ESTIMATION MODEL OF COMPRESSIVE STRENGTH OF CONCRETE CONTAINING EGGSHELL AND TIRE CRUMB

N.A Hakimah, R. Othman

Abstract

Recycling eggshell waste in concrete materials gives many benefits to minimising the cement demand, conserving natural limestone and recycling waste aggregate. This study is to identify the compressive strength and slump height of the concrete consisting of eggshell and tire crumb by using regression analysis in Excel and Response Surface Methodology (RSM) through Minitab. The method used in strength assessment of concrete is by combining more than one Non-destructive Test (NDT) test, which is Ultra Pulse Velocity (UPV) and rebound hammer (RH). The combination of UPV and RH test results were established with the percentage of eggshell, and tire crumb as partial replacement of cement and sand was used to estimate the compressive strength at 7 days and 28 days. Results had revealed that RSM has the lowest value of root-mean-square error (RMSE), which is 0.6854 for 7 days compressive strength, 1.6613 for 28 days compressive strength and 3.6433 for slump height. The ideal content of eggshell powder and tire crumb that created the maximum compressive strength of concrete is 10% and 0%, respectively, with 6.5 km/s of UPV and 42.1 number of RH, according to this study. The additional percentage of eggshell powder replacement up to 15% has reduced concrete compressive strength. A selected estimation model for compressive strength and slump height can create analysis reduction in the number of

---

N.A Hakimah[1], R. Othman[2]

[1]College of Engineering, Civil Engineering Department, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang, Malaysia.

[2]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Lebuhrya Tun Razak, 26300 Gambang, Pahang, Malaysia

Rokiah Othman (Corresponding Author)

e-mail: rokiah@ump.edu.my

Faculty of Civil Engineering Technology, UMP Research Series: Construction Engineering and Management, Vol. 1, [insert doi here later]

experiments, thus reducing the optimisation cost, besides reducing the environmental impact due to uncontrollable waste in landfills.

Keywords Response Surface Methodology, Regression Analysis, Slump, Eggshell, Tire Crumb, Rebound Hammer, UPV, Compressive Strength

Introduction

Concrete is a composite material that is widely used in the construction field and this caused cement to become an essential material in the building industry (Stajanca & Estokova, 2012). The production of the cement required a highly energy-intensive process that involved intensive fuel consumption for clinker making, thus making the cement industry a significant contributor to global anthropogenic Carbon Dioxide (CO_2) emissions (Bakhtyar, Kacemi, & Nawaz, 2017). The emissions of CO_2 were estimated at 900 kg for every ton of cement production (Parkash, 2017). The establishment of eggshell concrete containing tire crumb is one of the innovative green concrete that helps to reduce the environmental harm caused by excessive cement manufacturing (Chong et al., 2021). Parkash (2017) proved that the main component of eggshells was Calcium Carbonate ($CaCO_3$), and this signified that the chemical compositions of eggshell and cement were similar. The design strength of ordinary concrete is commonly referred to as its 28-day strength. However, if the test results fail to meet the desired strength due to an error in the mix design or manufacture, the entire procedure must be repeated. Hence, the process will be time consuming and costly. Besides, there are several non-destructive tests (NDT) that are commonly practised to assess the concrete compressive strength, such as rebound hammer and UPV (Fadhil & Alwash, 2017).

Regression analysis and RSM are statistical experiment design methods that have been practised frequently in determining the optimum concrete mixture design. Regression is a primary method to study the correlation between factors and responses. Then, RSM is a Minitab software analysis that generates statistically validated predictive models that may be tweaked to achieve the best process configuration (Salem Alsanusi & Loubna Bentaher, 2015). The Design of Experiments (DoE) method gives benefit in simplifying the relation between compressive strength and component composition of concrete. The most fitted model has the added attraction that can be used to perform predictions in a shorter time (Chopra, Sharma & Kumar, 2014).

This research investigates the possibility of using regression analysis and RSM to forecast the compressive strength and workability of concrete containing eggshell and tyre crumb at 7 and 28 days. Based on the theoretical principle, the combination of more than one NDT technique is influenced conversely by an influencing factor, and this factor can be reduced by combining RH and UPV to improve reliability of strength estimation (Fadhil & Alwash, 2017). Then, all of the obtained data will be analysed by using Microsoft Excel and Minitab 18. Minitab 18 gives central composite and Box-Behnken designs (Salem Alsanusi & Loubna Bentaher, 2015). The variables are classified into two categories, independent variables, which are the percentage of eggshell, percentage of tire crumb, RH and UPV, while its dependent variables are compressive strength and workability of eggshell concrete containing tire crumb. After the analysis of results is obtained from modelling, the optimisation of the mathematical models can be conducted. As the estimation model was achieved, the tested data are used to identify the accuracy for regression to compare the predicted responses and actual responses.

