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Rheological and mechanical behavior of concrete made with pre-saturated and dried recycled concrete aggregates

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HIGHLIGHTS

- Superplasticizer dosage decreases with pre-saturated recycled concrete aggregates.
- Rheological parameters increase with the replacement level of recycled aggregates.
- Pre-saturated recycled aggregates improve rheological parameter.
- Pre-saturated recycled aggregates decrease slightly compressive strength.

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ABSTRACT

This investigation aims to determine the influence of pre-saturation and dried recycled concrete aggregates (RCA) on mechanical and rheological properties of concrete. Coarse ordinary aggregates (COA) were partially substituted with RCA and an amount of superplasticizer was added to keep the same workability. The results found show that concrete with dried RCA aggregates requires a great dosage of superplasticizer and achieves high compressive strength and rheological parameters. However, for concrete with pre-saturated RCA aggregates, the needed dosage of superplasticizer is reduced and the compressive strengths and the rheological parameters are decreased. The use of pre-saturated RCA aggregates is better to keep adequate superplasticizer dosage and relevant rheological parameters. Mathematical relationships are proposed to express the variation of the compressive strengths and the rheological parameters according to the concrete composition with fair correlation coefficients.

1. Introduction

Concrete is the most consumed material after water in the world. Every person consumes an average of one cubic meter per year, which corresponds to about 25 billion tons of concrete [1]. During demolition of old buildings or natural disasters, the landfills of the demolition material cause a critical environmental problem because of its high durability without any degradation possibility. Recycling this material would both remove these landfills and recover useful materials. Now, using the demolition waste as a source of aggregates to make new concrete becomes very interesting for construction industry. The main reasons for this growing interest in recycling materials are related to environmental protection, preservation of natural aggregate resources and decreasing waste disposal land and waste treatment cost.

Recently, excellent recycled aggregates have been produced and were successfully used to produce structural concrete. The research works in this field have focused both on recycled fine and coarse aggregates. In 1977, Buck [2] realized one of the first investigations on concrete properties containing recycled aggregates from different sources at a constant w/c ratio. The results obtained showed that the decrease in compressive strength of concrete with recycled aggregates was only 20% compared to that of ordinary concrete. Later, others works [3–5] found that concrete with RCA aggregates reaches a compressive strength similar to that of ordinary concrete, and depend on the parent concrete strength. Furthermore, increasing the amount of cement from 325 to 345 kg/m^3 in concrete made with 50% dry recycled aggregates, the compressive

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strength observed was found to be similar to that of conventional concrete [6]. Otherwise, the curing conditions seem to affect the compressive strength of different concrete mixes made with RCA aggregates as that of conventional concrete with only 7.5% decrease [7].

It is known that the roughness and the shape of recycled aggregate play an important role in compressive strength concrete which improve the aggregate paste adhesion. Also, recycled aggregates were found to be more porous and usually partially carbonated due to the adhesion of old cement pastes on the aggregates surface. Thus; the ITZ microstructure of the recycled aggregate concrete will be different from that of the natural aggregate concrete [5]. It is possible to improve the mechanical properties of recycled aggregate concrete by modifying the surface properties and the pore structure of the recycled aggregates [8]. This will be possible by adding some pozzolanic admixtures which coat the surface of RCA aggregates and consume CH accumulated in the pores and on the surface of the attached mortar to form new hydration products; so the ITZ microstructure is then improved [9,10].

In general, the quality of recycled concrete aggregates are poor compared with ordinary aggregates due to its lower stiffness caused by crushing the waste concrete and higher water absorption capacity resulting from the old mortar attached to RCA surface. Some researchers [11–13] show that the loss in compressive strength of concrete manufactured with RCA occurred when increasing the substitution rate of recycled aggregates (fine and coarse). Other investigation [14] indicates that the mechanical properties of concrete made with recycled aggregate derived from low strength parent concrete ranging from 30 MPa to 45 MPa were significantly decreased. But these properties become similar or slightly better when RCA aggregates were derived from high strength parent concrete ranging from 80 MPa to 100 MPa. The reduction in mechanical strength is mainly due to the effect of the old porous mortar attached to recycled aggregates surface, the increase in the effective w/c ratio and the presence of crushing dust which increases the effective amount of water to maintain the consistency. Increasing the recycled aggregate content resulted in systematical decrease in compressive strength since the recycled aggregate contains a weak interfacial transition zone between surface aggregate and cement paste [12].

