ASSESSMENT OF FINE RECYCLED CONCRETE AGGREGATE IN CEMENT-BASED FLOWSCREED

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Summary

Recycled aggregates become more and more important as potential raw material to replace aggregates from natural origin. Since excavation of natural sand from the riverbed is already banned in some areas, fine recycled concrete aggregates come into view to replace sand in certain applications. This paper presents some test-results of using fine recycled concrete as a partial replacement of natural aggregates in cement-based flowscreed. Special attention is given to describing and studying the properties of cement-based flowscreed. In this study the properties and requirements of the composing materials for use in flowscreed are investigated. Rheological characteristics and mechanical properties were investigated. Experimental results indicate that it is possible to prepare flowscreed with partial replacement of natural aggregates by recycled aggregates and obtain a quality that meets the requirements. The practical application of this material is also discussed. This study was partially connected to the research-project RecyFlowscreed.

Keywords: Recycled aggregates (RA), fine recycled aggregates (FRA), cement-based flowscreed (CFS)

1 Introduction

Nowadays the recycling of demolition waste is more common and recycled material is used as a secondary raw material. Recycling in the construction industry is implemented for ecological reasons as well as for economical ones. Rubble from demolishing buildings or residues from industrial production can be used to replace virgin raw materials. Using recycled materials helps in reducing the pressure on landfilling sites for which the available space is getting scares. Often governments impose taxes on landfilling as a part of their environmental policy. This way demolition waste, after processing, becomes an economical interesting raw material. On the other hand recycled material is often lower in quality compared to natural materials. When used as partial replacement of natural aggregates in appropriate applications and by addition of suitable admixtures, the building product or application can achieve the required properties or quality as when only natural aggregates were used.

Today, the use of coarse recycled concrete aggregates is higher than before, but the fine fractions 0–4 mm and 0–8 mm still lack applications with an added value. The properties of fine recycled aggregates are worse than those of coarse recycled aggregates and they are less investigated compared to the coarse recycled aggregates.

Cement-based flowscreeds provide a high quality, cost effective solution to floor screeding. Flowscreeds constitute a large progress in technology of screeds. A flowscreed is characterized by it workability and self-compacting action. Cement based flowscreeds have several obvious benefits compared to traditional hand spread sand-cement screeds. Traditional sand-cement screeds are put in place by hand, which is hard labour and it takes a long time to install. They are also highly dependent upon the quality of the work by the installer. Flowscreeds are put in place by using a mobile concrete pump and are easy to spread open. They are self-compacting and often also self-levelling. After dipping the screed to push out the air bubbles, it is no longer necessary to pave and smoothen the levelled surface with a trowel. Thus, flowscreeds contribute to sustainable building in the context of the 'human factor' in sustainability as the labour to put it into place is physically less demanding.

Many countries have already imposed restrictions on the excavation of sand for the riverbed. They have done so for reasons of erosions of the riverbed which in turn could lead to flooding problems after heavy rainfalls. Since there is a lot of sand used in traditional sand-cement screed, trying to reduce the need for sand in screed by partially replacing it by fine recycled aggregates is a way of contributing to a sustainable material management in the building industry.

Technically flowscreeds contribute to a sustainable building industry since the mechanical properties are better compared to the traditional sand-cement screed, thus allowing thinner layers of screeds and consequently reducing the amount of used materials, and in the long run saving ending resources.

The flowscreed-layer thickness can be as thin as 50 mm (or even less) while layers in traditional sand-cement compositions are 70 to 100 mm thick. Piped Under Floor Heating (UFH) systems are typically laid in traditional screeds up to 50 mm thick. This reduced thickness of the screed-layer, combined with the increased thermal properties of flowscreed, can result in improved response time and efficiency of the UFH. The finished floor is levelled and usually able to take light foot traffic 24 to 36 hours after being laid. The only problem which could appear is a higher shrinkage which could be caused by the high water-cement ratio. Shrinkage cracks can be avoided by using fibres or by adding shrink reducing agents in the mixture. Other studies showed that it is very difficult to design a flowscreed with good rheological properties in the fresh state and good mechanical and physical properties in the hardened state. [1] The most common problem are micro-cracks formed during the drying period of the flowscreed.

