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Review

Prediction of the shrinkage behavior of recycled aggregate concrete: A review

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HIGHLIGHTS

- State of the art review on the effect of recycled aggregates on concrete shrinkage.
- Prediction models to determine the shrinkage strain of recycled aggregate concrete.
- Correction factors for shrinkage increase as a function of recycled aggregate content.
- The modulus of elasticity of recycled aggregates has a significant effect on shrinkage.
- All prediction models tend to overestimate the shrinkage strain of concrete.

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ABSTRACT

This paper provides a systematic literature review, based on the identification, appraisal, selection and synthesis of publications relating to the effect of incorporating recycled aggregates, sourced from construction and demolition waste, on the shrinkage of concrete. It identifies various influencing aspects related to the use of recycled aggregates such as replacement level, size and origin, as well as mixing procedure, curing conditions, and use of chemical admixtures and additions. A comparison between the shrinkage strain obtained experimentally and that calculated using existing models for predicting shrinkage is also presented. The results show that all prediction models analyzed in this paper tend to overestimate the shrinkage strain of concrete and would benefit from calibration in the form of short-term testing of an actual concrete to be used in a given project.

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1. Introduction

The increasing and unsustainable consumption of natural resources, along with the excessive production of construction and demolition wastes (CDW), has been the cause of great concern for the environment and the economy. In order to reverse this trend, there have been several efforts to promote the ecological efficiency in the construction industry, one of them being the reutilization of CDW in new constructions. By doing so, besides decreasing the amount of waste mass sent to landfills and the impacts of the extraction of natural resources, more value will be added to these materials, thus opening new market opportunities.

The global market for construction aggregates is expected to increase 5.2% per year until 2015, up to 48.3 billion tonnes [1]. In the USA, the Environmental Protection Agency [2] estimated that the generation of debris, from construction, demolition, and renovation of residential and non-residential buildings in 2003, was close to 170 million tonnes. According to Eurostat [3], the total amount of waste generated in the European Union, in 2010, was over 2.5 billion tonnes, of which almost 860 million tonnes belonged to construction and demolition activities.

Bearing this in mind, the use of recycled aggregates (RA) as replacement for natural aggregates (NA) in the production of concrete has been considered as one of the most salubrious approaches for recycling certain materials from CDW and thus contribute to greater sustainability in construction. Indeed, extensive scientific research and development work on this subject has been carried out over the last 40 years, some of which has concentrated on observing how the use of RA might influence the performance of structural concrete.

The scope of this investigation was to bring together, analyze and evaluate the published information on the effect of several factors related to the use of RA on the shrinkage of concrete. A statistical analysis was also performed on the collated shrinkage data from several studies, in order to comprehend the effect of introducing an increasing amount of RA on this property. Furthermore, these values were compared with those calculated using existing models to predict shrinkage, in order to learn whether these are sufficiently reliable or modifications are required.

2. Recycled aggregates sourced from construction and demolition wastes

According to existing specifications [4–19], there are three main types of RA arising from CDW, which, after being subjected to proper beneficiation processes in certified recycling plants, are suitable for the production of structural concrete; these materials are crushed concrete, crushed masonry, and mixed demolition debris.

Some of these specifications [8,13,14,16] have reached a consensus that, in order to be considered as recycled concrete aggregate (RCA), they must comprise a minimum of 90%, by mass, of Portland cement-based fragments and NA.

RA sourced from crushed masonry, or recycled masonry aggregates (RMA), may include: aerated and lightweight concrete blocks; ceramic bricks; blast-furnace slag bricks and blocks; ceramic roofing tiles and shingles; and sand-lime bricks [20]. RMA are composed of a minimum of 90%, by mass, of the summation of the aforementioned materials.

Aggregates acquired from mixed demolition debris, or mixed recycled aggregates (MRA), are a mix of the two main components obtained from the beneficiation process of CDW: crushed and graded concrete and masonry rubble. Some specifications [6,14] state that they are composed of less than 90%, by mass, of Portland cement-based fragments and NA. In other words, they may contain several other common CDW materials such as masonry-based materials.

3. Influencing factors in the shrinkage of recycled aggregate concrete

The shrinkage of concrete is basically the volume variation of a certain concrete product caused by the loss of water by evaporation, hydration of cement and also by carbonation [21]. However, it is a complex phenomenon influenced by many factors, including the constituents, the temperature and relative humidity of the environment, the age when concrete is subjected to the drying environment and the size and shape of the structure or member [22].

When concrete is exposed to a low relative humidity environment, the water in the capillaries, which is not physically bound, evaporates. This process induces internal relative humidity gradients within the cement paste structure that cause a movement of the water molecules from the large surface area of the calcium silicate hydrates (CSH) into the empty capillaries and then out of the concrete. The volume reduction caused by this phenomenon is known as drying shrinkage [21].

Apart from evaporation, the loss of water is caused by the binder's hydration reaction process. In the formation of CSH, the transference of moisture within the concrete causes a capillary depression mechanism, leading to autogenous shrinkage strain. This type of shrinkage is more noticeable in concrete with low water-binder ratio and with great cement content (e.g. high-performance concrete), in which, owing to its lower internal relative humidity, there is an even greater self-desiccation than in normal strength concrete [23].

While concrete is still in its plastic state, there may be loss of water by evaporation from the surface of concrete or by suction of dry concrete below. This phenomenon causes a volume reduction on the surface of concrete known as plastic shrinkage, which is proportional to the rate of evaporation/suction of water, which in turn depends on the air temperature, relative humidity, wind speed and concrete's temperature. The contraction induces tensile stress in the surface layers because they are restrained by the less-shrinking inner concrete, thus causing cracking at the surface [21].

The carbonation of concrete results in slightly increased strength and reduced permeability. In the presence of moisture,

Table 1
Correction factors to calculate shrinkage of RAC (adapted from Task Force of the Standing Committee of Spain [19]).

Source	Shrinkage correction factors	
	100% Coarse RCA	20% Coarse RCA
Belgium	1.50	1.00
RILEM	1.50	1.00
The Netherlands	1.35–1.55	1.00