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Use of Recycled Aggregates in Current Concretes

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***Abstract*—**The paper a summary of the results of concretes with partial substitution of natural aggregates with recycled concrete is solved. Design formulas of the concretes were characterised with 20, 40 and 60% substitution of natural 8-16mm fraction aggregates with a selected recycled concrete of analogous coarse fractions. With the product samples an evaluation of coarse fraction aggregates influence on fresh concrete consistency and concrete strength in time was carried out. The results of concretes with aggregates substitution will be compared to reference formula containing only the fractions of natural aggregates.

***Keywords*—**Recycled concrete, natural aggregates, fresh concrete, properties of concrete.

I. Introduction

RECYCLING of materials is very important for the sustainable development, environment and preservation of raw materials for next generations. A line of standard secondary raw materials like power station fly ash, blast furnace slag etc. included in concretes already exists. However, these materials originate from other industrial sectors than the production of cement and concrete. Recently we have been facing questions related directly to waste from building production, namely from concrete production. Application of recycled concrete as aggregates for new concrete is essentially important because it protects natural resources and eliminates the need of waste yards. The quality of such concretes depends on the quality of used materials for recycling. Origin of such materials is the most important, it depends if it is a concrete construction or element or materials from demolition of entire building where also wastes in the form of bricks and other materials are included. The crushed material may not contain wood, paper, plastics and asphalt. It can be subsequently utilized for road base layers. In the Table I there are recycled concrete types shown together with its percentage representations [1], [2], [6]. The recycled waste can also be used as a full substitution of natural aggregates provided sufficient characteristics are obtained. These materials are then utilised in selected applications, namely with ground constructions [7]

Table II shows a comparison of various European countries and their approach to utilisation of materials from demolition for recycling or, on the other hand, not-utilisation of materials ending in waste yards [1].

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TABLE I
RECOMMENDATION OF RECYCLED MATERIAL DEPENDING ON THE CHARACTERISTIC STRENGTH [2]

Recycled material origin	$f_{cu/ck}$	Percentage of recycled aggregates
Demolitions of buildings	< 15 MPa	up to 100 %
Demolition of concrete objects	≤ 25 MPa	up to 60 %
	≤ 35 MPa	to 30 %
Crushed prefabricated elements	≤ 55 MPa	to 5 %

TABLE II
RECYCLING FROM CONSTRUCTIONS AND DEMOLITIONS IN EUROPEAN COUNTRIES

Country	Recycling from constructions and demolitions (10^6 t)	Recycled material (%)	Material to waste dumps (%)
Germany	59	17	83
Great Britain	30	45	55
France	24	15	85
Italy	20	9	91
Spain	13	< 5	> 95
Netherlands	11	90	10
Belgium	7	87	13
Austria	5	41	59
Portugal	3	< 5	> 95
Denmark	3	81	19
Greece	2	< 5	> 95
Sweden	2	21	79
Finland	1	45	55
Ireland	1	< 5	> 95
Total in Europe	181	28	72

A. Recycling Process

The recycling process consists of four stages:

1) Selection of waste
2) Crushing of concrete blocks
3) Removal of contaminated components
4) Mixing with natural aggregates

Materials intended in this way for concrete production must be pre-crushed and re-sorted before mixing with natural aggregates. Mills for recycled concrete do not differ very much from crushers for natural aggregates. Recycling line and its placement then offer two possibilities:

a) A recycling equipment which is mobile and can be located in the place of demolition where the recycled concrete will be re-used for the production of new concrete
b) A central recycling line which is not so close to the application of recycled aggregates as the previous one, but thanks to automation it obtains higher productivity (even 100 t/hour), which compensates the transport distance [1].

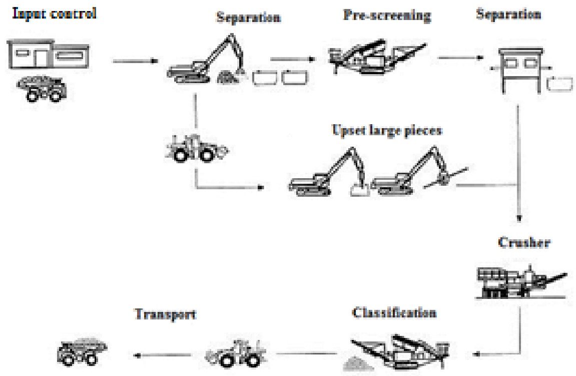

Fig. 1 Basic steps of the recycling process [9]

B. Influence of Properties of Fresh and Hardened Concrete

The recycled concrete aggregates have an essential influence on fresh concrete workability and segregation eventually at fresh concretes. If recycled aggregates are too porous then it is necessary to take measures to eliminate this undesirable workability aspect. Aggregates should be added in mixture already soaked in water or its surface should be processed in a different way in order to prevent the reduction of workability and water-cement ratio fluctuation [1], [3].

Due to presence of cement paste adhering to recycled grains, the recycled aggregates have significantly coarser texture compared to natural aggregates.

Fig. 2 Natural aggregates [4]

Fig. 3 Recycled aggregates [4]

Due to this texture causing bigger surfaces for aggregates wetting the mixture water batch must be increased by approximately 5%. To keep its workability, the recycled aggregates can be treated using a microfiller, for instance fly ash [3].

At using recycled concrete for self-compacting concretes it is necessary to bear in mind segregation tendencies of these aggregates [1]. The research involved in these questions came to recommended maximum segregation coefficient value 15% [4].

