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Model for mix design of brick aggregate concrete based on neural network modelling

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HIGHLIGHTS

- Exploring the possibility of predicting RBAC compressive strength with neural network modelling.
- Investigation of concrete components variation effects on the concrete compressive strength.
- Development of mix design model for concrete made of recycled brick aggregate.

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ABSTRACT

This article proposes an optimized quantitative model for proportioning concrete mixtures based on cement content, water-cement ratio and percentage of recycled aggregate replacement according to preffered recycled brick aggregate concrete (RBAC) compressive strength. A database compiled from 147 experimental tests of RBAC compressive strength was processed by neural network modelling to achieve a reliable prediction, which was investigated by three-fold validation. The performance of the representative neural network model was verified by parametric analysis with a brief review of the influence of each RBAC component. The focus of the main results is enhancement of the neural network modelling results and consequently new interpretation and conceptualisation for theoretical advancement and practical applied research on RBAC concrete content.

1. Introduction

Use of recycled materials as replacement for natural aggregate in concrete is of paramount importance due to the environmentally friendly aspect of their re-use. Crushed clay bricks and clay roof tiles as alternative aggregates have particular significance as their use in this fashion can considerably reduce the problem of waste storage as well as help in the preservation of natural aggregates [1]. Therefore, recycled brick aggregate concrete (RBAC) is an interesting, environmentally friendly material with unknown properties that need to be investigated.

Numerous studies have been performed to evaluate the potential applications of crushed brick as an aggregate. Debieb and Kenai [1] used coarse and fine crushed bricks and reported a reduction in compressive strength of RBAC concrete from 20% to 30%, depending of the degree of substitution. Cachim [2] concluded that crushed bricks can be used as natural aggregates with substitution up to 15% without any loss in compressive strength of concrete; however, for 30% natural aggregate substitution, there is a reduction of concrete properties (up to 20%, depending on the type of brick).

Other authors [3,4] have found that crushed brick aggregate concrete has a relatively lower strength at early age than normal aggregate concrete. They attributed this characteristic to the higher water absorption of crushed brick aggregate compared to gravel, which was used as the control aggregate. The compressive strength is lower for crushed brick concrete; the higher the rate of substitution normal aggregate with brick, the lower the compressive strength. The use of bricks as concrete aggregate caused a 40% reduction in compressive strength [5,6]. Concrete produced with these aggregates did not perform as well as concrete produced with natural aggregates in terms of strength. Strength properties of specimens with crushed brick aggregate are lower compared to the same properties for the reference mixtures with natural aggregate. Results of experimental investigations in [7]

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revealed lower compressive strength of concrete with recycled brick aggregate. These results are expected due to the lower grain hardness of a crushed brick/tile aggregate compared to a river aggregate. However, the concrete still has sufficient strength to make it suitable for some applications, with the added benefit that density values are much lower, making it suitable in situations where self-weight is a problem [3]. Poon and Chan [8,9] observed that incorporation of 20% fine crushed brick aggregate decreased the compressive strength and modulus of elasticity of concrete by 18%. Aliabdo [10] indicated that the highest reduction in compressive strength due to the presence of recycled aggregate is associated with the highest cement content at a comparable replacement level.

The main inference from previous studies is that using crushed brick aggregates as alternative reduces concrete compresive strength. These relationships between components and concrete properties cannot be demonstrated with a mathematical formula, and this knowledge is imperative for optimizing the quantities of components used in the manufacture of RBAC. In this aspect, numerical modelling for such relationships was accomplished by designing an artificial neural network model (ANN) of concrete compressive strength.

