Construction and Building Materials 176 (2018) 509–518

Contents lists available at ScienceDirect

Construction and Building Materials

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

Optimisation of EMI shielding effectiveness: Mechanical and physical performance of mortar containing POFA for plaster work using Taguchi Grey method

O.L.C. Narong [a,*], C.K. Sia [a], S.K. Yee [c], P. Ong [b], A. Zainudin [a], N.H.M. Nor [a], M.F. Hassan [a]

[a] Department of Engineering Design and Materials, University of Tun Hussein Onn Malaysia, Parit Raja 86400, Batu Pahat, Johor, Malaysia
[b] Department of Mechanic Engineering, University of Tun Hussein Onn Malaysia, Parit Raja 86400, Batu Pahat, Johor, Malaysia
[c] Research Centre for Applied Electromagnetic, Faculty of Electrical and Electronic Engineering, University of Tun Hussein Onn Malaysia, Parit Raja 86400, Batu Pahat, Johor, Malaysia

HIGHLIGHTS

- POFA is used as a cement replacement in plastering work to overcome electromagnetic interference.
- This study applies Taguchi-Grey method to assess the optimal mixtures in plastering work with multiple responses.
- POFA was used in EMI shielding is to reduce the uncontrollably dumped in landfills of agricultural waste and reduce numerous environmental harms.

ARTICLE INFO

Article history:
Received 23 August 2017
Received in revised form 10 April 2018
Accepted 4 May 2018

Keywords:
Plastering work
Palm oil fuel ash
Taguchi Grey method
Electromagnetic interference

ABSTRACT

A waste material which is collected from palm oil mill called POFA is used as cement replacement in plastering work to overcome electromagnetic interference issue. This study proposes Taguchi-Grey method to assess the optimal mixtures in plastering work with multiple responses of POFA. The responses under investigation are EMI shielding effectiveness, 28-days compressive strength, 28-days flexural strength, shrinkage, slump flow, initial setting time, final setting time, water retention and air content. In the application of this method, POFA admixture percentage, topcoat powder-to-binder ratio, water-to-binder ratio, latex agent content, particle size of POFA, and curing condition are selected as control factors. From the results it had been demonstrated and verified that the optimal mixture has 20% of POFA admixture, 0% of topcoat powder-to-binder ratio, 0.6 of water-to-binder ratio, 10% of latex agent content, 140 μm of POFA particle size and with water immersion curing condition are the optimal mixture. After comparison of the verification results, the Taguchi Grey method is applicable for this study due to the confirmation result which is comparable and fulfill the standard (IEEE Std 299-1997, BS EN 998-1, ASTM C1329, ASTM C596, and ASTM C1437) requirement.

1. Introduction

In recent times, most of the advanced technologies in electric and electronic devices, especially the wireless and communication systems are polluted by electromagnetic wave (EMW) radiation, which can be harmful to health and may cause death [1–3]. This radiation also called as electromagnetic interference (EMI), which is exposed freely, surrounding human especially in building. In order to deal with EMW radiation issue, this study proposed a palm mill waste namely palm oil fuel ash (POFA) as cement replacement to mitigate the EMW in plastering work. The cement-based composite electromagnetic (EM) absorbing materials, with the advantage of rich resources, good environmental adaptability and low cost, had been the research focuses [4–7]. The conventional plaster cement-based composite contains three main components; Ordinary Portland cement (OPC), sand and water. Usually, the mortar for plastering work is prepared with 1:3 fixed binder-to-sand ratio [8]. Current study stated that EMI shielding in building have been shielded by carbon filling cement materials and metal filling cement composite [9]. The carbon filling materials consist of graphite, carbon black, coke and carbon fiber. These carbon materials comparatively have high conductivity and EMI shielding [10]. The metal based fillers consist of metal powder, metal fiber and metal alloys, which are used in cement matrix composites [9]. The metals such as silver, copper, and nickel was used for a long time as con-

* Corresponding author at: C210, Block C, KKTSN, University of Tun Hussein Onn Malaysia, Parit Raja 86400, Batu Pahat, Johor, Malaysia.
E-mail address: gd150077@siswa.uthm.edu.my (O.L.C. Narong).

https://doi.org/10.1016/j.conbuildmat.2018.05.025
0950-0618/

ductive components in polymer due to their high conductivity [9], but high in cost.

Nowadays, Malaysia is one of the largest palm oil industry in the world. Furthermore, as the second largest global palm oil producer, Malaysia has the highest daily wastage [11] from burning of empty fruit bunch, fiber and palm oil shell in the boiler as fuel. The POFA is classified as Class-F fly ash as per ASTM C618 [12]. Currently, POFA usage is very limited and uncontrollable, and most of it is disposed in landfills. Consequently, it has caused numerous environmental harms [13,14] such as soil and water pollution. Earlier, POFA was applied for variety of application and typically used in concrete application. In concrete, POFA was used as filler to increase the strength of concrete [15,16]. Besides, POFA was used as pozzolanic material which can improve the durability of the concrete [17]. There are many other high conductive fillers like silver, copper, and nickel which can be used. However, these metal fillers are not only high in cost but very complicated in processing which make it not commonly used in cement matrix composite [9]. Therefore, the POFA was chosen to be used as filler to mitigate EMI. The motivation of using POFA in EMI shielding is to reduce the agricultural waste that is uncontrollably dumped in landfills.

