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Case study

Development of rubberized geopolymer interlocking bricks

Bashar S Mohammed[a,*], Mohd Shahir Liew[a], Wesam S Alaloul[a], Amin Al-Fakih[a], Wadhah Ibrahim[a], Musa Adamu[a,b]

[a] *Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia*
[b] *Department of Civil Engineering, Bayero University Kano, PMB 3011, Kano, Nigeria*

A R T I C L E I N F O

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A B S T R A C T

Waste tires contribute badly to the environment on a huge scale as they are bulky, non-biodegradable, and prone to fire and being a shelter for mosquitos and other insects. This paper reports on a novel approach towards the development of rubberized brick by utilizing crumb rubber as the sole fine aggregate in the production of geopolymer interlocking bricks. The response surface methodology (RSM) from Design Experts software has been used to determine the numbers of trial mixes and their corresponding ingredients. A total of thirteen trial mixes were carried out and tested for compressive strength and the RSM model was developed to predict the design mix based on the targeted compressive strength. The mix design was obtained to be an 18 M for NaOH and 0.8 solution to fly ash ratio. The geopolymer interlocking rubberized bricks were then produced and tested for compressive strength, dimension, modulus of rupture, water absorption, initial rate of absorption, and efflorescence. The geopolymer interlocking rubberised bricks presented a low compressive and flexural strength and a high-water absorption capacity. The bricks were rated as non-effloresced and classified as 3rd class bricks which can be used as non-load bearing material. It is recommended to utilize nano silica in order to increase the strength of the brick.

1. Introduction

The disposal of scrap tyres is considered as one of the most critical environmental problems worldwide due to its multiple disadvantages. The tyres are non-biodegradable even after a long period of landfill treatment [1,2]. Additionally, they are bulky with a 75% voided volume that provides breeding areas for mosquitoes and rodents [3,4]. Another problem associated with piles of scrap tyres, in case of fire, is the tremendous difficulty in putting out the fire, which will release huge amounts of thick smoke, CO_2, and toxic materials and which may heavily impair the environment [5]. However, natural aggregates could be used to deal with these issues. Unfortunately, the shortage of natural aggregates in the growing infrastructure industry has created the problem of depleting natural resources which has led to the need for artificial aggregates. Fortunately, artificial aggregates can be made out of materials which are considered waste and pollutants of the environment Consequently, the production of artificial aggregates solves two problems; it conserves the environment from pollution and prevents natural resources from depletion, thereby giving way to sustainable development and allowing the growth of eco-sustainable building [6]. Moreover, The compressive strengths of mixes containing artificial aggregates are better than those shown by mixes containing natural aggregates [7].

Therefore, recycling of the scrap tyre ingredients to produce or modify useful products or materials would be a viable solution. In the concrete industry, crumb rubber (CR) particles from scrap tyres have been used as partial replacement of fine aggregates,

* Corresponding author.
E-mail addresses: bashar.mohammed@utp.edu.my (B. S Mohammed), madamu.civ@buk.edu.ng (M. Adamu).

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producing rubbercrete [8,9]. Despite its multiple advantages, rubbercrete exhibits low mechanical properties and durability which is limiting its wide use in the construction industry [10,11]. CR has also been used for the production of hollow blocks to improve properties such as thermal conductivity, electrical resistivity, and sound absorption [12]. Therefore, to achieve an acceptable strength, more cement should be added to the rubbercrete mixture or specific treatments should be carried out on the CR particles. However, cement is concrete's main ingredient which is considered as environmentally un-friendly where the production of cement consumes a great amount of energy and emits significant amounts of carbon dioxide (CO_2) and other greenhouse gases [13]. Studies show that 4 GJ of energy is required to produce one tonne of cement and cement clinker manufacture releases approximately one tonne of (CO_2) into the atmosphere [14]. Moreover, production of one tonne of cement consumes about 2.8 tonnes of raw materials, including fuel and other natural resources [15].

