Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
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Analysis of moisture state of recycled coarse aggregate and its influence on compression strength of the concrete

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Abstract
This article analyzes the impact of the moisture level of recycled coarse aggregate additions to concrete on its compression strength, with the goal of finding a logical development process that can be reproduced at an industrial level and provide acceptable results for concrete production. This study takes into account the reality in the process of the production of concrete; while many authors suggest the use of recycled coarse aggregates in a saturated state to ensure the desired ratio water to cement in the concrete, in reality, the aggregates are introduced unsaturated. The main objective of this study is to observe and analyze the behaviour of recycled coarse aggregate in concrete, so that it is not stigmatized by the extra work involved in its use. The concrete was produced using three states of the recycled coarse aggregates. In the first one, the aggregates were added in their natural state, taking into account the total water in the dosage; in the second one, aggregates were added after being submerged in water for 10 minutes and drained for 10 minutes; and in the last one, the aggregates were added in their natural state, taking into account its absorption when adding the water. In order to evaluate the recycled coarse aggregates' resistance to compression at 28 days, four percentages of replacement of the recycled coarse aggregates, 0%, 20%, 50% and 100% were established among the concretes studied. The study finds that to define the resistance of a concrete, the effective ratio of water to cement plays a very important role; basically, the high absorption of recycled aggregates directly affects the quality of the concrete. The results showed that the values of compressive strength increased as the replacement percentage of the recycled coarse aggregates increased when the aggregates were added in their natural state, not considering their absorption in the mixed water. The opposite result was obtained when the aggregates were added in saturated state, reflecting a significant decrease in the resistance of the concrete as the replacement percentage of recycled coarse aggregates increased.

Keywords: Recycled concrete, recycled coarse aggregate, compression strength. .

1. Introduction

For years, people have been trying to keep the environment clean. Scientific studies provide us with information on how we can maintain the natural balance of life, and recycling has a primary role in these studies. Recycling of concrete waste is necessary from the viewpoint of environmental preservation and effective utilization of resources (Hansen T. C. and Narud H.[7]).

In this way the Ministry of the Environmental published in Spain a National Construction and Demolition Waste Plan PNRCD 2001-2006 (BOE [12]), where different studies were made with the purpose of being able to reuse construction waste in concrete production.

The recycled aggregates are rarely utilized in structural constructions, instead they have been used as fillers in road construction and in low-level applications due to material defects such as high water absorption capacity, their elongated and angular shape, attached mortar content on recycled aggregates that is around 25% to 60% (Sanchez M. and Alaejos P. [11]) of the aggregates by volume. Excessive attached mortar cause poor workability and large slump-loss of concrete due to the high absorption capacity of recycled aggregates (Su N. and Wang B.L. [13]).

A number of researcher has studied the effects on properties of concrete made with recycled aggregates, such as workability, strength, modulus of elasticity (Tu T.-Y.et al [14]), creep and shrinkage (Domingo A. et al [4]) durability (Levy S.M. and Helene P. [9]). This has been important to analyze reinforced concrete elements prepared with recycled aggregates in a safe way.

According to (Barra and Vazquez [2]) the poor result of concretes with saturated and dry recycled aggregates and the good result of those made from semi-saturated aggregates can be explained as being caused by formation of a more solid and denser interface in this condition.

The moisture states of the aggregates can change the workability and the uniformity of the concrete mixes and hence would affect the properties of the hardened concrete. In the production of recycled aggregate concrete, the moisture states of the recycled aggregates should be taken into account not only for determining the water requirement, but also for adjusting other technical parameters (such as mixing time, compacting time) during concrete production (Poon C.S., et al [10]).

This study aims to increase the knowledge about the recycled aggregates in structural concrete and effects of the moisture states of the recycled aggregates on the compressive strength of the concrete.

