INFLUENCE OF RECYCLED AGGREGATE QUALITY FROM PRECAST REJECTION ON MECHANICAL PROPERTIES OF SELF-COMPACTING CONCRETE

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ABSTRACT:

The use of coarse aggregates from crushing pre-existing concrete in the manufacturing of new concrete needs experimental results to validate its influence in the properties of the new concrete elements.

In the present study we assessed the impact of using different proportions of replacement up to 100% of natural aggregates with recycled aggregates in the concrete properties; moreover, the effect of pre-treatments of pre-saturation, washing and the aggregates' source (from precast concrete rejected pieces and construction and demolition waste) was analysed. The best results were obtained with dry and washed recycled aggregates, the compressive strength increment was between the 8 and 17% compared to conventional concrete. Results also pointed out that recycled aggregate that exclusively comes from precast concrete pieces lead to a better concrete mechanical characteristic than the aggregates which origin is construction and demolition waste. In addition, a clear relationship between the percentage of recycled aggregate substitution and the workability and mechanical performance of self-compacting concrete is observed. The results presented in this paper allow to state that precast concrete factories can recycle their rejected elements into recycled coarse aggregates for manufacturing new products, this will allow to protect the environment by reducing the need of raw material consumption and the C&DW landfill.

Keywords: recycled aggregates, concrete, self-compacting concrete, mix proportion, mechanical strength, waste

1.- INTRODUCTION

Environmental protection and the conservation of natural resources are essential targets for future generations. Construction and demolition activities in the European Union are responsible for generating 850 million tonnes of construction and demolition waste (C&DW) per year [1]. According to Wimala et al. [2], in the precast concrete industry a 3% and a 6% of precast concrete small-sized and large-sized products, respectively, are rejected due to manufacturing flaws. In Spain, in 2018, the production of precast concrete products was approx. 4,6 million tonnes [3], according to this figure and Wimala et al., estimations between 138000 and 276000 tonnes of concrete waste were generated.

The steady increase in waste generation and the difficulty involved in recycling [1,4,5] prompted us to analyse the mechanical performance of concretes made with recycled aggregates from precast rejects and their potential use in the manufacture of new precast elements. Recycling this waste *in situ* as aggregate in the manufacture of new elements would reduce the amount of waste material generated in the manufacturing process, aside from saving on raw materials, transport energy consumption, and landfill volume [6-8].

Research into recycled concretes in particular demands a high volume of test results, as the industrial use of these elements will be dictated by the different standards developed on a national level. This is why each country currently establishes limits on the percentage of recycled aggregates permitted in the manufacture of recycled concrete [9]. The results obtained over time will allow national technical regulations to progressively increase the amount of natural aggregate that can be replaced with recycled aggregate, this research aims to contribute to this goal.

Many previous studies have analysed the use of aggregates from RCD for the production of recycled concrete, it is worth highlighting a recent review "*Recycled concrete with coarse recycled aggregate. An overview and analysis*" by González-Fonteboa et al. However, the investigations focus on specific aspects of recycled concrete, such as: pre-treatment of aggregates, recycled concrete aggregates from precast concrete products and their influence on the behaviour of hardened and fresh concrete are significantly more scarce. This aspect justifies the interest of the results obtained in the present work.

The main objective of this study is to analyse the feasibility of using recycled aggregate ($RA_{PRAINSA}$) obtained from rejected precast elements in the factory operated by the Prainsa group of companies in Zuera (Zaragoza, Spain) in the production of new precast concrete structural elements. We were prompted to undertake this study after observing the excellent quality of recycled aggregate obtained from the rejects accumulated during the production of precast concrete, their characterisation results were presented in a previous research [10]. These elements undergo rigorous testing to guarantee the homogeneity of the aggregate and the absence of external contaminating agents, a factor that often limits the use of aggregates from C&DW (RA_{RCD}), which can contain a variety of waste materials (concrete, brick, wood, glass, etc). In the previously mentioned research we also presented the preliminary results obtained from producing recycled self-compacting concretes in which the coarse fraction (4/12 mm) of natural control aggregate (CA) was replaced with 20%, 50% and 100% of recycled aggregate. We evaluated overall mechanical performance trends as the percentage of substituted aggregate was increased.

In this study, we have continued in this line of research, focusing on the properties of concretes made with 100% replacement of coarse aggregate with recycled aggregate, in terms of workability, the effect of pre-saturation, washing, and the source of the recycled aggregate. We also present the results of our evaluation of these parameters in self-compacting concretes (SCC), reinforced concretes (RC), and high-strength reinforced concretes (HSRC), in order to obtain an insight into the performance of all potential types of concrete that can be made in the concrete plant. Recycled concrete test properties were compared with the ones from control concrete specimens - concrete in which only natural aggregate was used-.

