On the road to get structural recycled concrete

Auf dem Weg zur Gewinnung von wiederaufbereiteten Beton

R. El Dalati[1], P. Matar[2]

This paper presents new recommendations for recycling and reuse of concrete. It shows the influencing parameters for decreasing and increasing the concrete strength under compression. These parameters are the percentage of recycled aggregates used in new compositions of concrete, the age and the state of the original concrete, the addition of cement and plasticizer, and the nature of the original aggregates. Fixing some parameters and with some additions, we could increase the recycled concrete strength and even obtain the original value of concrete strength. The paper shows a new way to get structural recycled concrete.

Keywords: recycled concrete / recycled aggregates / strength / workability / W/C ratio

Schlüsselwörter: wiederaufbereiteter Beton / wiederaufbereitete Zuschlagstoffe / Festigkeit / Verarbeitbarkeit / W/C Verhältnis

1 Introduction

In order to preserve the environment, some countries have established national laws forcing the recycling of all construction materials waste [1]. Even concrete has been recycled, and its reuse has permitted to decrease the construction cost and to preserve the forests and the stored water in mountains [2].

The majority of the resulting concrete demolition waste has been used as unbound road foundation. Meanwhile, some researchers have shown the possibility of reusing the recycled aggregates in new structural works [3]. So, after establishing national guidelines for recycled concrete production, some countries have forbidden the reuse of concrete in structural elements, and some others have permitted it but with particular specifications [4].

In Lebanon and after the war of July 2006, the majority of the constructions of the south suburb of Beirut have been found damaged. Some of them were completely or partially burned due to their exposure to fatal bombs. In front of the huge amount of the demolished constructions, we should find green issues for the construction wastes. Also, we proposed to reuse them according to the national context.

The major difficulty of this research was the utilization of recycled aggregates of chalky origin. In fact, the majority of mountains of the Middle East region are calcareous, and the provided aggregates absorb much more water than siliceous or other types of gravels. Only this restriction has been shown responsible of getting lower values of strength for ordinary and recycled concrete [5].

The present research work consists of an experimental study assessing the impact of using recycled aggregates on the concrete behavior. We are especially interested in determining the best compositions for new mixtures of concrete resulting from reusing different types of recycled aggregates and with some additives. The ultimate goal is to provide safe structural concrete based on the use of recycled calcareous aggregates.

Different tests have been done depending on the aggregates sizes, their origin and the state of the original concrete (burned or safe), and also on the utilization of plasticizer and the addition of cement. The analysis is based on the comparison between compressive strengths, water/cement ratios, slumps or workability. The resulted recommendations indicate a special composition for obtaining acceptable values of concrete compressive strength.

2 Definitions

The Recycled Aggregates (RA) are obtained when screening the demolished concretes. The new mix of concrete containing a percentage of recycled aggregates is called Recycled Concrete (RC).

3 Experimental program

The aim of the tests was to establish the compression strength of different concrete mixtures.

Different types of original concrete have been treated. Some of them were completely or partially burned, and others were safe. Also, comparisons between old and new recycled concretes and between calcareous, silica-calcareous and even siliceous recycled aggregates have been undertaken. The influence of the used percentage of recycled aggregates and their dimensions was also a target.

[1] Lebanese University, Faculty of Engineering 1, Tripoli, Al Kobba, Lebanon
[2] Lebanese University, Faculty of Engineering 2, Roumieh, Main Road, Lebanon

Corrresponding author: P. Matar, Lebanese University, Faculty of Engineering 2, Roumieh, Main Road, Lebanon
E-mail: pmatar@ul.edu.lb

Table 1. Compressive strength of concretes with recycled aggregates obtained from newly manufactured concrete

Tabelle 1. Druckfestigkeit von neu hergestelltem Beton mit wiederaufbereiteten Zuschlagstoffen

Mix code	Recycled aggregate percentage [%]	W/C	Additions	Strength [MPa]
NC		0.55		24
RCN-A20	20	0.66		16.75
RCN-B20	20	0.66		16.83
RCN-A30	30	0.73		13.9
RCN-AB20-1%P	20		1% plasticizer	20

All new concrete mixtures, before any addition, have been made according to the composition of G. Dreux and J. Festa for 1 m^3 of concrete [6], which corresponds to 350 kg of cement, 0.8 m^3 of gravels, 0.4 m^3 of normal sand and 200 kg of water (in order to assure a water/cement ratio ranged between 0.58 and 0.6). For each mixture the apparent volume weights for gravels and sand were obtained in order to calculate the corresponding weights. All corrections were done to get an acceptable value for the volume weight of concrete (2400 kg/m^3).