2. Methodology and experimental procedure

In this study the concrete was produced using natural and recycled aggregates. This were added to the mix in different states:

C1. Natural state: the aggregates were added in their natural state, taking into account the total water in the dosage without including the absorption capacity of the coarse aggregate.

C2. Saturated coarse aggregate: the aggregates were added after being submerged in water for 10 minutes and drained for 10 minutes.

C3. Taking in the consideration the absorption capacity of the coarse aggregate in its natural state: in the mix's needed water, we took in the consideration the included moisture and the absorption capacity of the aggregate.

The concrete mixes were prepared with the use of natural and recycled coarse in four combinations: 0% recycled, 20% recycled+80% natural, 50% recycled +50% natural and 100% recycled. The design of concrete was made to obtain 40MPa of compressive strength for the control concrete (0% recycled aggregate).

2.1. Materials

The cement used in this study was type I Portland cement (CEM I 42.5 R/SR) .

The both natural and recycled aggregates were used in this study. The properties are shown in Figure 1. The natural aggregate was a crushed limestone with two nominal sizes, 10/20mm and 4/10mm. The recycled aggregate was generated by the demolition activity of a number of reinforced concrete buildings and the concrete highways, with nominal size 4/20 mm. The recycled aggregate was supplied by Tec-Rec factory, which is located in Madrid Spain. The physical and mechanical properties of the recycled aggregate are shown in Figure 2, where the adhered mortar of the recycled aggregates was determined using the methodology propose by Polytechnic University of Cataluña (Barra M. [3]). This method involves applying stresses to the adhered mortar in order to cause its detachment from the rocky matrix. The sample is weighed and immersed in water. Next, the sample is heated up in a furnace and, subsequently, a thermal crash is produced by dipping it again into cold water. Finally, the sample is sieved using a 4 mm sieve. The mortar that is still adhered is removed by hitting the sample with a rubber mallet. Once the cleaning has been done, the sample is weighed again. The weight difference represents the adhered mortar.

Properties	Materials			
	Sand	Aggregate 10/20mm	Aggregate 4/10mm	Recycled aggregate
Fineness modulus	3,34	8,40	6,09	6,30
Density (kg/dm^3)	2,39	2,51	2,58	2,32
Absorption (%)	4,03	1,67	2,40	5,19
(LA) Los Angeles test (%)	-	31,96	-	40,22

Figure 1. Physical properties of materials

Properties	Fraction 4/8 mm	Fraction 8/16 mm	Fraction total
Adhered Mortar (%)	31,5%	17,85%	-
Absorption (10 min.) (%)	-	-	4,65

Figure 2. Physical properties recycled aggregates

2.2. Dosage of concrete mixtures

The amounts of water and aggregates used in mixing were adjusted according to the actual moisture content of the aggregates, in the first case the aggregates are added to mix in the natural state C1 (Figure 3). In the second case the coarse aggregates were saturated, therefore, the dosage wasn't adjusted by moisture contents the aggregates, in this case the proportions of the concrete mixes were designed using the aggregates in saturated surface-dried condition C2 (Figure 4). In the last case the aggregates were added in their natural state. The aggregates humidity and absorption capacity were considered at the moment of concrete production. The recycled aggregate had a higher water absorption capacity, the amount of water added to the mix according to the percentage of recycled aggregate C3 (Figure 5).

The different mixes' compositions were designed using Bolomey's method (Fernandez [6]), with a common target slump between 100 and 150 mm. The mix design was primarily conceived for the reference concrete, made only of natural aggregates and it was then adapted for the remaining mixes. An additive superplastifying (Superplastifying Sikament 500) was used to increase the workability in the concrete produced usingthe recycled aggregates. In the (20%, 50% and 100%) mixes, the total coarse aggregate was considered as the joint of gravel 4/10 mm, gravel 10/20 mm and recycled aggregate, for the grading curve adjustment. The calculation of proportions of each coarse aggregate was carried out maintaining a costant ratio of gravel 10/20 mm / gravel 4/10 mm and taking into account the same total water/cement ratios (w/c=0.5) of the reference concrete (0% recycled aggregate).

