International Journal of GEOMATE, May, 2017, Vol. 12, Issue 33, pp. 127-133
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.33.2608

SHEAR STRENGTH OF CLAY REINFORCED WITH SQUARE AND TRIANGULAR ARRANGEMENT OF GROUP ENCAPSULATED BOTTOM ASH COLUMNS

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ABSTRACT: Soft clay is known to be a problematic soil that consists of low shear strength, low permeability and high compressibility where the existing soil on the given site is low with load bearing capacity, and by that ground improvement is required. Granular column methods are being used extensively as ground improvement technique for supporting a wide variety of structures and infrastructures. In practice, the bearing capacity on soft clay increased by a layer of compacted sand or gravel. Bottom ash as by product of coal burning that has similar properties to granular material can be applied as one of the stabilizing method to the existing soil. Hence, by using bottom ash as substitute, the cost of construction can be reduced and make great progress of a growing awareness of the sustainable engineering. This research discusses the results of the improvement in the shear strength of soft clay after being reinforced with a group of square and triangular encapsulated bottom ash columns. The physical and mechanical properties of the materials used such as kaolin and bottom ash were determined. The results show that kaolin can be classified ad clayey soil and bottom ash has similarities of characteristic with granular material. A total of 52 unconfined compression tests had been conducted on kaolin specimens to determine the shear strength. The diameter for specimen is 50 mm and 100 mm in height. The diameter of bottom ash columns are 10 mm and 16 mm respectively and the height of the column are 60 mm, 80 mm and 100 mm. The group columns have been arranged in square and triangular pattern. It can be concluded that the shear strength parameters were improved based on the different diameter and the height of the column.

Keywords: Soft clay, Group. Triangular. Encapsulated, Bottom Ash, Columns

1. INTRODUCTION

The stone column technique, also known as vibro-replacement or vibro-displacement, is a ground improvement process where vertical columns of compacted aggregate are formed through the soils to be improved. Pivarc [1] stated that the stone column technique has adopted in European countries in the early 1960s. The stone columns technique is one of the most used techniques for ground improvement processes all over the world among various methods of soft soil improvement. In practice, the bearing capacity on soft clay can be improved by a layer of compacted sand or gravel.

Many researchers have developed theoretical solutions for estimating the bearing capacity and settlement of foundations reinforced with stone columns. On the research done by Hughes [2], it is found that bulging is the one of the mode to show the characteristic of stone column. The experimental and numerical analysis on singles and group stone column were conducted by Ambily and Gandhi [3], Black et al. [4] and Hasan et al. [5].

Ground improvement techniques continue to make great progress of a growing awareness of the environmental and economic consideration. The significant aspect is to protect environment since more solid waste are produced from day to day. The selection of the correct ground improvement technique can have significant effect on foundation choice and can often lead to more economical solutions when compared to traditional approaches. It is noted that by nature, the existing soil on the given site unable to carry the load of proposed structure by itself, so the use of ground improvement is necessary. Considering for instance soft clay with relatively low shear strength, two kinds of column reinforcement techniques might be envisaged. One of the techniques is stone column technique which consists in introducing within the soft clay a vibro-compacted stone or ballast material.

The soil improvement directly depends on the stress distribution between soil and column. Stone columns act mainly as rigid inclusions with a higher stiffness, shear strength and permeability than the natural soil and the effects or improvements caused by these three properties were independently studied by different solutions (Castro et al. [6]).The soil types need to be enhanced in order to allow building and other heavy construction, so it is necessary to create stiff reinforcing elements in the soil mass (Zahmatkesh and Choobbasti [7]). The stone column consists of granular material such as crushed aggregates or sand.

Coal is being one of the main sources of energy in our country fuelling about 40% of the total. Two kinds of coal waste products consist of fly ash and bottom ash. Based on the findings by Singh and Siddique [8], bottom ash forms up to 25% of the total ash and fly ash forms the remaining 75%. Muhardi et al. [9] has reported that the Tanjung Bin power station is one of the four coal power plant in Malaysia, producing 180 tons/day of bottom ash and 1620 tons/day of fly ash from 18000 tons/day of coal burning As well known, coal bottom ash is formed in coal furnaces. Bottom ash by product of coal burning as stone column can be apply as one of the stabilizing method to the existing soft soil before construction to reduce the unacceptable settlement and improve the load bearing capacity of the foundations.

