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Strength of masonry blocks made with recycled concrete aggregates

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Abstract

The idea of recycling concrete of demolished buildings aims at preserving the environment. Indeed, the reuse of concrete as aggregate in new concrete mixes helped to reduce the expenses related to construction and demolition (C&D) waste management and, especially, to protect the environment by reducing the development rate of new quarries. This paper presents the results of an experimental study conducted on masonry blocks containing aggregates resulting from concrete recycling. The purpose of this study is to investigate the effect of recycled aggregates on compressive strength of concrete blocks.

Tests were performed on series of concrete blocks: five series each made of different proportions of recycled aggregates, and one series of reference blocks exclusively composed of natural aggregates.

Tests showed that using recycled aggregates with addition of cement allows the production of concrete blocks with compressive strengths comparable to those obtained on concrete blocks made exclusively of natural aggregates.

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Keywords: concrete blocks; recycled aggregates; strength

1. Introduction

The alarming increase of construction and demolition waste and the extensive extraction of natural resources required for the production of building materials have aroused opposition of ecologists. However, large parts of this waste can be partially recycled. One of the main construction wastes which can be recycled is demolished concrete. The idea of recycling concrete aimed at preserving the environment. Indeed, the reuse of concrete as aggregate in new concrete compositions helped to reduce expenses related to construction and demolition waste management and, most importantly, to protect the natural resources.

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The knowledge about using recycled aggregates in concrete is more or less wide [1-3]. However, the use of such aggregates in the manufacture of concrete blocks is quite limited [4, 5]. The particularity of the use of the recycled concrete in the manufacture of blocks, in comparison with other uses, consists of the following facts:

- the blocks are manufactured using the vibro-compaction and are demolded after a few seconds only; this requires consequently both ease of striking the molds, as well as a good binding of fresh concrete;
- the cement content is very low, i.e. about 100 to 150 kg/m³.

2. Objectives

The objective of this study was to determine the influence of recycled concrete aggregates used in new mixes of concrete blocks on the compressive strength of these blocks.

Tests have been carried out to determine the advantage of using recycled aggregates in the production of concrete blocks and their influence on the strength. Mixtures contained recycled aggregates with 6/12 mm fraction and natural sand with 0/6 mm fraction without any recycled fine aggregate.

3. Current state of knowledge

The study done by P. Pimienta at CSTB (France) aimed to determine the properties of concrete building blocks manufactured using recycled aggregates [4].

Preliminary laboratory tests have been achieved in order to determine the properties of materials, and this has led to the determination of the compositions of concrete with recycled aggregates required for the manufacture of concrete blocks. Productions have been performed in a manufacturing plant to define the optimal compositions for concrete blocks and the characteristics of these blocks.

The cement used in this study was a cement of type CPA HP. The used aggregates were a combination of natural silico-calcareous aggregates from the Seine River and recycled aggregates. The natural aggregates, as well as the recycled concrete, were broken into 0/6 mm and 6/12 mm graded aggregates. The characteristics of used recycled aggregates are given in table 1.

Table 1: Characteristics of recycled aggregates [4]

Aggregates dimensions (mm)	0/6	6/12
Density (kg/m ³)	2137	2280
Water absorption coefficient (%)	6	5
Saturated density (kg/m ³)	2267	2396
Water content (%)	6.05	4.97

Preliminary studies on the material were made to establish the optimum composition of concrete with recycled aggregates needed to manufacture blocks. The tests were carried out on 7x7x28 cm prisms prepared by vibro-compression. The samples were demolded after a few seconds only. Then, they were stored at a temperature 20°C ± 1°C and a relative humidity 95% ± 5%.

The mixes are characterized by the type of aggregates (natural: N, recycled: R), and they are defined as follows:

- G1 (NN): 0/12 mm natural aggregates (reference blocks);
- G2 (NR): 0/6 mm natural aggregates and 6/12 mm recycled aggregates;
- G3 (RR): 0/12 mm recycled aggregates.

The demolding ability and the performances of recycled aggregates concretes are essential criteria for manufacturing building blocks. The water content of concrete has been adjusted based on these two criteria. The composition of concrete mixes and the main test results are stated in table 2.

