

Concentrically Loaded Square Steel Plates Bearing on Plain Concrete Blocks Containing Fly Ash

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Abstract. This paper presents an experimental investigation into the bearing strength of concrete blocks containing fly ash under axially compressive loading. Fly ash can be used with the conventional concrete to produce concrete blocks having an extensive range of performance behaviours. Then, the main purpose of this study is to inspect the ultimate bearing strength and observe the failure modes of concrete blocks containing fly ash. A total of twelve (12) numbers of specimens with four different types of concrete blocks were experimentally investigated. There are three (3) specimens of plain concrete blocks, three (3) specimens of concrete blocks containing 20% of fly ash, three (3) specimens of concrete blocks containing 30% of fly ash and three (3) specimens of concrete blocks containing 40% of fly ash as cement replacements. The use of square steel plate helps in determining the bearing strength when concentrically loaded on top of the specimen. The results of the experimental testing herein were compared with the bearing values calculated based on previous researches. Experimental results indicate that concrete blocks containing 30% of fly ash as cement replacements gave higher value of bearing strength compared with other specimens. Meanwhile, the failure pattern of concrete blocks under the bearing load was found to vary with the increase in the fly ash percentage.

1. Introduction

Concrete is an artificial stone made from the combination of cement, fine aggregate, coarse aggregate and water, and has been used and applied in many civil engineering works. The use of concrete is not just for building construction, but it can be used for numerous numbers of applications such as roads, sidewalk, bridges, dam and many others. It is plentiful, strong, inexpensive, easy to make, friendly to environment and versatile (it can be moulded to form into any shape). Concrete can be combined with steel reinforcement bar to obtain higher strength due to its ability to resist tension and compression. With the provision of reinforcement, cracking strength of the concrete can be improved and acts as an added mechanism to counter the tension part.

As stated by a numerous number of researchers (Escobar-Sandoval *et al.*, 2006; Ince *et al.*, 2004; Kameswara Rao *et al.*, 1974), there was a case where the cracking such as vertical and radial cracking were occurred with the use of plain concrete blocks subjected to high compressive loading. In order to provide a much higher compressive load without facing the failure, the dimension of the concrete column should be enlarged. Nevertheless, the solution requires higher cost and not suitable to be used as a concrete member. Another way was by having steel plate on the top surface of concrete block as its application can be seen on concrete bridge pedestal and the capacity of that concrete towards the load applied on it can be called as load bearing capacity.



The load-bearing capacity was first investigated by Bauschinger (1876) followed by Meyerhof (1953), Shelson (1957), and Au and Baird (1960). Then, the empirical formula for the bearing strength of concrete that account for varying base plate of thickness was developed by DeWolf (1978). The researchers noticed a formation of an inverted pyramid under the loading bearing plate and formulated a theory for concrete bearing capacity based on that observation. Many types of concrete blocks such as rectangular section, square section and circular section were commonly used by many researchers to study the behaviour of load bearing strength of concrete blocks and observe its failure mechanism.

The bearing capacity of concrete somehow always related to the variety of design problems as demonstrates by Kameswara Rao *et al.*, (1974) and Yahya and Dhanasekar (2014). The bearing capacity can be estimated by the assist of the steel plate positioned at the touching surface of the concrete cubes. The increasing of the bearing capacity was related to the increasing of the concrete strength, reduce the height of the concrete blocks and the total to loaded area ratio either for the plain or reinforced concrete blocks (Ahmed *et al.*, 1998; Al-Ta'an *et al.*, 2005). Ince *et al.*, (2004) stated that the parameters like the loaded area, loaded member cross-section, specimen size, specimen height, conditions of loading and concrete compressive strength can hugely affect the bearing resistance of the concrete blocks. The position of steel plate at the touching surface of concrete blocks either at the center or the edge of the concrete blocks (concentrically and eccentrically loaded bearing strength) also plays an essential role in gaining the bearing strength of the concrete (Ahmed *et al.*, 1998).