Methodology

Design of Experiment

The initial design of experiments is considered under regression analysis, where the entire database is entered into Excel and Minitab. The purpose of using correlation is to evaluate the strength of the interaction between factors and responses. In this research, the factors used are eggshell percentage, tire crumb percentage, UPV and RH at 7 days and 28 days, while the responses are eggshell compressive strength and slump height. It is necessary to study the link between the assessment's quality and its influencing factors in order to obtain a more complete and accurate evaluation of the assessment's quality (Fadhil & Alwash, 2017).

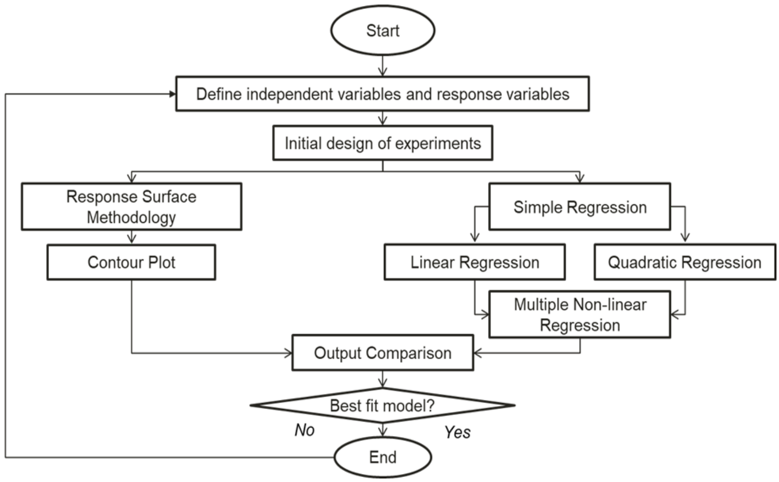

Figure 1: The flowchart in statistical modelling of estimation concrete strength.

Database

There are 20 sets of data gathered from laboratory test results to investigate the combined effect of the independent variables. The ratio of cement, coarse aggregate and fine aggregate was 1:2.16:1.4. The percentage of eggshell was calculated using a combination of UPV and RH test data, and tire crumb was utilised to evaluate compressive strength at 7 and 28 days.

Table 1 shows the mixture design of base concrete in this study. The cement utilised in this study is called Orang Kuat Ordinary Portland Cement, which meets the BS EN Portland Cement Specification. Then, the nominal size of crushed stone for coarse aggregate was 10mm while fine aggregate was within the range of 75 µm to 4.76mm.

A superplasticiser was added at 1% from the mixture design. The type of superplasticiser used was Pye Kwiset Plasticising Accelerator. The superplasticiser acts as a water reducer in order to attain the desired strength. Water-cement ratio of 0.32 was implemented for medium workability with higher compressive strength. The limitations of high strength concrete are bond strength between cement and aggregate was low, thus requiring high-vibration for better compaction (Kovacevic & Dzidic, 2018).

Table 1. A base concrete mixture design.

Materials	Mixture
Cement (kg/m^3)	648
Coarse aggregates (kg/m^3)	915
Fine aggregates (kg/m^3)	580
Superplasticiser (%)	1
Water-cement ratio	0.32

Table 2 shows the database of mixture design, which includes the eggshell percentage, tire crumb percentage, UPV and RH test results at 7 days and 28 days. The eggshell was rinsed and washed to remove the organic residue, then dried in the oven at 105°C for 24 hours to remove the organic residue. The eggshell powder was prepared by sieving the grinded eggshell through 150µm. The partial replacement of sand was adopted by sieving tire crumb through 180 µm. Tire crumbs must first be pre-treated for 30 minutes at room temperature using a sodium hydroxide aqueous solution. The process continued with washing tire crumbs with water and dried at ambient temperature for 24 hours to improve the rubber's capacity to form a stronger connection with cement

Response Surface Methodology

RSM is a set of statistical methods for establishing, improving and optimising the response variables. It considers quadratic interaction between each predictor to the response variables and produces the interaction effect between each factor. RSM is a type of DoE that can be used to assess the effect and relationship of many variables on response variables. The best model is analysed based on quantitative parameters such as coefficient of correlation, R^2, adjusted, R^2 adjusted and root mean square error (RMSE). The additional figures such as the Pareto chart, residual plot, interaction plot and deviation plot are the qualitative output to show more information of the model. The confidence interval used is 95% with the level of significance, α, is 0.05.

