# APPLICATION OF RESPONSE SURFACE METHOD (RSM) IN PREDICTING THE ALKALI SILICA EXPANSION AND ALKALI CONCENTRATION OF PALM OIL FUEL ASH (POFA) MORTAR

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**FACULTY OF ENGINEERING**
**UNIVERSITI MALAYSIA SABAH**
**2022**

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**YEE YI ZHEN**

**THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF BACHELOR OF ENGINEERING WITH HONORS (CIVIL ENGINEERING)**

**FACULTY OF ENGINEERING**
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Yee Yi Zhen
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# ABSTRACT

Alkali Silica Reaction (ASR) is a common phenomenon occurs in concrete. It is a reaction between the alkali content from cement and reactive aggregate that contains high in silica content with the present of water. This reaction caused the concrete to expand and crack due to the expansion of silica gel developed in the concrete. Past studies revealed that alkali content in the pore solution can trigger the occurrence of ASR expansion. Therefore, by partial replacing sufficient amount of Palm Oil Fuel Ash (POFA) as Supplementary Cementitious Materials (SCM), the expansion of mortar can be reduced. However, justification and support for this statement are lacking as limited research on this topic. This is due to the reason that complicated laboratory works as well as time and cost ineffective on this works. Hence, Response Surface Method (RSM) using Design Expert 13 is introduced to enhance the performance of the work. Besides, this study also important in creating a sustainable environment and saving production cost when POFA is used as SCM in cement production. In this study, the independent variables are heat treatment temperature and POFA replacement dosage while alkalinity and ASR expansion are the response variables. Through RSM, predicted data and optimum POFA mix proportion were generated and developed for ASR mitigation. Relationship between independent variables on ASR mitigation also been studied using contour and 3D plots generated in RSM of Design Expert 13. Centered Composite Design (CCD) and Optimal (Custom) Design are the model used for the simulation. Based on the simulation, Quadratic model was adopted to analyze the response variables. From the analysis, it can be concluded that lower ASR expansion and alkalinity can be obtained when POFA is treated with high temperature and has higher replacement dosage. Lastly, limitations and recommendations on this study have provided to ensure the works can be improved in future study.

# ABSTRAK

## Aplikasi Kaedah Tindak Balas Permukaan (RSM) Dalam Meramal Pengembangan dan Kepekatan Alkali Abu Kelapa Sawit (POFA) Mortar Terkena Reaksi Alkali Silika

*Reaksi alkali silica (ASR) adalah fenomena biasa berlaku dalam konkrit. Ia adalah tindak balas antara kandungan alkali daripada simen dan agregat reaktif yang mengandungi kandungan silika yang tinggi dengan kehadiran air. Tindak balas ini menyebabkan konkrit mengembang dan retak akibat pengembangan gel silika yang dibangunkan di dalam konkrit. Kajian lepas mendedahkan bahawa kandungan alkali dalam larutan liang boleh mencetuskan berlakunya pengembangan ASR. Oleh itu, dengan menggantikan sebahagian simen dengan Abu Kelapa Sawit (POFA) pengembangan mortar dapat dikurangkan. Walau bagaimanapun, justifikasi dan sokongan untuk kenyataan ini kurang kerana penyelidikan terhad mengenai topik ini. Ini disebabkan oleh prosedure untuk menjalankan kajian ini adalah rumit serta masa dan kos untuk kajian ini didapati kurang berkesan. Oleh itu, Kaedah Tindak Balas Permukaan (RSM) menggunakan Design Expert versi 13 diperkenalkan untuk meningkatkan prestasi kerja. Selain itu, kajian ini juga penting dalam mewujudkan persekitaran yang mampan dan menjimatkan kos pengeluaran apabila POFA digunakan sebagai SCM dalam pengeluaran simen. Dalam kajian ini, pembolehubah tidak bersandar ialah suhu rawatan haba dan dos penggantian POFA manakala kealkalian dan pengembangan ASR adalah pembolehubah bergerak balas. Melalui RSM, data ramalan dan optimum perkadaran campuran POFA telah dijana dan dibangunkan untuk mitigasi ASR. Hubungan antara pembolehubah tidak bersandar pada mitigasi ASR juga telah dikaji menggunakan kontur dan plot 3D yang dijana dalam Design Expert versi 13. Reka Bentuk Komposit Berpusat (CCD) dan Reka Bentuk Optimal (Tersuai) adalah model yang digunakan untuk simulasi. Berdasarkan simulasi, model Kuadratik telah digunakan untuk menganalisis pembolehubah bergerak balas. Daripada analisis, dapat disimpulkan bahawa pengembangan dan kealkalian ASR yang lebih rendah boleh diperolehi apabila POFA dirawat dengan suhu tinggi dan mempunyai dos penggantian yang lebih tinggi. Akhir sekali, batasan dan cadangan terhadap kajian ini telah disediakan untuk memastikan kerja-kerja dapat diperbaiki dalam kajian akan datang.*

