Applied Mathematical Modelling 38 (2014) 853–863

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

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

The use of optimisation for enhancing the development of a novel sustainable masonry unit

H.M. Vu, J.P. Forth *, D.V. Dao, V.V. Toropov

School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK

A R T I C L E I N F O

Article history:
Received 13 October 2009
Received in revised form 15 May 2013
Accepted 4 July 2013
Available online 22 July 2013

Keywords:
Empirical model building
Optimisation
Design of Experiments
Bitublock
Crushed glass

A B S T R A C T

This paper examines whether it is possible to utilise optimisation techniques to enhance the efficiency of the experiment-based development of a new product. Conventionally, a laboratory-based experimental investigation requires to check all combinations of all independent parameters describing the product; hence the optimum levels of the tested parameters is obtained. As a result there may be many thousands of samples produced to optimise these parameters; this is a time consuming, costly and laborious process. Instead, it is suggested that an empirical model is established and validated using the results of the laboratory investigation making it suitable for optimisation.

In this paper the empirical model describes the compressive strength of a new masonry unit (bitublock) in terms of two parameters that are the proportion of the coarse aggregate and the compaction pressure. The expression for the compressive strength obtained from all experimental data was optimised showing a similar result to that from an experimental investigation. A much reduced set of experimental data was then used to establish further empirical models. The predictions from these models were compared with the output from the full set of experimental data to assess the accuracy of these empirical models and arrive at recommendations for the reduction of an experimental programme for future studies.

From the experimental investigation alone, the optimal compressive strength (35.82 MPa) of the new unit was obtained from a mix containing 30% coarse aggregate compacted at 24 MPa. Empirical modelling using only half of the original experimental data predicted that a coarse aggregate content of 31.95% and a compaction pressure of 21.73 MPa would provide an optimum compressive strength of 35.95 MPa. This shows that the use of optimisation techniques can improve the efficiency and economy of laboratory investigations and also has a potential to provide economies during future scaling-up and manufacturing processes, e.g. in this case, by reducing compaction pressures.

1. Introduction

This paper examines whether it is possible to utilise empirical modelling and optimisation techniques to reduce the amount of experimental data required to develop a new product.

A range of novel masonry unit is being developed to possess properties which match or exceed current existing coarse aggregate concrete block products. These properties have to be evaluated based on a number of parameters, e.g. grading of material, mix composition, curing, etc. Traditionally, the effect of these parameters will be studied experimentally in a laboratory and as a result there may be many thousands of samples produced to optimise these parameters.

* Corresponding author.
E-mail address: j.p.forth@leeds.ac.uk (J.P. Forth).

0307-904X/$ - see front matter © 2013 Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.apm.2013.07.026

Conventionally, a laboratory-based experimental investigation requires to check all combinations of all independent parameters describing the product; hence the optimum levels of the tested parameters is obtained. This is a time consuming, costly and often laborious process that also depends on the skill and experience of the investigator as there may be errors introduced.

However, once the set of parameters and the governing properties of the product are identified it is potentially possible to reduce the scale of the laboratory investigation (i.e. the number of tests) by planning the laboratory tests according to an advanced Design of Experiments (DOE) followed by an empirical model building and optimisation.

The paper, therefore, suggests an experimental strategy in which it is recommended to initially use a rather limited set of samples to build a mathematical model, use it explore the space of the parameters and identify a promising region in the parameter space. This initial stage should then be followed by a second stage where additional experimental samples with the parameters covering the identified region are tested. This allows rebuilding the analytical models using the new data and hence produce more accurate results. This strategy allows to considerably reduce the total number of experimental samples in comparison to the conventional uniform coverage of the whole space of parameters. This investigation trials the approach presented above. Also, a baseline empirical model is built using all the available experimental data in order to provide a basis for comparison of all developed strategies.

Section 1.1 provides the background to the new masonry unit and presents results of the experimental optimisation of the compressive strength in terms of the parameters of coarse aggregate contents and compaction pressure. It is then followed by a section which describes the empirical model building and validation as well as the optimisation approach adopted in this investigation.

1.1. Background to the novel masonry unit

The new masonry units being developed are considered innovative as they do not use traditional binders (cement or clay) or aggregates (limestone, sand) but alternative binders (in this case bitumen) and 100% waste aggregates, such as crushed glass (CG), incinerated bottom ash (IBA) and pulverised fuel ash (PFA). The unit is required to possess physical properties which are at least equivalent to current coarse aggregate concrete blocks as well as class C and some of class B clay bricks. The unit has been developed in stages i.e. initially only an alternative binder was introduced and traditional aggregates (limestone, sand and china clay) were utilised. As the intention was to utilise waste aggregates, these mixes acted as control mixes to observe any change in physical properties when the traditional aggregates were replaced.

The experimental procedure adopted for manufacturing of the new unit [1–3] is not discussed in detail in this paper; here the focus is only on the results of the tests examining the effects of several parameters on the properties of the different units. Previously it has been shown that two of the major parameters affecting the performance of the new unit are the percentage of coarse aggregates and the compaction pressure and that the primary property indicator of the new unit is the compressive strength. The present study is therefore aimed at optimising the crushed glass contents and the compaction pressure of the mixes with 100% replacement waste aggregates to maximise the compressive strength property.

2. Experimental investigation

2.1. Materials

Typical properties of the materials used in this research are summarised in Table 1 and their gradation is plotted in Fig. 1.

Initially, as mentioned before, traditional materials were used to produce the control mixes. Limestone was used as the coarse aggregate (>2.36 mm) and concrete sand as the fine aggregate (2.36–0.075 mm). China clay acted as the filler (<0.075 mm).

For the control mixes the maximum limestone particle size was 8 mm. This was to ensure that the surface of the units would be sufficiently smooth and suitable for manual handling. The waste aggregates were introduced in stages. Initially,

Table 1
Typical properties of materials used in investigation.

Materials	Bulk density (g/cm^3)	Particle density (g/cm^3)	Water absorption (%)
Limestone	1.39	2.72	
Sand	1.52	2.66	
China clay	0.35	2.83	
CG			
10–5 mm	1.48	2.51	0.57
5–0 mm	1.28	2.51	
IBA			
10–5 mm	1.11	2.42	4.42
5–0 mm	0.79	2.42	
PFA	0.63	2.16	
ISSA	0.45	2.18	