The results presented in this paper correspond to the mean value of 4 or 6 specimens conforming to standards i. e. cylinders of 15 cm diameter and 30 cm height. The concrete was placed in layers in the cylindrical molds and consolidated using a standard vibrator, the top and bottom surfaces were finished smooth and leveled to allow thin caps. All specimens have been immersed in water maintained at a temperature of 20 ± 2 °C for 24 hours. The air humidity was between 60 and 75%. The compression tests have been carried out at least after 28 days from the date of manufacturing using a compression testing machine with a maximum capacity of 1500 kN. This machine is fitted with a special pressure-compensated flow control valve which automatically allows a precise rate of loading over the complete test. The test speed was fixed according to the cylinders sizes and it was equal to $176\ cm^2 \times 50\ N/cm^2 \cdot s = 8800\ N/s$.

The test was considered complete when the specimen was broken to complete failure. The failure shape for all the specimens was the same and as for normal concretes i. e. the diabolo shape. The recorded parameter given by the testing machine dial pointer was the concrete compression strength.

The standard deviation values for all tests were ranged between 0.25 MPa and 1.25 MPa.

4 Influencing parameters

All the previous researches have shown that the compressive strength, the durability and the workability of concrete decrease when using recycled aggregates [7]. In opposite, the porosity increases. In fact, the tests have shown that recycled aggregates absorb a higher amount of water than natural aggregates. The water demand is not only affected by the porosity of the recycled aggregates, but also by the particle shape, i. e. the angularity. Therefore, when the water/cement ratio increases, the characteristics of the concrete will be badly affected.

5 Test results

5.1 Effect of the original concrete age and state and the aggregates dimensions and percentages

Table 1 shows the compressive strength of concretes with recycled aggregates (RA) obtained from new manufactured concrete. The original value of the concrete compressive strength was 24 MPa. After making the new compositions of recycled concretes, the compressive strength decreased by:

- 30.2% for 20% RA content with dimensions between 8 and 16 mm;
- 29.9% for 20% RA content with dimensions between 4 and 8 mm;
- 42.1% for 30% RA content with dimensions between 8 and 16 mm.

Also we can see that for both 20% RA content which dimensions are between 8 and 16 mm, and between 4 and 8 mm, the decrease in compressive strength is more acceptable than for 30% RA content. The mean decrease for 20% RA content is 30%.

Table 2 shows the compressive strength of concretes when using recycled aggregates obtained from old concrete. We can note the following decrease in concrete compressive strength for:

a) Old concrete not exposed to fire:

- 36% for 10% RA content with dimensions between 8 and 16 mm;
- 20% for 10% RA content with dimensions between 4 and 8 mm;
- Approximately 34.3% for 20% RA content of both categories A (RCO-A20) and B (RCO-B20);
- 39% for 30% RA content of both categories A (RCO-A30) and B (RCO-B30).

We can note the difference between the strength decrease corresponding to 10% RA content which dimensions are between 8 and 16 mm (RCO-A10) and between 4 and 8 mm (RCO-B10).

b) Old concrete exposed to fire:

- 36.2% for 10% RA content of both categories A (RCF-A10) and B (RCF-B10);
- 36.8% for 20% RA content of both categories A (RCF-A20) and B (RCF-B20);
- 43.7% for 30% RA content of both categories A (RCF-A30) and B (RCF-B30).

We remark here that the difference between the strength decrease corresponding to 10% RA content of category A (8 and

Table 2. Compressive strength of concretes with recycled aggregates obtained from old concrete

Tabelle 2. Druckfestigkeit von Beton mit wiederaufbereiteten Zuschlagstoffen erhalten von altem Beton