Table 2: Used mixes used and materials test results; values are given for 1000 kilograms of concrete [4]

Component	G1 (NN)	G2 (NR)	G2/A (NR)	G2/B (NR)	G3/B (NR)
Gaurain CPA HP Cement (kg/m ³)	65.6	67	72	79	70.8
Natural aggregates 0/12 mm (kg)	866	-	-	-	-
Natural aggregates 0/6 mm (kg)	-	602.4	594	586	-
Recycled aggregates 0/6 mm (kg)	-	-	-	-	566.8
Recycled aggregates 6/12 mm (kg)	-	258.1	260	260	251.9
Water (l)	68.4	72.5	74	74.5	110.5
Density (kg/m ³)	1853	1761	1847	1889	1675
Compressive strength at 7 days (MPa)	7.9	5.1	7.65	9.62	2.3
Compressive strength at 28 days (MPa)	11.6	7.9	7.8	10.2	6.4
Shrinkage after 28 days (mm/m)	-305	-309	-	-	-734
Bulking after 7 days (mm/m)	30	30	-	-	87

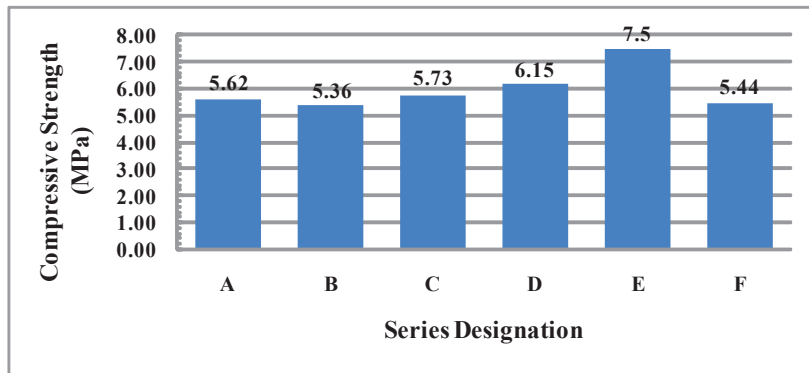
The analysis has been concentrated on the compression test results at 7 days and on the shrinkage and bulking values. The comparison of results between G1, G2 and G3 mixes showed that the use of recycled aggregates substantially reduces the short-term strength of concrete. It was also clear that the results obtained with recycled aggregates concretes are not as good as those obtained for reference concrete. These findings are in accordance with those reached by other researchers, namely, that the use of recycled aggregates leads to a decrease in the strength of concrete up to 35%.

Concrete hollow blocks 20x20x50 cm were manufactured (Table 3). Five concrete mixes (A to E) containing recycled aggregates were defined based on G2, G2/A and G2/B mixes. A reference mix (F) was prepared using only 0/12 mm natural aggregates. This mix meets the criteria of the French Standard and is classified B40 (compressive strength greater than 4 MPa). Except the color, the blocks A, B, C, D and E showed no significant difference with the blocks F; the blocks containing recycled aggregates were grey and the blocks containing natural aggregates were brown.

Table 3: Mixes used in the manufacture of hollow blocks; values are given for 1000 kg of concrete [4]

Component	A	B	C	D	E	F
Gaurain CPA HP Cement (kg/m ³)	69	71	73	75	77	62
Natural aggregates 0/6 mm (kg)	597	595	593.5	592	590.5	-
Recycled aggregates 6/12 mm (kg)	261	260	259.5	259	258	-
Natural aggregates 0/12 mm (kg)	-	-	-	-	-	873
Water (l)	73	74	74	74	74.5	65

Each of the six series of manufactured blocks was weighed and its compressive strength determined. The compression tests were performed at 21 days according to the methods described in the French Standard NF P 14-301. The load is applied with a constant speed within the range 0.5 MPa/s \pm 0.2 MPa/s. The mean compressive strength for each series of blocks is given in Figure 1. The concrete blocks containing recycled aggregates have a lower strength than the blocks with natural aggregates. The weaker density of recycled aggregates is the essential reason for this difference. The increase on the compressive strength with the increase of cement content is confirmed for D and E series. On the other hand, the compressive strength is almost constant for A to C series having the lowest cement content.

**Figure 1: Average compressive strength determined on each Series of blocks [4]**

4. Laboratory tests

4.1. Manufacture of blocks

The present study was carried out within the Civil Engineering Laboratory at the Faculty of Engineering of the Lebanese University. The composition of concrete needed for the manufacture of blocks with natural aggregates was determined based on local industry experience and is illustrated in table 4. Five series of five concrete blocks each were fabricated by using different rates of recycled aggregates, as well as a series of reference blocks without recycled aggregates (Figure 2). They were tested to determine the optimal composition of concrete and their compressive strength.

Table 4: Mixture used in the manufacture of blocks with natural aggregates

Component	Weight (kg) per block
Cement	1
Aggregates 0/6 mm	10
Aggregates 6/12 mm	5
Water	1



Figure 2: Manufacture of blocks

The five mixes containing recycled aggregates and the reference mix containing only natural aggregates have been prepared and marked as follows: A, B, C, D, E and F. The tables 5a and 5b show the composition of each mix.