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| | |
|---|---|
| AMBT | - Accelerated Mortar Bar Test |
| ANOVA | - Analysis of Variance |
| ASR | - Alkali Silica Reaction |
| ASTM | - American Society for Testing and Materials |
| BBD | - Box-Behnken Design |
| CCD | - Central Composite Design |
| CCD | - Central Composite Design |
| DOE | - Design of Experiment |
| FYP | - Final Year Project |
| POFA | - Palm Oil Fuel Ash |
| RSM | - Response Surface Method |
| SCM | - Supplementary Cementitious Materials |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Research

The Federal Aviation Administration (FAA) defines Alkali Silica Reaction (ASR) as the formation of alkali silica gel due to deleterious chemical reaction between hydroxyl ($OH^-$) ions from cement (sodium and potassium) and reactive siliceous components found in coarse or fine aggregates. This reaction occurs at the concrete structure which continuously suffered from damp and moisture condition, mostly are dams and bridges. The existence of moisture at the surrounding of gel causing absorption and expansion to be occurred, tensile stresses created eventually lead to crack and affect the strength as well as durability of the concrete structure. There are three factors that activate the occurrence of ASR, mainly high content of alkali from cement, reactive form of silica from aggregates and sufficient of moisture. The formation and expansion of alkali silica gel will not happen if any one of the mentioned factors does not present.

Based on Okpin et al. (2016), limiting the alkali content of Portland Cement to 0.6% is one of the options to prevent the occurrence of ASR. However, this suggestion is opposed by Farny and Kosmatka (1997). Both researchers claimed that implementing low alkali cement content also possesses potential for ASR to occurs if the concrete structure experiences wetting and drying cycle frequently. The alkali in the concrete structure will become concentrated when the concrete is dry and could be sufficient to initiate the reaction to occurs. Hence, restricting the alkali concentration in cement is ineffectual as there could be other possibilities to trigger ASR to be happened. For example, mineral admixtures, chemical admixtures and aggregates. Apart from that, Asrah et al. (2015) suggested that replacing reactive aggregates with non-reactive aggregates to mitigate the phenomenon of ASR. However, this method might be less effective in terms of application as the non-reactive aggregates in some countries are limited or difficult to be found. Therefore, the application of Supplementary Cementitious Materials (SCM) is the better option to control the ASR in concrete (Asrah et al., 2015; Seyed et al., 2012; Marie et al., 2021).

Supplementary Cementitious Materials (SCM) is a material that added to concrete as a partial replacement of cement in order to enhance the overall properties of hardened concrete through pozzolanic activity. Previous studies have proven that the use of SCM such as silica fume, fly ash and slag in concrete able to improve concrete properties and also help in mitigating the ASR effectively through alkali dilution and binding (Thomas, 2011; Shayan et al., 1996; Thomas, 1996).

