. In particular, the cement paste portion contains the raw materials that can be reactivated in the cement kiln. Crushed fines samples (BS-L) from the laboratory were specifically made with 40%, 55% and 70% cement paste. The cement paste content of real crushed fines (BS-R) was determined on prepared thin sections by polarized light microscopy (Figure 2).

It was observed that the content of cement paste in the real crushed fines samples was 14% - 15%, which is lower than the expected typical content of about 30% (Figure 3). It is assumed that parts of the cement paste were lost in the demolition and separation process.

Material analysis by X-ray fluorescence spectroscopy (XRF) was performed on each of the real crushed fines samples (BS-R). The CaO content was between 24 % and 29 % and the LSF (Limestone Saturation Factor) was between 16.9 and 27.8. This reflects the low cement paste content, which is decisive for the maximum substitution of natural raw material. Calculations showed that only small amounts of the raw material can be substituted. To raise the substitution rate, the cement paste of crushed sand must be separated completely. Hardened cement paste by itself could replace more than 90% of the natural raw materials (Figure 4).

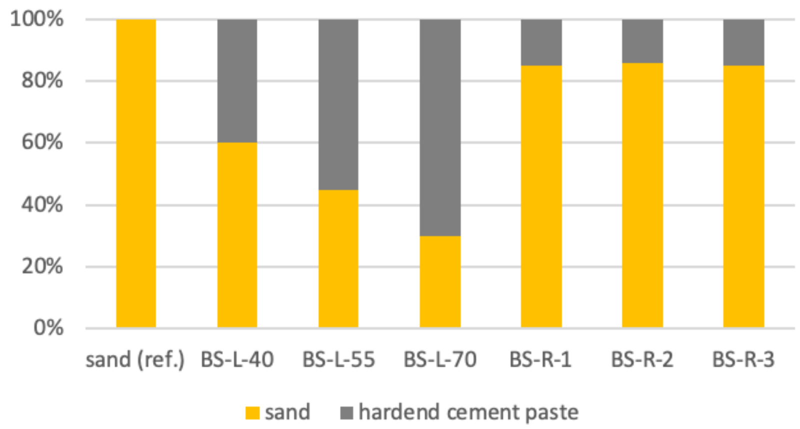

Figure 3. Samples of crushed sand and their content of hardened cement paste.

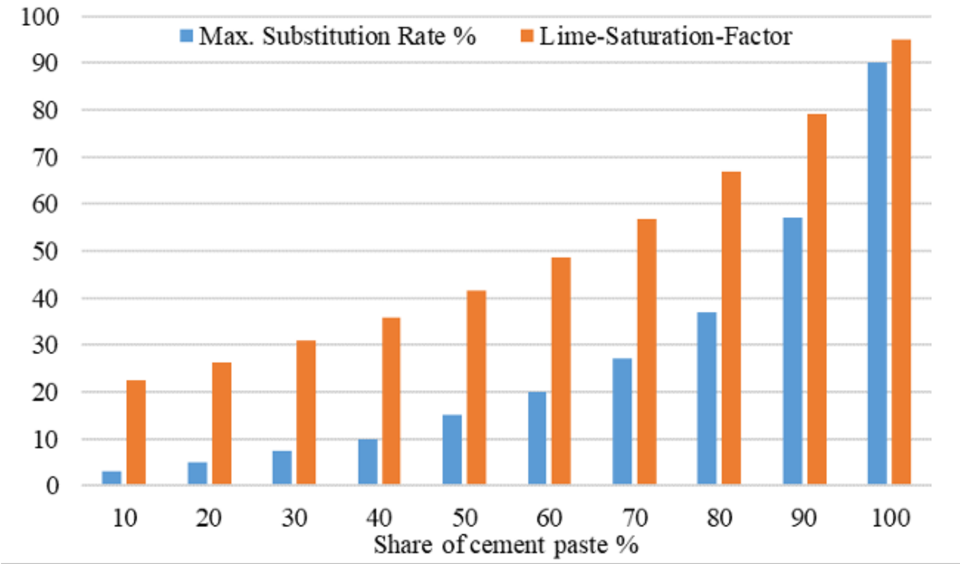

Figure 4. Maximum substitution rate depending on Lime-Saturation-Factor (LSF).