In order to conduct an experiment, the most important thing is to reduce the cost and time of an experiment. To meet the optimal parameters takes a long time. To achieve desired experiment objective, the optimisation method is needed. The assessment of an optimal mixture for obtaining desired quality is an important issue in the field of material engineering. The difficulty of optimal mixture assessment can be described as $y = f(x_1, x_2, \ldots, x_n)$, in which y denotes the key response used to represent quality, and x_1 to x_n are the control factors that will mainly affect the performance of the response [18]. The traditional Taguchi method is one of the handy method had been applied in cement-based application especially in designing the high strength concrete [19–24]. Taguchi method was used for evaluating more influencing factors with fewer experiments [25] by employing an orthogonal array and signal-to noise ratio (S/N) ratio analysis which was proposed to improve the effectiveness and efficiency of DOE. This analysis technique reduced the time/cost of experiments and obtained good evaluations. Besides, Taguchi methods also have been successfully employed to solve mixture proportion problems of epoxy-TiO_2 particulate filled functionally grade composite [26], pulsed current gas tungsten arc welding (PCGTAW) [27], and laser welding of thin foil nickel – titanium shape memory alloy [28]. However, traditional Taguchi method can only consider a single response at a time. Practically, the presentation of quality has to consider multiple response at a time, i.e., the difficulty of optimal mixture assessment must be described as $(y_1, y_2, \ldots, y_m) = f(x_1, x_2, \ldots, x_n)$ where y_1 to y_m are different responses used to represent quality [18].

To determine the optimal mixture problems with multiple response by DOE and Taguchi methods, the optimal mixture for each response is frequently assessed individually, and then, the overall optimal mixture is determined by engineering experience or cross analysis [18]. This approach still unable to solve too many responses at the same time due to the increased complexity of the calculations and the erroneous judgment possibility. Therefore, a Taguchi-Grey method with grey relational analysis in the Taguchi method [29] has been proposed to effectively solve the optimal mixture problem with multiple responses/objectives. Grey relational analysis can provide a comprehensive index, which is grey relational grade (GRG), to represent the complete performance of all responses $((y_1, y_2, \ldots, y_m)$. Recently, the Taguchi-Grey method has been selected to solve optimal process problems with multiple response in various fields such as recycled aggregate concrete mixtures [18], analysis of process parameters in surface grinding [30], and development of oleo-hydrophobic cotton fabric [31], characteristics of hard facing [32], MIG welding on 316L austenitic stainless steel [33], process parameters in friction stir welded AM20 magnesium alloy [34], and sintering parameters of Al-Si alloy/fly ash composite [35].

Finally, this research mainly focuses on plastering wall of building which results in the wall can absorb the EMF radiation to reduce the EMI problem while considering other mechanical and physical performance. This paper proposed Taguchi-Grey method to solve optimal mixture problems with the multiple responses. This study utilised a set of experimental data on EMI shielding effectiveness, 28-day compressive strength, 28-day flexural strength, shrinkage, slump flow, initial setting time, final setting time, water retention and air content to assess the optimal mixture. The selected control factors on nine responses are POFA admixture percentage, topcoat powder-to-binder ratio, water-to-binder ratio, latex agent content, particle size of POFA, and curing condition. Initial experiment data, predicted data by grey relational analysis and confirmation of experimental data was also performed to determine the applicability and correctness of the Taguchi-Grey method for plastering work with multiple response.

2. Material and experimental work

2.1. Materials

In order to prepare the plastering mortar, five main materials were prepared including ordinary Portland cement (OPC), a local river sand, latex agent for plaster cement (LA), topcoat powder (TP) and POFA, OPC and local river sand. In this work, the OPC and TP were supplied in fine powder form from supplier. Meanwhile, the POFA was supplied in coarse condition. The fresh POFA was refined by using water-immersion method [36] to wash up the dust due to the received fresh POFA was originally supplied in large particles and impurities. The POFA was dried in oven for 24 h at 100 ± 5°C and grinded to become fine powder. POFA was sieved by 140 μm and 45 μm sieves to create the fine POFA (FPOFA) and ultra-fine POFA (UPOFA) respectively [3]. The materials physical properties such as specific gravity, fineness, median particle size and appearance are shown in Table 1. In this study, the POFA elemental composition of materials is determined by using Bruker S4 Pioneer X-ray fluorescence (XRF) instrument to conform with ASTM C618 [12] standard. Based on the XRF analysis as shown in Table 2, the total of SiO_2 + Al_2O_3 + Fe_2O_3 of this POFA is greater than 70% which satisfies the chemical composition required for Class-F fly ash as accomplished to ASTM C618 [12]. The chemical composition of OPC, TP and POFA are given in Table 2. The local river sand was used with the grading given in Table 3. This gradation of sand is accordance with the requirement in ASTM C144 [37].

2.2. Plastering mortar preparation

The plaster mortar was prepared with 1:3 fixed binder (OPC + POFA)-to-sand ratio [8]. The six main control factors and its levels

Table 1
Materials physical properties.

Materials	Specific gravity	Fineness m^2/kg	Median particle size, d50 (μm)	Appearance
OPC	3.146	321.4	15.2	Grey
TP	1.201	150.3	10.7	Off-grey
FPOFA	2.352	250.1	130	Dark grey
UPOFA	2.237	241.2	40	Black
Sand	2.875	302.0	450	Reddish yellow