In the experimental part of the study, the design and testing of cement-based flowscreed with partial replacement of natural aggregates by fine recycled aggregates (FRA) is investigated. The aim of the research is to compose a flowscreed with use of FRA, having comparable characteristic as flowscreed without FRA. The mixtures will be tested for workability and segregation or bleeding. Based on the test-results the maximal percentage replacement of sand with FRA in the flowscreed-composition will be determined. The positive and/or negative influence of using FRA in the mixture on the properties of the flowscreed will be discussed.

2 Use of recycled aggregates

Generally recycled aggregates have other, worse properties than natural aggregates. Recycled aggregates (RA) consist of original aggregates with attached mortar. The attached mortar is porous causing the RA to have a higher water absorption and lower density. Bulk density is lower by 15 to 18 % and void percentage is up to 10 to 15 % higher than that of natural aggregates of the same particle size distribution. The RA has a water absorption of about 4 to 12 % higher than that of natural aggregates and the fine fraction of RA has the highest absorbability. RA has lower compressive strength and coefficient of elasticity compared to natural aggregates (e.g. granite has compressive strength 110–360 MPa, concrete 15–210 MPa) [2][3][5].

Generally there is some doubt about the soundness of RA. This is due to the origin of the RA, which is demolition waste without known composition or history. However, thanks to selective demolition, and advanced techniques for sorting and crushing the rubble, the obtained RA complies with the requirements imposed by several regulations. These requirements are mainly about geometric properties, physical aspects and durability of RA. RA should also be tested for their content of chemical contaminations such as chlorides and sulphates, which could disturb the binding of cement or could lead to rapid deterioration of reinforced concrete. All aggregates used in concrete have to measure up to the requirements in the European Standard EN 12620: Aggregates for concrete. It is important to examine the geometry aspects separately for fine RA 0–4 mm and coarse RA over 4 mm size [3]. Specifications for RA are not detailed in EN 206-1: Specification, performance, production and conformity.

Nowadays RA are used in low grade applications with no or limited requirements for strength, chemical composition and other requirements for aggregates. The overall believe is that the final quality of applications with RA is depends on the quality of demolition waste and sorting of waste on the demolition side or at recycling centres. The quality of the RA is also influenced by the crushing and cleansing technology used in the recycling plant. [4].

Nearly one third of the crushed demolition waste is fine RA (FRA), the fraction 0–8 mm. At this moment these FRA are often used in sand-cement-mixtures for roadwork. The use in mortar and screed is new. In screed the fraction 0–4 mm is used. This fine fraction contains a high percentage of particles under 0,25 mm (grinded hardened cement phase). These FRA have a high water absorption and influence the water-demand and also the water/powder-ratio when used in a flowscreed-mixture. The filler-content in FRA is about 20 % (particles smaller than 0,25 mm). The filler becomes part of mastic cement and increases the flow of the screed-mixture.

3 Materials used for design of flowscreed

Aggregates as a filling agent constitute 60–75 % of the mixture. Normally fractions 0–8 mm and 0–4 mm are used. Riverbed-sand is better than quarry-sand because of its round shape. Aggregates should not contain impurities and other unwanted constituents which could influence screed properties in a negative way. Cement should be conform to European Standards EN 197-1 (2002): 'Cement Composition'. Blast-furnace-slag-cement, which has higher specific surface, is suitable and improves the flow of the mixture. CEM I Portland cement is most widely used. The cement dosage is minimally 300 kg/m^3. Type I fillers, e.g. limestone powder, are added to the mixture to increase the amount of fine particles and in case of type II additions, e.g. fly ash, also to decrease amount of cement. The specific surface of this powder materials is from 250 to 30 000 m^2/kg. Adding these fillers helps to create a stable mixture and avoid bleeding and/or segregation. Admixtures are used to improve the properties of the final product. In case of flowscreeds plasticizer or superplasticizer is used to decrease the water-demand and increase the workability of the mixture. Due to the high amount of water used in flowscreed-mixtures, high shrinkage will appear as the excess water evaporates during hardening and drying of the screed. To decrease shrinkage it is possible to use dispersed reinforcement like a polypropylene fibers (dosage 2 kg/m^3) or steal fibers (dosage 25–50 kg/m^3).