In this project, Palm Oil Fuel Ash (POFA), a SCM from agriculture waste product is selected to study the effect of mortar in terms of ASR expansion and alkali concentration under occurrence of ASR. POFA is a by-product from palm oil industry, produced through burning of the palm oil fibre, kernels, empty fruit bunches and shells which are categorized as palm oil waste materials in order to generate energy in the power plant (Khankhaje et al., 2016). In recent, POFA has gained researcher's attention to use in concrete study as it not only helps in creating more environmentally friendly surrounding by reducing carbon emission in cement production but also reducing by-product waste materials in landfills (Hussein et al., 2018). As in Awal et al. (1997) study, it claims that millions of tonnes of POFA have been thrown into lagoon or sand landfills since the ash does not contain enough nutrients to be used as fertiliser. During a humid day's wind may easily carry the ash, which is light and tiny enough to escape detection. This result reduced vision and possessed road hazards. Till now, the reutilization rate of POFA in current industry still low, disposal and disturbance to the environment still can be seen. (Altwair & Kabir, 2010). Hence, investigation on the effectiveness of POFA as SCM is significance to the concrete industry as well as environment.

According to literature study, POFA contains higher alkali than cement, but it still performs excellent in mitigating the ASR expansion (Asrah et al., 2018). However, the mechanism and effectiveness of POFA in mitigating ASR by controlling the alkali concentration and the ASR expansion still in a doubt as limited research regarding on this topic. Moreover, the application of modelling method to predict the experimental result on this topic also seldom to be seen as most of the study carry out through lab experiment method. Therefore, this research will focus on investigating the performance of POFA on alkali concentration mortar subjected to ASR using Response Surface Method (RSM).

## 1.2 Problem Statement

Alkali content of pozzolanic material is one of the dependant variables that affect the expansion of mortar due to ASR aside from calcium content, fineness and pozzolanicity. It was reported that pozzolanic materials can reduce and control the alkali concentration of mortar or concrete (Awal and Hussin, 1997). POFA, one of the pozzolanic materials that has been known can be used as SCM for ASR mitigation. However, the study using POFA as partial cement replacement on ASR mitigation was not thoroughly investigated, especially the relationship between alkali content of POFA with ASR expansion. From literature review, most of the studies tend to investigate the engineering properties of mortar when POFA was used as SCM.

Besides that, records from past studies have restricted the POFA partial replacement usage from ranging 0-40% by weight of the total cementitious material (Awal and Hussin, 1997; Mannan and Ganapathy, 2001). The trends and conditions of mortar or concrete with POFA exceed 40% on ASR mitigation still unsure as lack of study to support on this scope. This is because most of the studies indicated that the replacement dosage of POFA beyond the threshold amount which is 40% will affect the properties of concrete and increase the cost of production. Furthermore, there is lack of study to determine the effect of heat treated and untreated POFA on ASR expansion and alkalinity of mortar as well. Eventually, the optimum amount of POFA replacement on ASR mitigation is difficult to determine as lack of experimental data to study it.

Moreover, to study the effect of POFA on ASR expansion and alkali concentration, the Accelerated Mortar Bar (AMBT) Test and Pore Solution Analysis using the hot water extraction method need to be carried out. However, the procedures and processes to obtain ASR expansion and concentration of pore solutions required longer period if the experiment repeated for different replacement level of POFA (Shafaatian et al., 2012). It will be difficult to complete the whole experiment if time is limited.

Hence, modelling using RSM is introduced to identify the optimum dosage or replacement level of POFA. This is to minimize the occurrence of ASR in concrete structure by controlling the alkali concentration of mortar with POFA. Besides, through RSM, an equation will be developed and used to predict the amount of pore solutions as well as ASR expansion in the mortar replaced with treated and untreated POFA at different replacement level ranging from 10-50%. Lastly, relationship of ASR expansion and pore solution alkalinity of mortar will be studied as well through analysing the result from RSM modelling.

## 1.3 Research Question

There are three (3) research questions that inspired the study on this topic

1. What is the optimum dosage of Palm Oil Fuel Ash (POFA) to suppress the Alkali Silica Reaction (ASR)?
2. How treated and untreated Palm Oil Fuel Ash (POFA) affect the Alkali Silica Reaction (ASR) expansion and alkalinity of mortar?
3. Is there any relationship between Alkali Silica Reaction (ASR) expansion and alkalinity of mortar with treated and untreated Palm Oil Fuel Ash (POFA) on Alkali Silica Reaction (ASR) mitigation?

