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Mini Review

Self-Compacting Concrete with Low Binder Content and Recycled Aggregates - Economical or Ecological Solution?

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Abstract

Despite the fact that the self-consolidating concrete is present on the market since the 1990s, it still faces a number of problems that limit its use in many countries. In Poland, in addition to economic barriers (the standard self-compacting concrete is much more expensive than standard concrete, which is most obtainable at low classes such as C16/20 and C20/25), there are also problems with a higher shrinkage resulting from the large amounts of grout There are also frequent problems with a high viscosity of the standard self-consolidating concrete, limiting the areas of its use.

Development of a concrete technology and, in particular, the new generation of stabilizers (VMA) produced an alternative to the traditional self-consolidating concretes, i.e. the self-consolidating concretes with a low binder content - less than 380 kg/m^3, or even down to 315 kg/m^3. The low binder content in the new generation of the self-consolidating concretes, comparable to the binder content of standard products, makes them more economically competitive. The low viscosity of these mixtures result in much easier application, and the contraction rate lower in comparison to the standard self-consolidating concrete, which make them ideal substitutes of standard concretes.

In the age of sustainable development, the requirements of the certification related to multi-criteria evaluation system such as LEED, BREEAM and DGNB, considerable importance to the issue of CO2 emission reduction. The production of self-compacting concrete with low binder content and recycled aggregates result in lower CO2 emissions than production of other self-consolidating concretes with high binder content. The use of recycled aggregates coupled with reducing the binder content make the self-compacting concrete more attractive in terms of their environmental impact. This solution allows for reduction in both the heat of hydration due to low cement content, and also for higher scores in multi-criteria evaluation building systems, due to the use of waste materials. This paper attempts to present the advantages and disadvantages of economical and ecological analyze of waste material usage such as recycled aggregates in SCC solutions.

Introduction

The increased use of multi-criteria evaluation systems results in investors and contractors searching for materials that provide the highest possible score at the lowest financial cost. Lack of special expenditures or a minimal increase in monetary investment joined with increased score may result in heightened attractiveness of the used solution. Therefore, utilization of concrete with recycled aggregate seems to be an extremely simple measure that results in higher scores.

When designing new objects into consideration are taken, apart the ecological aspects, other architectural solutions that will increase the visual appeal of the construction. Architects and designers, aiming to make the object more interesting, propose ever more complicated shapes and in many cases pay no mind to the construction challenges posed by the novel solutions. Taking into consideration all the aspects, i.e. the necessity of increasing the score in the multi-criteria evaluation systems, the need for minimal construction costs, and the drive to create highly complex structures, an obvious move would be utilization of self-compacting concrete with low content of binder produced using recycled aggregate [1-5].

Normative Solutions

Introduction of a new norm PN-EN 206:2014 makes production of SCC concrete with low content of binder with recycled aggregate, on one hand, easier and, on the other hand, limits the possibility of actually using the recycled aggregate. Inclusion of norm PN-EN 206-9 into the norm PN-EN 206 will result in self-compacting concrete being treated as a standard solution and may facilitate utilization of this material.

However, the introduced limits concerning use of aggregate from recycling, included in Attachment E, strongly limit the ability of using this type of aggregates. The sole fact that recommendations are made only for aggregates with grades above 4mm will result in significant increase of aggregate cost as all the grades below 4mm will be excluded and there will be a need to find a suitable use for this part of the material. What is more, limiting the quantity of aggregate used depending on the exposition class results in the recycled aggregate being less used [6-10] (Table 1).

Table 1: Quantity of aggregate used depending on the exposition class results in the recycled aggregate.

Recycled aggregate type	Exposure classes			
	X0	XC1, XC2	XC3, XC4, XF1, XA1, XD1	All other exposure classesa
Type A: (Rc_{90}, Rcu_{95}, Rb_{10}, Ra_1, FL_2, XRg_1)	50%	30%	30%	0%
Type B[b]: (Rc_{50}, Rcu_{70}, Rb_{30}, Ra_5, FL_2, XRg_2)	50%	20%	0%	0%

a Type A recycled aggregates from a known source may be used on exposure classes to which the original concrete was designed with a maximum percentage of replacement of 30%.
b Type B recycled aggregates should not be used in concrete with compressive strength classes > C30/37

Multi-Criteria Evaluation Systems and Recycled Aggregate

Taking into consideration the benefits of recycled aggregate in self-compacting concrete it should be stated that in case of the LEED system there is a possibility of getting an additional 1 point in case of using a minimum of 10% and 2 points when using a minimum of 20% of recycled aggregate. According to the Green Buildings Design & Construction Reference Guide, if a given material is to receive additional points in the LEED certification it is unacceptable to manufacture it using refuse from one production process. Post-production waste cannot be taken into consideration. This means that when calculating the content of recycled materials the only material that can be used is the recycled aggregate, i.e. aggregate created in processing of non-organic material that was previously used in construction. It is unallowable to include aggregate acquired via flushing (aggregate acquired via flushing them from a concrete mix) and aggregates acquired by processing (aggregates created by crushing hardened concrete which was not used in construction) [11-14].

