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Aggregates for quality concrete from debris using optimised crushing

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Abstract

Worldwide, natural disasters and conflicts result in damaged or collapsed buildings requesting clearing of debris and reconstruction. The on-site recycling of concrete waste into new structural concrete reduces the utilization of raw materials, decreases transport and production energy cost, and saves the use of limited landfill space. Currently, recycling involves the use of recycled concrete aggregates (RCA) as road base material or in non-structural concrete with low strength requirements. Hence, the application in structural concrete is limited. In order to improve the applicability of RCA in structural concrete, an optimised crushing and sieving method is advised. To this aim, a modular rapid deployable clearing kit has been designed, clearing (concrete) debris, and processing this into quality aggregates for new concrete to be used in local reconstruction. Since the quality of the initial concrete is unknown, errors can be made when it was produced (e.g. not enough cement, too much water, etc.). These defects are not detectable by the naked eye; however, they cause a weakening of the structure. In term, clearing the hardened cement paste from the aggregates via optimised crushing minimises the influence of the initial concrete quality on the quality of the recycled concrete aggregates. Together with the fact that cement paste absorbs a significant volume of water, optimised crushing makes application of recycled concrete into new concrete far less troublesome.



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Introduction

Emergency response innovation

This study into the production of aggregates for quality concrete from debris using optimised crushing has been performed within the framework of the EU project S(P)EEDKITS. The main objective of S(P)EEDKITS is to develop rapid deployable kits for emergency response units, i.e. these will be SPEEDKITS. Following best practice guidelines from humanitarian organisations, these solutions will also be SEEDKITS, i.e. kits that form the seeds for the long term self-recovery process after a disaster strikes. The project enlists 5 topics on improvement of emergency response (ER), namely system design (modularity, packaging & tracking), shelters, facilities (water & sanitation), deployment & transport, and Infrastructure (medical, communication, energy & re-building). All developments are to be field-tested by the end of the project in 2016.

The system design improvement focuses on removing redundant aspects, minimizing volume, and reducing weight. Towards this end, commonly applied and thoroughly tested folding mechanisms and collapsible solutions from other fields of industrial products are implemented. Additionally, transport dimensions are standardized applying the “matryoshka doll” principle, minimising the transport volume. Furthermore, packaging is optimised for handling during transport.

Objectives for the improvement of deployment and transport are: (i) a decision support tool for determining which units and which type of unit should be deployed as well as prioritized in the emergency area, (ii) a tracking system for individual transported packages, (iii) a software tool for central operational planning and local situation assessment.

Novelties for infrastructure ER consist of: (i) an autonomous and modular container-based rapid deployment field hospital (ii) a thermal energy system based on producing methane gas from faecal sludge, (iii) a small photovoltaic system for shelter application, (iv) unfolding solar panels (robust, large, lightweight, and compact) combined with an energy storage solution and plug and play connectors, (v) a kit to be used for debris recuperation; preparing post-disaster debris for recycling and reuse of the material into new concrete applications. By combining these solutions, the aim is to be able to reuse 100% of the debris, so that nothing is lost, and the demolished material becomes part of the new infrastructure.

Optimised crushing

The optimized crusher is a jaw crusher specially designed for concrete recycling. The purpose of the machine is to separate concrete into its constituent sand, gravel and cement paste, based on the principle of Smart Crushing. Ordinary crushers are usually used only for the purpose of reducing particle sizes which will crush all the component materials randomly; in the case of concrete, this will include crushing through the aggregates as well as between them. This optimized type of crusher is intended to separate concrete into the composite materials without the risk of the components themselves being damaged, by adjusting the crushing force to an intermediate one between the average compressive strengths of the aggregates and the one of the hardened cement paste.



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The main concern for using recycled concrete aggregates in new concrete is attached (or residual) mortar; it accounts for the main difference between RCAs and natural aggregates. The attached paste is the main factor that causes the degradation of the new concrete incorporating recycled concrete aggregates.

Previous studies dealt with properties (particle size distribution, density, oxide and mineralogical composition) of a number of recycled concrete fractions, obtained through both conventional and optimized crushing. Results show that, through an optimized technique, the generated RCA can have a significantly lower amount of residual attached mortar than in the case of conventional crushing (Schenk 2011, Florea and Brouwers 2013, Florea et al. 2014). Moreover, mortar tests have shown that such RCA, virtually free of attached mortar, can be used as total replacement of river aggregates without loss of mechanical properties. Recycled concrete sand was tested to replace 100% of the Norm sand in standard mortars. A significant decrease of flowability was observed; however, this was compensated with the addition of 1% superplasticizer by mass of cement. The mechanical properties of the RCS mortars proved to be promising, the samples achieving higher strengths than the reference samples, especially for short curing times. The 3, 7 and 28 days flexural strengths increased with 45.3%, 33.2% and 13.7% respectively, compared to the reference mortar. The 3 and 7 days compressive strengths had even higher increases, of 65.6% and 40.3%, respectively. However, the 28 days compressive strength of the RCS mortar increased only by 1.1%, indicating that the positive effect of RCS is predominantly manifested at early ages.

