PERFORMANCE PROPERTIES OPTIMIZATION OF TRIAXIAL CERAMIC-PALM OIL FUEL ASH BY EMPLOYING TAGUCHI DESIGN AND FLOWER POLLINATION ALGORITHM

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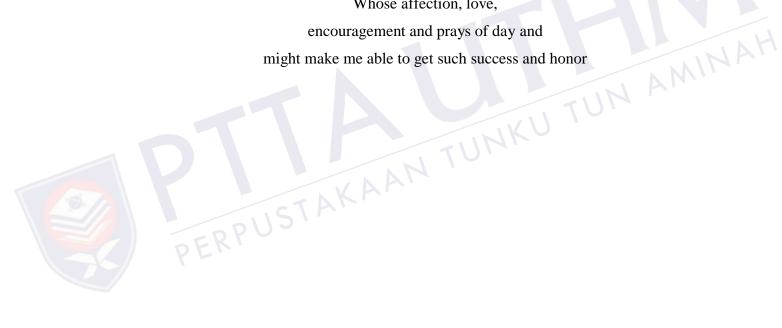
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Every challenging work needs self-efforts as well as guidance of elders especially those who were very close to our heart

My humble effort I dedicate to my sweet and loving

Mother and Late Father Kamariah binti Yaacob and Zainudin bin Abdullah

Whose affection, love,



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ABSTRACT

The combustion of wasted palm oil materials leads to the formation of Palm Oil Fuel Ash (POFA). The lack of use of POFA for beneficial applications causes environmental problems. The introduction of new raw material in an original composition can affect original optimal parameters. The excessive cost and time consumed is a main issue if high number of experiments need to be performed. Primarily, this research is about the optimization of triaxial ceramic employing the POFA process by the Taguchi design and Flower Pollination Algorithm (FPA). The recycled POFA was evaluated through the POFA layer formation method where selected POFA layers were employed as filler raw material. This research also provided the chronology of Taguchi design and FPA regarding the production of triaxial ceramic product. The research was then continued with the development of optimal parameters of the triaxial ceramic process containing POFA, specifically the following performance properties: shrinkage, water absorption, apparent porosity, bulk density, and flexural strength. Mainly, the Taguchi L₁₈ orthogonal array was used as the design of experiment. Primarily, this research successfully attained the POFA layer formation for the triaxial ceramics. It was concluded that POFA could be successfully applied as filler material in triaxial ceramic application. Besides that, the Taguchi design and FPA were also successfully employed in this research field through the effectiveness of developed optimal design parameters. Taguchi Grey Relational Analysis (GRA) developed following optimal parameters: 15 wt.% of unground POFA, pressed at 2 t, and sintered at 1200 °C for 300 min of soaking time. In the meantime, both linear and interaction approach of FPA developed following optimal parameters: 5 wt.% of ground POFA, pressed at 4 t, and sintered at 1200 °C for 300 min of soaking time. It was successfully validated by the confirmation experiments including through crystalline phase and morphology analyses.

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ABSTRAK

Proses pembakaran bahan terbuang minyak kelapa sawit membawa kepada pembentukan Palm Oil Fuel Ash (POFA). Kekurangan penggunaan POFA untuk aplikasi yang bermanfaat menyebabkan masalah alam sekitar. Pengenalan bahan mentah baru dalam komposisi asal dapat mempengaruhi parameter optimum yang asal. Kos yang tinggi dan masa yang digunakan adalah isu utama jika jumlah eksperimen yang banyak perlu dilakukan. Penyelidikan ini adalah mengenai pengoptimuman proses seramik tiga paksi yang menggunakan POFA oleh reka bentuk Taguchi dan Flower Pollination Algorithm (FPA). POFA yang dikitar semula dinilai melalui kaedah pembentukan lapisan POFA dengan lapisan POFA yang dipilih telah digunakan sebagai bahan mentah pengisi. Penyelidikan ini juga menyediakan kronologi reka bentuk Taguchi dan FPA mengenai pengeluaran produk seramik tiga paksi. Penyelidikan kemudiannya diteruskan dengan pembangunan parameter optimum proses seramik tiga paksi yang mengandungi POFA, khususnya ciri-ciri prestasi berikut: pengecutan, penyerapan air, porositi ketara, ketumpatan pukal, dan kekuatan lenturan. Ortogonal Taguchi L₁₈ digunakan sebagai reka bentuk eksperimen. Penyelidikan ini berjaya mencapai pembentukan lapisan POFA untuk seramik tiga paksi. Kesimpulannya, POFA dapat digunakan sebagai bahan pengisi dalam aplikasi seramik tiga paksi. Selain itu, reka bentuk Taguchi dan FPA juga berjaya digunakan dalam bidang penyelidikan ini melalui keberkesanan parameter reka bentuk optimum yang dibangunkan. Taguchi Grey Relational Analysis (GRA) memberi parameter optimum seperti berikut: 15 wt.% daripada unground POFA, ditekan pada 2 t, dan disinter pada 1200 °C bagi 300 minit waktu perendaman. Sementara itu, kedua-dua pendekatan linear dan interaksi daripada FPA memberi parameter optimum seperti berikut: 5 wt.% daripada ground POFA, ditekan pada 4 t, dan disinter pada 1200 °C bagi 300 minit waktu perendaman. Ia telah berjaya disahkan oleh eksperimen pengesahan termasuk melalui analisis fasa kristal dan morfologi.