Soft clay is known as a problematic soil and the design of foundation on soft clay has been the concern of engineers since the beginning of soil engineering. Soft soil foundations can cause excessive settlement, initiating undrained failure of the infrastructure if proper ground improvement is not carried out (Indraratna et al. [10]). The substitution of granular material such as coal bottom ash could lead to significant effect on soft clay improvement. According to Marto et al. [11]), coal is one of natural resources that existed due to the chemical and geological alteration of materials formed by plants over tens or hundreds of millions of year in the past.

The utilization of waste material is one of the best techniques to achieved sustainable development (Hasan et al. [5]). Most of the waste disposals are being dumped near the factory. Hence, it will increase the expenses as there need to obtain large areas of dump yard. In construction industry, the utilization of coal ash which needs large quantity of material shows the problem of coal ash disposal. Other than that, the power industry need to take responsibility of disposal unused coal ash and finally places a concern to the electricity consumer. It has been reported that the Tanjung Bin power plant needs about 18,000 tons/day of coal to generate electricity (Marto et al., [11]).

However, the large quantity disposal of coal ash in landfills will be considerable concern to an environmental issues and creating to the increase requirement for disposal space. The disposal of coal ash becomes an environmental issues due to coal bottom ash is simply disposed of on open land. Environment concerns are increasing day by day because the disposal of bottom ash is risk to human health and the environment. The method of burning the residues create the fuss of environmental problem which it generates air pollution.

Previously, stated that there is strongly possibility of coal bottom ash being as substitute as granular material for ground improvement technique. The using of bottom ash as an alternative to replace the natural sand in produced concrete. Bottom ash use in concrete is important to show the fact that sources of natural sand are getting depleted gradually. The methods of burning the residues often become environmental issues which generates air pollution. But, if in the positive side, it is an alternative method that has provided to optimize the usage of waste as product in construction industry.

2. METHODS

2.1 Preparation of Samples

The soft clay was prepared using customized compaction method and bottom ash columns (BAC) had been installed in the soft clay using the replacement method. Every kaolin specimen was created with 50 mm in diameter and 100 mm in height. The kaolin was air dried and then mixed with 20% of water which is the optimum moisture content of the kaolin. After uniform mixing of kaolin and distilled water, the 341 g of wet kaolin was required to fill into the customized mould to create one test specimen. The kaolin was poured into the customized mould in 3 layers. Every layer was compacted with 5 free fall blows by customized steel extruder. The customized mould was designed so that the amount of clay using inside it will be compressed into a 50 mm diameter and 100 mm high of specimen. By this uniformity, the dimension and volume of each specimen could be maintained since the mass and volume of the mould were almost same.

2.2 Installation of Bottom Ash Column

One batch of kaolin specimen had 52 samples with 50 mm in diameter and 100 mm in height. Each batch of kaolin specimen contains the same penetration ratio which is 0, 0.6, 0.8 and 1.0, but different size diameter of columns and area replacement ratio. The sample without any reinforcement of bottom ash which is 0 penetration ratio was used as the ‘controlled sample’ to determine the shear strength of unreinforced sample. Unconfined compression test was applied to test every same penetration ratio for four times to obtain an average value. For installation of bottom ash, the holes were drilled in square and triangular for different sizes with 10 mm and 16 mm in different height of 60 mm, 80 mm and 100 mm. The raining method was used through the process of installation and densification of bottom ash. The, the non-woven geotextile with 6 different holes has been encased for each sample.

There were four different batches of specimens installed with geotextile tested as tabulated in Table 1. The replacement method was selected to remove clay and created holes for the bottom ash column to be installed. Fig. 1 and 2 show the detailed arrangement of the columns with different area replacement ratio.