In this study, we also compare the flakiness index [11-13], shape index [11,12], particle density [10,13-15], absorption [11,12,16,17], Los Angeles abrasion test [14,18], resistance to frost [19] and attached mortar [20,21] of $RA_{PRAINSA}$, RA_{RCD} and natural aggregates with references to previous research. The favourable results obtained in this research and also in related research [22-26] should lead to changes in design codes and design guidelines that allow a cleaner production in the concrete industry. There are two reasons for this: first, the significant reduction of raw materials consumption; second, the C&DW reduction.

2. MATERIALS AND METHODS

2.1. MATERIALS

The concretes used in this study were made using the same materials employed by the factory in its manufacturing process. Both materials and manufacturing process were in accordance with the requirements of current Spanish Concrete Structural Code (EHE-08) [27]:

- Cement: Portland cement CEM I - 52,5R.
- Additive: polycarboxylate-based superplasticizer
- Natural aggregates (control aggregates, CA): natural crushed aggregates composed of quartz, rock fragments (limestone, quartzite, sandstone and granite) were used.
- Recycled aggregates: 2 types of recycled aggregate were used in the study: $RA_{PRAINSA}$ and RA_{RCD}.

The $RA_{PRAINSA}$ recycled aggregates consist of crushed rejects from the Prainsa factory itself and they were obtained from rejected precast concrete pieces made with concretes with minimum H30 to H50 strength, free from external contaminants (Table 1 and Fig. 1). This type of aggregate was obtained using a 2-stage crushing process. The product was sieved to obtain only the 4/12 mm fraction, and the aggregate was not washed at this stage.

% of total waste	Pieces	Type of Concrete
82.53	Alveolar Slabs	Self-compacting 40 MPa
2.39	Purlins and Columns	Self-compacting 40 MPa
8.63	Wall Panels	Self-compacting 30 MPa
6.55	Pre-stressed Beams	Self-compacting 50 MPa

Table 1: Percentage of different types of reject concrete pieces

Figure 1. Precast rejects in the Prainsa group precast concrete factory

The second type of recycled aggregate (RA_{RCD}), used in several recycled concrete blends for comparison purposes, contains material from the demolition and crushing of structural concrete elements, pavements and surfaces. It was also sieved to obtain the 4/12 mm fraction, but the original mechanical properties of these concretes and their level of homogeneity were unknown.

The basic properties of the aggregates used and their comparison with reference values in the literature consulted are shown in Table 2. A more detailed analysis and description of aggregates used in this research was shown in a previous research [10].

Test	Results				
	Limitations EHE-08	**$RA_{PRAINSA}$ *(4/12 fraction)***	**RA_{RCD} *(4/12 fraction)***	**Natural aggregates *(6/12 fraction)***	**Reference values Literature consulted**
Flakiness index UNE-EN 933-3	≤ 35	4	17	11	9 - 20.9 [11-13]
Shape index UNE-EN 933-4	-	4	10	11	0.20 - 0.466 [11,12]
Saturated particle density (g/cm³): UNE-EN 1097-6	-	2.43	2.37	2.568	2.32 – 2.526 [10,13-15]
Water Absorption (%) UNE-EN 1097-6	≤ 5	7.3	4.63	0.97	3.8 - 8.49 [11,12,16,17]
Los Angeles index (UNE-EN 1097-2	≤ 40	31	29	20	32 - 40.22 [14,18]
Magnesium sulphate (%) UNE-EN 1367-2	≤18	20	-	1.8	2-22 [19]
Attached mortar (%)	-	61.70	-	-	9.9 - 55 [20,21]

Table 2: Properties comparison of recycled 4/12 recycled aggregate sizes, 6/12 natural aggregate size and values from previous research

It should be highlighted that the saturation of washed aggregates was that derived from the washing process itself.

$RA_{PRAINSA}$ showed a higher water absorption than RA_{RCD}, and RA_{RCD}, in turn, had a larger absorption than natural aggregates. It is due to the amount of attached mortar of each type of recycled aggregate, the larger amount of attached mortar the larger water absorption. The quantity of attached mortar is directly related to the quantum of cement in the aggregate parent concrete.

2.2. METHODS – TEST SCHEDULE

For the purposes of this study, we manufactured 5 standard mixtures for laboratory testing. The composition of these mixtures is shown in Table 3.

