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Influence of effective mixing water in recycled concrete

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HIGHLIGHTS

- An improved mixing methodology for the recycled concrete manufacturing has been recommended.
- Recycled concrete needs a minimal time, over 12 min, to get an adequate mix.
- An increase of total water in recycled concrete does not result in a strength reduction.
- The important is the mixtures have the same effective water.

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ABSTRACT

This study analyzes the influence of two different modes for estimating the volume of mixing water (total water and effective water) on the dosing and behavior of recycled aggregate concrete. Different concrete mixtures of conventional and recycled concrete are analyzed to determine the relationship between slump and compressive strength according to the total and effective water/cement ratios. Furthermore, to avoid the pre-saturation of recycled aggregates, an improved mixing methodology for manufacturing of recycled concrete based on the best characteristics of two-stage mixing methods as well as on the water absorption speed is recommended. The results suggest that recycled concrete requires a minimal time to achieve an adequate mix and demonstrate that an increase in total water in recycled concrete does not result in strength reduction when the mixtures were dosed with the same volume of effective water. Furthermore, these results conflict with the recommendation to increase the cement content due to the extra volume of water needed for the recycled mix to maintain the slump and a constant water/cement ratio.

1. Introduction

The construction industry uses a substantial amount of natural resources as raw materials, a situation that highly modifies the natural surroundings of the area where they are located [1]. The latest estimates suggest that this sector accounts for approximately half of all extracted materials [2] and also generates approximately one-third of all waste [3]. Thus, the different directives prompt the use of recycled materials or the reuse of waste as potential materials to reduce the construction and demolition waste in landfills and lower energy consumption [4].

Additionally, the European Commission has concluded that concrete is the most used material in construction and that it can be reused as recycled material in new buildings [5]. However, although recycled concrete (RC) for structural use is allowed according to various European structural codes [6,7], it is not commonly used due to the lack of knowledge about the management of the recycled concrete aggregates (RCA). Moreover, the adequate way to adapt RCA to current manufacturing processes supposes a drawback regarding conventional concrete. An additional factor impeding the use of RCA is the decrease of approximately 10 to 35% of the strength properties of the concrete [7].

The main difference in the RCA is its higher porosity caused by the attached mortar to the old aggregates from the original concrete [8], which directly influences water absorption, density and strength properties of the concrete [9,10]. This phenomenon directly affects the water volume available for the chemical reactions, i.e., the 'free' water, and, consequently, the change in the water/cement ratio [11]. Thus, different authors [12,13] have concluded that RC requires increases of 10 to 15% in the total mixing water to guarantee the workability of normal concrete (NC). As a consequence, this extra water volume induces a decrease in the strength properties due to an excessively high W/C ratio. As a solution, various researchers have suggested complementing the

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Nomenclature

Notation

cNA	crushed natural aggregates
f_c	compressive strength
h_{abs}	water absorption of the different aggregates
NC	normal concrete
R	recycled replacement rate
RCA	recycled concrete aggregates
RAC	recycled aggregate concrete
rNA	rounded natural aggregates
W/C	water/cement ratio
w_{ad}	water volume due to additive
w_{agg}	water in aggregates due to absorption
W_{ef}	free or effective mixing water volume
w_m	added mixing water volume
w_{mc}	residual water in the mixing components
W_{total}	total mixing water volume

mixture with an equivalent volume of extra cement volume, i.e., 5 to15% [14,15,7], and following the theoretical rules of Lyse [16], who has demonstrated that mixtures of NC with the same W/C ratio yield similar strength properties and that the richness of the cement from the concrete mix does not induce increments in strength for the same W/C conditions [17].

However, the experiment conducted by Laserna and Montero [18] on concrete mixtures with equivalent W/C ratios indicates that the strength of the recycled concrete is clearly induced by the richness of the cement, especially for mixtures with high replacement ratios of RCA, i.e., R > 50%. Accordingly, they (Laserna and Montero) have suggested that the behavior of the recycled concrete conflicts with the findings of Lyse's experiment as it requires a specific mixture design. Thus, because the concept of effective water supposes the real available water involved in the cement reaction in the mixing, it is important to define the precise concept of effective water (W_{ef}) (Fig. 1) when developing recycled concrete mixtures.