Nowadays, to improves concrete performance such as strength and durability, the use of natural fibers in concrete have been studied by numerous numbers of researchers. The use of natural fibers such fly ash is also cost effective. When these fibers such as fly ash is added to concrete, the amount of cement may be reduced. Many of construction material resources come from man-made element which can give bad impact to the environment. Nevertheless, it is difficult to adapt the usage of completely natural resources in production of construction material but it can be combined or merged with man-made resources in order to achieve environmental friendly product (Worrell *et al.*, 1999).

Numerous numbers of investigations have been performed in many countries on the use of man-made fibers or natural fibers such as coconut husk, palm, bamboo, sugarcane, sisal, jute and other type of fibers (Ahmad Z., 2010, Ramli M., 2010). The exploitation of these agro-waste materials may tackle the problem of their disposal that would improve the agricultural economy and at the same, conserving the energy and protecting the environment. A wide variety of natural fibers has been used for numerous trial applications but, whilst many of these shows considerable promise, the use of natural fibers such as fly ash as replacement of cement in concrete blocks for estimating ultimate load bearing capacity still remains to be a subject of further research and investigation.

An understanding on the bearing capacity of concrete block containing natural fibers such as fly ash was essential for the various design type of material in concrete. The effects of several important variables such as the different percentage of fly ash in mass replacement of cement used in concrete blocks can also affect the load transfer and failure mechanism of concrete bearing. The problems may arise if lack of quantitative understanding on the concrete bearing capacity and its generation mechanism (or cause of a concrete failure). Therefore, due to this and keeping in mind the important of estimation on concrete bearing strength for the design of concrete members, a series of compression tests on concrete blocks containing fly ash loaded through square steel plate were performed and its failure mechanism has been observed.

2. Theoretical development

The analytical development of empirical formula to estimate the ultimate load bearing capacity of concrete have increased year by year from the un-reinforced concrete to confined concrete and with the use of bearing steel plate. The empirical equation formulated by Shelson (1957) was that the ultimate bearing strength of concrete, f'_{cc} , be conservatively calculated as the product of the concrete strength,

f'_c , and a factor equal to $\sqrt[3]{(A_2/A_1)}$, where A_2 is denoted as gross area of the concrete foundation and A_1 as concrete bearing area or bearing plate area.

$$f'_{cc} = f'_c \left(\sqrt[3]{\frac{A_2}{A_1}} \right) \quad (1)$$

Then, Hawkins (1968) developed an expression for ratios of A_2/A_1 ranging from 1 to 40 as follows:

$$\frac{f'_{cc}}{f'_c} = 1 + \frac{4.15}{\sqrt{f'_c}} \left(\sqrt{\frac{A_2}{A_1}} - 1 \right) \quad (2)$$

In which, f'_{cc} and f'_c represents the concrete bearing strength and concrete compressive strength (MPa), respectively, A_1 as the bearing plate area, and A_2 as the area of the lower base of the largest frustum of a pyramid. The American Concrete Institute (ACI) also proposed an equation to determine the bearing strength of concrete as defined in ACI-318 as follows:

$$f'_{cc} = 0.85\phi_c f'_c \left(\sqrt{\frac{A_2}{A_1}} \right) \quad (3)$$

where, A_1 denotes bearing plate area, A_2 as the area of the lower base of the largest frustum of a pyramid, ϕ_c as the capacity reduction factor for concrete in bearing and $0.85f'_c$ as the concrete compressive strength under sustained loads. After numerous number of developments on strength of concrete bearing capacity, recent researchers realised that with the additional of agro-waste materials in the concrete such as silica fume, oil palm trunks, fly ash and many others, improves the bearing strength of the concrete than plain concrete, besides able to preserve the environment.

Ravindrarajah (1999) had proposed an expression for the prediction of ultimate bearing strength of polystyrene aggregate concrete as follows:

$$f_b = (0.635 + p) f'_c (A_c/A_b)^{0.5} \quad (4)$$

In which, f'_c denotes the cylinder strength, 'p' as the polystyrene content based on coarse aggregate replacement, A_c and A_b represent the total area and bearing area, respectively.