3.2. SCMs in cement mill or concrete production

To evaluate the possible use of crushed sand as an admixture, selected samples of crushed sand (BS-R-1, BS-L-40, BS-L-55 and BS-L-70) were milled and mixed in a ratio of 40:60 % with CEM I 52.5 R. These cements were then used to prepare cement paste for further testing of strength (according to EN 196-1), setting time and room stability (both according to EN 196-3). Results of CEM II/B-LL were used as reference.

The results of the tests (Table 1) indicate, that a lower compressive strength compared to a CEM II/B-LL must be expected. Since the strengths of cements with crushed fines do not differ significantly, it can be assumed that the crushed fine is inert. The results of the setting time do not show a clear picture. While the cement with BS-R-1 crushed fine sets significantly faster than a CEM II/B-LL, the cement with BS-L-40 shows a somewhat slower setting time. The room stability test does not indicate any significant differences between the cements tested.

The processing and preparation of the crushed sand as an additive is more complex than for the other two types of use since high demands are made on purity and homogeneity of the material.

3.2.1. Substitution of Sand in Concrete Production

Using the crushed fines as a substitute for natural sand is a good method to reduce the consumption of primary resources. However, sand is often segregated from demolition material because the fresh and hardened concrete properties may deteriorate.

First, the particle size distribution (Figure 5) and the properties of the crushed sands (Table 2) were determined.

In a test series on concrete mixtures, it was investigated whether samples of crushed sand are suitable as a substitute for sand and which concrete properties are derived. In each mixture, the entire aggregate fraction 0/4 was replaced by recycled crushed sand.

		CEM BS-L-70	CEM BS-L-55	CEM BS-L-40	CEM BS-R-1	CEM II/B-LL
Water [%]		30.1	30	30	28	28
Compressive strength [N/mm^2]	2 d	21.3	21.6	20.9	20.8	25
	7 d	30.8	34.9	32.4	33.3	37
	28 d	36.9	41.4	39.4	39.2	47
Flexural strength [N/mm^2]	2 d	4.8	4.5	4.4	4.9	N/A
	7 d	5.7	5.9	6	6.3	N/A
	28 d	6.2	6.3	5.9	6.3	N/A
Setting time [min]	begin	157	187	216	127	200
	end	204	231	256	207	240
Volume stability [mm]		0.5	1	1	1.5	1

Table 1. Results of cement paste tests compared to CEM II B/LL.

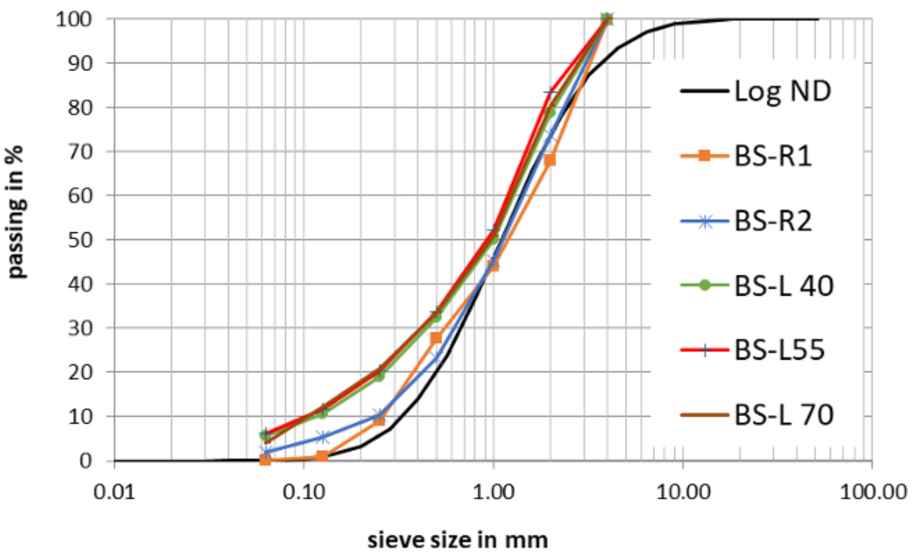

Figure 5. Particle size distribution of crushed sands.

A mixture with natural sand was used as a reference. The different water absorption of the crushed sand samples was considered, so that a constant effective w/c ratio of 0.6 should be achieved.