In the research-program “RecyFlowScreed” [5] a blast-furnace-slag-cement with low alkali content (CEM III/A 42,5 N LA) was used. The cement was conform to European Standards EN 197-1 (2002): ‘Cement Composition’, and was manufactured by Holcim, Nijvel, Belgium. The compressive strength of this cement at 2, 7 and 28 days is respectively 18 MPa, 34 MPa and 56 MPa. The limestone powder (LP) used as an additive, was “Calcitec 2001 M” from the Carmeuse factory, Seilles, Belgium. The chemical analysis and physical properties of these materials are presented in “Table 1”.

Tab. 1 *The chemical composition and physical properties of cement and limestone powder [6]*

Basic compounds (%)	**Cement**	**Limestone powder**
$CaCO_3$	-	98,70
CaO	51,8	-
SiO_2	26,0	0,14
$Al_2 O_3$	8,2	0,05
$Fe_2 O_3$	2,8	0,05
MgO	4,2	0,34
$Na_2 O$	0,34	-
$K_2 O$	0,61	-
SO_3	3,2	-
Cl	0,05	-
Lose on ignition	1,20	-
Insoluble residue	0,50	-
Specific surface (m^2/kg)	410	475
Volume density (kg/m^3)	3010	2690

The sand fraction 0–4 mm with absolute volume density 2680 kg/m^3 and water absorption of 0.88 %, is riverbed sand coming from Germany. The recycled aggregates fractions 0–4 mm with absolute volume density 2420 kg/m^3 and water absorption of 7.5 % are obtained from ARC – Antwerp Recycling Company, a recycling plant in Antwerp, Belgium.

The superplasticizer (SP) GIMARCOPLAST FM 643 was produced by BASF, Oosterhout, Netherlands. The solid content is 19 %, pH 6.0 ± 1 and volume density (at 20 °C) of admixture is 1.04 g/cm^3 ± 0.02. The water used in the experiments was tap water.

4 Mix – design

The first phase in designing new mixtures is to control the properties of all components. A blast-furnace-slag-cement with low alkali content is chosen as a safety measure because recycled aggregates can contain a higher percentage of alkali than natural aggregates (sand). This type of cement is grounded to a relatively high fineness. The advantage of this type of cement is an increase of early strength compared to ordinary Portland cement (OPC), which makes the flowscreed hard enough after 24 hours to allow light foot traffic. The superplasticizer (SP) helps to decrease the water-demand in the mixture and yet provides a good workability. It is necessary to test for opposite actions between SP and other components. There could be a reaction with cement or limestone which could cause segregation. In this research poly-carboxylate-ether SP is used with dose 0.68 % [M/M] of the cement content. The SP was tested in advance for reaction with cement and there is no any negative reaction between these components. Limestone powder (LP) is an inert admixture which influences the workability and the viscosity of fresh mixture. In all mixtures the LP is 16.9 % of the fine material (<0.250 mm). The FRA are the weakest component of the mixture. The required compressive strength of flowscreed can range from 5 to 80 N/mm² depending on the use of the floor. In this study is the aim for the compressive strength was set at 20 MPa, which is generally enough for use in houses. The aim was to determine maximal amount of replacement sand with FRA without negative influence on the properties of fresh and hardened flowscreed. Tests showed that even with 50 % replacement of the sand with recycled aggregates, the compressive strength is still sufficient. FRA contains a higher amount of fines ("Figure 1") which influences the viscosity of the fresh flowscreed-mixture. FRA also have a higher water absorption (7.5 %) compared with sand (0.88 %). This resulted in a higher need for water in mixture, which could cause higher shrinkage during drying of the flowscreed.

Packing of the mixtures is based on some general rules for the mortar and screed mixing. [6][7][8][9] The natural aggregates and FRA were added in dry state. The amount of water in mixtures was increased to compensate the water absorption of the aggregates. The reference mixture contains 0 % of recycled aggregates and in the other compositions the percentage of recycled aggregate was successively increased by 10 %. "Table 2" lists the mix proportions for 1m3 flowscreed.