When dosing the different components of the concretes used in this study with a manual mixer, no adjustment was made for recycled aggregates; therefore, regardless of the use of natural or recycled aggregate, all the concretes contained 800 kg of sand and 840 kg of coarse aggregate. Table 3 shows the cement, filler, superplasticizer content and the water/cement ratio of the different mixtures prepared in laboratory for the study, using the terminology explained below.

Name of mixture	Test Performed	Cemex 52.5R (kg)	Filler (kg)	Standard Superplast. (kg)	Water/cement ratio
Type 1	Workability and effect of pre-saturation on RA	360 & 400	165 -205	6.8	0.43
Type 2	Effect of $RA_{PRAINSA}$ purity	400	165	6.8	0.43
Type 3	Effect of origin of RA	360	205	6.3 -7.0	0.45
Type 4	Effect of SCC vs. RC	400	0 -165	4.0 -6.8	0.43
Type 5	Performance in HSC	425	Variable	Variable	Variable

Table 3: Different mixtures used for hand mixing. Mix dosages per cubic meter

We made a series of test cylinders in accordance with UNE-EN 12350-1:2006, and measured the following variables: pre-saturation, humidity, purity, and origin of the recycled aggregate, self-compacting concrete vs. traditional concrete, and the performance of $RA_{PRAINSA}$ in high strength concrete. All variables were compared with those measured in the control cylinder. Sampling of the fresh concrete used to manufacture the test cylinders was performed in accordance with UNE-EN 12350-1, and the cylinders were cured in a humid chamber, according to UNE 83-301-91. The consistency of the fresh concrete was evaluated using the slump-flow test and measurement of the spread, according to UNE 83361, while the mechanical performance of the hardened concretes was evaluated by testing the compressive strength on 15x15x15 cm test cubes, in accordance with UNE-EN 12390-3; tensile stress was tested in accordance with UNE 83-306-85.

Mixtures 1 and 6 were used to evaluate differences in the workability of the fresh concretes relative to the control cylinders, since they were manufactured using the RC containing $RA_{PRAINSA}$. Workability of mixtures made in the laboratory using a 30 L mixer and those made in the batching plant was evaluated for use in reinforced and pre-stressed beams. In the latter case, we were also able to analyse the consistency of the fresh concrete with different replacement percentages (0%, 20%, 50% and 100%) of $RA_{PRAINSA}$ recycled aggregate vs. natural aggregate. These Type 1 mixtures were also used to assess the influence of pre-saturation of recycled aggregates on the mechanical performance of the recycled concrete. At this stage, 8 concrete mixtures were made.

Type 2 mixtures were made to analyse the influence of the purity of $RA_{PRAINSA}$ on the consistency and in the mechanical performance of concretes made with this type of aggregate. At this stage, 6 concrete mixtures were made.

In the case of Type 3 mixtures, we analysed the differences observed in the mechanical performance of concretes made with both recycled coarse aggregates studied ($RA_{PRAINSA}$ and RA_{RCD}), and the effect of washed and unwashed aggregate. At this stage, 5 concrete mixtures were made.

Type 4 mixtures were developed with the aim of comparing the mechanical behaviour of self-compacting and conventional concretes made exclusively with coarse recycled aggregate of the $RA_{PRAINSA}$ type. At this stage, 3 concrete mixtures were made.

Finally, Type 5 mixtures were designed to evaluate the performance of high strength concretes made exclusively with $RA_{PRAINSA}$ recycled coarse aggregate. At this stage 4 mixtures were made.

Moreover, an additional series of mixes (Type 6 mixture) was prepared in the mixing plant. This additional series was made with different percentages of recycled aggregates ($RA_{PRAINSA}$ substitution, Table 4).

Table 4 shows the composition of the batching plant-mixed concretes to achieve a concrete strength of 40 N/mm^2 in reinforced concrete and 50 N/mm^2 in pre-stressed concrete.