Mix code	Recycled aggregate percentage [%]	W/C	Additions	Strength [MPa]
OC				25
RCO-A10	10	0.72		16
RCO-B10	10	0.72		20
RCO-A20	20	0.75		16.33
RCO-B20	20	0.75		16.53
RCO-A30	30	0.92		15.25
RCO-B30	30	0.78		15.23
RCO-B10-C10	10	0.68	10% cement	22.43
RCF-A10	10	0.72		16.25
RCF-B10	10	0.75		15.66
RCF-A20	20	0.79		16.25
RCF-B20	20	0.79		15.33
RCF-A30	30	0.79		13.83
RCF-B30	30	0.78		14.33
RCF-B10-C10	10	0.68	10% cement	20.67
RCAB20-2.5%P	20		2.5% plasticizer	20.6
RCAB20-2.9%P	20		2.9% plasticizer	22
RCAB20-5%P	20		5% plasticizer	1.5

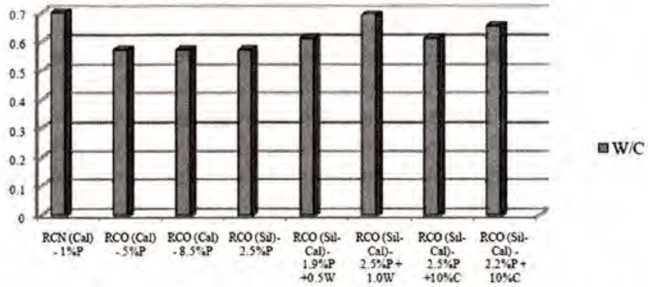

Figure 1. Influence of the original aggregates nature and the plasticizer content on the water/cement ratio

Bild 1. Einfluss der ursprünglichen Art der Zuschlagstoffe und des Anteils des Plastiziermittels auf den Wasser-Zement-Anteil

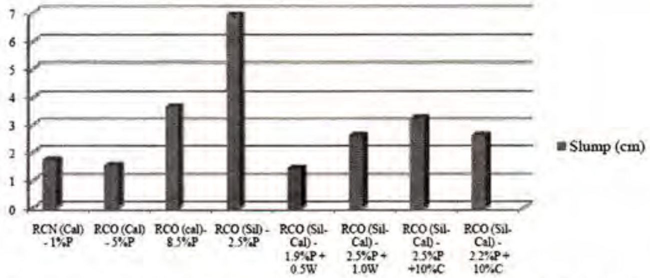

Figure 2. Influence of the original aggregates nature and the plasticizer, cement and water contents on the workability of concrete

Bild 2. Einfluss der ursprünglichen Art der Zuschlagstoffe, des Anteils des Plastiziermittels und des Wasser-Zement-Anteils auf die Verarbeitbarkeit des Betons.

16 mm) (RCF-A10) and category B (4 and 8 mm) (RCF-B10) is not important. The same remark is valid for the other percentages, i. e. 20% and 30% RA content.

5.2 Effect of the nature of the original aggregates

Three types of aggregates have been used: calcareous, siliceous and silica-calcareous. Three alternative additions have been undertaken in order to get workable concrete. These alternatives correspond to the utilization of water reducer plasticizer, a 10% addition of cement and/or the addition of water. It is important to note that the addition of cement implies the addition of water within a quantity respecting the water/cement ratio. *Figure 1* shows the used water/cement ratio in each mix, and *Figures 2* and *3* present the results of the tests which have been carried out.

The examination of Figure 1 shows the following:

1. A big difference in the required content of plasticizer when using calcareous RA (RCO(Cal)-5%P and RCO(Cal)-8.5%P) and siliceous RA (RCO(Sil)-2.5%P). For the same W/C ratio, the content of plasticizer for the siliceous RA was more acceptable.

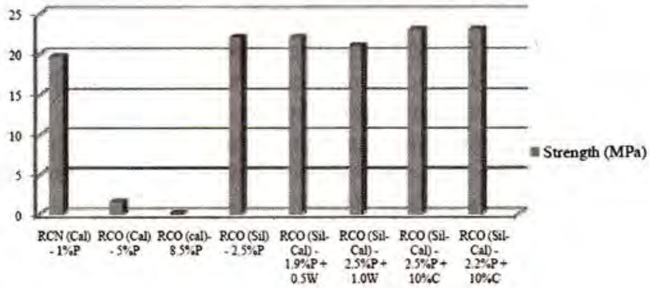

Figure 3. Influence of the original aggregates nature and the plasticizer, cement and water contents on the compressive strength of concrete

Bild 3. Einfluss der ursprünglichen Art der Zuschlagstoffe, des Anteils des Plastiziermittels und des Wasser-Zement-Anteils auf die Druckfestigkeit des Betons.