The compressive strength of concrete with recycled crushed sand was only reduced by about 10-15%. However, this reduction may also be related to differences in the effective water content and need not be related to the mechanical properties of the crushed sand. Crushed sand with high content of cement paste (BS-L-70) show a young's modulus that is up to 17 % lower, while a mixture with low content of cement paste shows a young's modulus that is about 6 % lower compared to the reference.

Natural sand can be completely replaced by recycled crushed sand. If the cement paste is separated during processing, the remaining sand can be used to produce concrete, which is technically equivalent to concrete made from primary material.

4. Discussion

The results show that the crushed fines can, with certain restrictions, be used for the investigated application possibilities in the value chain of concrete production. The results of the mortar tests (section 3.2.) indicate that a complete substitution of limestone powder is possible without any significant loss of quality. The use as a substitute for natural aggregates is also possible according to the results in 3.3. To do this, however, further concrete technology measures must be taken to prevent any significant loss of quality. The use as a raw material substitute in cement production (3.1.), however, does not seem to be possible without further processing steps. This is due to the low cement content found in the real samples, which leads to a low lime saturation factor and thus prevent a high degree of substitution.

An aspect not presented here in detail is the CO_2-uptake of the concrete waste. The cement paste absorbs CO_2 from the air through natural carbonation

	BS-R-1	BS-L-40	BS-L-70
ratio of cement paste [%]	14	40	70
dry density [kg/m^3]	2332	2175	1940
water absorption WA24 [%]	6.2	9.7	12.4

TABLE 2. Properties of the crushed sands.

		reference	BS-L-70	BS-L-40	BS-R-1
cement	[kg/m^3]	300	300	300	300
water	[kg/m^3]	180	180	180	180
w/z (eff.)	[−]	0.6	0.6	0.6	0.6
aggregate	[kg/m^3]	1887	1605	1678	1738
density	[kg/m^3]	2367	2085	2158	2218
air content	[Vol. %]	1.5%	1.5%	1.5%	1.5%

TABLE 3. Concrete mix and properties of fresh concrete mixtures.

		reference	BS-L-70	BS-L-40	BS-R-1
Density concrete	[kg/m^3]	2400	2310	2300	2320
Strength 28d	[N/mm^2]	40.5	36.0	37.0	34.5
E-modulus	[N/mm^2]	38ă419	32ă883	31ă867	35ă976

TABLE 4. Properties of hardened concrete mixtures.

and binds this in the formation of calcium carbonate ($CaCO_3$). This effect has already been investigated by various studies, although there is still no generally valid assumption about the exact maximum possible degree of carbonation [14–16]. Carbonation occurs particularly when the cement stone is ground and therefore has a very large surface. The CO_2 uptake is particularly useful in the production of clinker, as the CO_2 emissions of the rotary kiln can be kept in the "cycle" by means of forced carbonation. In this way, we could achieve a certain degree of CO_2 neutrality in clinker production.

Based on these results, we would like to suggest the following approaches:

- The greatest possible separation and recovery of the cement paste when processing concrete demolition. When developing processing methods, the aim should be to separate the cement stone as far as possible and to hold it back as a separate fraction. This gives you (i) a high-quality and climate-neutral secondary raw material for cement production and (ii) a high-quality RC aggregate for concrete production, which enables the further optimization of recipes to produce RC concretes.
- As far as possible carbonation of the cement paste in the entire process chain of the preparation of the cement paste in the concrete demolition (i.e. the preparation and storage in the various process stages). We assume that concrete demolition in Switzerland has a significant potential for rebinding CO_2, since it is mostly concrete that was produced with Portland cement and only absorbed limited amounts of CO_2 during use. In the development of processing methods, the aim should be to increase the carbonation of the cement paste in the concrete demolition. This is achieved above all by increasing the surface area and designing the storage conditions in a targeted manner. This allows CO_2 to be extracted from the air and stored in the building material. This corresponds to the "carbon capture and storage" approach that is much discussed today, with which one would like to reduce net CO_2 emissions by 2050.