Tab. 2 *Dosages of mixtures for 1 m3 [5]*

Material [kg]	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**
% content of FRA [M/M%]	0	10	20	30	40	50
Cement	323	323	323	323	323	323
Limestone powder	248	248	248	248	248	248
Natural aggregates 0–4 mm	1429	1286	1143	1001	858	715
Fine Recycled aggregates 0–4mm (FRA)	-	129	258	387	516	645
Water [L]	253	262	270	279	287	296
Superplasticizer (SP)	2,21	2,21	2,21	2,21	2,21	2,21

5 Rheological properties of flowscreed

All tests to determine the rheological properties are made in accordance to the standards. In case of tests for consistency of mixtures, an often used non-normative test for examining the matrix for self-compacting concrete was used.

The main emphasis was given to the consistency of fresh flowscreed, good flowability and resistance to segregation. Consistency was determined by slump flow tests. The required value for the flow was from 230 to 250 mm. The consistency was determined with the mini V-funnel equipment and the cone tester. These tests also showed resistance to segregation and to bleeding. Mixture 1 was tested for air-content with the pressure method. Fresh flowscreed was tested for open time test with use of mini-conical slump flow test. The mixture was tested every 5 minutes, starting immediately after mixing until the flow decreased by 20 % in regards to the initial measurement. When all tests of fresh flowscreed were carried out, the samples were moulded in prisms of 40 x 40 x 160 mm^3 and put in a climate chamber at a temperature of 23,7 ºC and a relative humidity R.H. of 98 %.

The specimens were cured in the climatic chamber for 3 and 28 days, after which the bending and compressive strength was determined on the prisms. The resistance to wear was determined according to the Böhme Abrasion test-method on samples of 71 x 71 x 50 mm^3. The bulk density of fresh and hardened flowscreed was also determined.

6 Results and discussion

6.1 Properties of fresh flowscreed

Six flowscreed-mixtures were designed and tested to see if they meet the specified requirements. The replacement of sand with recycled aggregates is increased form 0 up to 50 % with an interval of 10 %. On each mixtures the influence of recycled aggregates to the physical and mechanical properties of fresh and hardened flowscreed, was monitored. The main attention was given to the workability and the compressive strength and compared to the reference mixture with only sand. The results are presented in the following tables and figures.

Tab. 3 *Fresh flowscreed test-results [5]*

	% content of FRA [M/M%]	Bulk density [kg/m^3]	Slump-flow [mm]	Mini V-funnel [s]	Cone test [s]	Open time [min]
Mix 1	0	2210	247	4,41	21,25	75
Mix 2	10	2200	242	4,31	21,20	60
Mix 3	20	2180	257	4,19	18,65	60
Mix 4	30	2160	241	4,28	18,55	40
Mix 5	40	2150	254	3,82	18,10	40
Mix 6	50	2130	249	3,19	17,05	40

The results of the slump-flow test showed that FRA does not have a negative influence on flowability of CFS. The results values of test were in the range of 241 to 257 mm ("Table 3"). A flow of minimal 240 +/- 10 mm was required.

The flowability showed an increasing trend with an increasing amount of FRA, which can also be concluded out of the decrease of the time measured with the mini V-funnel test and Cone test. The fine compound content in FRA has positive influence on flowability and stability of mixture, no segregation or bleeding was observed.

Open time test showed that the FRA increasing rate of solidification of the flowscreed. The open time for the reference mix 1 with 0 % of FRA was 75 minutes. Mixtures 2 and 3 had a good workability during 60 minutes, which is still sufficient. When using more than 20 % of FRA, the open time rapidly drops and speeds up the solidification and hardening of fresh flowscreed. The acceleration of the solidification could be caused by the water absorption of the FRA. Water from cement matrix is absorbed by the FRA and causes the mixture to lose workability. This could be countered by pre-wetting the FRA before adding the other components in the mixer. This was not done in this testing program. The amount of water which should be added to compensate the absorption can be calculated if the water absorption of the FRA was measured on beforehand.