Nevertheless, in this research, f'_c represents the concrete compressive strength obtained from a cube test and a factor of 0.79 was chosen as has been proposed by Haagsma (1969) when cube strength is used. The second factor 'p' is equal to the fly ash content in relation to cement replacement. As an example, when 20% of cement is replaced with the fly ash, the value for 'p' is 0.20.

Therefore, the proposed empirical formula to calculate the bearing strength of concrete blocks containing fly ash is expressed as follows:

$$f_b = \phi (0.79 + p) f'_c (A_c/A_b)^{0.5} \quad (5)$$

where, ϕ denotes the strength reduction factor (= 0.6) as specified by the Australian Standards AS3600 (2001).

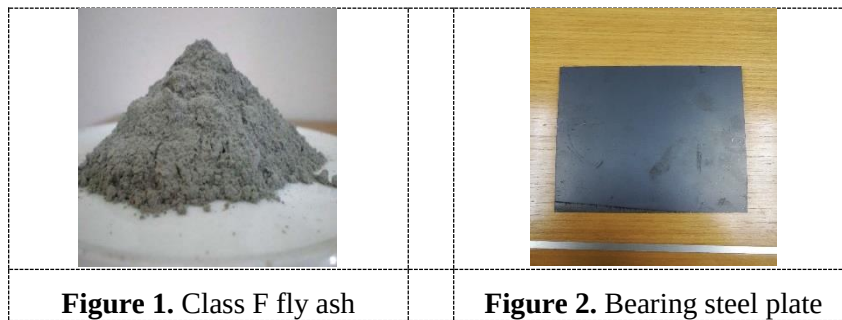
3. Methods

In this study, a series of experimental testing have been carried out to inspect the bearing capacity of concrete blocks and observe its failure mechanism. The test was performed under axially compressive loading using compression testing machine as preferred by numerous number of researchers. All

laboratory works were conducted at the Concrete and Heavy Structures Laboratories, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam. Details explanation with regards to the preparation of specimens, test set-up and experimental testing were described and discussed as on the following sub-topics.

3.1. Material Properties

In this study, among the general materials that have been used for experimental investigations are plain concrete block, concrete block containing fly ash, and bearing steel plate. The basic ingredients of mix design of control specimens are cement, water, fine aggregates and coarse aggregates. Meanwhile, the ingredients of mix design for concrete blocks containing fly ash are class F fly ash, cement, water, fine aggregates and coarse aggregates. Class F fly ash contain lime that less than 10% and chemical contents ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) more than 70% as shown in Figure 1. In addition, mild steel was chosen as bearing steel plate (100mm x 100mm in cross section and 10mm thickness) due to its characteristics of rust resistance and can be weld as shown in Figure 2.



3.2. Preparation of specimen

The concrete with the characteristic strength of 30N/mm^2 was poured into the mould (200mm x 200mm in cross section and 200mm high). All specimens were cast from a concrete mix as shown in Table 1.

Table 1: Detail of the concrete mix

Specimen Designation	Water, kg/m^3	Cement, kg/m^3	Fly ash, kg/m^3	Fine aggregate, kg/m^3	Coarse aggregate, kg/m^3	
					10 mm	20 mm
FA00	180	390	-	522	426	852
FA20	180	312	78	522	426	852
FA30	180	273	117	522	426	852
FA40	180	234	156	522	426	852

Note: FA00 represents plain concrete without fly ash.

FA20 represents plain concrete with 20% of fly ash as cement replacement.

FA30 represents plain concrete with 30% of fly ash as cement replacement.

FA40 represents plain concrete with 40% of fly ash as cement replacement.

