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A novel approach in modelling of concrete made with recycled aggregates

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ABSTRACT

The adhered old mortar paste of recycled concrete aggregates (RCA) plays an important role in production of new concrete with RCA and has positive environmental impacts. A larger number of research papers are available on the properties of concrete where different percentage of natural aggregates (NA) is being replaced by RCA. The outcomes of those research papers have shown that if the good quality of certain percentage (up to 30–50%) RCA is used; the properties of new concrete don't change when it is compared with concrete made from 100% NA. However, the properties of RCA vary significantly from its source to source. Therefore, it is very important to know the optimum level of RCA that can be used in new concrete. This paper conducted experimental and numerical studies to reveal the probable relationship between the parameters such as percentage of RCA replacement, water to cement ratio, aggregate to cement ratio, percentage of air content in the concrete mix and relate them to the mechanical strength of RCA concrete. Finally, automated neural network search (ANNS) analysis was applied to predict the mechanical strength of RCA concrete when other parameters were used as the inputs of the model. It is observed that proposed relation predicts the compressive and splitting strength of RCA concrete that closely matches the experimental results.

1. Introduction

In recent years, the cement industry, like the rest of the construction industry, is facing unprecedented challenges relating to energy resources, CO_2 emissions and the use of alternative materials like green cement, industry by-products, demolition waste etc. that can use ensure a sustainable built environment [1–3]. In this regard, recycled concrete aggregate (RCA) can be considered as a replacement for natural aggregate (NA) in concrete structures to improve the sustainability in our current construction practices. RCA is usually considered as a doubled phase material comprising of the original natural aggregate (NA) and the adhered residual mortar. Thus, there are two types of interfacial transition zones (ITZs) in RACs: one, the old ITZ between the original natural coarse aggregate (NAC) and the adhered mortar; and the second one between the new mortar and the RCA [4]. As a result of high amounts of adhered mortar content in RCA, high water absorption, low density, low specific gravity, and high porosity properties are usually observed compared to NA [5]. In addition, some procedural problems, including weak ITZs between cement paste and aggregate, porosity and traverse cracks within demolition concrete, high level of chemical impurities such as sulphate and chloride contents, poor grading, and high variations in quality also make the usages of RCA quite difficult in building practices. It is therefore believed that adhered mortar is the main cause of the lower properties of the RCA compared to the NAC [6].

Literature reveals, vast amount of publications on RCA that dealt with physical, mechanical and durability properties of concrete when RCAs were partially or fully replaced with NA in production of new concrete [7–13]. A study by the American National Ready Mix Concrete Association (NRMCA) has concluded that up to 10% RCA is suitable as a substitute for NA for most concrete applications, including structural concrete [14]. UK research recommends that up to 20% RCA can be used for most applications including structural concrete [15]. Australian guidelines state that up to 30% RCA can be used for structural concrete without any noticeable difference in workability and strength compared with NA [16]. The Dutch standard allows up to 20% replacement of NA with RCA without a need for additional testing, for all concrete up to a characteristic strength of 65 MPa and all relevant environmental classes [17]. From these above standards and guidelines, it is perceived that certain amount of RCA can be used in production of new concrete for structural application [18]. However, there is a need to model the influence of replacing different percentage of RCA on its mechanical performance, so that the final quality can be improved. In this regard, our current study firstly aims to find out the limit of RCA

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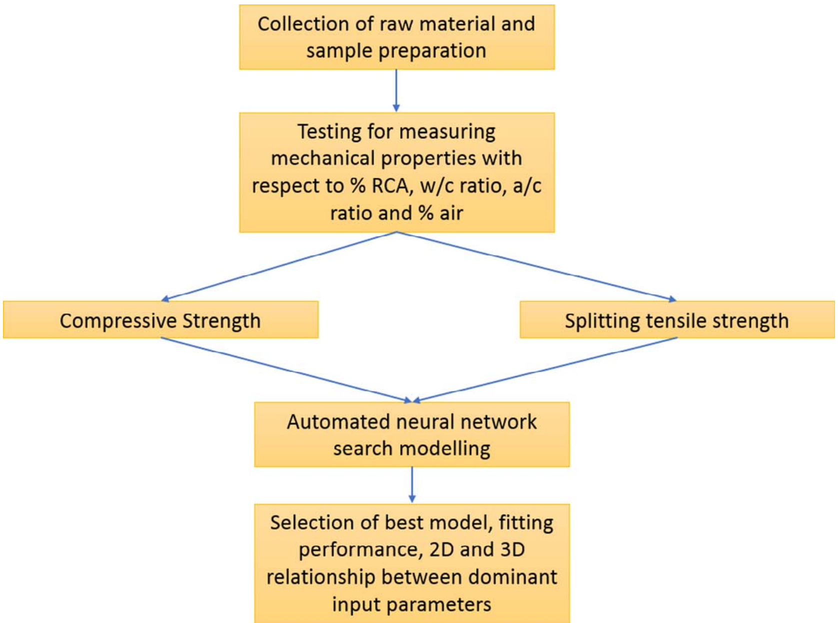