Materials	**% Recycled Aggregates**			
	0%	20%	50%	100%
Cement (kg)	380	380	380	380
water (kg)	190	190	190	190
Sand (kg)	713,90	744,45	709,54	714,56
Aggregates 10/20 (kg)	882,20	665,28	414,06	0,00
Aggregates 4/10 (kg)	121,59	91,69	57,07	0,00
Recycled aggregates 4/20 (kg)	0,00	189,24	471,12	874,04
Aditive %	0,70	0,70	0,70	1,50
Effective w/c	0,44	0,42	0,40	0,37

Figure 3. Dosage C1

Materials	**% Recycled Aggregates**			
	0%	20%	50%	100%
Cement (kg)	380	380	380	380
water (kg)	190	190	190	190
Sand (kg)	781,43	794,31	811,37	838,29
Aggregates 10/20 (kg)	665,44	512,76	303,34	0,00
Aggregates 4/10 (kg)	307,93	237,28	140,37	0,00
Recycled aggregates 4/20 (kg)	0,00	187,51	443,71	807,97
Aditive %	0,70	0,70	0,70	0,70
Effective w/c	0,52	0,52	0,53	0,55

Figure 4. Dosage C2

Materials	**% Recycled Aggregates**			
	0%	20%	50%	100%
Cement (kg)	380	380	380	380
water (kg)	190	190	190	190
Sand (kg)	735,17	724,38	755,89	809,52
Aggregates 10/20 (kg)	459,89	368,91	219,69	0,00
Aggregates 4/10 (kg)	548,23	439,77	261,88	0,00
Recycled aggregates 4/20 (kg)	0,00	202,17	481,57	884,82
Aditive %	0,70	0,70	1,00	1,00
Effective w/c	0,50	0,50	0,50	0,50

Figure 5. Dosage C3

3. Tests

3.1. Slump

The consistency of the concrete was measured by the Abrams cone method, according to the code UNE-EN 12350-2: 2006.

3.2. Compressive strength

The compressive strength of the hardened concrete was determined at the age of 28 days on cylindrical specimens (150x300mm) according to the code UNE 83304:84. These were removed from the moulds after 1 day and were cured in water at 20 °C and moisture 95% such as the code UNE-EN: 196-1:1996 before testing.

4. Results and discussion

4.1. Slump

The results obtained are showed (Figure 6), give an idea about the workability of the concrete for the different cases. In C1 the results of slump don't indicate a clear tendency. However the better slump value was obtained for concrete with 20% and 100% of recycled aggregate. For C2 the change in the concrete slump was minimum between the different substitution grade and their values were about 180-220 mm, therefore, the slump values don't meet the slum design value (100-150 mm). The last case C3 the slump of concrete mixes was increased with the increase of the content of the recycled aggregate. This due to the fact that the recycled aggregate has a higher water absorption value, but, during the mix, the absorption value reaches 80%(Etxeberria et al [5]) of the total absorption capacity of the used recycled aggregate. In turn, more free water was available to increase the fluidity of the fabricated concrete. Therefore the best slump values were obtained for C3, because they are close to the slump design value.

