Influence of recycled aggregates on compressive strength of concrete

A.A. Tsoumani [1], T.E. Matikas [1], N.-M. Barkoula [1]

[1]Department of Materials Science and Engineering, University of Ioannina, 45110 Ioannina, Greece
Presenting author's email: anna.tsoumani@gmail.com

Abstract
The recycling of construction and demolition waste as a source of concrete aggregates has attracted increasing interests from the construction industry. While the environmental benefits of using recycled aggregates are well accepted, the concrete's performance characteristics require reassessment in relation to natural aggregate concrete. This paper presents an experimental study on the properties of concrete prepared with recycled aggregates. Concrete mixes with a target compressive strength of 25 MPa are prepared using recycled aggregates at the levels from 0 to 100% of the total coarse aggregate. Their influence on concrete's compressive strength is investigated. As a result, we found out that the effect of their use on compressive strength depends on the percentage of coarse aggregate substituted. For low percentages of substitution (less than 25%) it can be said that this influence is practically negligible. Concluding, the use of recycled aggregates in concrete production may help solve a vital environmental issue apart from being a solution to the problem of inadequate concrete aggregates.

Keywords: construction and demolition waste (C&D Waste), recycled aggregates (R.A.), concrete, compressive strength, recycled concrete

1. Introduction

The amount of construction and demolition (C&D) waste has increased considerably over the last few years. The increasing cost of landfill, the scarcity of natural resources coupled with the increase in aggregate requirement for construction, has attracted increasing interests, from the construction industry, concerning the use of recycled aggregate (RA) to partially replace the virgin aggregate. Indeed, in some European countries, a large proportion of aggregate comes from secondary sources and recommendations for the use of recycled aggregate have been set out by RILEM [1].

While the environmental and economical benefits of using recycled aggregates are well accepted, some hypothetical problems related to durability aspects resulted in recycled aggregates being employed practically only as base filler for road construction. Concrete, however, is one of the high-grade applications where recycled aggregates can be used. Their use in concrete opens a whole new range of possibilities in the reuse of materials in the building industry. The utilization of recycled aggregates is a good solution to the problem of an excess of waste material, provided that the desired final product quality is reached. Accordingly, the performance characteristics of concrete incorporating commercially produced recycled aggregates, hereafter, referred to as recycled concrete, require reassessment in relation to natural aggregate concrete [2].

Literature reports [3, 4] confirm that the performance of recycled concrete is affected by the cement mortar attached to the aggregate particles. This residual mortar alters aggregate absorption and density and can have adverse effects on concrete performance [2]. While studies on the engineering properties of concrete made with laboratory – crushed concrete aggregate abound [5, 6], only limited data are available on commercial – grade recycled aggregate, including concrete mixture proportions, fresh concrete performance and durability aspects. Thus, this paper evaluates the effects on the compressive strength of hardened concrete containing commercially crushed and graded recycled aggregates.

2. Experimental program

2.1 Materials

The mixes' constituents were cement, water, fine aggregate, coarse aggregate and superplasticizer water reducing agent. Ordinary Portland cement, designated type CEM II was used. The coarse aggregates used in this study included both natural and recycled aggregates. The natural aggregates were crushed limestone sourced from a local quarry, with nominal sizes of 9.5 mm (3/8") and 25mm (1"). The recycled aggregates were derived from C&D wastes, which had been processed by mechanized crushing and sieving at a C&D waste recycling plant that is located in the industrial area of Thessaloniki. The origins of the C&D waste were unknown, therefore, the composition was evidently heterogeneous, depending on the type, age, use and size of the structure it came from. The material contains: gravel, pieces of concrete / brick / tile / mosaic / marble, sand, carved stones, pieces of plumbing parts, plasterboard, plywood and asphalt. Besides the above, it contained a small percentage of: wood, plastic parts, metal objects (wire, screws, etc.), cables, paper, dirt and other pollutants.