The concrete block was remoulded and placed in the curing tank after 24 hours of casting. Thirty-six (36) numbers of concrete cubes including plain concrete, and concrete cubes containing 20%, 30%, and 40% of fly ash as cement replacement, all 150 x 150 mm in cross section and 150 mm high, were cast as control specimens. These concrete cubes were tested up to the failure for their compressive strength after being stored in a curing tank for 7, 14 and 28 days to inspect the mechanical properties of the mix as shown in Figure 1.

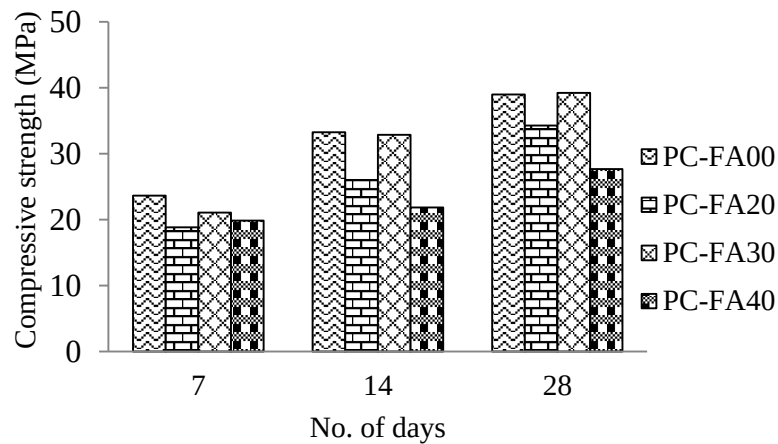
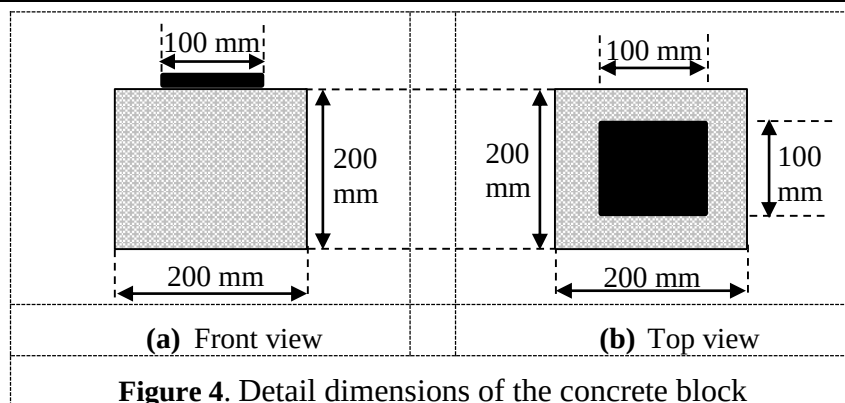


Figure 3. Mechanical properties of the concrete mix

A total of twelve (12) numbers of concrete blocks were casted and tested up to failure subjected to axially compressive loading after 28 days achieving its designated age. There are three (3) plain concrete blocks labelled as PC-FA00, three (3) concrete blocks containing 20% fly ash denotes as PC-FA20, three (3) concrete blocks containing 30% fly ash denotes as PC-FA30 and three (3) concrete blocks containing 40% fly ash as cement replacement denotes as PC-FA40 as shown in Table 2 and Figure 4. Each of these specimens had bearing steel plate (100mm x 100mm in cross section and 10mm thickness) concentrically placed on top of the specimens.

Table 2. Details configuration of concrete block specimens

Specimen designation	Block Cross section	Block height	Plate cross section	Type of Test	Remarks
PC-FA00-01	200mm x 200mm	200mm	100mm x 100mm	Axial compressive test	Plain concrete blocks
PC-FA00-02					
PC-FA00-03					
PC-FA20-01					Concrete blocks containing 20% fly ash
PC-FA20-02					
PC-FA20-03					
PC-FA30-01					Concrete blocks containing 30% fly ash
PC-FA30-02					
PC-FA30-03					
PC-FA40-01					Concrete blocks containing 40% fly ash
PC-FA40-02					
PC-FA40-03					



In this study, 10mm plate thickness was selected due to the reason that it is a typical range for the steel plate thickness in most experimental setup performed by previous studies, ranging from 8mm to 15mm (Escobar-Sandoval *et al.*, 2006; Ahmed *et al.*, 2005).