Type	Mixture (dry)	Sand (kg)	Crushed gravel (kg)	Recycled washed gravel (kg)	Becontres limestone filler (kg)	CEMEX 52.5R (kg)	Additive P-180 (litres)	Water/cement ratio
Reinforced concrete								
CH5005001	1AR40-0%	860	890	-	175	360	5.3	0.38
CH5005002	1AR40-20%	860	712	178	175	360	5.3	0.38
CH5005003	1AR40-50%	860	445	445	175	360	5.3	0.38
CH5005004	1AR40-100%	860	-	890	175	360	5.3	0.38
Prestressed concrete								
CH5005005	2AR50-0%	860	890	-	100	420	6.2	0.41
CH5005006	1AR50-20%	860	712	178	100	420	6.2	0.41
CH5005007	1AR50-50%	860	445	445	100	420	6.2	0.41
CH5005008	2AR50-100%	860	-	890	100	420	6.2	0.41

Table 4: Identification of mixtures using batching plant-mixed specimens

3. RESULTS AND DISCUSSION

3.1. CONSISTENCY TESTING. WORKABILITY

The values of workability of the concretes with 100% $RA_{PRAINSA}$ manually mixed in a 30 L concrete mixer was on average a 7% lower than the control concretes (Fig. 2). In the case of concretes mixed in the batching plant, the workability of the recycled concretes with respect to control concretes progressively decreased with the increment of natural aggregate substitution by $RA_{PRAINSA}$. Figure 3 compares the mixtures made in the batching plant with 4 replacement percentages of $RA_{PRAINSA}$. The workability of mixtures containing 100% $RA_{PRAINSA}$ was 15% lower on average, compared with their equivalent control mixes (made with non-recycled aggregate).

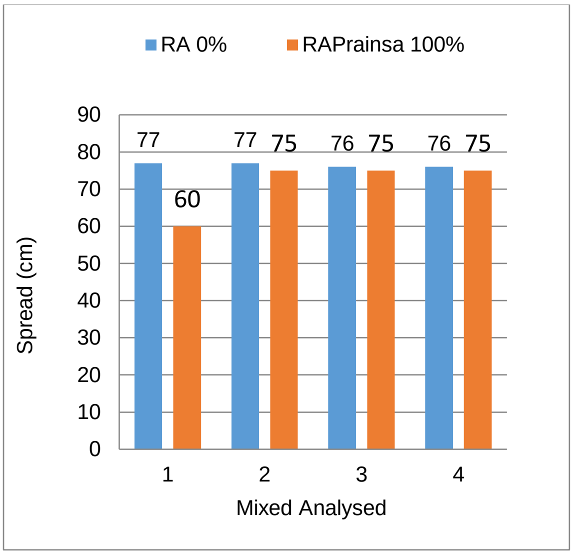

Figure 2. The influence of the percentage of RA on RC with respect to its consistency, for concretes mixed manually in a 30 L mixer

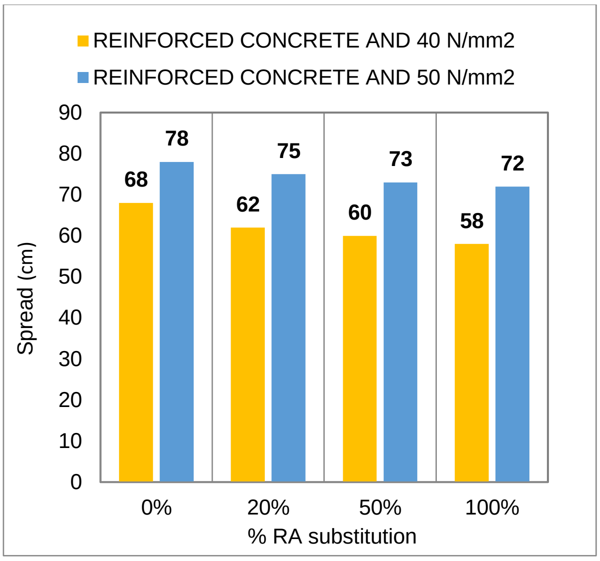

Figure 3. The influence of the percentage of RA on RC with respect to its consistency, for concretes mixed in a batching plant

Consistency values of concretes mixes in the laboratory are almost twice as much as of those mixed in the concrete plant. We believe this is due to the time elapsed between mixing and consistency testing, which gave the $RA_{PRAINSA}$ time to start absorbing the water in the mixture. The longer the time between mixing and testing, the greater the absorption of water in the mixture. In this research, in the laboratory the lapse of time between the concrete mixing and the workability test was 5-10 minutes, while in the the concrete plant this time was 30-40 minutes. It should be noted that the absorption capacity of the recycled aggregates used in the study is approximately 7%, while in the control aggregates is around 1% [10], a difference that undoubtedly affects the consistency and workability of fresh concretes made with both types of coarse aggregate.