Modular, rapid deployable clearing kit; pilot scale

The clearing and crushing of debris is not new to post-disaster areas. However, reusing the debris into structural concrete instead of low grade reuse or landfilling the material is innovative. A kit for debris recycling is therefore a novel item when it comes to emergency aid. As such, determining the capacity and the scale of operations are not straightforward and therefore open for debate. When considering the range of options (e.g. from setting up a “real plant” to only manual labour), it was decided to focus on a processing capacity of 10-15 ton/hour. This relatively low capacity, compared to industrial standards, has been chosen since it enables ease of transport, rapid deployment, mobility to get on site (even in an urban area), and a limited investment. Next to that this scale of operation enables a manual approach (potentially aided by small scale equipment), employing local people and stimulating the rehabilitation of the local economy. This approach is supported by the humanitarian actors represented within the S(p)eedkits consortium (International Federation of Red Cross and Red Crescent Societies, Médecins Sans Frontières). This in term does not mean that the impact should also be small scale, multiple kits can be deployed in parallel or the technology can be scaled up to enable an (semi-)automated approach.

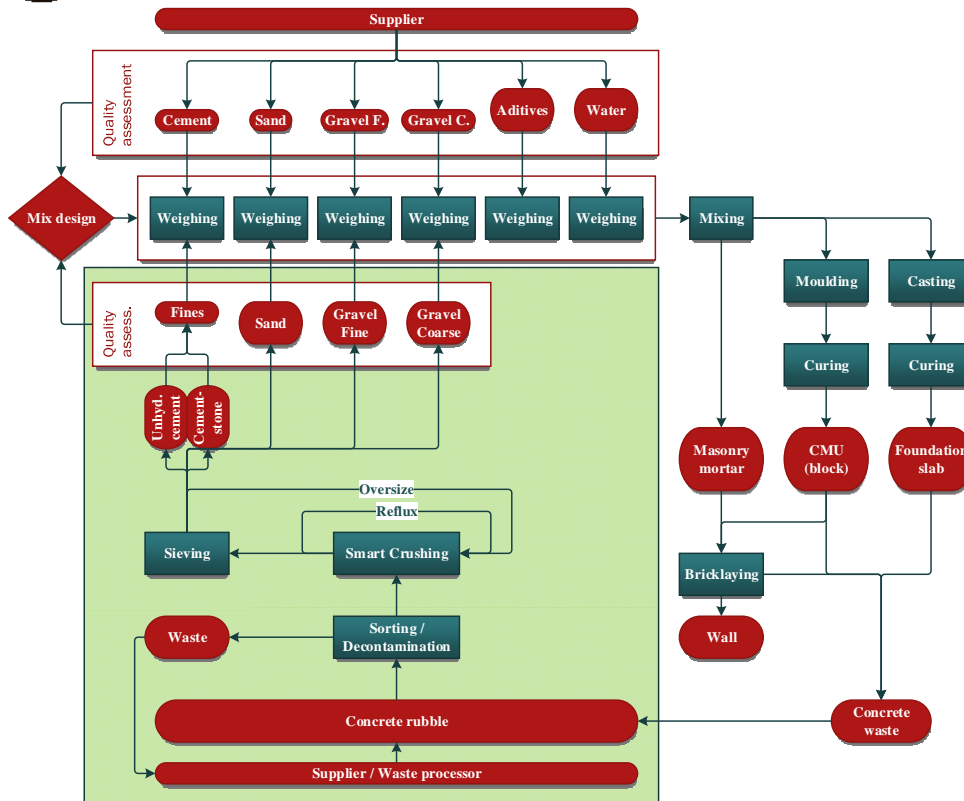


Fig.1: Process scheme optimised crushing towards recycling of concrete into safe structural concrete

In Figure 1, the schematic concrete production process can be seen when virgin aggregates are (partially or fully) substituted by recycled concrete aggregates (green area). The best case scenario would be when solely reclaimed materials and no virgin aggregates have to be used. However, virgin aggregates can be used when reclaimed aggregates are not produced in the right proportions or when complete substitution is not applicable. Therefore, the original supply chain remains intact.