Sieve Designation ASTM E11	Sieve size (mm)	Fine aggregate	Coarse aggregate		Coarse aggregate	
			Natural	Recycled	Natural	Recycled
			nominal size (mm)			
			9,5	11	25	25
		% passing				
1 1/2"	38,1	100,00	100,00	100,00	100,00	100,00
1"	25,0	100,00	100,00	100,00	96,17	98,73
3/4"	19,0	100,00	100,00	100,00	65,15	84,37
1/2"	12,5	100,00	100,00	100,00	8,32	45,01
3/8"	9,50	100,00	93,20	98,45	3,34	19,35
No 4	4,75	99,99	36,10	25,77	2,08	5,07
No 8	2,36	86,96	2,50	1,80	1,74	3,65
No 16	1,18	53,35	1,50	1,26	1,53	2,70
No 30	0,60	33,38	1,40	0,80	1,48	1,75
No 50	0,30	22,36	1,40	0,35	1,39	0,75
No 60	0,25	20,57	1,30	0,27	1,37	0,58
No 200	0,075	13,47	1,30	0,12	1,24	0,32

Table 1 Particle size distribution of aggregates.

Only coarse recycled aggregates with the maximum nominal sizes of 11 mm and 25 mm were used in this study. The characteristics of the aggregates were established in order to study their possible application in concrete production. The procedures and test methods were in accordance with international standards (ASTM and/or EN specifications). The fine aggregates used was crushed limestone sand (nominal size: 4.75mm). Tests' results, led us to the conclusion that fine recycled aggregates (nominal size: 5mm) should not be used in concrete production because of their low quality (sand equivalent value and blue methylene test value are lower than those required). The particle size distribution, water absorption and density of the different types of aggregate are given in Table 1 and Table 2.

	Fine aggregate	Coarse aggregate		Coarse aggregate	
		Natural	Recycled	Natural	Recycled
		nominal size (mm)			
		9,5	11	25	25
Absorption (%)	2,60	1,35	4,80	1,40	5,40
Bulk specific gravity/ saturated- surface -dry (kg/m^3)	2,52	2,56	2,36	2,60	2,39

Table 2 Water absorption and bulk specific gravity of aggregates.

2.2 Concrete mixtures

The aim of this study was to produce C20/25 (28-day cylindrical compressive strength of 20 MPa and 28-day cubic compressive strength of 25 MPa) quality concrete. Several preliminary trial mixtures were proportioned to evaluate water requirements for such a concrete. In producing new concretes, in place of natural aggregates, 0%, 15%, 25%, 35%, 50% and 100% of recycled aggregates were added as coarse aggregates. Therefore, the purpose was to determine the optimum amount of recycled aggregates used. The concretes were produced in an automatic mixing machine, aggregates were used in a dry condition (using an oven), however they were presaturated for 8 minutes in the mixer and brought to room temperature prior to mixing the concrete. The proportions of the concrete mixes were designed using the absolute volume method. Mixture proportion data are given in Table 3. The effective water – cement ratio of all mixtures was adjusted to achieve comparable consistency and hence equal nominal slump of 10$\pm$5 cm.

Mix	Replacement Percentage (%)	Cement	Water	Effective W/C ratio	Superplasticizer	Fine aggregate	Coarse aggregate		Coarse aggregate	
							Natural	Recycled	Natural	Recycled
							nominal size (mm)			
							9,5	11	25	25
M1	0,0	280	177,60	0,500	2,85	935,22	285,02	-	675,43	-
M2	15,0	280	173,51	0,466	2,85	935,22	242,27	40,75	574,12	93,52
M3	25,0	280	210,56	0,586	2,85	935,22	213,76	67,91	506,58	155,87
M4	35,0	280	170,86	0,432	2,85	935,22	185,26	95,08	657,25	259,80
M5	50,0	280	199,97	0,518	2,85	935,22	142,51	135,83	337,72	311,74
M6	100,0	280	227,73	0,561	2,85	935,22	-	262,75	-	620,88

Table 3 Details of concrete mixes (kg/m^3).