3.3. Experimental details and test set-up

All concrete block specimens have been tested up to failure subjected to axially compressive loading using 2500kN Universal testing machine (UTM). The aim of this experimental investigation was to determine the increase in bearing strength resulting from different percentage of fly ash as cement replacement. To ensure smooth contact between the bearing plate and concrete surface, the bearing surface of the machine and specimen was cleaned either on the top or bottom surface. The upper platen of the testing machine bore directly on the entire area of the bearing plate. The piston was lowered gently to the top of the concrete block specimen using a lever. The specimens were loaded continuously until failure. The experimental set-up of the concrete block specimens is shown in Figure 5. A linear variable differential transformer (LVDT) was used to measure cross-head displacement under the applied bearing load. The ultimate load and any crack deformities on the concrete block specimens were observed and recorded.

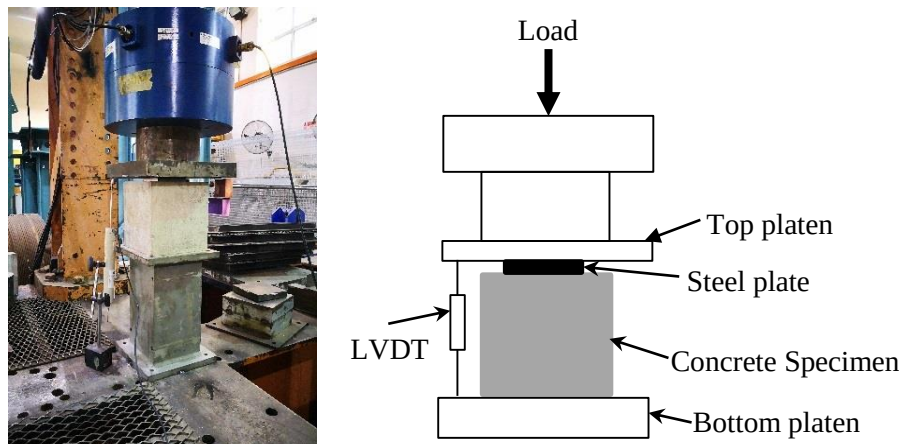


Figure 5. Experimental set-up

4. Results and Discussion

Readings were recorded for typical specimens and a relationship between the bearing load and displacement was developed and discussed on the following sub-topics.

4.1 Load bearing capacity-deformation relationship

With the addition of natural fibers such as fly ash in concrete blocks as cement replacement, the bearing capacity of concrete blocks are known to be increased when compared with the plain concrete blocks. One of the reason of increment was due to the reduction of water to cementation ratio. Then, the study on the concrete block containing fly ash have been performed to understand more about the optimum percentage of fly ash and area of uncertainty in prediction of higher bearing strength. Twelve (12) numbers of specimens have been tested up to failure under axially compressive loading.

The load carrying capacity and displacement values were obtained using data acquisition system, recorded by the computer. Based on the obtained results via experimental measurements for twelve (12) numbers of concrete block specimens, the ultimate load bearing capacity and displacement relationship were plotted. The graph of load bearing capacity versus deformation for all specimens are shown in Figure 6.