3.2. INFLUENCE OF PRE-SATURATION OF $RA_{PRAINSA}$ ON THE MECHANICAL PERFORMANCE OF REINFORCED CONCRETE (RC)

Figure 4 (left) shows the average changes in the compressive strength of the concrete at 7, 28 and 90 days for RC with 100% $RA_{PRAINSA}$ substitution of the coarse aggregate fraction, the effect of this on tensile strength, and changes in the elastic modulus at 360 days. Compressive strength (f_c), which was measured at 28 days, was 19% lower on average in concretes with pre-saturated aggregates compared with concretes containing dry aggregates. Tensile strength (f_{ti}), Figure 4 (middle), was on average 28% lower in concretes containing pre-saturated vs. dry aggregate.

In the case of the elastic modulus (E_c), Figure 4 (right), a similar trend to compressive and tensile strength was observed. The highest values were obtained from the control cylinders, which were over 9% higher than RC containing dry $RA_{Prainsa}$. Concretes containing presaturated aggregate presented values that were on average 5% lower than RC containing dry $RA_{Prainsa}$.

These results clearly show the negative effect of pre-saturation on the mechanical performance of the hardened concrete. The trends and values obtained in this research are similar to the ones stated in Ferreira et al. study [26] for the compressive strength and elastic modulus. For the tensile strength they are similar to Pickel et al. investigation [24]. The results show a progressive decrease in the concrete mechanical properties when the percentage of substitution of natural aggregates by recycled aggregates increases. However, it should be pointed out that despite the substitution all the concretes made with recycled aggregates met the requirements of the Spanish design concrete code EHE-08 [27].

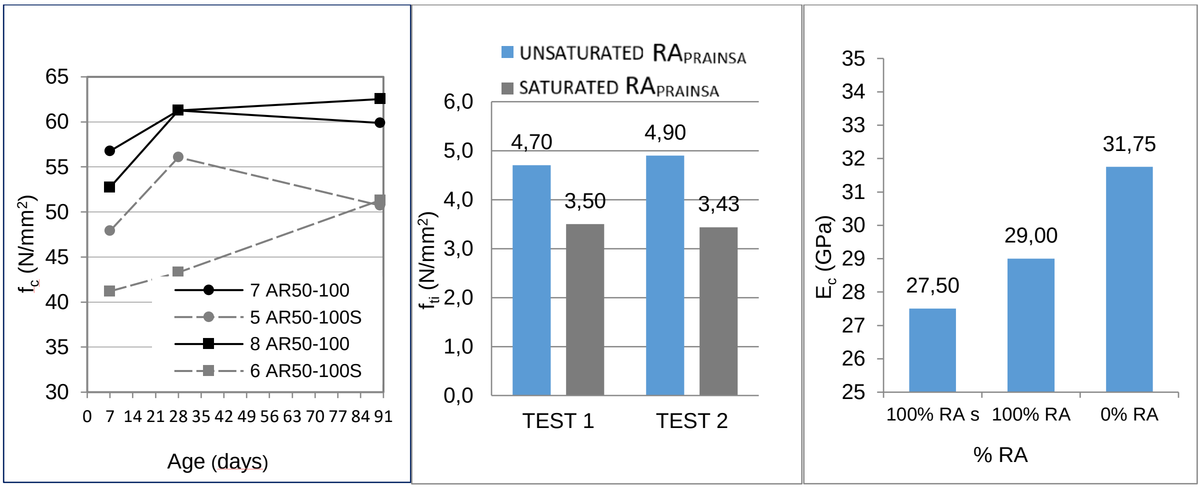

Figure 4. Effect of pre-saturation of $RA_{PRAINSA}$ on left: f_c at different concrete ages; middle: f_{ti} and right: E_c

3.3. EFFECT OF $RA_{PRAINSA}$ PURITY ON THE MECHANICAL PERFORMANCE OF RC

With the aim of expanding the knowledge on the effect of the pre-treatment of recycled aggregates on the properties of fresh and hardened concrete, in this research the impact that the washing and prior drying of aggregates has both in the compression concrete strength and in the consistency of mixtures has been analysed.

In this regard, changes in the compressive strength of concretes containing washed and unwashed and dry $RA_{PRAINSA}$ are shown in Fig. 5, and the different consistencies of the 6 cylinders made for each type of $RA_{PRAINSA}$ are shown in Fig. 6.