The BREEAM system approaches the utilization of recycled aggregate in the following manner:

a) The total amount of recycled and/or secondary aggregate specified is greater than 25% (by weight or volume) of the total high-grade aggregate specified for the development.
b) To contribute to the total amount, the percentage of high-grade aggregate specified per application (where present) that is recycled and/or secondary aggregate, must meet the following minimum levels (by weight or volume) (Table 2):

Table 2: BREEAM system's guidelines.

Application	Min. % One Credit	Min. % Exemplary Performance
Structural frame	25%	50%
Floor slabs including ground floor slabs	25%	50%
Bitumen or hydraulically bound base, binder, and surface courses for paved areas and roads	50%	75%
Concrete road surfaces	25%	50%
Pipe bedding	50%	100%
Building foundations	25%	50%
Granular fill and capping (see Compliance notes)	75%	100%
Gravel landscaping	100%	100%

The aggregates are EITHER: obtained on site OR, obtained from waste processing site(s) within a 30km radius of the site; the source will be principally from construction, demolition and excavation waste (CD&E) – this includes road planning OR, secondary aggregates obtained from a non-construction post-consumer or post-industrial by-product source.

As we can see, such systems introduce the requirement of utilization of the largest possible amount of recycled aggregate and the PN-EN 206 norm enforces the maximal amount and, in certain cases, makes it virtually impossible to meet the requirements of the multi-criteria systems.

Recycled Aggregate available in Poland

The need to assess recycled aggregate, and the associated need for additional expenses, resulted in producers providing mostly the final aggregate for road bases. The prevalent grades produced in Poland are 0/16, 0/31.5, 0/64. At special request other grades can be produced, e.g. 4/16. The necessity of using the 4/16 grade instead of the generally available grade 0/16 results in significantly higher cost of the specially-produced aggregate. In many cases the cost of recycled aggregate 4/16 is higher than standard grit of the same grade. This results in a situation where a mixture with recycled aggregate is more expensive than the mix without this aggregate and when coupled with the current economic situation in Poland translates into non-use of the recycled aggregate (Figure 1).

Figure 1: Recycled aggregate - grade 0/16.

and without Recycled Aggregate

Testing results for concrete mix

Table 3: Comparison of parameters of Green-SCC with and without the recycled aggregate, grades 0/16 and 4/16 and standard SCC for class C30/37.

		C30/37 Green-SCC	C30/37 SCC	C30/37 Green-SCC + 0/16 rec.	C30/37 Green-SCC + 4/16 rec.
cement	kg/m³	280	340	285	285
fly ash	kg/m³	100	190	100	100
sand 0/2	kg/m³	700	652	615	700
grit 2/16	kg/m³	1066	985	939	848
recycled aggregate 0/16	kg/m³			212	
recycled aggregate 4/16	kg/m³				212
stabilizer	% t.w.	0.27		0.27	0.27
superplasticizer 1	% t.w.	2.28		3.4	2.7
plasticizer	% t.w.		0.8		
superplasticizer 2	% t.w.		2.32		
water	kg/m³	170	160	170	170
density m.	kg/m³	2260	2260	2215	2245
SF	cmxcm	71x71	70x70	66x66	69x69

Concrete testing results

Table 4: Comparison of parameters of SCC low content of binder (LB SCC) with and without the recycled aggregate, grades 0/16 and 4/16 and standard SCC for class C30/37.

	C30/37 LB-SCC	C30/37 SCC	C30/37 LB-SCC + 0-16 rec.	C30/37 LB-SCC + 4-16 rec.
Compression strength after 28 days [MPa]	44.7	46.8	41.2	42.7

Worst results were obtained with the recycled aggregate 0/16. This is due to high content of ash fractions in this aggregate.

CO_2 Total Emission Factor

Table 5: Calculation of total emission factor for CO_2.

	C30/37 LB-SCC	C30/37 SCC	C30/37 LB-SCC + 0-16 rec.	C30/37 LB-SCC + 4-16 rec.
Production of materials (cement, aggregate, other components)	263.5	319.3	263.51	263.5
Transport of materials (cement, aggregate, other components)	28.31	33.89	29.82	28.31
Production of concrete (electric energy, heating oil, fuel)	3.89	3.89	3.89	3.89
total:	295.7	357.07	297.22	295.7

Due to low content of recycled aggregate in the low binder SCC the impact of the aggregate itself on the CO_2 total emission factor is limited (Tables 3-5).

Conclusion

a) Taking into consideration the new legal requirements related to introduction of norm PN-EN 206, the use of SCC concrete with recycled aggregate should become much easier and much more common.

b) In case of a requirement of performing a multi-criteria evaluation - utilization of SCC concrete with recycled aggregate will allow for additional points however this will not always be the case due to requirements introduced in PN-EN 206.

c) Lack of standardized production of recycled aggregate 4/16 in Poland, and the resultant increase in material costs make this aggregate more expensive than standard aggregate resulting in limited usability of the recycled aggregate.

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