2.3 Casting, curing and testing

The slump of the fresh concrete prepared was measured using the standard slump test apparatus, according to ASTM specifications (ASTM C143). Slump values were measured immediately after mixing. For each mix, 6 cubes of 150 mm in size were cast in steel moulds and kept in a mist room at 20 ºC for 24 h until demoulding. The cubes were then placed in water at 20 ºC. Compression tests were conducted on the cubes at the ages of 7 and 28 days to determine the compressive strength of the concrete, according to the EN specifications (EN 12390-3). All the tests were conducted in the laboratory environment at room temperature of about 20–24 ºC.

3. Results and discussion

The workability, expressed in terms of slump, varied within a 10-mm band, as presented in Table 4. It was essential that concretes should have the workability feature. In order to achieve the same workability in all mixtures, the effective water/cement ratios varied from 0.43 to 0.59 (Table 3).

Mix	Replacement Percentage (%)	Slump (cm)
M1	0,0	10,50
M2	15,0	9,83
M3	25,0	10,00
M4	35,0	9,50
M5	50,0	9,50
M6	100,0	9,50

Table 4 Slump of concrete mixtures (cm).

The results of the compression tests on concrete cubes are shown in Table 5, where each value is the average of three measurements. Also, relations between R.A. percentages and cubic compressive strengths are presented in Figure 1 and Figure 2 (7-day compressive strength and 28-day compressive strength respectively). It can be seen from Table 5 that the compressive strength increases slightly for low replacement percentage (up to 25 %) and then decreases as the percentage of recycled aggregate increases. When 100% recycled aggregate was used, the compressive strength of concrete was reduced by about 25% (7-day) and 34% (28-day).

The increase of the compressive strength for low replacement percentage (up to 25 %) may be due to the containing a higher percentage of fine soil, which was capable of filling up the voids more effectively. However this assumption needs further research.

Mix	Replacement Percentage (%)	7-day Compressive Strenght (MPa)	Percentage of effect (compared to M1 -0%)	28-day Compressive Strenght (MPa)	Percentage of effect (compared to M1 -0%)
M1	0,0	23,86	-	32,83	-
M2	15,0	27,98	17,27	35,52	8,19
M3	25,0	26,30	10,23	34,31	4,51
M4	35,0	22,17	-7,08	28,63	-12,79
M5	50,0	20,74	-13,08	24,33	-25,89
M6	100,0	17,93	-24,85	21,67	-33,99

Table 5 Effect of recycled aggregates on 7-day and 28-day compressive strenght of concrete.

All experimental results are compared with predictions made with different approaches, in order to check their validity for determining the compressive strength of recycled aggregate concrete. All results are consistent with international literature [7,8,9].

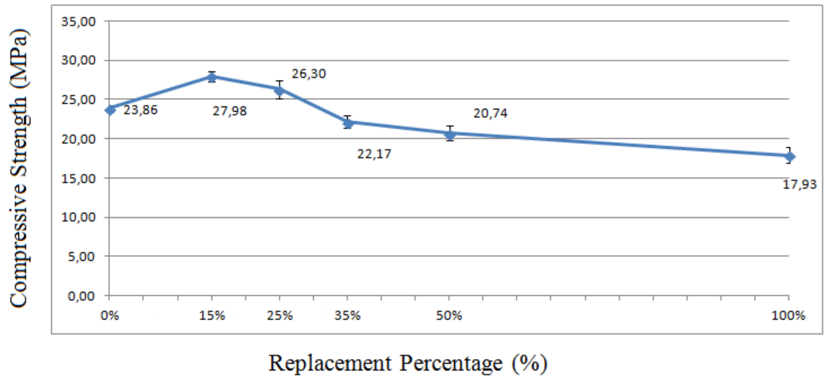

Figure. 1 Effect of recycled aggregates on 7-day compressive strength.

