



Creep strain of recycled aggregate concrete



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HIGHLIGHTS

- Analysis and evaluation of 9200 data matrix developed from 100 publications.
- Creep increases with recycled concrete aggregate (RCA) at a decreasing rate.
- A simple empirical method developed in estimating creep of RCA concrete.
- Methods to minimise creep of RCA concrete are proposed.

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ABSTRACT

Aimed at providing an in-depth study of globally published literature in the English medium on creep of concrete made with recycled aggregates, literature search establishing research published from 27 countries since 1984 undertaken and for its systematic analysis, evaluation and synthesis, 9200 data matrix developed. Of all the recycled aggregates those produced from crushed concrete, recycled concrete aggregates (RCA), have been vastly reported. It is shown that the creep of concrete increases at a decreasing rate with increasing coarse RCA, giving an average increase of 32% at 100% coarse RCA content. Factors influencing creep of concrete made with recycled aggregates, such as aggregate size and type, use of pozzolanic cements, water/cement ratio/design strength, curing and loading age have also been reviewed. The experimental creep coefficient data have been compared with the estimated values using selected prediction models. A simple empirical method developed from the globally published data is proposed for estimating creep of concrete made with coarse RCA. To make RCA more acceptable to specifying structural engineers and to improve its perception as a sustainable construction material that can be successfully used in practice, methods for making the creep of concrete made with coarse RCA similar to the corresponding concrete made with natural aggregates are also proposed.

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1. Introduction

Sustainability is a global trend that is used to promote and drive carbon footprint reduction in the concrete construction industry. To sustain this, requires a synergy between government departments, developers, design engineers, construction engineers, researchers and certifying authorities. Within this framework, the use of materials with less environmental impact, sustainable materials, particularly the recycled and secondary materials, is now considered increasingly important.

Approximately 820 million tonnes of construction and demolition waste (CDW) was generated in the EU-28 in 2012, which accounts for 32% of the total waste generated [30]. On a world

scale, this figure rises to 1.5 billion tonne per annum [18] and is predicted to increase further as sustainability is embraced and the three-fifth of the world seeks to rebuild its infrastructure to the standard currently enjoyed by the developed countries. Indeed, this growing potential resource has always been the key material to be recycled back in the construction industry. Indeed, with the national standards and specifications becoming more rational in their approach, the use of recycled aggregate (RA), arising from CDW, in the application of concrete is becoming acceptable, albeit slowly.

Whilst such a practice, in principle, answers the sustainability call, it is essential that RA should be used in a responsible manner taking into account its characteristics and how they may affect the performance of structural concrete. One such property is creep (time-dependent deformation under sustained load), particularly in pre-stressed concrete, which assumes importance in determining the stability of structures.

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Although there is general consensus in the literature that the use of RA would change the creep behaviour of concrete, beyond this the published information remains fragmented and the design engineer, as well as the Standards, remain sceptical on the use of recycled aggregates in structural reinforced and pre-stressed concrete.

2. Aim and objectives

The main aim of this study was to establish an insight into the globally published literature in the English medium on the effect of RA on creep of concrete and determine how this may be used in practice. Additionally, it was also intended that with identifying what is already known, this study would assist in minimising repetitive research and instead direct resources to what is needed.

In achieving the prime aim of the study, a series of objectives were set up, namely:

- (1) To provide an overview of the available literature on the effect of RA on creep of concrete.
- (2) To analyse, evaluate and synthesize the published data on creep of concrete made with RA that can assist to develop its use in practice.
- (3) To test the applicability of the existing creep models to concrete made with coarse RCA.
- (4) To propose an empirical method, based on the published data in the literature, for estimating creep of concrete made with coarse RCA.
- (5) To recommend possible measures for minimising creep of concrete made with coarse RCA.

3. Approach adopted

Limited to the English language, exhaustive literature search was undertaken using combinations of keywords defining and

elaborating the subject area considered, using many sources/search engines such as: American Concrete Institute/American Society of Civil Engineers/Institute of Civil Engineering Libraries, Engineering Village, Google, Google Scholar, ScienceDirect, Scopus, Springer Link, Taylor and Francis Online and Wiley Online Library.