For the pilot test setup, an electrically powered stationary crusher (capacity up to 20 t/h) was modified (low tech, minimal additional cost) to enable optimised crushing. Next in line, a sizer with 5 sieve decks of variable mesh sizes (between 0.125 and 32.0 mm) was placed and conveyors were applied to connect everything (see Fig 2); its scope is to be containerised and deployed as a kit module in post-disaster areas. Future versions will contain tracked, diesel powered models of the equipment ensuring a highly mobile setup.

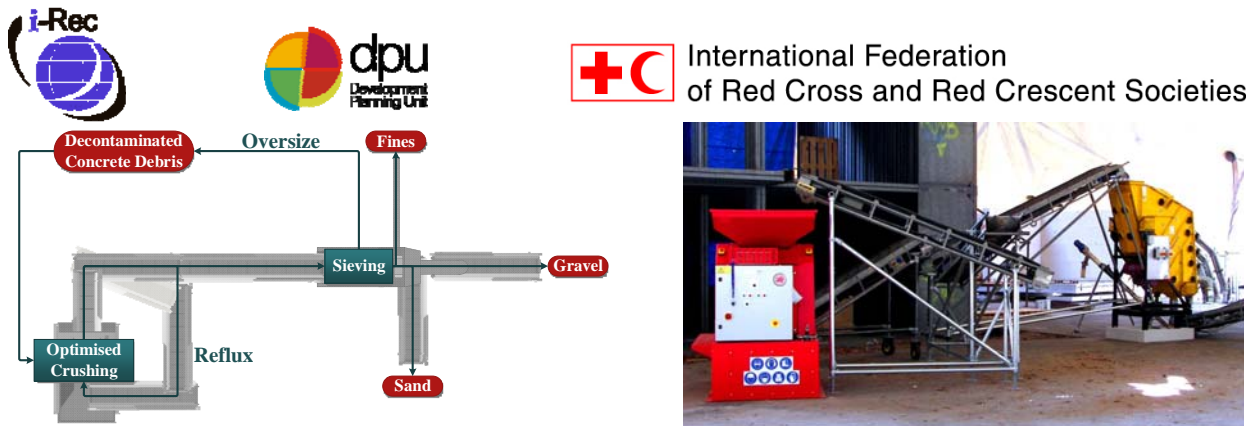


Fig.2: Floor plan of the pilot setup (Left), prototype pilot setup at Eindhoven University of Technology (Right)

Currently, the prototype is under initial testing and first results proved hopeful. The design will be optimised before further extensive testing will be carried out ensuring the prototype is ready for take up in field trials.

Tab. 1: Technical specifications prototype pilot setup

<i>Target price</i>	< €100,000.00	<i>Power</i>	400V, 32A / Diesel
<i>Transport</i>	20ft container	<i>Sieving</i>	up to 6 fractions
<i>Target weight</i>	< 30,480 kg	<i>Time to set up</i>	1-2 days
<i>Capacity</i>	up to 15 ton/hour	<i>Compatibility</i>	Independent / alongside concrete production facility

Conclusion

In conclusion, it is shown that the proposed method extracts clean aggregates from the debris, removing and splitting off the hardened cement paste fines, eliminating the initial concrete properties, producing reclaimed gravel and sand similar to virgin materials. With this method, the area is cleared of debris, on-site produced reclaimed aggregates can directly be incorporated in quality concrete for reconstruction, hence eliminating the need for raw materials and costly transport of debris and virgin aggregates from and towards the urban area.

Through optimised crushing the cement paste is separated from the aggregates enabling;

- robust mix designs,
- high quality concrete,
- diverse concrete applications.

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Authors' Biography



P.M.F. van de Wouw obtained a Master's degree in Building Technology at the TU/e and afterwards worked as a researcher in the field of concrete recycling and optimised crushing. Currently he is working as a PhD candidate developing eco-concretes using industrial by-products.



M.V.A. Florea holds an Engineering Diploma in chemical engineering with a specialization in silicate-based building materials and a PhD on using secondary materials in cement-based products. She is currently an assistant professor at the Eindhoven University of Technology and specializes in development of novel building materials and their environmental impact.



Dr. ir. Guy Buyle holds a Masters of Engineering degree and obtained his PhD in Physics on the subject of the simulation of the magnetron sputter deposition process. He started working at Centexbel in 2006 in the group of Textile Finishing and Surface Modification. His main topic was the plasma treatment of textiles. He has mainly been working on European projects FP6 and FP7, being strongly involved in their coordination and management and is now Manager EU Research of Centexbel.



H.J.H. Brouwers is professor Building Materials and head of the unit Building Physics & Services at Eindhoven University of Technology.