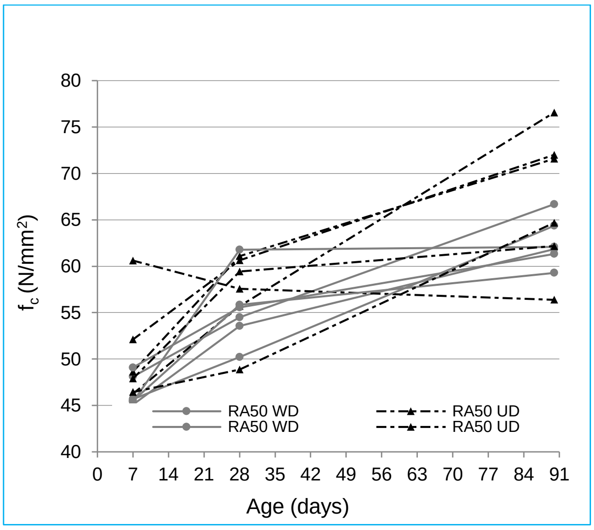

Figure 5: Values of f_c tests using washed and dry (WD) and unwashed and dry (UD) RA$_{PRAINSA}$

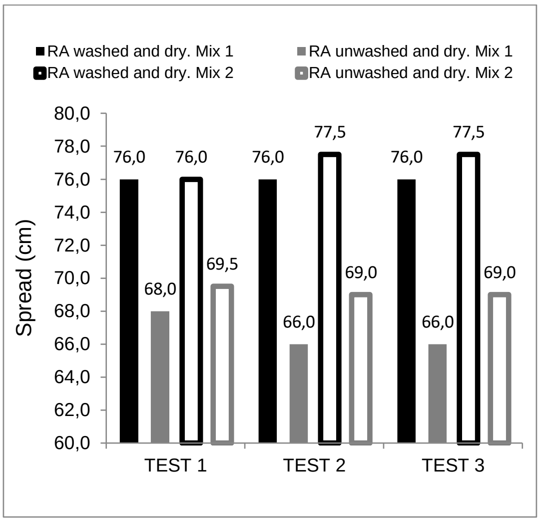

Figure 6. Consistency values of the different combinations and tests performed

The results show a more uniform performance in baseline strength and strength over time in the concretes containing washed RA$_{PRAINSA}$. Conversely, in the case of concretes containing unwashed aggregates, differences in strength varied by as much as 40% at 90 days; there was no correlation between the WD and UD aggregate.

Regarding the consistency, the highest workability values were obtained from cylinders containing washed aggregate which, due to a lack of fine aggregates, has less water absorbing capacity than unwashed.

The obtained results show that the effect of previously washing the recycled aggregates influences positively the workability of fresh concrete and also causes a more homogeneous mechanical performance of hardened concrete. This improvement is due to the fact that the washing has removed the fine particles on the surface of recycled aggregates (and possibly also part of the adhered mortar). These fine particles have negative effects because of their water absorption capacity that affects the water/cement ratio, thus increasing the consistency of mixing fresh concrete and also reducing the water available for the cement setting reaction.

3.4. EFFECT OF THE SOURCE OF RECYCLED AGGREGATE ON THE COMPRESSIVE STRENGTH OF RC

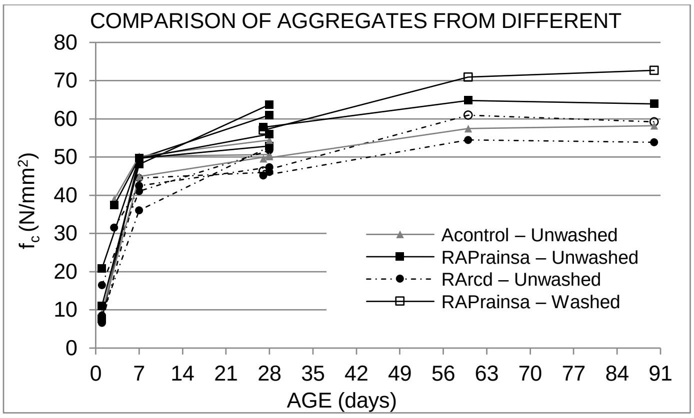

Figure 7: Average f_c values of the different concrete series tested

The compressive strength of 5 concrete mixtures in which 100% of the coarse fraction was replaced with dry RA$_{PRAINSA}$ and RA$_{RCD}$, both washed and unwashed, vs. control cylinders is shown in Fig. 7.

Concretes containing RA$_{PRAINSA}$, both washed and unwashed, showed greater compressive strength than controls with an average increase in strength of 16% at 28 days. In the case of concretes made with RA$_{RCD}$, both washed and unwashed, compressive strength was lower than both controls and RC containing RA$_{PRAINSA}$.

The same trend was observed in tests with washed aggregate, showing the higher performance of washed recycled aggregates, as it is described in section 3.3 of this paper.

