Advanced Materials Research Vol. 324 (2011) pp 348-351
Online available since 2011/Aug/22 at www.scientific.net

doi:10.4028/www.scientific.net/AMR.324.348

Relationship between the Compressive and Tensile Strength of Recycled Concrete

Rouba EL DALATI[1,a], Pierre MATAR [2,b], Sara HADDAD[1,c],

Fadi HAGE CHEHADE[3,d]

[1]Lebanese University, Faculty of Engineering 1, Tripoli, Lebanon

[2]Lebanese University, Faculty of Engineering 2, Roumieh, Lebanon

[3]Lebanese University, University Institute of Technology - Saida & Doctoral School of Science & Technology – PRASE - Beirut

[a]rdalati@ul.edu.lb, [b]pmatar@ul.edu.lb, [c]tharaa.haddad@jinan.edu.lb, [d]fchehade@ul.edu.lb,

Keywords: Recycled concrete, aggregates, compressive strength, tensile strength, workability.

Abstract: Concrete recycling consists of crushing the concrete provided by demolishing the old constructions, and of using the resulted small pieces as aggregates in the new concrete compositions. The resulted aggregates are called recycled aggregates and the new mix of concrete containing a percentage of recycled aggregates is called recycled concrete.
Our previous researches have indicated the optimal percentages of recycled aggregates to be used for different cases of recycled concrete related to the original aggregates nature. All results have shown that the concrete compressive strength is significantly reduced when using recycled aggregates. In order to obtain realistic values of compressive strength, some tests have been carried out by adding water-reducer plasticizer and a specified additional quantity of cement. The results have shown that for a limited range of plasticizer percentage, and a fixed value of additional cement, the compressive strength has reached reasonable value.
This paper treats of the effect of using recycled aggregates on the tensile strength of concrete, where concrete results from the special composition defined by our previous work. The aim is to determine the relationship between the compressive and tensile strength of recycled concrete.

Introduction

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

The majority of the resulting aggregates have been used as filling under roads. Meanwhile, some researchers have shown the possibility of reusing the recycled aggregates in new structural constructions. So, after establishing national guidelines for recycled concrete production, some countries have forbidden the reuse of concrete in the structural elements, and some others have permitted it but with particular specifications [2].

In Lebanon and after the war of July 2006, all the constructions of the 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

[3]. Therefore, different tests have been done depending on the aggregates sizes, their origin, and also on the utilization of plasticizer and the addition of cement. The resulted recommendations have indicated a special composition for assessing acceptable values for concrete compression strength.

The present research work consists of an experimental study assessing the impact of using recycled aggregates on the concrete tensile strength. We are especially interested in determining the relationship between the compressive and tensile strength for the special mixture of recycled concrete which has been considered satisfactory.

Nomenclature

RC: Recycled Concrete
RA: Recycled Aggregates
F: old concrete set to Fire
O: Old concrete (obtained from the demolition of old buildings)
Type A: aggregates ranged between 8 and 16 mm
Type B: aggregates ranged between 4 and 16 mm
(Cal): Calcareous Recycled Aggregates
(Sil-Cal): Silica-Calcareous Recycled Aggregates
RCN (Cal) - α%P: Recycled Concrete – New – Calcareous Recycled Aggregates + α% Plasticizer.
RCO (Sil-Cal) - β%P+ γW: Recycled Concrete - Old – Silica-Calcareous Recycled Aggregates + β % Plasticizer + γkg Water
C10: With the addition of 10% cement

Tests data

All new concrete mixtures, before any addition, have been made according to table 1, and with respecting the volume weight of concrete i.e. 2400 Kg/m^3.

Table 1. Composition for 1 m^3 of new concrete mixtures before any addition

Cement	Aggregates	Sand	Water
CPA Type 1: 354 Kg	Range 4/16: 1256 Kg	Normal: 587 Kg	203 L

All compressive strength results presented in this paper correspond to the mean value of 4 or 6 cylinders of 30 cm height and 15 cm diameter that have been crushed at least, 28 days from the date of manufacturing. The tensile strengths obtained correspond to the mean value of 4 specimens having the same shape, dimensions, and age as in the case for compression but failing by the Brazilian test.

Previous recommendations

Our previous studies based on calcareous recycled aggregates obtained from the "South Suburbs of Beirut" have shown that no difference appears in the new concrete when using 20% of Recycled Aggregates, either the original concrete constituting the Recycled Aggregates was new or old, and burned or safe. But for other percentages, the difference was significant. Also we recommended using old concrete, as Recycled Aggregates, when making the normalization tests, especially because it will be the reality after wars or natural catastrophes.