4. Conclusions

From the observed experimental behavior the following conclusion can be drawn: The effect of the use of recycled aggregate on the compressive strength depends on the percentage of coarse aggregate substituted. For low percentages of substitution (less than 25%) it can be said that this influence is practically negligible. For higher percentages of substitution the compressive strength of decreased with an increase in the recycled aggregate content. In conclusion, recycled aggregates obtained from the construction waste sorting facility have potential to be used as concrete aggregates and it seems possible to produce concrete of C20/25 quality. For the recycled aggregates, the optimal percentage that can be used to replace natural coarse aggregates is 25%.

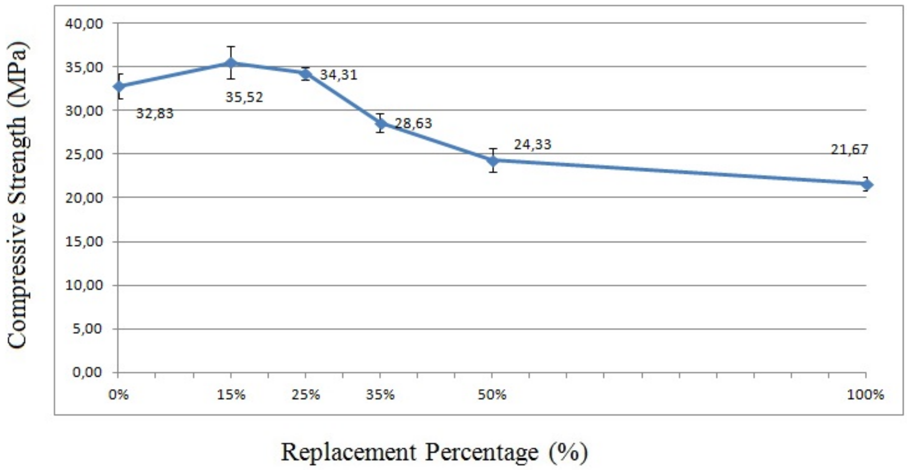

Figure. 2 Effect of recycled aggregates on 28-day compressive strength.

5. Acknowledgements

The authors would like to thank “Anakiklosi Adranon Macedonias” (Macedonia’s aggregates recycling company) for providing the samples of recycled aggregates and especially Mr. Christoglou for his useful advice. The authors also wish to acknowledge Domylco Ltd. for providing the superplasticizer water reducing agent CHEMIUM-274. Finally we would like to thank TITAN Group and Mr. Leptokaridis in particular for their advice and experimental assistance.

6. References

[1] RILEM 121-DRG, Specification for concrete with recycled aggregates, Mater. Struct. 27 (173) 557– 559, (1994).

[2] K.K. Sagoe – Crentsil, T.Brown, A.H. Taylor, Performance of concrete made with commercially produced coarse recycled concrete aggregate, Cement and concrete research, (2000).

[3] T.C. Hansen, Recycling of demolished concrete and masonry, RILEM Rep., No 6, E&FN Spon, London, UK.

[4] I.B. Rasheeduzzafar, A. Khan, Recycled concrete – a source of new concrete, ASTM Cem, Concr. Aggregates 6 (1), (1984), 17-27

[5]T.C. Hansen, H. Narud, Strength of recycled concrete made from crushed concrete coarse aggregate, ACI. Concr. Int. 5 (1), (1983), 79-83

[6]V.M. Malhotra, Use of recycled concrete as new aggregate, Proceedings of the Symposium on Energy and Resource Conservation in the Concrete Industry, CANMET Rep. No. 76-8, CANMET, Ottawa, Canada, (1978), 4-16

[7] Chi-Sun Poon, Shi-cong Kou , Hui-wen Wan, Miren Etxeberria, Properties of concrete blocks prepared with low grade recycled aggregates, (2009)

[8] Vivian W.Y. Tam, X.F. Gao, C.M. Tam, Microstructural analysis of recycled aggregate concrete producedfrom two-stage mixing approach, (2007)

[9] Etxeberria, Miren , Gonzalez, Andreu and Valero, Ignacio, Application of low grade recycled aggregates for non-structural concrete production in the city of Barcelona, (2004)