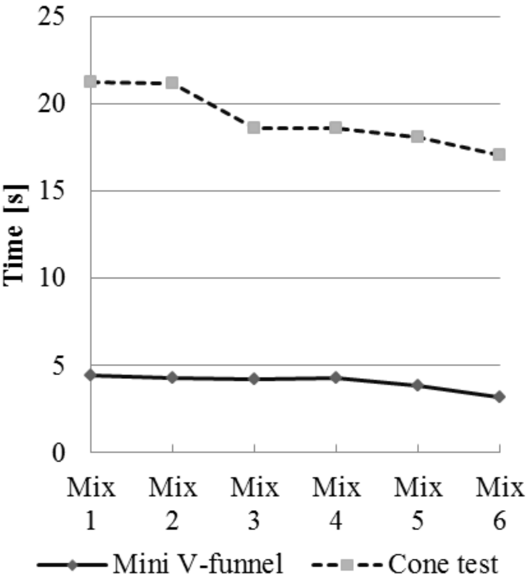

Fig. 1 *Mini V-funnel and Cone test*

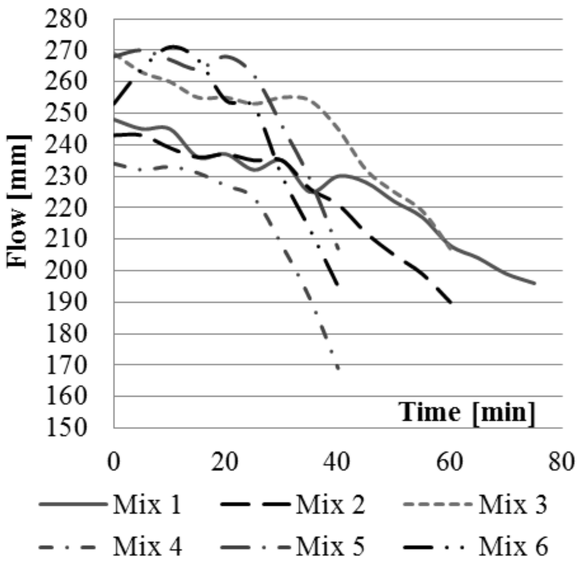

Fig. 2 *Open time test*

Adding this amount of water to the dry mixture at once is not a good idea since this will lead to an initial amount of water that is too high and which would lead to segregation of the mixture. Adding an extra amount of water to the dry mixture and mixing during a longer time to allow the FRA to absorb the excess of water could also be considered, but this will affect the flow.

6.2 Mechanical properties

The air-content in fresh flowscreed is 2,5 %. This test was carried out only on Mix 1, just to detect if the superplasticiser had any influence on the air-content. This wasn't the fact.

Test-results for the mechanical properties of flowscreed after 3 and 28 days of hardening are shown in tables and figures hereafter. The aim for the flexural strength was 2 MPa and 20 MPa for the compressive strength.

Reference mixture with 0 % FRA had the highest flexural strength. In the mixtures with replacement of sand with FRA, the flexure strength at 28 days increased with the raising percentage of FRA. In other cases the flexural strength was in the same range. In all cases the requirement of 2MPa for the flexural strength was reached.

Although the compressive strength of all mixtures is higher that the requested value of 20 MPa, the compressive strength showed a slight decrease with an increasing amount of sand replacement by FRA. The only exception was Mix 6 with 50 % replacement of sand by FRA, where the compressive strength was 32,7 MPa, which is comparable with the result of 32,9 MPa for Mix 3 (at 20 % replacement of sand by FRA). The cement matrix could be more compact due to a higher amount of fine particles in FRA. This hypothesis was not checked in this study and could be a subject for future investigations on the use of fine FRA, fraction 0–4 mm.