Table 5a: Mixes used in the manufacture of blocks; values are given for the manufacture of 5 blocks (kg and l)

Component	A	B	C	D	E	F
CPA Cement (kg)	5.5	5	5.5	5.5	5.5	5
Natural aggregates 0/6 mm (kg)	50	50	50	50	50	50
Recycled aggregates 6/12 mm (kg)	7.5	7.5	12.5	17.5	25	0
Natural aggregates 6/12 mm (kg)	17.5	17.5	12.5	7.5	0	25
Water (l)	5.5	5	5.5	5.5	5.5	5

Table 5b: Mixes used in the manufacture of blocks (%)

Component	A	B	C	D	E	F
CPA Cement addition (%) ⁽¹⁾	10	0	10	10	10	0
Natural aggregates 0/6 mm (%) ⁽²⁾	100	100	100	100	100	100
Recycled aggregates 6/12 mm (%) ⁽³⁾	30	30	50	70	100	0
Natural aggregates 6/12 mm (%) ⁽³⁾	70	70	50	30	0	100

⁽¹⁾: percentage of cement addition compared with the normal quantity (used in reference blocks)

⁽²⁾: percentage compared with the total quantity of aggregates 0/6 mm

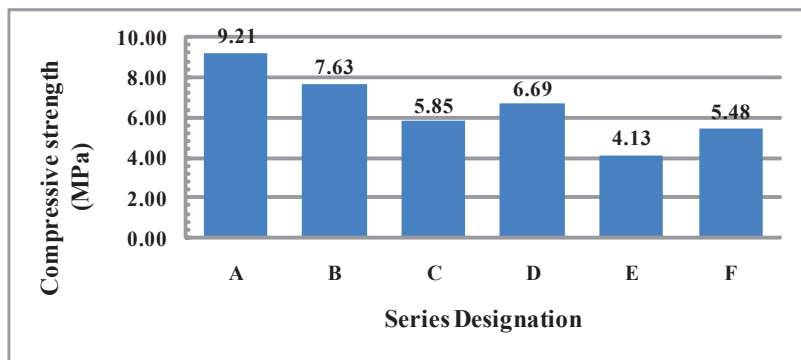
⁽³⁾: percentage compared with the total quantity of aggregates 6/12 mm

4.2. Test description

Three blocks from each of the six series were weighed and their compressive strength determined. Compression tests were performed at 28 days. The load was applied with a constant speed of 3 kN/s. The mean values of compressive strength, as well as the density of blocks of each series, are given in table 6. The mean values of the compressive strength of blocks of each series are also illustrated in figure 3. The analysis of the results is done based on a comparison of the characteristics of blocks containing different rates of recycled aggregates, as well as on a comparison of the characteristics of these blocks with the those of blocks not containing any recycled aggregates (reference blocks).

Table 6: Mean values of density and compressive strength of blocks

Characteristics	A	B	C	D	E	F
Density (kg/m ³)	2201	2177	2184	2109	2060	2170
Compressive strength (MPa)	9.21	7.63	5.85	6.69	4.13	5.48

**Figure 3: Average compressive strength determined for each series of blocks**

4.3. Interpretation of test results

The test results have shown that all blocks have a density between 1974 kg/m³ and 2236 kg/m³.

The blocks containing 30% recycled aggregates, i.e. those of series A (with 10% addition of cement compared with the normal quantity) and series B (without cement addition), have the highest compressive strength (9.21 MPa and 7.63 MPa respectively). The 10% cement addition in series A has increased the compressive strength by 20% as compared to those of series B.

The blocks containing 50% recycled aggregates (series C) have a lower compressive strength than those containing 30% recycled aggregates (series A and B), which is logical.

The compressive strength of the blocks with 30%, 50% and 70% recycled aggregates (series A, B, C and D) is greater than the one of reference blocks (series F), which represented some incompatibility in the test results of reference blocks.

The blocks containing only recycled aggregates (series E) have the lowest density and the lowest compressive strength, which is reasonable.

We can notice that the compressive strength of series C blocks (50% R + 50% N + 10% cement addition) and the series D (70% R + 30% N + 10% cement addition) is the more comparable with the compressive strength of the series F (100% N).

5. Conclusions, recommendations and perspectives

The tests showed that the use of recycled aggregates with a 10% cement addition compared with normally used cement quantity could allow the production of concrete blocks having characteristics similar to those of concrete blocks with natural aggregates.

According to the results of this study, we can clearly conclude that using recycled aggregates without natural aggregates in the manufacture of concrete blocks is not economical due to the necessity of a high rate of cement addition in order to obtain the required compressive strength.

In case of using recycled aggregates in the manufacture of concrete blocks, we recommend that the quantity of these aggregates should not exceed 50% of the total quantity of aggregates.

Finally, it might be useful to extend this experiment to cover other features of blocks such as porosity, insulation and fire resistance, as well as the study of the effect of plasticizers.

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