Regression Analysis

A key principle in statistical analysis is regression analysis, which is used to determine the relationship between a single response variable and other variables. Firstly, the regression analysis should start with simple regression to evaluate the linear relationship. The linear relationship is obtained by considering the single predictor to estimate the response. The best fit model for calculating slump height and compressive strength of eggshell concrete containing tire crumb was created using a combination of linear and quadratic connections.

Table 2: The experiment data.

No.	Eggshell (%)	Tire Crumb (%)	UPV7 (km/s)	RH7 (nos.)	UPV28 (km/s)	RH28 (nos.)
1	0	0	4.23	28.00	6.44	43.00
2	0	5	4.11	26.00	6.25	40.00
3	0	10	3.84	22.00	5.84	34.00
4	0	15	3.77	20.00	5.74	30.00
5	0	0	4.31	25.80	6.16	36.80
6	5	0	4.53	27.90	6.47	39.80
7	10	0	4.55	29.50	6.50	42.10
8	15	0	3.88	23.70	5.55	33.80
9	0	5	4.419	26.00	4.61	29.00
10	5	5	4.419	28.00	4.59	30.00
11	10	5	4.385	23.00	4.50	27.00
12	15	5	4.132	21.00	4.37	24.00

No.	Eggshell (%)	Tire Crumb (%)	UPV7 (km/s)	RH7 (nos.)	UPV28 (km/s)	RH28 (nos.)
13	0	10	3.83	21.80	5.79	27.30
14	5	10	4.09	22.30	6.21	28.50
15	10	10	3.97	19.30	6.04	23.70
16	15	10	3.83	17.70	5.82	22.70
17	0	15	1.12	13.00	1.71	20.00
18	5	15	1.15	14.00	1.76	21.00
19	10	15	1.34	14.00	2.04	21.00
20	15	15	1.05	11.00	1.60	17.00

Result and Discussion

Response Surface Methodology

The RSM was carried out by utilising a backward elimination method with $\alpha = 0.05$. The backward elimination is the simplest model of all model selection procedures strategy. Selecting the best model of backward elimination begins with starting all the model predictors. The least significant variable was deleted and the analysis was repeated until the remaining model had a meaningful impact on the outcome (Chowdhury & Turin, 2020). Then, the p-value that is higher than $\alpha = 0.05$ was removed. Hence, the model will be refitted and this process will stop when the p-value is lesser than $\alpha = 0.05$.

Equation

The equations below are the output from Minitab 18 through RSM modelling. The equations generated by Minitab 18 for 7 days, 28 days of compressive strength and slump height are in Equation (1), (2) and (3). The generated equations from Minitab 18 were selected based on p-value lesser than 0.05, lowest RMSE, highest value of R^2 and a_{-20} index approached to 1.

*CS7 = - 9.2 - 2.82 Eggshell - 2.434 Tire Crumb - 13.67 UPV7 + 0.0134 Eggshell*Eggshell+ 0.0983 Tire Crumb*Tire Crumb + 1.47 UPV7*UPV7 - 0.1314 RH7*RH7 + 0.1020 Eggshell*Tire Crumb + 0.1001 Eggshell*RH7 + 0.009UPV7*RH7* (1)

*CS28 = 33.8 + 1.93 Eggshell - 2.776 Tire Crumb + 10.52 UPV28 + 0.57RH28 – 0.1038 Eggshell*Eggshell + 0.0969 Tire Crumb*Tire Crumb + 0.17 UPV28*UPV 28 + 0.0508 RH28*RH28 – 0.0187 Eggshell*Tire Crumb – 0.0228 Eggshell*RH28 - 0.567 UPV28*RH28* (2)

*Slump = 48.30 + 1.414Eggshell - 0.459Tire Crumb - 0.1208Eggshell*Eggshell - 0.0860Tire Crumb*Tire Crumb - 0.0758Eggshell*Tire Crumb* (3)

Residual Plot and Pareto Chart

The residual plot and Pareto chart were used to examine the magnitude of each variable in calculating the best fit model. The residual versus order plot was used to evaluate the factors' accuracy in predicting concrete compressive strength (Chong et al., 2021). The residual plot observation for 7 days compressive strength was dispersed in a zig-zag pattern, with no discernible trend. According to Chong et al. (2021), a zig-zag trendline is referred to, as RSM's regression analysis did not incorporate any other key factors.

