Construction and Building Materials 173 (2018) 600–614

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Green interlocking paving units

A.O. Sojobi [a,*], O.J. Aladegboye [b], T.F. Awolusi [c]

[a] Architecture & Civil Engineering Department, City University of Hong Kong, Hong Kong, China
[b] Department of Civil Engineering, Landmark University, Kwara State, Nigeria
[c] Department of Civil Engineering, Ekiti State University, Ekiti State, Nigeria

HIGHLIGHTS

- Ultra, lightweight paving units were produced with sawdust and laterite.
- The paving units can be used in low-traffic buildings and pedestrian walkways.
- Optimum sawdust content of 10% is recommended with 90 curing days.
- Preferable order of curing media: water > laterite > alkaline > acid.
- ANN model prediction efficiency of compressive strength is very good.

ARTICLE INFO

Article history:
Received 11 July 2016
Received in revised form 5 April 2018
Accepted 7 April 2018

Keywords:
Artificial neural network
Bulk density
Compressive strength
Curing media
Durability
Green interlocking paving units
Laterite
Sawdust
Skid resistance
Elevated temperature

ABSTRACT

Our research produced ultra-lightweight green interlocking paving units through combined usage of sawdust and laterite as partial cement and fine aggregate replacements respectively. Interlocking paving units, water-cured for 90 days at optimum 10% sawdust content, achieved compressive strength of 16.6 MPa and skid resistance of 64.5 PVT, which exceeded the minimum requirements of 3.45–15 MPa and 45PVT respectively. The developed ANN model was classified as very good in terms of prediction efficiency of compressive strength (CS) and skid resistance for different curing media based on Nash & Sutcliffe criterion of efficiency (NSE). However, the prediction efficiency for CS was better than SR in terms of NSE, root-mean-square error (RMSE) and mean-square error (MSE), and was able to capture the interactive effects of considered factors. In line with ANN results, CS and SR increased with curing age but decreased with increasing sawdust content. In terms of durability performance and compressive strength development, the preferable order of curing media is water > laterite > alkaline > acid. Multi-criteria evaluation of ANN models is recommended for better interpretation of model efficiency.

1. Introduction

Globally, there is increasing demand for sustainable, cost-effective and durable materials in the construction industry to support eco-friendly and green construction [1,2].

Waste recycling has been recognized as one of the viable means to achieve such noble objectives albeit without compromising construction standards [3,4]. Such approach supports circular economy, promotes conservation of natural resources, encourages resource efficiency and is crucial in reducing the environmental footprint of the energy-intensive construction industry [5,6].

However, the sustainable adoption of green concrete by the construction industry is slow and therefore requires effective, concerted and continuous collaborations among built-environment professionals and decision-makers in the construction industry value chain [7,8]. Their slow adoption in the construction industry is attributed to perceived low strength and durability as well as difficulty in using them for tall buildings [9]. Furthermore, there is inadequate infrastructure to collect and recycle these wastes in developed countries.

The green waste materials remains a green-field with enormous environmental benefits as shown in Table 1.

2. Literature review and significance of study

2.1. Literature review

Several research efforts advocate for the utilization of local available materials in construction [7,15]. The locally available

* Corresponding author.
E-mail address: aosojobi2-c@my.cityu.edu.hk (A.O. Sojobi).

https://doi.org/10.1016/j.conbuildmat.2018.04.061
0950-0618/

Nomenclature

CS	compressive strength
CS_{28}	28th-day compressive strength
CS_{60}	60th-day compressive strength
CS_{90}	90th-day compressive strength
HCl	hydrochloric acid
HSC	high-strength concrete
UHSC	ultra, high-strength concrete
NSC	normal-strength concrete
LSC	low-strength concrete
MSC	medium-strength concrete
LWC	lightweight concrete
ULWC	ultra-lightweight concrete
NWC	normal-weight concrete
ANN	artificial neural network
NSE	Nash & Sutcliffe coefficient of efficiency
MSE	mean square error
RMSE	root mean square error
ANOVA	analysis of variance
IST	initial setting time
FST	final setting time
SD	sawdust
GIPU	green interlocking paving units
IPU	interlocking paving units
GGBS	ground granulated blast furnace slag
RHA	rice husk ash
SR	skid resistance
MPE	mean prediction error
PVT	pendulum test value

Table 1
Green, eco-friendly waste material and benefits.