As it is shown in this research and in agreement with other studies, the use of recycled aggregates from precast construction industry rejects in the fabrication of new concrete, the use of this type of recycled aggregates, causes generally a slightly improvement in the mechanical properties of hardened concrete [28-30]. The recycled aggregates from precast rejects have a high quality and a considerable homogeneity which avoids the scattering of results and the unpredictability associated with the use of recycled aggregates from C&DW.

3.5. EFFECT OF SCC vs. RC ON THE MECHANICAL PERFORMANCE OF CONCRETES CONTAINING $RA_{PRAINSA}$

Figure 8 shows compressive strength values for 4 different types of concrete, the aim of this chart is to study the differences between SCC and RC. In all the cases the recycled aggregate was $RA_{PRAINSA}$. The cylinders used in tests B and C were naturally cured in January, at a room temperature of no less than 2º C, and those used in test C were cured in a cure chamber. In A batch, the concrete test was analysed at 7,28 and 91 days, while in B and C batches at 2, 7 and 28 days.

In all 3 batches, SCC showed a higher compressive strength than RC, both with control aggregate and with $RA_{PRAINSA}$. This is undoubtedly due to the superior performance of the cement paste-aggregate interface in self-compacting concretes. This, is turn, is due to their higher paste content and greater capacity for movement within the fresh material, and also to the effects of vibration on the water in the paste in conventional concretes, which tends to weaken the adherence of the aggregates.

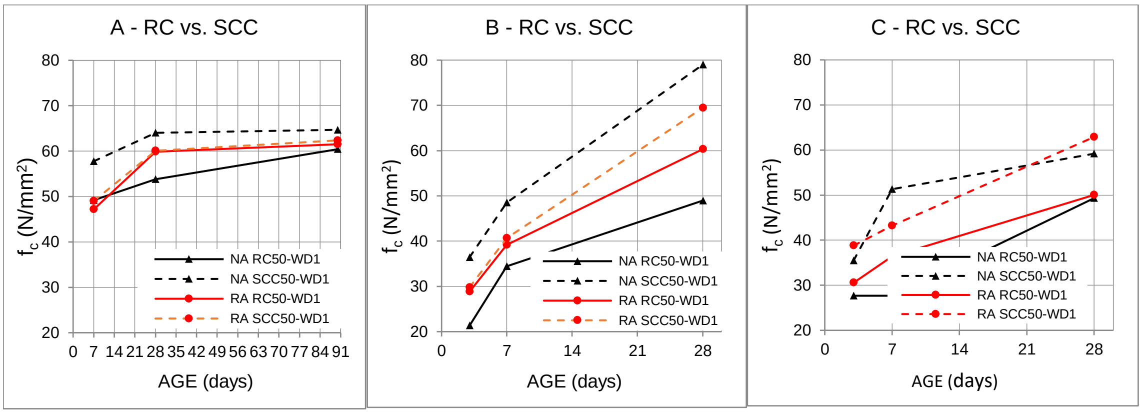

Figure 8: Results of the different tests performed to evaluate f_c of SCC vs. RC containing washed and dry aggregate (WD) in three similar batches (A, B, C)

The compressive strength of the 4 mixtures of air-cured concretes analysed showed a slower increase in the early ages, though values recovered at 28 days. Under these conditions, conventional concrete performed better than RC.

These results could allow -if the construction regulations change- to elaborate self-compacting concretes even with substitution percentages of the control aggregate for precast recycled aggregate up to 100%. Similar statements were found in related research [28-30].

3.6. HIGH-STRENGTH RC

The charts, Figure 9, reveal how with compression strengths of 70 N/mm², RC containing $RA_{PRAINSA}$ is superior to control concrete. This shows that the strength of the recycled concrete, far from being limited to the strength of the concrete of origin, is up to 75% stronger. With higher values the trend is reversed, and the greatest compressive strength is achieved with the control concretes.

