Performance of recycled concrete made with precast concrete rejects. Optimisation of mix proportions based on mechanical properties

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Keywords: circular economy, precast concrete; mechanical properties, recycled aggregates.
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1. Introduction

The greatest challenge for humanity is to make the level of resource consumption sustainable in a growing world population. The construction sector is responsible for a third of waste production in the EU (Eurostat, 2016). Concrete is the most widely generated building material in the world. Precast concrete produccion is increasing in weight compared to conventional concrete (Delvoie et al. 2018).

The production of precast concrete depends on the location; in the Netherlands or Germany, the use of precast concrete elements represents 45% and 38% (Fiol et al 2018), respectevely, respect to the total of concrete construction. In Spain the percentage of prefabricated element solutions is lower, approximately 20%.

The National Association of the Precast Concrete Industry, ANDECE, declares that in 2018 4.6 million tons of products were generated from the industrialization of concrete in Spain. This figure represents 10% more production of precast concrete than in 2017. Compared to 2017, the consumption of precast in homes grew by 23%, in non-residential buildings consumption increased by 28%, however, in construction Civil consumption fell 14% in 2018.

In Spain, elements that are defective or rejected in the quality processes of precast industries represent approximately five percent of the total production (Thomas et al., 2016, Benedicto et al., 2010). In Belgium, it is estimated that rejects precast elements reach two percent of the precast production (Zhao et al. 2020). These elements are also considered as Construction & Demolition Waste (C&DW). The recycling rate of this waste in the state members of the EU is far from the 70% of its weight stablished by the framework Directive (2008/98/EC) by 2020. This, along with the fact that precast concrete production is gaining market position respect to conventional concrete, makes an opportunity to set up the basis of a more sustainable thriving construction sector. The optimization of concrete production considering the incorporation of recycled aggregates (RA) can outweigh the drawbacks of this incorporation, hence, laboratory studies could provide valuable results in order to be implemented to the concrete industry (Sanchez-Roldan et al., 2020).

This study analyzed the maximum percentage of substitution in the manufacture of precast concrete carried out in the laboratory with rejects elements from the precast concrete plant. The mixes were carried out with different percentages of substitution (0%, 5%, 10%, 15%, 20% and 30%) of RA from the precast concrete plant. This substitution in a proportional way in the different aggregates fractions of natural aggregates of the reference concrete (0% substitution). The production of precast concrete has been done trying to reproduce the conditions of the precast plant, so cating was made by virbrocompacting. The specimens manufactured in the laboratory were subjected to compression, density, absorption and capillarity tests. From the results, it is highlighted that the percentage of substitution in which the greatest resistance was found was 20%.

2. Materials and methods

The natural aggregates used for manufacturing the mixes concrete were coarse gravel (4-10 mm), fine gravel (2-6) and sand (0-4 mm), with limestone nature. The cement used was CEM I 52.5-R. The recyled aggregate (0-10 mm) used came from the block rejects of an precast industry. In the laboratory, it was aimed to produce a concrete similarly to the one produced in the precast industry, so, concrete casted through vibro compaction (Figure 1) and the same mix proportion aggregates was used (Table 1) as in precast plant. Fresh density was used to determine the amount of mixture to cast the specimens of 100 x 100 x 100 mm^3. The incorporation of the recycled aggregate was done proportionaly of each fraction of natural aggregates beacause of the similarity of the particle size distribution between the recycled aggregate and the combination of each fraction of natural aggregates.

Table 1. Dosage of the different concrete mixes (kg(m3)

Materials used	Ref-C	C-5	C-10	C-15	C-20	C-30
Water	69.2	69.2	69.2	69.2	69.2	69.2
Fine Gravel	601.5	571.4	541.4	511.3	481.2	421.1
Coarse gravel	300.8	285.7	270.7	255.6	240.6	210.5
Sand	902.3	857.1	812.0	766.9	721.8	631.6
Recycled Aggregate		87.8	175.7	263.5	351.3	527.0
Cement	165.4	165.4	165.4	165.4	165.4	165.4

Figure 1. Images from vibro-compacting method and specimens casted.

3. Results and discussion

Table 1 shows some of the properties studied in the hardened state of the concrete specimens at the age of curing at 28 days. The addition of recycled aggregate enhanced the compressive strength values, it reached the maximun at 20% of incroporation ratio. The fact that the mix C-5 presented the highest dry density and the lowest water absortion and open porosity values, could be attributed by the particle size of RA presented similar to the one of the combination of the natural aggregates. The greatest capillarity coefficent values presented by the mixture without recycled aggregates due to the fact that the vibrocompacting fragments easily the recycled aggregate used, which fulfilles the voids in the cementitous matrix.

Table 1. Comparison between theoretical predictions and experimental measurements.

Properties in hardened concrete	Ref-C	C-5	C-10	C-15	C-20	C-30
Compressive strength (Mpa) UNE-EN 12350-2:2009	6.57	6.67	7.21	9.09	9.29	8.43
Dry Density (kg/m^3) UNE 83980 - 2014	2181	2222	2193	2183	2175	2137
Water absorption (%) UNE 83980 - 2014	8.54	7.58	7.95	8.27	8.53	9.23
Open porosity (%) UNE 83980 - 2014	18.63	16.84	17.41	18.05	18.52	19.73
Capillarity coefficient, k, (kg/m^{2}min$^{0.5}$) UNE 83982:2008. Fagerlund Method	0.051	0.033	0.031	0.038	0.044	0.043

4. Conclusions

This study shows the feasibility of using a replacement percentage of up to 20% of recycled aggregate in the dosage used for the production of a concrete manufactured analogly as in the precast industry. These results can be attributed to the fact that the recycled aggregate can contain cement particles without previously hydrating. The compressive strength results obtained from the tests performed worsened for the 30% replacement batch, so this percentage of substitution should be discarded under the dosage used. For future investigations, it would be interesting to delve into aproaching a mix desgin taking into account the recycled aggregate used.

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