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LIST OF SYMBOLS AND ABBREVIATIONS

°C - Degree Celsius

ANOVA - Analysis of Variance

AP - Apparent Porosity

ASTM - American Society for Testing and Materials

BD - Bulk Density

DOF - Degree of freedom

EDX - Energy-Dispersive X-ray

FPA - Flower Pollination Algorithm

FS - Flexural Strength

g - gram

GPOFA - Ground Palm Oil Fuel Ash

GRA - Grey Relational Analysis

GRC - Grey Relational Coefficient

GRG - Grey Relational Grade

h hour

ICDD - International Center for Diffraction Data

kN - kilo Newton

min - minute

MPOB - Malaysian Palm Oil Board

OA - Orthogonal Array

POFA - Palm Oil Fuel Ash

rpm - Revolution per minute

SEM - Scanning Electron Microscope

SH - Shrinkage

SNR - Signal to Noise Ratio

UGPOFA - Unground Palm Oil Fuel Ash

UPOFA - Ultrafine Palm Oil Fuel Ash

t - ton

TPOFA - Treated Palm Oil Fuel Ash

μm - micrometers

WA - Water Absorption wt.% - weight percent

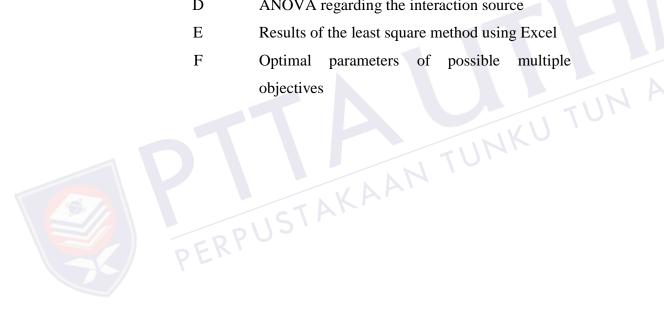
XRD - X-ray Diffraction

XRF - X-ray fluorescence



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CHAPTER 1

INTRODUCTION

This chapter deals with the introduction of research. The chapter starts with a research background, followed by problem statements, objectives, scopes, significant of research, and outline of the thesis.

1.1. Research background

Ceramic application can be classified into advanced and traditional ceramics. Advanced ceramics are made from artificial and chemically modified raw materials. They include five major industry segments which are structural, electrical, coatings, chemical and environmental ceramics. Meanwhile, traditional ceramics are mainly made from natural raw materials such as porcelain, stoneware, earthenware, whitewares, concretes, refractories, and structural clay products. The traditional ceramic is simply called triaxial ceramic because of the triaxial composition (Bhattacharyya & Snehesh, 2015; Bó & Hotza, 2013; Conconi et al., 2014; Ngun et al., 2014; Serra et al., 2015). It is basically composed of plasticity material (clay or kaolin), fluxing agent (feldspar), and filler material (silica or quartz) (Barry Carter & Grant Norton, 2013).

Industrial activity produces huge industrial waste, including any material regarded useless during the manufacturing processes such as in factories, industries, mills, and mining operations. Some examples of industrial wastes are chemical solvents, pigments, sludge, metals, ash, paper products, industrial by-products, and radioactive wastes. Recently, most of these wastes are found to have potential for use in certain applications. The motivation for using those wastes is to reduce the agricultural and industrial wastes that are uncontrollably dumped in landfills.