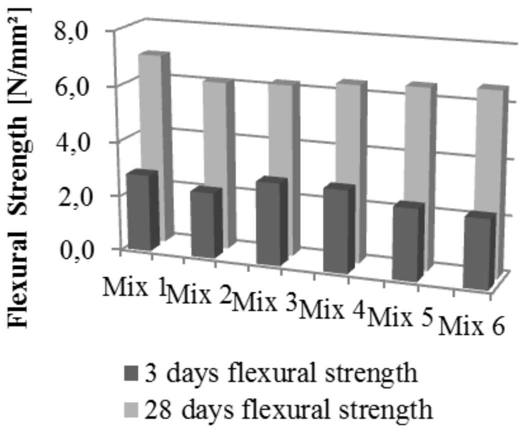

Fig. 3 *Flexural strength*

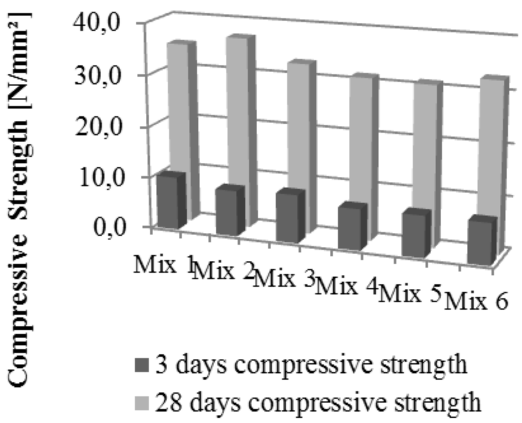

Fig. 4 *Compressive strength*

Tab. 4 *Strength after the mixing*

	% content of FRA [M/M%]	Bulk density [kg/m^3]	Flexural strength [N/mm^2]		Compressive strength [N/mm^2]	
		28days	3 days	28 days	3 days	28 days
Mix 1	0	2180	2,8	6,9	10,3	34,9
Mix 2	10	2180	2,4	6,1	8,9	36,9
Mix 3	20	2140	3,0	6,2	9,4	32,9
Mix 4	30	2110	3,0	6,4	8,0	31,2
Mix 5	40	2110	2,6	6,5	8,1	30,9
Mix 6	50	2120	2,5	6,6	8,1	32,7

6.3 Böhme wear resistance

The maximum loss of material for screeds to be wear resistant is 22 cm^3/50 cm^2. No mixture matched this requirement. It is clear that this kind of flowscreed is not meant to be used without applying a finishing layer, such as tiling, on top of it.

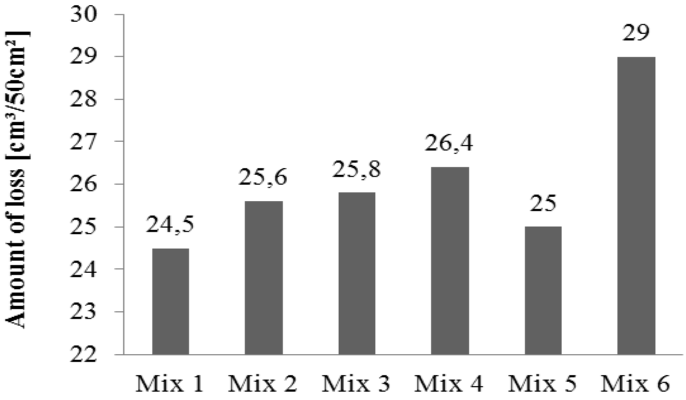

Fig. 5 *Wear resistance by Böhme method*

7 Conclusion

All mixtures proved to have a self-compacting character. No segregation or bleeding on fresh flowscreed appeared. All mixtures had good properties in fresh state. The open time test showed a decline of properties of mixtures with higher amount of FRA. An open time of 60 minutes with a flow of 230 mm is probably too short to be practically useful on construction sites. To prolong the workability of the mixtures, adding a setting retarder admixture could possibly be of use. This has not yet been investigated in this study.

Tests on hardened flowscreed proved that even with 50% replacement of sand with FRA, the necessary requirements for the mechanical properties can be reached. All mixtures had very good flexure and compressive strength and reached the required values. The Böhme Abrasion test to measure the wear resistance, showed that this kind of flowscreed is not suited to be used without being covered with tiles or another wear resistant covering layer. Based on these results it can be concluded that CFS can be applied as a screed layer under decking.

After assessment of all results in this study, the optimal amount of replacement for sand by recycled aggregates in cement based flowscreed is 20 % (Mix 3). This mix had good properties in fresh and hardened state. The open time was appropriate for use, even without adding setting retarder admixtures. Maximal replacement of natural aggregates by recycled aggregates is from 30 to 35 %. Even 50 % replacement with FRA can be achieved with special attention for water-demand, segregation and shrinkage. The replacement of natural aggregates by recycled aggregates can reduce the cost of cement-based flowscreed and contributes to a sustainable material management.

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