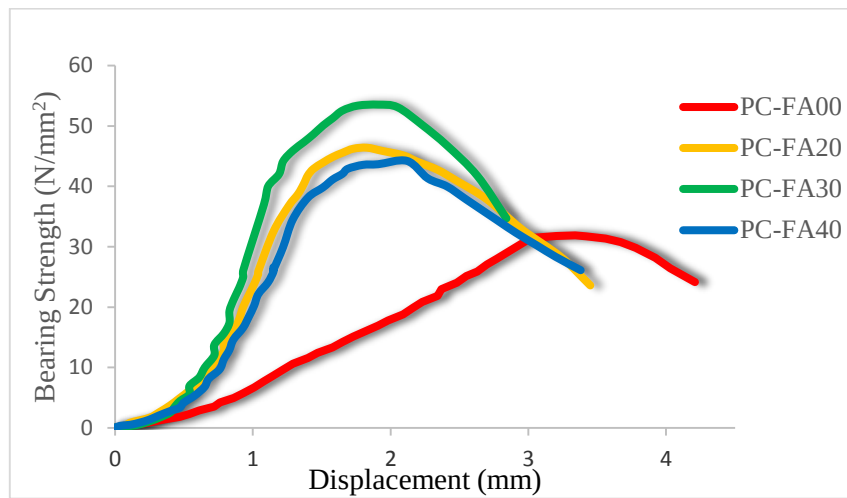


Figure 6. Graph of load bearing capacity versus deformation

Based on the results depicted in Figure 6, for the plain concrete blocks labelled as PC-FA00-01, PC-FA00-02 and PC-FA00-03, its average ultimate value of load bearing capacity was recorded as 0.03034kN/mm² with 3.44mm deformation. Meanwhile, for concrete block specimens containing 20% of fly ash as cement replacement denotes as PC-FA20-01, PC-FA20-02 and PC-FA20-03, the average value of bearing strength was recorded as 0.04195kN/mm² with 1.62mm deformation. Meanwhile, for concrete block specimens containing 30% of fly ash as cement replacement denotes as PC-FA30-01, PC-FA30-02 and PC-FA30-03, the average value of bearing strength was recorded as 0.05217kN/mm² with 2.04mm deformation. Besides that, as can be seen in Figure 6, the average value of bearing strength for concrete block specimens containing 40% of fly ash labelled as PC-FA40-01, PC-FA40-02 and PC-FA40-03 was recorded as 0.04073kN/mm² with 1.85mm deformation. The result of each type of specimen was then presented in Table 3.

Table 3. Results of bearing strength test

Specimen designation	Ultimate Load capacity, Nu (kN)	Nu _{ave.} (kN)	Displacement (displ.), (mm)	Average displ., (mm)	Bearing strength, f _b (N/mm ²)	Average bearing strength, f _b (N/mm ²)
PC-FA00-01	276.76	303.43	3.85	3.44	27.68	30.34
PC-FA00-02	314.79		3.13		31.48	
PC-FA00-03	318.73		3.34		31.87	
PC-FA20-01	431.53	419.50	1.55	1.62	43.15	41.95
PC-FA20-02	421.04		1.37		42.10	
PC-FA20-03	405.93		1.94		40.59	
PC-FA30-01	511.54	521.71	2.01	2.04	51.15	52.17
PC-FA30-02	535.15		1.76		53.32	
PC-FA30-03	518.43		2.34		51.84	
PC-FA40-01	436.45	404.31	1.80	1.85	43.66	40.73
PC-FA40-02	369.23		1.58		36.93	
PC-FA40-03	407.26		2.16		40.73	

Experimental results demonstrate that the bearing strength of concrete block containing 30% fly ash as cement replacement gave a higher value as compared to concrete block specimens containing 20% and 40% fly ash. Test on the bearing strength of plain concrete have served to fill an essential gap in the experimental data. As can be observed on the deformation of specimen, it specifies that the concrete block specimen containing fly ash have the tendency to reduce the deformation of the concrete specimen

by half compared to plain concrete. The comparison between experimental results and previous studies of the concrete block specimens are shown Table 4.