The search yielded a total of 100 publications in the English medium originating from 27 countries over a period of 30 years since 1984 and these are given at the end of the paper under the heading of references. Since the entire information found in the sourced literature is used to develop 9200 data matrix for its systematic analysis, evaluation and synthesis, except for specific cases, references are not, as per the norm, cited in the text to avoid it becoming unnecessarily long-winded and cumbersome.

The recycled aggregates studies reported in the literature have been separated into four different types based on the main composition of the material [96] as noted below:

- (i) Recycled concrete aggregate (RCA): aggregates derived from crushed concrete.
- (ii) Recycled masonry aggregate (RMA): aggregates originated from masonry rubble.
- (iii) Mixed recycled aggregate (MRA): combination of RCA and RMA.
- (iv) Construction and demolition recycled aggregate (CDRA): aggregate derived from construction and demolition waste which has not been properly processed.

4. Overview of literature

Initial literature appraisal showed that three distinct groups provided information on creep of concrete made with recycled aggregate. Whilst vast majority of the literature was of experimental nature, 32% amounted to an expression of opinion either individually (as summarised in Table 1) or in the form of committee reports (Table 2).

Table 1
Compilation of main observations of studies of review nature, during 1986–2014.

Reference	RA size*	No. of papers**	Main observation
<i>(a) Recycled concrete aggregate (RCA)</i>			
Agrela et al. [3]	C	3	Creep of RAC is higher due to greater cement content
Anderson et al. [9]	C	n.a.	Creep of RAC is higher due to higher cement paste fraction. Creep of RAC is 20–40% higher than NAC
Balazs et al. [10]	n.a.	4	Creep of RAC is at least 40 higher than NAC
de Brito & Robles [19,20]	C	2	Creep of RAC increases with decreasing density and increasing water absorption of RCA
de Brito & Saikia [21]	C, F	15	Creep increases with the use of RCA
Hansen [41]	C, F	4	Creep of RAC is 40–80% higher than NAC due to adhered mortar of RA
Hansen [42]	C, F	6	Creep of concrete made with coarse and fine RA is expected to be much higher
Hendricks & Hendrichsen [43]	C	1	Creep of RAC is higher than NAC
Obla et al. [73]	C, F	1	Creep of RAC needs to be verified when more than 20% coarse RCA is used. Fine RCA adversely affects creep
PCA [78]	C, F	1	Fine RCA increases creep of concrete significantly
Rao et al. [82]	C, F	1	The combined of shrinkage and creep of RAC is unchanged
Safiuddin et al. [90]	n.a.	2	Creep of RAC is higher due to greater cement content
USACE [103]	C, F	n.a.	Fine RCA increases creep of concrete significantly
Vasquez [104]	C, F	3	The use of equivalent mortar volume method reduces the creep of RAC
Xiao et al. [107]	C	4	Creep of RAC is higher than NAC but it can be reduced with the use of high quality RA and slag
Xiao et al. [108]	C	9	Creep of RAC is 20–60% higher than NAC and it increases with increasing RCA content
<i>(b) Recycled masonry aggregate</i>			
Schulz & Hendricks [95]	C	1	RAC shows higher creep than NAC
Hendricks & Pietersen [44]	n.a.	n.a.	Creep of RAC is 15–40% higher than NAC
<i>(c) RCA or mixed recycled aggregate</i>			
CCAA [14]	n.a.	n.a.	RAC shows higher creep than NAC
<i>(d) RA type not specified</i>			
Behera et al. [11]	n.a.	7	RAC has higher creep due to increase of total mortar content which is contributed by adhered mortar of RA
Marinkovic et al. [67]	n.a.	2	For the same w/c, creep of RAC is increased up to 50%
Parekh & Modhera [75]	n.a.	4	Magnitude of RAC creep shall be taken care of. The use of fly ash reduces creep of RAC

RA: Recycled aggregate. RAC: Recycled aggregate concrete, NAC: Natural aggregate concrete, n.a.: Not available.

* C: coarse, F: fine.

** Number of references used in the review papers.

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