The residual plot of 28 days compressive strength showed a non-uniform zig-zag pattern compared to 7 days compressive strength. This observation happened because of the weakness of using the backward elimination approach. As discovered in the literature review, the backward elimination will remove the variables that have contributed the least significant effect on the response (Chowdhury & Turin, 2020).

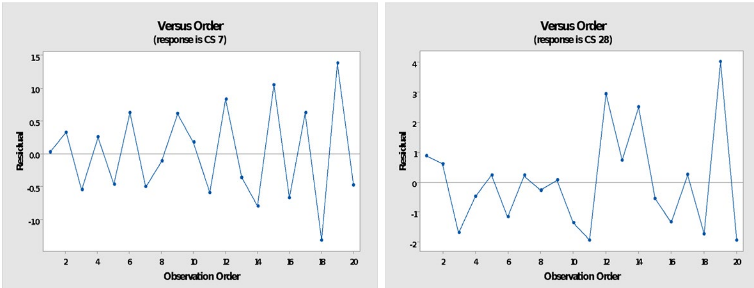

Figure 2 (a): Residual versus order plot for compressive strength.

The residual plot for the slump height estimation shows a similar pattern with 7 days compressive strength of the residual plot. The zig-zag pattern indicates that all the factors are being included in the estimation model. The linear, quadratic and two-way interactions have been considered in the estimation model of slump height.

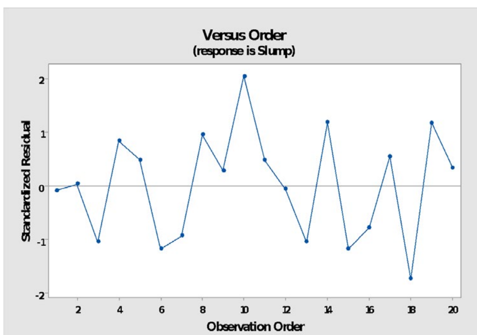

Figure 2 (b): Residual versus order plot for slump height.

The estimation of 7 days compressive strength shows that tire crumb in quadratic term (BB) has a major significant effect to predict the concrete strength. Then, the significant primary effect on concrete strength was followed by the linear term of RH 7 (D) and UPV 7 (C). The two-way interaction between UPV 7 and RH 7 (CD) has the most negligible significant influence on 7 days compressive strength. The results showed a difference from the studies conducted by Chong et al. (2021), It is shown that eggshell has a substantial impact on concrete strength after seven days.

The standardised effect of 28 days compressive strength revealed that tire crumb in quadratic term (BB) has a substantial impact on the strength qualities of concrete. The Pareto chart for 28 days compressive strength shows a similarity with the Pareto chart for 7 days compressive strength, as the tire crumb variable has a significant standardised effect towards the concrete strength. Then, it is followed by eggshell quadratic term (AA) and quadratic terms for tire crumb (BB). It was observed that UPV 28 in quadratic term (CC) has contributed to the least standardised influence on compressive strength at 28 days.

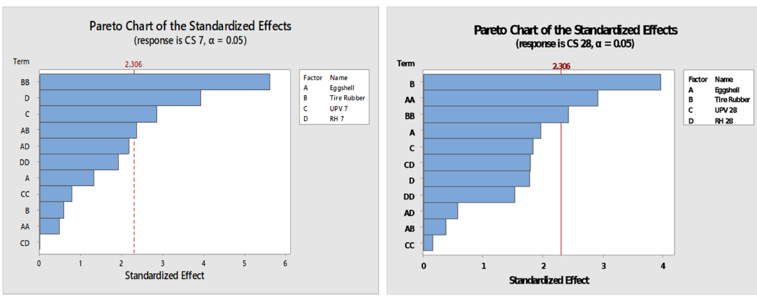

Figure 3 (a): Pareto chart for compressive strength.