Table 1 Sample with Variables of Bottom Ash Installation

Sample	No. of Columns	Diameter of Columns (mm)	Area Ratio, A_c/A_s (%)	Height of Penetration Ratio (H_c/H_s)
A	3	10	12.0	0, 0.6, 0.8 , 1.0
B	3	16	30.72	0, 0.6, 0.8 , 1.0
C	4	10	16	0, 0.6, 0.8 , 1.0
D	4	16	40.96	0, 0.6, 0.8 , 1.0

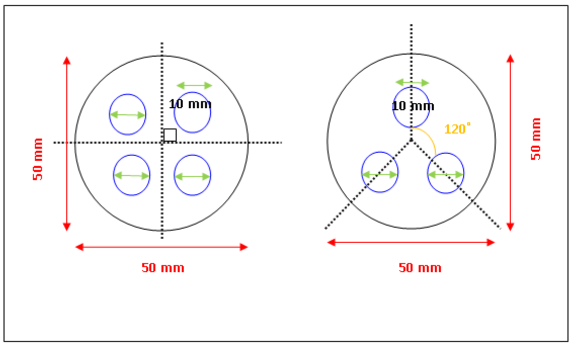

Fig. 1 Detailed Columns Arrangement for 12% and 16% Area Replacement Ratio

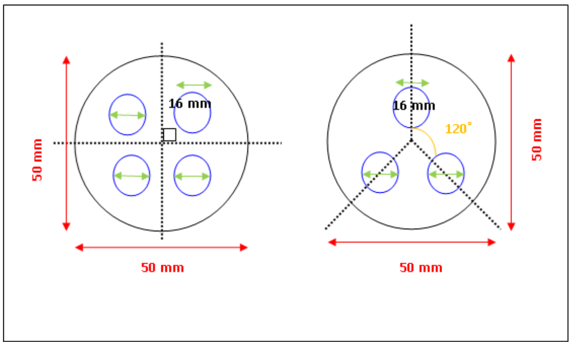

Fig. 2 Detailed Columns Arrangement for 30.72% and 40.96% Area Replacement Ratio

3. RESULTS

3.1 Summary of Main Materials

Table 2 and 3 show the summary of the properties of kaolin clay and bottom ash. A summary of non-woven geotextile was tabulated in Table 4. Based on the tests done kaolin clay, it can be observed that kaolin clay had the similarity characteristic with the soft clay. Meanwhile, bottom ash was proven that are relatively similar to the granular material such as sand and fine gravel. Therefore, bottom ash has the potential to be used as substitute for granular column.

Table 2 Summary of kaolin clay properties

Properties	Result
Liquid Limit	41.3%
Plastic Limit	31.25%
Plasticity Index	10.05%
Specific Gravity	2.62
Falling Head Permeability	1.124 x 10^{-9} m/sec
Standard Compaction Characteristic:	
-Maximum dry density, $\rho_{d\ max}$	1.58 kg/m^3
-Optimum moisture content , w_{opt}	20%
Soil Classification	
-(AASHTO)	A-7-6^b
-USCS (Plasticity Chart)	ML

Table 3 Summary of bottom ash properties

Properties	Result
Particle Size Range	2 mm to 0.6 mm
Relative Density Test	98%
Specific Gravity	2.33
Constant Head Permeability	1.57 x 10^{-3} m/sec
Standard Compaction Characteristic:	
-Maximum dry density	1.34kg/m^3
- Optimum moisture content	21.75%
Shear Strength (Direct Shear Test)	
- Cohesion	89.71 kPa
- Friction Angle	23.93°

Table 4 Summary of Polyster Non-woven Geotextile Needle punched properties (MTS 130)

Properties (Typical)	Unit	MTS 130
Material		Polyster
Unit Weight, ɣ	g/m^2	130
Thickness	mm	1.08
Mechanical Properties	Unit	MTS 130

Max. Tensile Strength, MD	kN/m	10.0
Max. Tensile Strength, MD	kN/m	9.3
Elongation at Max. Tensile Strength, MD	%	56.0
Elongation at Max. Tensile Strength, CD	%	84.0
CBR puncture strength	kN/m	2.2
Trapezoid Tearing Strength, MD	N	350
Trapezoid Tearing Strength, CD	N	280
Index puncture Strength, MD	N	310.3
Apparent opening size	µm	140
Vertical permeability	cm/s	0.27
Grab Tensile Strength, MD	N	620.2
Grab Tensile Strength, MD	N	668..0

3.2 Unconfined Compression Test

3.2.1 Stress-Strain Behaviour under Axial Load

A total of 52 unconfined compression test (UCT) had been conducted on kaolin specimens to determine the shear strength of soft clay reinforced with bottom ash column. Each batch of kaolin specimen contains the same penetration ratio, which is 0, 0.6, 0.8, and 1.0, but different size diameter of columns and area replacement ratio. Unconfined compression test was applied to test every same penetration ratio for four times to obtain an average value. The sample without any reinforcement of bottom ash, which is of 0 penetration ratio, was used as the 'controlled sample' to determine the shear strength of unreinforced sample. The non-woven geotextile with 6 different sizes as same as the drifted holes has been encased for each samples.