The production of the geopolymer binder (cement-less binder) has gained huge interest amongst researchers because of the environmental benefits, such as the reduction in the consumption of natural resources and the decrease in the production of CO_2 [16]. Geopolymer contains fly ash as the source materials and an alkaline activator solution where the common soluble alkaline activator used in developing geoplolymer is sodium hydroxide (NaOH) combined with sodium silicate (Na_2SiO_3) [17]. In order to produce a dry mix of the geopolymer binder, the solid ingredients are mixed for three minutes and then, the liquid ingredients are added to the mixture followed by wet mixing for another four minutes [18,19]. Mustafa Al Bakri, et al. [20] have indicated that the sodium hydroxide (NaOH) molarity and the ratio of sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH) influence the compressive strength of the fly ash-based geopolymer pastes. Whilst, Manjunath and Giridhar [21] have reported that the solution to fly ash ratio and sodium hydroxide influence the compressive strength of the geopolymer pastes based on fly ash.

The geopolymer binder exhibits great advantages, including high compressive strength at an early age, high resistance to fire, good resistance to chemical attack, and low permeability [22]. Moreover, depending on the type of binder and type of pelletisation, etc., it is possible to produce artificial aggregates of satisfactory physico-mechanical properties for concrete-based facilities of average performance [23]. In order to expedite the production process and minimise the cost of casting, a dry mix of geopolymers is used [24]. Therefore, this paper has utilized a dry mix geopolymer as the binder and crumb rubber to produce geopolymer interlocking rubberized bricks.

2. Mix design of geopolymer using response surface methodology

Response surface methodology (RSM) is one of the commonest available mathematical and statistical methods for analyzing and developing models between a single or more variables and the dependent variables (responses) [8,25]. RSM can be used for several applications and different areas of knowledge. In concrete technology, RSM has been utilized to develop mechanical properties models and determine the optimized mixture proportions for rubbercrete [26]. Mohammed et al. [27] developed models for predicting the compressive strength of concrete containing paper mills as a fine aggregate. In another study, Mohammed, et al. [28] used the RSM to develop mix design models for self-compacting engineered cementitious composites (SC-ECC).

The development of dry mix designs of geopolymer has the potential to get the solution to fly ash ratio required to achieve the targeted compressive strength where crumb rubber particles are utilized as the aggregate to develop the geopolymer rubberized interlocking bricks. A statistical software called Design of Experiment was used for the RSM analysis. The face centered central design (FCCCD) type available in the RSM has been used to suggest reasonable trial mixes in order to achieve the target compressive strength in the final product; as a result, 13 runs have been obtained as shown in Table 1. The amount of fly ash and crumb rubber was fixed to be in an equal amount (1:1 ratio) and the activator solutions (sodium hydroxide (NaOH) to sodium silicate (Na_2SiO_3) ratio to be 1:3, respectively, as proposed by the RSM software for the targeted strength of 4 MPa. Then, three cubes from each trial mix were tested for compressive strength according to the requirements of the standard test method (ASTM C67-14).

Table 1
Mix proportions based on design runs from RSM.

Run	Solution/Fly Ash	NaOH Molarity (M)	Fly Ash (kg/m^3)	Crumb Rubber (kg/m^3)	Alkaline Solution (kg/m^3)	NaOH (kg/m^3)	NaSiO3 (kg/m^3)
1	0.6	8.343146	250	250	150	37.5	112.5
2	0.6	19.65685	250	250	150	37.5	112.5
3	0.4	10	250	250	100	25	75
4	0.882843	14	250	250	220.7107	55.17767	165.533
5	0.6	14	250	250	150	37.5	112.5
6	0.8	18	250	250	200	50	150
7	0.6	14	250	250	150	37.5	112.5
8	0.8	10	250	250	200	50	150
9	0.6	14	250	250	150	37.5	112.5
10	0.4	18	250	250	100	25	75
11	0.317157	14	250	250	79.28932	19.82233	59.46699
12	0.6	14	250	250	150	37.5	112.5
13	0.6	14	250	250	150	37.5	112.5