5. CONCLUSIONS

The demolition of concrete is not yet considered as a problem and the potential of its recycling is not yet sufficiently recognised. This will change in the coming years or decades, because: (i) The amount of concrete demolition will increase once the concrete structures from the second half of the last century have reached the end of life. Therefore, the proportion of mixed demolition in mineral construction waste will decrease in the future and the proportion of concrete demolition will increase accordingly. (ii) The possible uses of RC concretes in structural engineering will increase and with it the demands on the building material. Today, qualitative deficiencies in the concrete granulate are compensated by adjustments in the concrete mix design (more cement, more admixtures). This leads to higher costs and environmental pollution. In the future, attempts will be made to improve the quality of concrete demolition. (iii) The pressure on the cement industry to make its contribution to climate protection is increasing (e.g.

through higher CO_2 fees and measures taken by public clients). Many representatives of this industry see a promising approach to solving this problem by rebinding CO_2 in concrete. For this, the greatest potential lies in the rebinding capacity in the crushed sand of the concrete demolition.

For these reasons, efforts to develop new processes for the separation and processing of C&DW will increase significantly in the coming years and further investigations for the usage of C&DW will be necessary. The here described research project improves the decision-making basis for the development of new technologies and possibilities to use a material which, until now, is down-cycled or landfilled.

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References

[1] Sia. Recyclingbeton, SIA 2030, 2010. Zürich.

[2] J.-L. Gálvez-Martos, D. Styles, H. Schoenberger, et al. Construction and demolition waste best management practice in Europe. *Resources, Conservation and Recycling* **136**:166-78, 2018. https://doi.org/10.1016/j.resconrec.2018.04.016.

[3] A. Müller. Baustoffrecycling: Entstehung - Aufbereitung - Verwertung. *Wiesbaden: Springer Vieweg*, 2018.

[4] C. Hoffmann, F. Jacob. Recyclingbeton aus Beton- und Mischabbruchgranulat. Dübendorf, 2007.

[5] N. Heeren, S. Hellweg. Tracking Construction Material over Space and Time: Prospective and Geo-referenced Modeling of Building Stocks and Construction Material Flows. *Journal of Industrial Ecology* **23**(1):253-67, 2018. https://doi.org/10.1111/jiec.12739.

[6] C.-T. Galbenis, S. Tsimas. Use of construction and demolition wastes as raw materials in cement clinker production. *China Particuology* **4**(2):83-5, 2006. https://doi.org/10.1016/s1672-2515(07)60241-3.

[7] M. Menegaki, D. Damigos. A review on current situation and challenges of construction and demolition waste management. *Current Opinion in Green and Sustainable Chemistry* **13**:8-15, 2018. https://doi.org/10.1016/j.cogsc.2018.02.010.

[8] S. Guignot, S. Touzé, F. Von der Weid, et al. Recycling Construction and Demolition Wastes as Building Materials: A Life Cycle Assessment. *Journal of Industrial Ecology* **19**(6):1030-43, 2015. https://doi.org/10.1111/jiec.12262.

[9] A. Di Maria, J. Eyckmans, K. Van Acker. Downcycling versus recycling of construction and demolition waste: Combining LCA and LCC to support sustainable policy making. *Waste Management* **75**:3-21, 2018. https://doi.org/10.1016/j.wasman.2018.01.028.

[10] C. Müller, J. Reiners, S. Palm. Closing the loop What type of concrete re-use is the most sustainable option, 2015.

[11] CEMBUREAU. The European Cement Association. Cementing the European Green Deal: Reaching Climate Neutrality along the Cement and Concrete Value Chain by 2050. Brussels, 2020.

[12] R. Andersson, H. Stripple, T. Gustafsson, et al. Carbonation as a method to improve climate performance for cement based material. *Cement and Concrete Research* **124**, 2019. https://doi.org/10.1016/j.cemconres.2019.105819.

[13] J. Schneider. Decarbonizing construction through carbonation. *Proceedings of the National Academy of Sciences* **117**(23):12515-7, 2019. https://doi.org/10.1073/pnas.1913867116.

[14] N. Zhang, H. Duan, T. R. Miller, et al. Mitigation of carbon dioxide by accelerated sequestration in concrete debris. *Renewable and Sustainable Energy Reviews* **117**, 2020. https://doi.org/10.1016/j.rser.2019.109495.

[15] E. Possan, E. F. Felix, W. A. Thomaz. CO2 uptake by carbonation of concrete during life cycle of building structures. *Journal of Building Pathology and Rehabilitation* **1**(1), 2016. https://doi.org/10.1007/s41024-016-0010-9.

[16] W. Ashraf. Carbonation of cement-based materials: Challenges and opportunities. *Construction and Building Materials* **120**:558-70, 2016. https://doi.org/10.1016/j.conbuildmat.2016.05.080.