Fig. 1. Procedure of modelling mechanical properties of recycled concrete.

Table 1
Properties of NA and RCA.

Aggregate type	Relative density	Aggregates crushing value (%)	Flakiness index	Water absorption (%)
NA	2.72–2.75	11	25	0.52–0.65
RCA	2.63–2.77	10.8–12.5	18–21	1.67–5.25

Table 2
Material compositions for different mixes.

	Materials compositions (kg/m^3)				
Mix	Cement	NA	RCA	Sand	Water
RCA 0	292–333	1006–1076	0	821–960	175–183
RCA 15	292	855	146	960	175
RCA 30	292–333	503–753	322–486	821–960	175–183
RCA 50	292	704	292	960	175
RCA 100	292–333	0	968–973	821–960	175–183

that can be mixed in concrete with NA without any changes in the properties. Secondly, to develop a modelling tool using automated neural network search (ANNS) that can be used to predict the strength development in concrete when certain percentages of NA are being replaced by RCA. The water to cement ratio (w/c), aggregates to cement ratio (a/c) and percentage of air in the fresh concrete mix are also considered to predict the strength of RCA. These parameters are considered to be the important for both mechanical and durability properties of concrete which never been highlighted in prediction of mechanical strength of concrete containing RCA. The objectives were assessed through examining the aggregates properties such as relative density, crushing value, water absorption capacity and the fresh and hardened concrete properties of concrete which contains RCA as a constituent. The procedure involving the experimentation planning and the modelling mechanical properties with respect to four inputs is shown in Fig. 1. Motivations for adopting recycled concrete as an aggregate source include the preservation of natural resources, effective utilization of the growing waste stream and financial and energy savings.

Table 3
Input and output parameters for ANNS modelling.

Input parameters				Output parameters	
% RCA	w/c ratio	a/c ratio	% air	Comp. strength (MPa)	Split. strength (MPa)
0	0.60	6.73	4.5	35.7	3.7
0	0.60	6.73	4.1	33.5	3.8
0	0.60	6.73	5.8	26.6	3.8
0	0.55	5.70	2.2	42.5	3.2
0	0.50	5.46	2.2	42.5	3.8
0	0.50	5.46	1.8	50.7	3.8
0	0.51	5.31	1.5	43.4	2.7
15	0.60	6.72	4.5	36.5	4.0
15	0.60	6.72	4.2	31.9	3.5
15	0.60	6.72	5.4	28.9	3.4
30	0.60	6.67	4.9	32.9	3.6
30	0.60	6.67	4.2	33.2	3.6
30	0.60	6.67	5.7	27.8	3.2
30	0.55	5.70	2.2	47.8	3.2
30	0.50	5.46	2.4	46.1	3.6
30	0.50	5.46	1.4	47.5	3.4
50	0.51	5.19	1.4	45.2	3.2
50	0.60	6.70	4.9	36.0	3.7
50	0.60	6.70	4.9	34.5	3.6
50	0.60	6.70	7.8	27.5	3.0
100	0.60	6.62	5.5	35.4	3.5
100	0.60	6.62	5.9	34.9	3.5
100	0.60	6.62	7.4	30.2	3.3
100	0.55	5.37	2.2	39.0	3.2
100	0.50	5.21	2	41.2	3.2
100	0.50	5.21	1.3	47.1	3.4
100	0.51	5.07	1.3	45.7	2.8

2. Material and methods

2.1. Experimental design

In this study, RCAs were collected from the different sources of construction and demolition waste (C & DW) site in the Western Cape region of South Africa. A reference concrete was also made from 100% NA and assigned it as RCA0. After collecting RCAs, all the impurities such as wood, ceramic, glass, steel wire, etc. were removed manually. A laboratory jaw crusher machine was used to crush the RCAs for desire size. After crushing, different sieve sizes were used to sieve the