The values of average stress and average axial strain for 'controlled sample' and specimens reinforced with triangular and square pattern of bottom ash columns had been tested under Unconfined Compression Test were tabulate in the Table 5. The stress-strain responses of 12% and 30.72% area replacement ratio at different penetration ratio (0, 0.6, 0.8 and 1.0) were plotted in Fig. 3 and Fig. 4, respectively. From the graph, the shear strength and axial stiffness of the specimens increase after being reinforced by triangular bottom ash column. Similar behavior was obtained in 16% and 40.96% area replacement ratio with different penetration ratio (0, 0.6, 0.8 and 1.0) and the graph were plotted as shown in Fig. 5 and 6 respectively. Both triangular and square pattern of bottom ash columns reinforcement increase the stiffness of the specimens.

Table 5 Average stress and average axial strain at different replacement ratio and different penetration ratio

Area replacement ratio, A_c/A_s (%)	Height of penetration ratio, H_c/H_s	Average Stress (kPa)	Average Axial Strain (%)
0	0	18.88	1.79
12%	0.6	19.45	1.37
	0.8	28.23	1.82
	1.0	22.11	1.35
16%	0.6	24.12	1.86
	0.8	27.54	1.93
	1.0	25.25	1.78
30.72%	0.6	22.12	1.3
	0.8	19.62	1.23
	1.0	19.07	1.43
40.96%	0.6	21.48	2.26
	0.8	19.68	1.55
	1.0	20.82	1.45

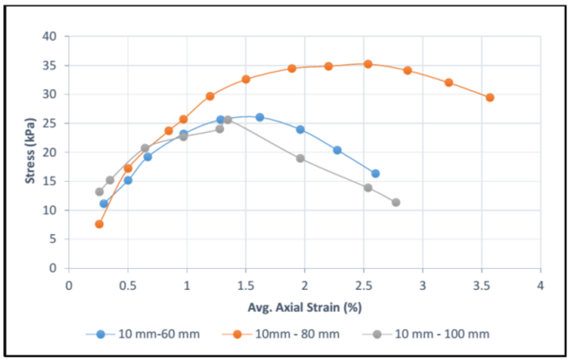

Fig. 3 Average Stress versus Axial Strain for 12% area replacement ratio

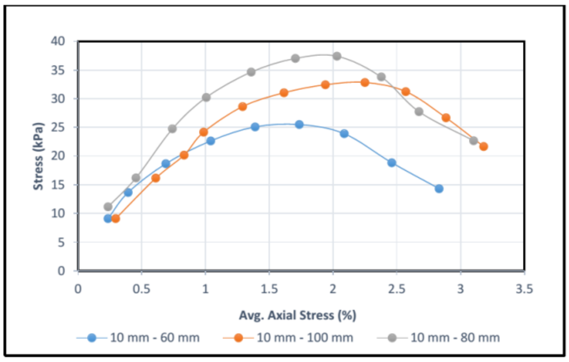

Fig. 4 Average Stress ve
30.72% area replacement rati

Table 6 Result of Unconfined Compression Test

Sample	No of Columns	Column Diameter (mm)	Area Ratio, A_c/A_s (%)	Column Height (mm)	Column Height Penetration Ratio, H_c/H_s	Shear Strength (kPa)	Improvement Shear Strength (%)
			Controlled Sample				
C	0	0	0	0	0	18.88	0
			Triangular Column (10 mm)				
	3	10		60	0.6	19.46	3.05
Batch 1	3	10	12	80	0.8	28.23	49.54
	3	10		100	1.0	22.11	17.09
			Triangular Column (16 mm)				
	3	16		60	0.6	22.12	17.16
Batch 2	3	16	30.72	80	0.8	19.62	3.9
	3	16		100	1.0	19.07	1.03
			Square Column (10 mm)				
	4	10		60	0.6	24.12	27.74
Batch 3	4	10	16	80	0.8	27.54	45.88
	4	10		100	1.0	25.25	33.75
			Square Column (10 mm)				
	4	16		60	0.6	21.48	13.78
Batch 4	4	16	40.96	80	0.8	19.68	4.24
	4	16		100	1.0	20.82	10.25