Authors	Type of wastes	Name of waste	Generating industry	Potential benefits
Siddique, et al. [10]	Industrial	Spent foundry sand	Metal casting/metallurgical industry	US$ 1.06/at 20% sand replacement
Yu, et al. [11]	Industrial	Ultra-HVFA	Coal thermal power plant	15% reduction in material cost at 80% cement replacement; reduction of 70% CO_2 emission and reduction of >60% embodied energy
Zeyad, et al. [12]	Agricultural	Ultrafine Palm-oil fuel ash	Palm oil mills industry	Reduction of slump loss, improved workability, high CS_{28} & improved service life
Khan, et al. [4]	Agricultural	Rice husk ash	Rice milling industry	14.2% reduction in construction cost & 31.5% reduction in cement cost at 25% cement replacement
Topcu and Canbaz [13]	Municipal	Waste glass (WG)	Post-consumer glass	1–2.8% reduction in concrete cost at 60% WG as coarse aggregate
Rebeiz and Craft [14]	Municipal	Plastic waste	Post-consumer plastic wastes	Improved fire resistance; fast curing time
Raut and Gomez [9]	Agro-industrial wastes	Waste glass, palm oil fly ash, oil palm fibres & quarry dust	Local waste yard, oil palm industry & quarry industry	Low thermal conductivity and reduced dead weight of structure

construction materials include laterite, clay, bamboo and have been found useful in construction of foundations, floors and floor tiles, walls and roofing sheets.

Compared to conventional materials, such locally available materials are cheaper and abundantly available. Their effective and judicious utilization has the potential to reduce construction costs, increase strength and durability of structures, improve self-sufficiency and accelerate achievement of sustainable development [16] (Danso, 2013). In addition, re-engineering of their properties is required to mitigate their natural defects for construction applications [17].

Previous studies have shown that sawdust concrete and laterized concrete improved fire resistance, enhanced durability and shrinkage reduction and improved cracking and spalling resistance [7,18].

2.2. Significance of study

This research study supports green construction which involves *building more with less*. Building more with less implies reduction of virgin material usage in design and construction, reduction of embodied energy in construction through the use of less-energy intensive materials and improved construction methods.

Also, our research also fills some gap in literature caused by paucity of research on alternative lightweight fine aggregates to replace conventional sand in concrete. Promotion of such applications can has the potential to reduce construction costs and improve durability of concrete structures as reported by experts [8].

Also, our research also showcases the durability performance of the green interlocking paving units in various media (water, laterite solution, HCl and alkaline) and at different elevated temperature from 200 to 1000 °C, which is often scarce in literature.

Furthermore, skid resistance of the concrete interlocking paving units in wet condition and in different curing media was investigated owing to its crucial importance in safety for pavement applications as highlighted by experts [19,20]. Skid resistance study is also important to reduce accident frequency and severity.

In addition, artificial neural network (ANN) was also used to investigate the interactive effects of the various considered factors. ANN has been known as an effective approach for nonlinear multivariate modeling and has the ability to learn from historical data. Likewise, the application of ANN in civil engineering research has recorded a number of successes [21,22].

Therefore, this study aims to showcase the mechanical performance of green interlocking paving units using sawdust waste as alternative fine aggregate and laterite as partial replacement of sand. The objectives of the study are:

1. Evaluate the fresh concrete properties of green interlocking paving units
2. Evaluate the compressive strength of green interlocking paving units at ambient temperature