The Pareto chart in Figure 3 (b) shows that the linear term of tire crumb (B) has the highest magnitude of significant effect towards the workability of eggshell and tire crumb concrete. A linear term of eggshell (A) has a more significant influence than its quadratic term (AA). Two-way interaction between eggshell and tire crumb (AB) almost has a similar effect with a quadratic term of tire crumb (BB).

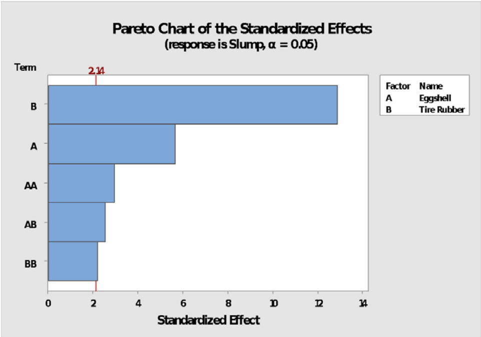

Figure 3 (b): Pareto chart for slump height.

Regression Analysis

Multiple non-linear regression was used to simulate the concrete compressive strength and workability. As a result, the connection between each independent variable and the dependent variable differs (Chong et al., 2021).

Equation

The equations generated from data analysis in Microsoft Excel are expressed in Equations (4), (5) and (6). The generated equations from Excel were selected based on p-values lesser than 0.05, lowest RMSE, the highest value of R^2 and a_{-20} index approached to 1.

CS7 = 32.4363 – 0.8387 Eggshell – 1.3262 Tire Crumb + 0.3198 UPV7 +
*1.6219 RH7 – 0.0696 Eggshell*Eggshell – 0.8115 UPV7*UPV7 – 0.0228 RH7*RH7* (4)

CS28 = 54.934 + 1.0907 Eggshell – 1.3983 Tire Crumb – 0.242 UPV28 +
*0.6097 RH28 – 0.0934 Eggshell*Eggshell – 0.2134 UPV28*UPV28*
*– 0.0014 RH28*RH28* (5)

$$Slump = 51.7069 + 0.8462\ Eggshell - 0.9140\ Tire\ Crumb - 0.1208\ Eggshell*Eggshell - 0.0860\ Tire\ Crumb*Tire\ Crumb \quad (6)$$

Comparison between RSM and Regression

A comparative procedure has been conducted to identify the deviation between RSM and regression analysis, and the results are presented in Table 3. In summary, the estimation model from RSM has been selected to perform the estimation of compressive strength and slump height of concrete containing eggshell and tire crumb based on UPV and RH values. The establishment of RSM allowed for analysis reduction in the number of tests, lowering the cost of optimisation (Jamal, Neelakantan, & Chokkalingam, 2019).

Table 3 shows the comparison between experimental and statistically parameters to justify the selected prediction model in estimating the responses. The observation from RSM and regression in Excel revealed that RSM has the lowest value of root-mean-square error (RMSE), which is 0.6854 for 7 days compressive strength, 1.6613 for 28 days compressive strength and 3.6433 for slump height. This statistical validation is also similar for 28 days compressive strength and slump height. Based on the literature review, RMSE below 5 was considered to have good accuracy and acceptable.

Conclusion

Based on the mathematical modelling, the best estimation model from RSM has been selected due to the fitness of the statistical requirements. Several conclusions can be drawn from this study. Firstly, the implementation of eggshell in the concrete mixture improved the compressive strength by increasing slump height to achieve acceptable workability. Secondly, the mathematical modelling predicts the compressive strength and workability, and it was concluded that RSM produced more accurate and reliable data. Thirdly, the optimum percentage of eggshell powder is 10%, with 0% of tire crumb to achieve maximum compressive strength. Compressive strength has been lowered by up to 15% as a result of the additional eggshell powder replacement.

Table 3: Experimental and statistically parameters.

Parameter	7 Days Compressive Strength (MPa)		28 Days Compressive Strength (MPa)		Slump Height (mm)	
	RSM	Regression	RSM	Regression	RSM	Regression
RMSE	0.6854	1.5814	1.6113	2.3275	3.6433	4.4025
R^2	0.9912	0.9531	0.9737	0.9451	0.9365	0.9074
Adjusted R^2	0.9791	0.9258	0.9375	0.9131	0.9139	0.8827
a_{-20} index	1	1	1	1	0.90	0.75

Acknowledgement

This study was supported by the Malaysian Ministry of Higher Education and Universiti Malaysia Pahang.