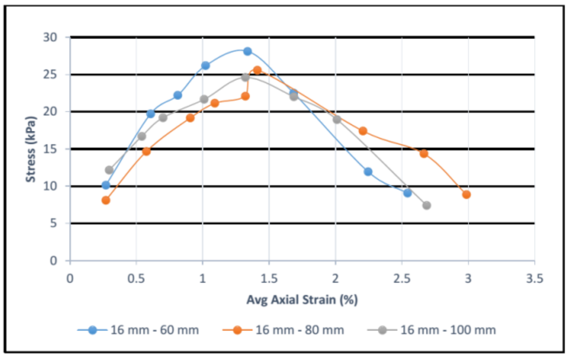

Fig. 5: Average Stress versus Axial Strain for 16% area replacement ratio

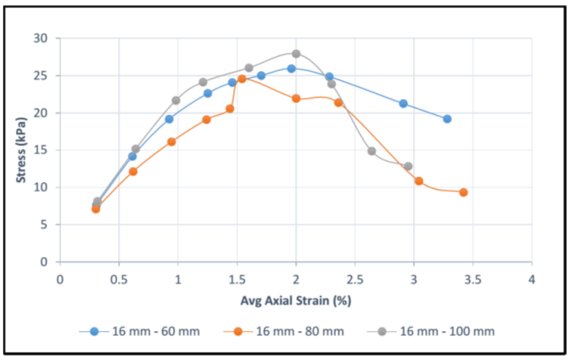

Fig. 6 Average Stress versus Axial Strain for 40.96% area replacement ratio

3. 3 Effect of Bottom Ash Columns on Shear Strength

Table 6 shows the result of shear strength for 'controlled sample' and samples reinforced with different diameters for both triangular and square pattern of bottom ash at different column penetration under Unconfined Compression Test (UCT).

For triangular bottom ash column reinforcement ement ratio, the increase in improvement shear strength are 3.05 %, 49.54 % and 17.09 % at sample penetration ratio, Hc/Hs of 0.6,0.8 and 1.0 respectively. As for 30.72% area replacement ratio, the improvement shear strengths are 17.16%, 3.9% and 1.03% for 0.6, 0.8 and 1.0 of sample penetration ratio respectively.

Meanwhile, for square bottom ash column reinforcement with 16% area replacement ratio, the increase in improvement shear strength are 27.74%,45.88% and 33.75% at sample penetration ratio, Hc/Hs of 0.6,0.8 and 1.0 respectively. While for 40.96% area replacement ratio, the increasing of improvement shear strength are 13.78%, 4.24% and 10.25% at 0.6, 0.8 and 1.0 sample penetration ratio respectively. The shear strength of triangular and square pattern reinforced with bottom ash column was increased significantly compared to the samples without reinforcement.

3.4 Effect of Bottom Ash Columns on Shear Strength

Improvement shear strength versus area replacement ratio is shown in Fig. 7, Ac/As of triangular and square pattern for area 12%, 30.72%, 16% and 40.96% with sample penetration ratio at

0.6, 0.8 and 1.0 respectively. For triangular encapsulated bottom ash column, the performance of 12% area replacement ratio contribute the greater increment in improvement shear strength compare to 30.72% area replacement ratio. While, the square encapsulated bottom ash column with area replacement of 16% has the greater value in improvement shear strength compare to area 40.96%. This is due to the area replacement of column is too big. As reported by Malarvizhi and Ilamparuthi [12], when the encased stone column is subjected to vertical load, the column material tends to dilate and induces lateral pressure.

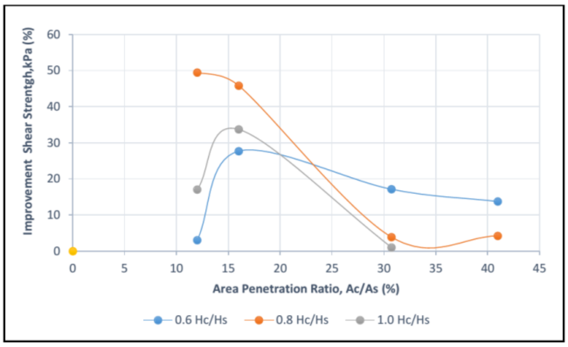

Fig. 7 Improvement Shear Strength versus Area Replacement Ratio

The results show that as the shear strength decrease as the diameter of the bottom ash columns increase. The results are in contradicted with the results done by Maakaroun et al. [13]. They explained that as the reinforcement area ratio increased, both the stiffness and shear strength of the specimens increased.