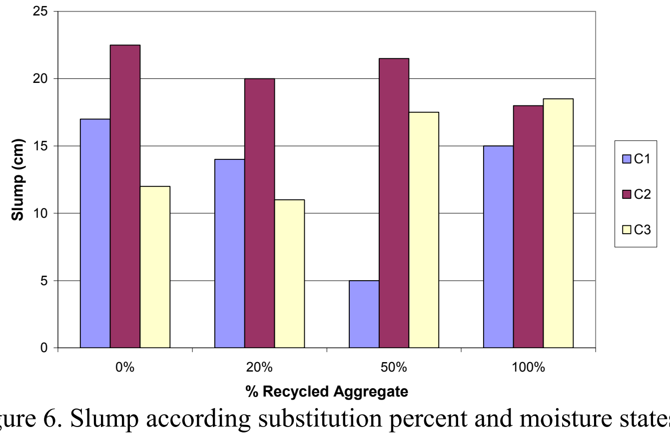

Figure 6. Slump according substitution percent and moisture states

4.2. Compressive strength

The figure 7 show the compressive strength results of the concrete mixes in C1, C2, C3, respectively, found different tendencies. It can be seen when using the same total w/c ratio the results are influenced by moisture state of recycled aggregates. The compressive strength of the concrete for C1, improved when increase recycled aggregate contents. This may be due to the high initial absorption capacity of the recycled aggregate, this phenomenon reduce the free water that act with the cement, that is, the effective w/c ratio was less. It is generally acknowledged the lower the w/c ratio, the higher the compressive strength (Hwang C.L. et al [8]) Therefore C1 were obtained strength value over the target compressive strength of 40 MPa at 28 days. According to the reviewed literature (Ajdukiewicz and Kliszczewicz A. [1]), excessive amount of paste produces a weak interface-zone and low density, which might also generate a reduction or a poor development of compressive strength. This can be observed in the C2 and C3 cases.

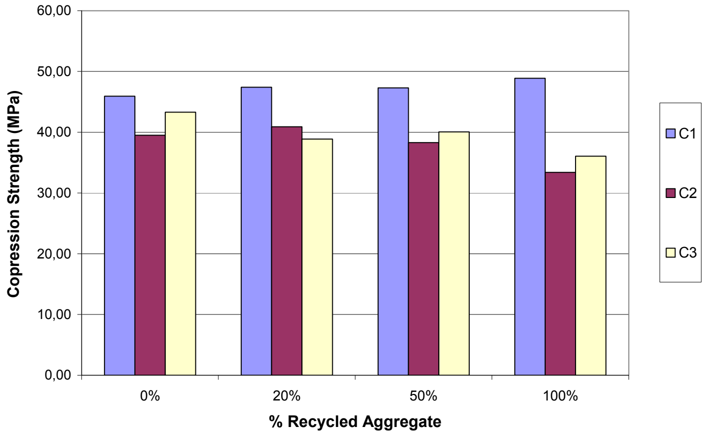

Figure 7. Compressive strength according substitution percent and moisture states

Comparing the compressive strength values of the studied cases shows that the moisture's state effect of the coarse aggregates on the compressive strength of the concrete were quite different for diverse combinations. When natural and recycled aggregates were used in natural state, the prepared mixes had different compressive strength values in comparison with the other cases. The strength in C2 and C3 cases tends to decrease 15% and 17% respectively, when recycled aggregate content increase in the mix. In the C1 case the effective w/c decrease up to 25% with 100% of recycled aggregate in the concrete and in the C2 case the effective w/c increase up to 10% when the substitution of recycled aggregate is 100%.

5. Conclusions

1. The moisture states of the aggregates affects the workability of the concrete. The less favourable case was presented when the recycled aggregates had been added to the mix in natural state. The workability in C2 and C3 was appropriate for the concrete mix designed.
2. The concrete prepared with recycled aggregates in natural state, exhibited the highest compressive strength. The pre-saturated recycled aggregates seemed to impose the largest negative effect on the concrete strength, which might be attributed to “bleeding” of excess water in the pre-saturated aggregates in the fresh concrete.
3. Based on the results of this study and taking in consideration the concrete manufacture process simplification, we recommend the use of recycled aggregates including the absorbed water in the concrete’s dose, even though the results shows better strength values for the other cases.
4. The concrete shouldn’t contain more than 50% of recycled aggregate, to fulfil the expected parameters of compressive strength and workability. For the implementation of the recycled aggregates in the concrete manufacture, it is important to carry out investigations for intermediate percentage for the range of 50 and 100%.

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