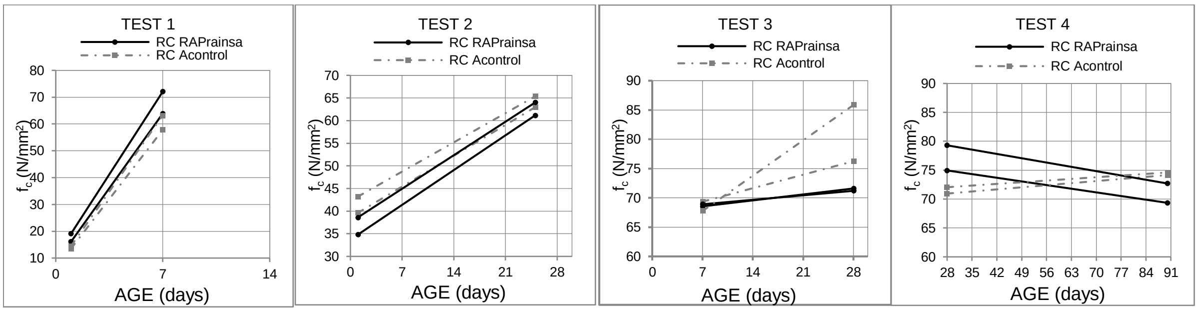

Figure 9: Comparison of the average results of 4 no. tests performed with high strength RC that has been stressed to breaking point at different ages, with RC containing $RA_{PRAINSA}$ (RC $RA_{PRAINSA}$) and RC containing control aggregate (RC $A_{Control}$)

The analysis of the evolution of compressive strength at 90 days shows that in both tests performed, f_c in RCs was greater at 28 days than at 90, and was lower than controls. Bearing in mind the technique used to shape the test cylinders (where the RC remained stuck to the trowel), we believe that this phenomenon may be caused by a discontinuity in the cylinder itself, as a result of the low workability of these concretes, in which the w/c ratio is 0.28. To compensate this loss of workability more superplasticizer can be added to the mix.

4. CONCLUSIONS

This paper presents a comprehensive analysis of the fresh and hardened properties of recycled concrete made with recycled coarse aggregate substitution of 100% from rejected precast products. Based on previous results and discussions, the following conclusions can be drawn.

Replacing conventional coarse aggregate with recycled aggregate has a negative effect on the workability of the fresh concrete: the greater the percentage of recycled aggregate, the worse the workability, using the same water/cement ratio. This is due to the loss of runoff as a consequence of the absorption capacity of the recycled aggregates. Further studies are needed to determine the correct water/cement ratio for recycled aggregate. We also found differences in the consistency of concretes mixed in the laboratory and in the batching plant using the same dosage. This is due to the time needed to transfer the concrete from the batching plant to the test point. This fact is very important from a methodological point of view, and should be taken into account when comparing the values reported in different studies.

Regarding the mechanical properties of concretes made exclusively with recycled coarse aggregate from rejected precast pieces, a comparison of concretes containing pre-treated and non-pre-treated aggregates showed that pre-saturation had a negative effect on compressive strength, and the best results were obtained with dry, washed aggregate, which increased compressive strength by 8% and 17% vs. conventional concrete.

We were also able to show that the source of the recycled aggregate affects the mechanical performance of RC. The compressive strength of concretes containing RA_{RCD} was more than 20% lower those of the control concrete and RC with $RA_{PRAINSA}$ in all tests. This shows the importance of discriminating between different sources of aggregates when manufacturing recycled concrete. Recycled aggregate that comes exclusively from precast pieces has a much greater homogeneity than aggregate obtained from recycled pavements and structural elements of diverse origin, and gives the concrete far better mechanical characteristics. The use of recycled aggregates from a single and known source allows a better adjustment of the concrete dosages (in particular the water/cement ratio and the use of admixtures), getting a more homogenous product.

A comparison between self-compacting and conventional concretes showed that the parent concrete has a higher compressive strength than both new recycled concrete (with $RA_{PRAINSA}$) and new control concrete (with control aggregates). This may be due to their higher paste content, their greater capacity for movement in the fresh state, and the effects of vibration on conventional concrete.

Finally, we observed that the strength of recycled concrete does not rely entirely on the strength of the original concrete from which the aggregate was obtained. In other words, the maximum compressive strength of the RC with 100% substitution was greater than 75 N/mm^2, which is twice as strong as the original concretes from which the recycled aggregate was obtained. This increase in compressive strength is due to the capacity of the recycled aggregate to absorb water, which in turn reduces the w/c ratio of the mixture.

In conclusion, there is a clear relationship between the workability and mechanical performance of self-compacting recycled concrete and the properties and percentage of recycled aggregate used in its manufacture. Concretes in which 100% natural coarse aggregate has been replaced with recycled aggregate from precast rejects exhibit a mechanical strength that far exceeds the maximum value permitted in the Spanish Code on Structural Concrete (EHE-08) [27]. This will allow concrete plants to recycle the waste structural elements produced during the manufacturing process, and thus protect the environment by reducing both the need of the consumption of more raw materials and the C&DW landfill.

In the specific case of a precast concrete factory, quality control can easily establish the volume of waste produced based on the percentage of rejected pieces, and thus calculate the percentage of recycled aggregates that they would need to incorporate into their process of manufacturing to compensate for that production of rejects, which would become a by-product that would be used in the production process itself.

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