References

Bakhtyar, B., Kacemi, T., & Nawaz, A. (2017). International Journal of Energy Economics and Policy A Review on Carbon Emissions in Malaysian Cement Industry. *International Journal of Energy Economics and Policy* |, 7(3), 282–286. Retrieved from http:www.econjournals.com

Chong, W., Othman, R., Putra, R., Li, X., Rosli, M., Hasan, M., … Bakri, A. (2021). Journal of King Saud University – Engineering Sciences Meta-analysis of studies on eggshell concrete using mixed regression and response surface methodology. *Journal of King Saud University - Engineering Sciences*, (xxxx). https://doi.org/10.1016/j.jksues.2021.03.011

Chopra, P., Sharma, R.K., & Kumar, M. (2014). Predicting Compressive Strength of Concrete for Varying Workability Using Regression Models. *International Journal Of Engineering & Applied Sciences*, 6(4), 10–10. https://doi.org/10.24107/ijeas.251233

Chowdhury, M.Z.I. & Turin, T.C. (2020). Variable selection strategies and its importance in clinical prediction modelling. *Family Medicine and Community Health*, 8(1), 1–7. https://doi.org/10.1136/fmch-2019-000262

Fadhil, M. & Alwash, A. (2017). *Assessment of concrete strength in existing structures using nondestructive tests and cores : analysis of current methodology and recommendations for more reliable* Maitham Fadhil Abbas Alwash To cite this version : HAL Id : tel-01531241 DOCTEUR DE L ' UNI.

Jamal, S.M., Neelakantan, T.R., & Chokkalingam, R.B. (2019). Regression Analysis by Taguchi Method on Strength of Weathered Crystalline Rock Sand Concrete. *International Journal of Engineering and Advanced Technology*, 9(1S3), 182–187. https://doi.org/10.35940/ijeat.a1006.1291s419

Kovačević, I., & Džidić, S. (2018). High-strength concrete (HSC) material for high-rise buildings. In *12th Scientific Research Symposium with International Participation* «Metallic and Nonmetallic Materials: production-properties-application (No. 12, pp. 214-223).

Parkash, A., & Singh, E. R. (2017). Behaviour of concrete containing egg shell powder as cement replacing material. *Int. J. Latest Res. Eng. Comput.(IJLREC)*, 5(4), 1-5.

Salem, A., & Loubna, B,. (2015). Prediction of Compressive Strength of Concrete from Early Age Test Result Using Design of Experiments (RSM). *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 9(12), 1522–1526. Retrieved from https://zenodo.org/record/1110457/files/10003114.pdf

Stajanca, M. & Estokova, A. (2012). *Environmental Impacts of Cement Production. Technical University of Kosice*, Civil Engineering Faculty, Institute of Architectural Engineering, 296–302. Retrieved from http://ena.lp.edu.ua

Author(s) Biodata

Nur Arif Hakimah Wahab was born on 12 October 1997. She is a student from the College of Engineering, Civil Engineering Department in Universiti Malaysia Pahang. Previously, she graduated from Universiti Malaysia Pahang with a Diploma of Civil Engineering. She has experience performing engineering software such as ESTEEM Structural, AutoCAD and Terra Alpha during her industrial training in Technipro Consult, Terengganu. She can be contacted via arifhakimah14@gmail.com.

Ts. Dr. Rokiah Othman was born on 12 March 1977 in Pekan, Pahang. She is a senior lecturer from the Faculty of Civil Engineering Technology, Universiti Malaysia Pahang. Previously, she graduated from UiTM Shah Alam with Bachelor's and Master's in Civil Engineering, and a Ph.D. from UMP. Before she joined UMP, she worked as a project engineer at C&S at SM Pelangi Sdn. Bhd. in Kuantan in 2002, and then in the same year, she became a lecturer at KPTM Kuantan for 3 years. In July 2005, she has joined UMP and was appointed as the Head of Diploma Programme (2008-2011). She has been teaching for 16 years in structure and material courses. Her research interest areas include structure and materials, IBS, sustainability and green technology, geotechnical, and environmental. To date, she has supervised more than 50 undergraduate students, published few articles in the high impact journal in Scopus and Web of Science, and became a reviewer in local and international conferences. She can be contacted via rokiah@ump.edu.my.