ANN modelling has been widely used for prediction of concrete properties with natural aggregates [11–21]. Nevertheless, few studies focused on modelling the compresive strength of concrete containing recycled aggregate. Topçu and Sarıdemir [22] completed a trial that used ANN to predict the compressive and splitting tensile strengths of recycled aggregate concrete (RAC) containing silica fume. Duan [23] demonstrated the possible applicability of ANNs to predict the compressive strength of RAC obtained from old buildings or pavements containing small amounts of soft soils, natural stones, clay bricks, and other impurities like paper, wood, glass, tiles, and metals. Dantas [24] used ANN models to predict compressive strength at 3, 7, 28, and 91 days of concrete containing construction and demolition waste (i.e., mortar, concrete, red ceramic, and other recycled materials).

The literature review, as discussed above, reveals that no research has been undertaken on the use of ANN to predict the compressive strength of concrete made only of recycled brick aggregate.

So far, research involving ANN models has mainly aspired to gain insight into the possibility of predicting as well as elucidating the relationship between concrete components and concrete properties, with the main emphasis on performance measures. The intention of this paper is not to characterize the statistical measures of neural network prediction, but rather to provide a representative model for RBAC compressive strength from the perspective of concrete content based on parametric analysis.

Consequently, the main issues of the study can be stated as:

- To explore the possibility of predicting RBAC compressive strength;
- To examine the parametric analysis of and investigate how concrete components' variation influences concrete compressive strength;
- To develop a model for defining concrete content made of recycled brick aggregate for required concrete compressive strength.

2. Experimental database

Regardless of the numerous experimental studies on recycled aggregate concrete, there is no algorithm for defining concrete compressive strength. Furthermore, experimental tests are quite expensive: testing one mixture costs approximately €6125 [25]. To resolve these issues, we attempted to establish the relationship between concrete compressive strength of RBAC and general concrete components by collecting test data.

The collected experimental database contains data from 147 published tests (Table 1). Database parameters were selected according to all available data samples. However, some parameters were excluded as they were not available for the entire database (admixture). Several of the latest research studies on RBAC concrete used a large experimental database with no modification to the replacement ratio of brick aggregate [26–28]. Therefore, these data are not applicable for the present study.

The concrete mixture components were the input data parameters: cement, w/c ratio (w/c), crushed tile ratio (CT), crushed brick ratio (CB), and natural aggregate (NA) ratio. Physical and mechanical properties of crushed bricks and tiles from various studies are shown in [1–10]. The main conclusion that can be drawn regarding the individual effect of specified parameters is that the type or quality of clay aggregate (i.e., brick or tile) used in this investigation can be neglected.

Total aggregate ratio was 100% according to the following equation:

$$CT[\%] + CB[\%] + NA[\%] = 100[\%] \quad (1)$$

Furthermore, each aggregate partition was divided into two sub-parts: fine (0–4 mm) and coarse aggregate (4–16 mm). In accordance with this division, the experimental database has eight input parameters. For evaluation of the performance of recycled brick aggregate, it is necessary to estimate the compressive strength of concrete. According to the availability and uniformity of data in the experimental database, compressive strength at the age of 28 days was used as the output parameter. The general distribution of input and output data is presented in Table 2, and the complete database with all data is provided in Appendix. Minimum and maximum values of input parameters in the experimental database were chosen based on the literature review and results of experimental investigations by the authors of this paper [1–10]. Maximum w/c ratio is 1,08 based on the research [1], in which has been decided to carry out the research project at a constant workability (slump between 60 and 70 mm), and

Table 1
Experimental database of RBAC: list of authors and samples (see Appendix for complete database).

Author	Year	No. of samples	Aggregate type	Refs.
Miličević	2011	62	Crushed brick and tile	[7]
Debieb & Kenai	2008	12	Recycled brick and limestone	[1]
Khalaf & DeVenny	2004	9	Crushed brick	[3]
Rühl & Atkinson	1999	2	Recycled brick	[4]
Khatib	2005	5	Recycled brick	[6]
Cachim	2009	10	Recycled brick	[2]
Poon et all -I	2007	3	Recycled brick and tile	[8]
Poon et all -II	2007	4	Recycled brick and tile	[9]
Topçu & Canbaz	2007	18	Crushed brick	[5]
Alibdo et all	2014	22	Crushed clay brick	[10]