## 1.4 Objective of the Research

There are three-fold of objectives to achieve for this research, which are:

1. To predict the alkalinity and expansion of mortar at 10%-50% of heat treated and untreated Ultrafine Palm Oil Fuel Ash (UPOFA) toward Alkali Silica Reaction (ASR) mitigation using response surface method (RSM).

2. To determine the optimum dosage of heat treated and untreated Palm Oil Fuel Ash (POFA) on Alkali Silica Reaction (ASR) mitigation using response surface method (RSM).
3. To study the relationship between Alkali Silica Reaction (ASR) expansion and alkalinity of mortar with treated and untreated Ultrafine Palm Oil Fuel Ash (UPOFA).

## 1.5 Scope of Research

In this study, Central Composite Design (CCD) of RSM was used to analyse the experimental result from the previous study. There was a total of nine (9) sets of primary data were used for predicting 10-50% of treated and untreated POFA on alkali concentration mortar subjected ASR. The software used for designing the experiment is Design Expert version 13. A series of validation using analysis of variance (ANOVA) and analysis of regression were done to determine the accuracy of the results. By using Design Expert version 13, RSM was also used to find the optimum dosage of POFA which helps in minimizing the expansion of ASR. Apart from that, the developed equation from the RSM modelling were used to predict the ASR expansion and alkalinity of mortar with UPOFA at a range 10 to 50% at four (4) different temperature, 0 °C, 500 °C, 700 °C and 1000 °C. Then, a comparison result study was done by using another model of RSM, which is Optimal (Custom) Design in order to verify the obtained result in terms of accuracy and prediction errors. Lastly, the relationship between mortar alkalinity incorporating UPOFA and ASR expansion have been studied and discussed based on the predicted data.

## 1.6 Significance of Research

There is very limited study on the ASR mitigation using RSM, especially for POFA as partial cement replacement in concrete. To investigate and identify the effectiveness of POFA as SCM in ASR mitigation, experimental work on this must be carried out. In this experiment, different mortar or concrete mixtures will be prepared in order to determine the optimum replacement dosage of POFA for achieving the mitigation purpose. However, the process of optimization performed by laboratory approach is extremely time consuming, especially when executing the pore solution analysis. If researcher performs the test at uniform mix proportion (replacement dosage 5%, 10%, 15% and so on), lots of time will spend to complete the analysis. If the experiment has planned for long term observation and study, that would not be a problem to the researcher, but for short term, it is not a best option. Hence, with statistic modelling based software, it can help researcher to reduce the sample data in research work. By using RSM in the optimization process, it can predict the optimum dosage of POFA that are required in order to give the best result in controlling the ASR in concrete. It also can predict the effect of treated and untreated pore solution alkalinity, which relate to the alkali dilution factor in ASR. From this investigation, it can help to promote and introduce the advantages of using RSM in investigating experimental study such as pore solution analysis. RSM is a powerful statistical analysis software tool that able to predict the result by inserting the important parameters (inputs) and the achieve output in the software. Therefore, through this research, it might provide some new information for the next researchers who doing future research related to this topic.

Last but not least, creating a sustainable environment by using agrowaste like POFA is also one of the significances in this study. Numerous research studies have shown that cement production possess a serious issue on environmental which is the emission of $CO_2$ greenhouse gaseous (Mugahed et al., 2021; Jonida et al., 2018; Hussein et al., 2018). From Mineral Products Association (2007), the production of 1 tonne of cement generates about 1 tonne of $CO_2$, which means cement production itself has in charge of 7-10% of the world's total $CO_2$ emissions. Numerous research has proven that agrowaste ashes such as POFA can use as alternative constituents in concrete as these ashes contained high amount of silicon dioxide in amorphous form and could be used as pozzolanic materials (Altwair and Kabir, 2010; Liyana et al., 2015). By using POFA in cement production, it is not only reducing the emission of carbon dioxide in cement production, but it also helps in solving environmental and health issue due to the excess of POFA during the combustion of palm oil waste materials. Aside from that, implementing POFA in cement production also able to reduce the production cost as well as a new alternative to other pozzolana materials such as fly ash and slag due to the recent decline of both coal and steel industry (Pone et al, 2018).