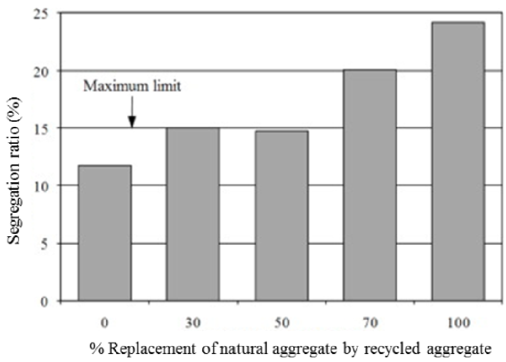

Fig. 4 Dependence of recycled aggregates from concrete to segregation [4]

In view of hardened concrete the lower compressive strength when used recycled aggregates is clear compared to concretes made from natural aggregates only due to higher porosity and lower density of recycled concrete aggregates [2].

TABLE III
COMPARISON OF DENSITY OF NATURAL AND RECYCLED AGGREGATES

Type of aggregate	Density (kg/m^3)
Recycled fine	2300-2500
Recycled coarse	2150-2350
Natural	2600-2700

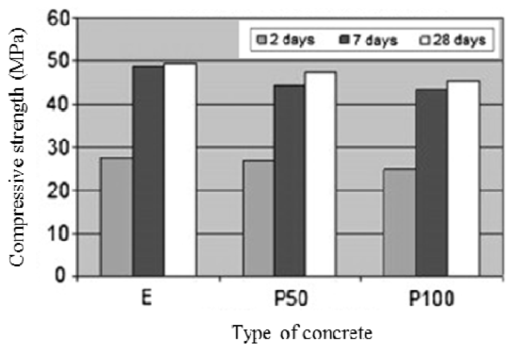

Fig. 5 Dependence of compressive strength on the replacement of natural aggregates recycled aggregates [8]

Modulus of elasticity is lower compared to natural aggregates due to smaller stiffness of natural aggregates. For the same reason also the shrinkage by drying and concrete creeping are significantly higher which makes the difference in application of coarse recycled aggregates between 25 to 50% compared to natural aggregates [1].

Also the lower density of the mixture supports decrease of modulus of elasticity when at 100% substitution of natural aggregates with recycled concrete the elasticity modulus decrease can be expected by 8% [5].

II. Composition Designs and Results of Particular Concretes

A reference formula with natural aggregates (REF) and three versions of concrete formulas with recycled concrete aggregates in 20, 40 and 60 % substitution (REC 20, REC 40 and REC 60) were prepared.

TABLE IV
Composition of Particular Concrete Formulas

Input materials	REF	REC 20	REC 40	REC 60
Cement CEM I 42,5 R	315	315	315	315
Natural aggregate 0-4 mm	820	820	820	820
Natural aggregate 8-16 mm	1044	835	626	418
Recycled concrete aggregate 8-16 mm	-	209	418	626
Superplasticiser	2.8	2.8	2.8	2.8
Water	180	180	180	180

From the fresh concrete monitored parameters the workability using the slump method immediately after mixing and 30 minutes after mixing was evaluated. Further the density and compressive strength were monitored with hardened concrete after 28 and 60 days of concrete maturing.

Workability of fresh concrete by slump test was with all the samples within the slump class S3 and S4 in case of REC 60. After 30 minutes from concrete production, one grade lower consistency was found with all concretes, i.e. S2. Density was always the highest with the REF formula. With the growing amount of coarse fraction recycled concrete substitution the fresh concrete density decreased from reference value 2480 kg/m^3 to 2270 kg/m^3 at 60% substitution of natural aggregates.

TABLE V
Properties of Fresh Concretes

Marking	Water-cement ratio	Slump flow		Fresh concrete density (kg/m^3)
		0 min.	30 min.	
REF	0.57	150	80	2480
REC 20	0.57	150	90	2410
REC 40	0.57	150	80	2340
REC 60	0.57	160	80	2270

TABLE VI
Properties of Hardened Concretes

Marking	Density (kg/m^3)		Compressive strength (MPa)	
	28 days	60 days	28 days	60 days
REF	2460	2450	52.6	56.6
REC 20	2430	2420	47.8	51.8
REC 40	2330	2320	40.5	44.7
REC 60	2280	2280	36.6	39.8

In Table VI there are basic values of set properties of 28 and 60-day old hardened concrete. At first sight the decrease of compressive strengths of concretes with recycled concrete is evident compared to the reference formula. On the other hand, with all concretes the development in time of compressive strengths was monitored when with reference concrete the increase was by approximately 4 MPa, with concretes with 20, 40 and 60% substitution 3, 5 and 3 MPa respectively.

III. Conclusion

Comparing particular results the decrease of compressive strengths was generally confirmed with concretes where 8-16 mm coarse fractions were substituted with the recycled concrete. Compressive strength decreased with the growing substitution of natural aggregates at all types of concrete formulas. Between 28 and 60 days, a growth of strength was recorded with all the concretes. The compressive strength growth values were comparable for both, the concrete with natural aggregates and concrete with recycled concrete aggregates, at level 3 - 5 MPa. The reference formula obtained after 28 days compressive strength about 53 MPa while the formula with 20% recycled concrete substitution obtained 47.8 MPa. With 40% substitution the formula obtained after 28 days compressive strength at 40 MPa level and 36 MPa at concrete with 60% substitution.

The application of recycled concrete reduces costs for its disposal and primarily saves natural resources of aggregates. Practically the recycled concrete can be used anywhere if given mixture meets particular requirements by which it is set. At present the recycled concrete is mostly used for concretes with lower strength requirements, namely at base bodies, as a base under railway sleepers or for subconcrete mixtures. Recycled concrete has a high potential as ground concrete for roads.

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