Recycled aggregates influence the properties of the fresh concrete because of the angular shape, the roughness and the high water absorption of these aggregates [15–19]. The porosity of RCA aggregates is commonly higher than that of ordinary aggregates due to the attached mortar on recycled aggregates. Several mixing methods were developed to control workability problems of concrete containing RCA aggregate such as increasing the amount of added water, increasing the moisture content of RCA aggregate, increasing the superplasticizer amount or increasing cement content in the concrete composition. Mathias et al. [20] noted that the high RCA water absorption capacity has a great influence on the mixing water which can affect the workability of concrete. Thus, it is necessary to estimate the amount of mixing water that is absorbed by the RCA and accurately determine the mixing time as this can affect the workability and the strength of concrete. Padmini et al. [21] also reported that the 10 min water absorption value of RCA aggregate satisfied the desirable workability performance of concrete. Etxeberria et al. [5] added higher amounts of superplasticizer to mixes containing RCA aggregate than to the control mix to guarantee constant slump and water to cement ratio. In the same way, Gonzalez-Fonteboa and Martinez-Abella [6] increased the cement content by 6.2% in concrete prepared by replacing 50% of coarse ordinary aggregate with coarse recycled concrete aggregate to keep the slump similar to that of the control concrete.

Nowadays, it has been shown that it is possible to obtain recycled aggregate concrete where the mechanical strength is comparable to that of conventional concrete, provided that the mixing is facilitated by the addition of superplasticizer [22,23], or by water compensating methods [24,25]. Poon et al. [16] found that concrete with air dried RCA, used as received in the laboratory at about 50% of potential water content, showed a normal evolution of slump with time and presented the highest compressive strength. Concrete containing a pre-saturated RCA leads to high compressive strength concretes as concluded by Tam et al. [26]. The results were explained by the author as a consequence of a better ITZ caused by the filling of RCA's surface pores with a denser cement paste. Barra and Vazquez [27] obtained high compressive strength by using dried RCA aggregates at approximately 90% of water content. In the same way, Etxeberria et al. [5] recommended 80% pre-saturation of the potential water content in RCA aggregates to reach the best compressive strength.

Recently, the image analysis method was used to quantify the residual mortar content in RCA aggregates, in which it was shown that crushed limestone aggregates include particles commonly covered with residual mortar. Moreover, more than 50% of natural aggregates contain less than 15% of residual mortar [28]. The failure process investigated shows that for ordinary aggregate concrete, the first crack appears around the ITZ, and then propagates into the mortar matrix [28]. In concrete made with RCA aggregates, the initial crack occurs around both new and old ITZs, and propagates across the old mortar region connecting with each other [29]. Besides, this enables the determination of the width and the depth of cracks inside and at the interface of mortar-RCA aggregates. This allows to take into account these cracks to update the mechanical and durability properties of this concrete [30,31].

In the literature, there is a few works related to the study of the rheological properties of concrete made with recycled concrete aggregates. It is known that the consistency of concrete containing RCA aggregates drops easily and leads to unworkable concrete. The aim of this work is to study the combined effect of superplasticizer and pre-saturated recycled aggregate to improve workability concrete performances. Ordinary coarse aggregates were partially replaced by RCA aggregates in which mechanical and rheological properties of the new concrete were quantified and compared with those of the ordinary concrete aggregates. RCA aggregates are used in their dried and pre-saturated state to determine the superplasticizer requirement for each mixture and choose the most appropriate procedure to achieve the best performances. Experimental results are used to establish mathematical relationships to quantify each parameters effect.

2. Experimental program

2.1. Materials

Blended cement (CEM II), widely produced in Algeria and containing 10% of limestone powder, was used for all mixtures at specific surface area of 320 m^2/kg. The coarse ordinary aggregates used are obtained from the quarry and the natural sand is provided from the river (NS). RCA aggregates were made from crushing old concrete blocks manufactured in the laboratory and partially substituted to COA aggregates. The old concrete is made with the same cement and has similar composition to that of concrete made with only ordinary aggregate. After one year, this concrete was crushed and used as RCA aggregates. The crushed product was sieved to remove undesired particles size less than 4 mm. Fig. 1 shows the sieve analysis results of various aggregates used. The physico-mechanical characteristics of the used aggregates are summarized in Table 1. Superplasticiser based on ether polycarboxylates was used to improve the rheological properties of fresh concrete, compensate the water absorbed by RCA aggregates and keep the same consistency of all mixes. COA aggregates were used only in dried state but RCA aggregates were used both in dried and pre-saturated state. Pre-saturation was carried by immersion in water for a determined period of time. The aggregate's surface should be dried to avoid the increase of w/c ratio.