Table 2 shows the compressive strength of concretes when using recycled aggregates obtained from old concrete. 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). Also we remark here that the difference between the strength decrease corresponding to 10% RA content of category A (8 and 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.

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

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

Other tests have been carried out by adding 10% of cement and/or some percentages of plasticizer playing the role of water reducer. The table shows that the strength of RCO-B10 and RCF-B10 has increased when adding 10% of cement. It also shows that for an addition of 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 (Fig. 1).

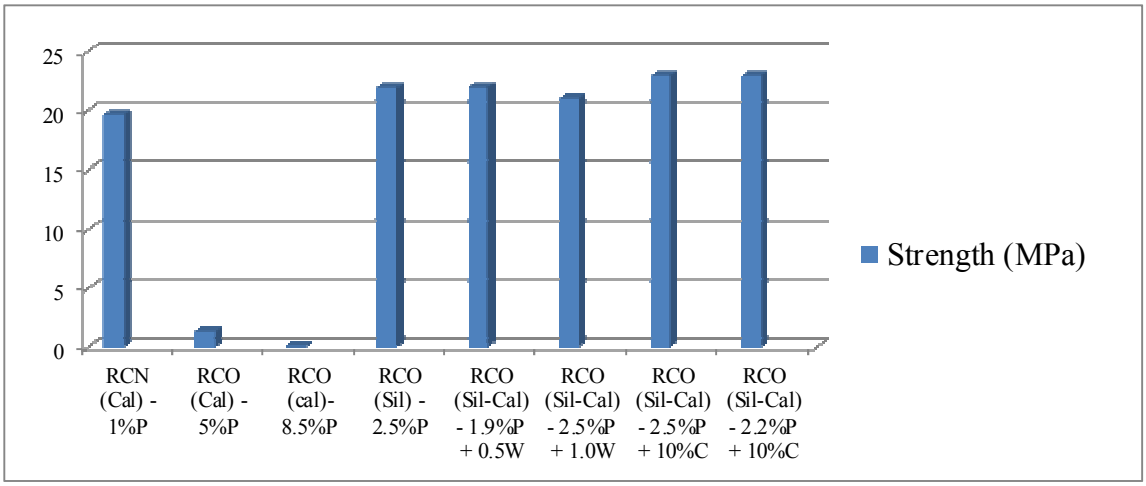

Fig. 1: Influence of the original aggregates nature and the plasticizer, cement and water contents on the compressive strength of concrete

Finally, for the fabrication of structural concrete based on recycled aggregates, we recommended to

- 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.

Tensile strength

Respecting the recommendations for getting an acceptable mixture of recycled concrete, i.e. by adding 10% more of cement and/or by adding an acceptable percentage of water reducer plasticizer, new mixtures have been done in order to be tested under compression by crushing and tension by the Brazilian test. Two mixes have been considered, and for each mixture 3 specimens have been subjected to compression vertically and 4 other specimens have been subjected to compression laterally on all the length of the cylinders (Brazilian test). Also one ordinary mixture has been done (table 2).

Table 3: Results for two mixes of recycled concrete and one ordinary concrete

	Mix 1 (RC)	Mix 2 (RC)	Mix 4 (OC)
Characteristics	with 10% C & 1.3% Pl	with 10% C & 2.25% Pl	with 1.5% Pl.
Compressive strength fc [MPa]	20	21.5	20.1
	22	18	20
	21.6	22.1	21
Tensile strength ft [MPa]	2.576	2.123	2.149
	2.690	2.774	2.477
	2.562	2.350	2.165
	2.619	2.477	-
Mean value for fc [MPa]	21.2	20.53	20.36
Mean value for ft [MPa]	2.61	2.431	2.26
ft-(0.6 +0.06fc) [MPa]	0.738	0.599	0.43

Relationship between the compressive and tensile strength

The relationship between the tensile and compressive strength for ordinary concrete is:

$$f_t = 0.6 + 0.06f_c \ \ [\text{MPa}] \qquad (1)$$

Where f_t is the tensile strength and f_c is the compressive strength.

The examination of the last line in table 3 shows that the real tensile strength f_t is always bigger than the value calculated using Eq. 1, even for ordinary concrete. Also for recycled concrete this difference is higher than for ordinary concrete, and for more plasticizer percentage the equation may be considered as acceptable. Finally, the known relationship between the tensile and compressive strength for recycled concrete cannot be applicable without some specifications. Meanwhile the tensile strength provided by our special composition for recycled concrete is higher than for ordinary concrete. More tests and studies should be done in order to determine the appropriate relationship.

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Advances in Innovative Materials and Applications
doi:10.4028/www.scientific.net/AMR.324

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