One of the industrial wastes is from the palm oil industry. Currently, Malaysia is surrounded by 5.81 million hectares of oil palm planted area as reported by MPOB (2017). Malaysia is one of the world's largest producers of palm oil. Due to the operations, Malaysia generates a huge quantity of wastes including trunks, fronds, empty fruit bunches, palm kernel shell, palm mesocarp fiber, and palm kernel cake. Other than trunks and fronds, wasted materials have been recycled as a combusted material in the palm oil mill boilers to generate electrical energy. The ash produced from this burning is called Palm Oil Fuel Ash (POFA) (Awal & Hussin, 1997). With hundreds of palm oil mills operating in Malaysia, thousands of tons of ash are produced annually as reported in studies about previous POFA usages (Abdul Shukor Lim et al., 2015; Altwair et al., 2012; Chandara et al., 2010; Khalid et al., 2016; Megat Johari et al., 2012; Salih et al., 2014; Yusuf, Megat Johari, et al., 2014a).

POFA in respective application are normally presented as unground POFA (UGPOFA), ground POFA (GPOFA), treated POFA (TPOFA), and ultrafine POFA (UPOFA). Generally, collected POFAs are obtained in the form of irregular, porous, and large shapes. Researchers initially sieve the collected POFA to remove excessive size particles called UGPOFA. If these UGPOFAs are grounded and re-sieved, GPOFA is then produced. Furthermore, when it is heated at the right temperature, TPOFA is produced. Meanwhile, if TPOFA is re-grounded and re-sieved, UPOFA is produced. However, various chemical composition of POFA have been reported from different POFA that were used by various researchers (Thomas et al., 2017). Hence, each particle part of established POFA is highly present in various significant levels for a respective application. This means, only a few parts of POFA particles are needed in the respective application. In a review process by Thomas et al. (2017), there are researchers who explained that carbon does not help in the strength developments of concrete. However, higher silica content during the burning process is highly needed. It shows that POFA contains both significant and insignificant parts. Therefore, a process for separating these two parts of POFA are considered in this research to collect just the significant POFA.

The modifications of triaxial ceramic products are evaluated in terms of performance properties. The performance properties present both physical and mechanical properties. Those performance properties are continually improved from various areas of triaxial ceramic research. Shrinkage, water absorption, apparent

porosity, and bulk density are the physical properties in this research. Meanwhile, flexural strength represents the mechanical property. Shrinkage is frequently applied to a ceramic product as quality and process control parameters, where it controls the dimension of that ceramic product. Water absorption is also a character of a triaxial ceramic specimen where it points to the lower water absorption condition. It means that the specimen is frost resistant and able to prevent liquid from permeating. Meanwhile, apparent porosity relates to a condition of open pore where it is a cavity that communicates with the surface of the ceramic body. Following that, maximum bulk density and flexural strength is desired. Flexural strength represents the highest stress experienced by the ceramic product at its moment of yield.

The substitution of new material causes a change of the optimal parameter. To obtain a new optimal parameter, the design of experiment tools is usually applied. Recently, a mixture design tool has been used in a triaxial ceramic application to obtain an optimized composition of the three raw materials (Coronado et al., 2014, 2015; Dal Bó et al., 2014; Ngun et al., 2014). However, other parameters like sintering temperature, soaking time, molding pressure, and heating rate have been controlled as constant parameters. Following that, optimization represents a process to obtain the new optimal condition for process. In this research, optimization process is performed to obtain optimal condition for the highest performance properties.

Jurków & Stiernstedt (2014) had applied the Taguchi design to optimize many parameters by considering cost and time-consuming factors. The Taguchi design orthogonal array (OA) is the familiar generalized optimization tools that was introduced by Taguchi a long time ago. Taguchi design is still widely used among researchers from various fields today. Furthermore, Taguchi design was also found in POFA study which is a study of geopolymer product using treated POFA (TPOFA) (Mijarsh et al., 2014). Traditional Taguchi design analysis is specifically used to optimize single objective, while Taguchi Grey Relational Analysis (GRA) is used for multiple objectives. Theoretically, single objective represents that the property is individually targeted such as to produce the largest flexural strength specimen without considering other properties. Meanwhile, multi-objective involves several properties or at least two properties. This research involves the five single objectives and one multiple objective condition.

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