3.5 Effect of Height Penetration Ratio

Fig. 8 shows the increment of improvement shear strength at different height penetration ratio (0.6, 0.8 and 1.0) for triangular and square pattern encapsulated bottom ash column respectively. The percentage of improvement shear strength increased as the column penetration of bottom ash is increased. This is due to where the amounts of soil replaced by stiffer material which is bottom ash that help increase the strength improvement of the specimens. The result is in line with the previous research which done by Hasan et al. [5], who explained the shear strength of soft clay was increased as the height of the column increased. The improvement of shear strength for group column is in line with the increase of height of the bottom ash column.

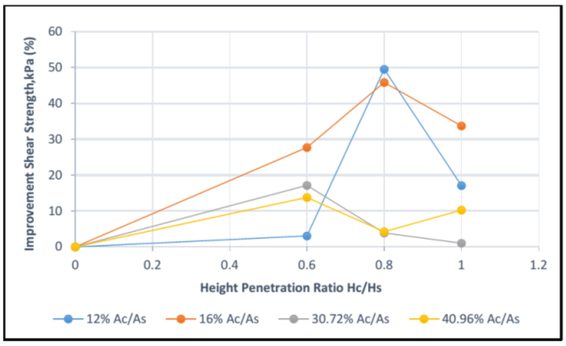

Fig. 8 Improvement Shear Strength versus Height Penetration Ratio

Based on figure above, it shows that the samples triangular partially reinforced with bottom ash column at 0.8 penetration ratio with area penetration 12%, the improvement shear strength is much higher compared to partially at 0.6 and fully-reinforced at 1.0 with area 30.72%. Similar to triangular column, the square partially penetrating column at 0.8 with area penetration ratio of 16% gives high increment in improvement shear strength compared to partially at 0.6 and fully-reinforced at 1.0 with area 40.96%. It proves that the improvement shear strength does not depend on area penetration only, but the height penetration ratio of bottom ash column as well.

The result from this study is in line with the ‘critical column length’ idea proposed by McKelvey et al. [14], Maakaroun et al. [13] and Hasan et al. [5] where there is no improvement in shear strength beyond the ‘critical column length’. Results of the experimental investigations indicate that ‘critical column length’ occurred particularly in the top 4 to 5 diameter of the column. The column length greater than five diameters may no longer participate in increasing the load carrying capacity of soft cohesive clays attributed to the brittleness of bottom ash; the risk of the column to fail is higher beyond this critical length.

4. CONCLUSIONS

The improvement of shear strength for group triangular and square column is in line with the increase of the height of the bottom ash column. It proves that the improvement shear strength does not depend on area penetration only, but the height penetration ratio of bottom ash column as well. The samples triangular partially reinforced with bottom ash column at 0.8 penetration ratio with area penetration 12%, the improvement shear strength is much higher compared to partially at 0.6 and fully-reinforced at 1.0 with area 30.72%. Similar to triangular column, the square partially penetrating column at 0.8 with area penetration ratio of 16%

gives high increment in improvement shear strength compared to partially at 0.6 and fully-reinforced at 1.0 with area 40.96%.

The results proved there is no improvement in shear strength beyond the 'critical column length'. The column length greater than five diameters may no longer participate in increasing the load carrying capacity of soft cohesive clays due to the brittleness of bottom ash, the risk of the column to fail is higher beyond the critical length. The results show that in the area ratio of 12%, shows more significant improvement at penetration 0.8 of bottom ash column. Hence, it can be concluded that both area replacement ratio and height penetration ratio possessed an important role in improving the shear strength of the sample.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Universiti Malaysia Pahang (UMP) and Ministry of Higher Education Malaysia for financing this research through the UMP Short Term Grant RDU 140373 and Fundamental Research Grant Scheme RDU150112, respectively. The cooperation given by all parties involved in this research is greatly acknowledged.

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