2. The alternative which corresponds to a 10% addition of cement gave better results for W/C ratio than the alternative corresponding to the addition of water alone.

3. For the silica-calcareous RA, the W/C ratio had increased in comparison with the siliceous RA. It is normal because the calcareous aggregates absorb more water.

The examination of Figure 2 shows the following:

1. A better workability of the concrete with siliceous RA in comparison with the concrete with calcareous RA even for a smaller quantity of plasticizer.
2. A diminution of workability when using a mix of siliceous and calcareous RA. This phenomenon is also due to the absorption of water by the calcareous RA. However, the 10% addition of cement has shown a better workability of concrete in comparison with the case when only water is added.

The examination of Figure 3 shows the following:

1. For 1% plasticizer addition and calcareous RA, the strength of concrete is acceptable even it is hard to be workable.
2. For 5% plasticizer addition and calcareous RA, the strength is negligible and no strength exists for 8.5% plasticizer. This proves that the limit value of plasticizer content has been overcome.
3. For the siliceous RA, the compressive strength of the original concrete has been more or less recuperated when adding 2.5% plasticizer even without adding cement.
4. For the mix of siliceous and calcareous RA, the compressive strength of the original concrete has been also more or less recuperated when adding 2.5% plasticizer but with addition of water (comparison between RCO(Sil)-2.5%P and RCO(Sil-Cal)-2.5%P+1.0W).
5. For 10% cement addition and 2.2 to 2.5% plasticizer additions, the original value of the normal concrete compressive strength has been obtained. It is equal to 23 MPa.

5.3 Effect of the additives

Since the principal responsible of the recycled concrete deficiency is the addition of water, we aimed to substitute the addition of water by addition of plasticizer and/or a 10% cement addition. The content of plasticizer has been varied in order to determine its limit needed to assure a workable concrete.

The first test of RCN(Cal)-1%P has been done to respect the limit value of the plasticizer percentage for normal concrete, indicated by the product manufacturer. When examining the W/C ratio values given in Figure 1, we remarked that for 1% plasticizer content, we should also add water to assure an acceptable workability. And as the W/C ratio was not significantly affected by this value of plasticizer, we thought about fixing the value of W/C to the value 0.57 used for normal concrete and searching the corresponding value of plasticizer content, workability and strength of the RC (Figures 2 and 3). Therefore, the tests corresponding to RCO(Cal)-5%P, RCO(Cal)-8.5%P and RCO(Sil)-2.5%P have been done. Then, other tests have been carried out using silica-calcareous RA. Herein, two alternatives have been considered to assure adequate values for workability and W/C ratio. These alternatives correspond to the addition of water or 10% of cement.

Table 2 shows that the strength of RCO-B10 and RCF-B10 have increased when adding 10% of cement. It also shows that for 2.5% and 2.9% of plasticizer, the strength of RCO-AB20 has increased and attained an acceptable value. Meanwhile, the best result was obtained when adding both 10% of cement and 2.5% of plasticizer (shown in Figure 3).

6 Conclusion and recommendations

The presented results show that the behavior of the concrete manufactured with recycled aggregates depends on:

- the age and state of the original concrete,
- the type, dimensions and content of the recycled aggregates,
- the presence of additives and their content.

Finally, for the fabrication of structural concrete based on recycled aggregates, we can recommend the following:

- use 20% recycled aggregates whatever the original concrete was old or new, burned or safe;
- add 10% cement and/or 2.5% water reducer plasticizer.

Nomenclature

C:	Concrete
R:	Recycled
O:	Old concrete (obtained from demolished buildings)
F:	old concrete set to Fire
N:	Newly manufactured concrete (less than 3 months)
A:	category of aggregates with dimensions between 8 and 16 mm
B:	category of aggregates with dimensions between 4 and 8 mm
(Cal):	Calcareous recycled aggregates
(Sil-Cal):	Silica-Calcareous recycled aggregates
RCN(Cal)-α%P:	Recycled Concrete Newly manufactured with Calcareous RA and α% Plasticizer addition
RCO(Sil-Cal)-β%P+γW:	Recycled Concrete Old with Silica-Calcareous RA, β% Plasticizer addition and γ kg of Water addition
C10:	with 10% Cement addition

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