It is evident that various studies [19,15,20] have underscored the importance of this concept regarding the workability and strength properties of the recycled concrete. Although the dosing recommendations for the RAC do not differ from the NC methodology [7], the particular porosity property of the RCA induces certain ideological nuances. One of the most common solutions entails offsetting the water absorption effect either by the pre-saturating or pre-drying of the RCA [21]. However, the final adaptation of these treatments to the current industrial process supposes a technical-economical non-viable solution. Other researchers have proposed increasing the water volume corresponding to the 30 min of RCA water absorption in the middle of the mixing process, similar to a lightweight aggregate [22,23].

Furthermore, different mixing alternatives have been studied to improve the strength of the recycled concrete. Otsuki et al. [24] and Vivian Tam et al. [25] agree that the best results are obtained using double-step mixing methods in which a pre-mixing step with the dry solid components (aggregates and binders) is conducted before adding the mixing water. However, the proposed mixing times in these methods are too short to obtain homogeneous recycled mixtures that, together with the higher water absorption of RCA, induces a quick decrease in the workability. Thus, Younis and Pilakoutas [26] suggest increasing the mixing time after the water is incorporated to improve the stability of the final consistency of the RC. However, they do not include the pre-mixing step of the cement with aggregates, as recommended by Vivian Tam and Tam [27]. This pre-mixing step of the cement with aggregates before any water is added strengthens the weak areas of the RCA as well as the interface connection between the aggregates and the new cement mortar. Accordingly, this step should never be avoided in any RAC mixing methodology.

Although the above methods achieved important improvements related to the strength properties of the RAC, they also include disruptions in the mixing process that supposes a low via-

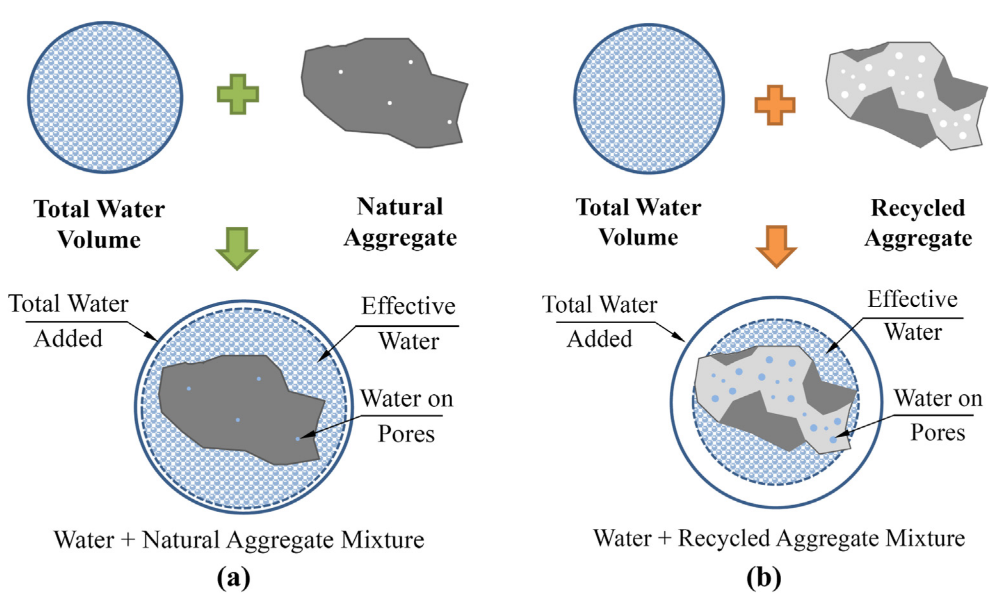

Fig. 1. Dynamics of effective water on normal concrete (a) and recycled concrete (b).