Table 4. Comparison between experimental test and previous studies

Specimen designation	f_b (N/mm ²)	$f_{b(R1)}$ (N/mm ²) (Ravindrarajah, 1999)	$f_{b(R2)}$ (N/mm ²) (Equation 5)	$f_b/f_{b(R1)}$	$f_b/f_{b(R2)}$
PC-FA00	30.34	61.59	36.95	0.49	0.82
PC-FA20	41.95	67.87	40.72	0.62	1.03
PC-FA30	52.17	85.52	51.31	0.61	1.02
PC-FA40	40.73	65.81	39.49	0.62	1.03

4.2 Mode of failures

The failure of concrete blocks occurs when the forces applied on top of it exceeded the strength of concrete. The type of failure modes that have been observed during the experimental testing is in the forms of localized damage especially at the outer edge of the contact area. It has found that these observations are comparable with previous studies (Mohd Raizamzamani Md Zain *et al.*, 2017; Al-Sahawneh *et al.*, 2013; Zhou *et al.*, 2013; Kameswara Rao *et al.*, 1974) where the vertical cracks, splitting wedge and inverse pyramid failure have been observed at the outer edge of contact area, as shown in Figure 7 until Figure 10.

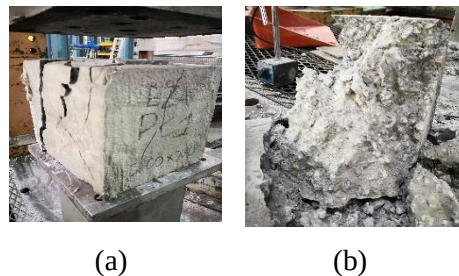


Figure 7. Mode of failure of plain concrete block; (a) Vertical crack, (b) Brittle fracture

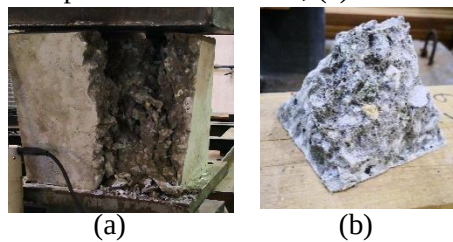


Figure 8. Modes of failure when concrete blocks containing 20% fly ash were concentrically loaded through 10 mm thick steel plate; (a) Splitting wedge, (b) Inverted pyramid shape

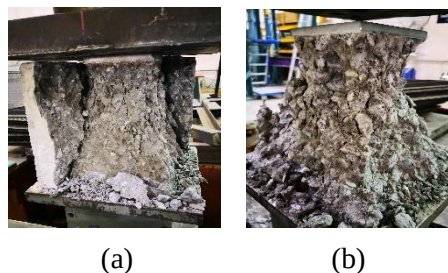


Figure 9. Modes of failure when concrete blocks containing 30% fly ash were concentrically loaded through 10 mm thick steel plate; (a) Brittle fracture, (b) Non-explosive

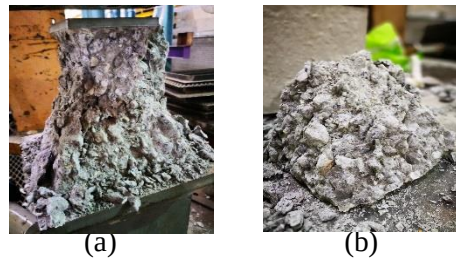


Figure 10. Modes of failure when concrete blocks containing 40% fly ash were concentrically loaded through 10 mm thick steel plate; (a) Non-explosive, (b) Conical shape failure

As depicted in Figure 7(a and b), the initial failure that can be seen was the vertical crack. Then, when the tensile stress at the top of concrete block was achieved its maximum stresses and exceed the tensile strength of the concrete block, brittle fracture was observed. Meanwhile, the type of failure modes for concrete block specimens containing fly ash are nearly the same, as shown in Figure 8 up to Figure 10. The occurrence of crack was due to the reason that no reinforcing bar to hold the failure when the concrete specimen reaches its limiting value. The crack start with the same phase which are vertical crack and then, splitting wedge failure until it brittle. At the end of the phase, the shape of the concrete block became inverted pyramid and conical shapes. The concrete start to crack when the maximum load of the concrete was achieved and the tension of the concrete at the maximum value.

5. Conclusions

The following conclusions were derived through this study:

- 1) Concrete block specimens containing 30% fly ash gave higher value of bearing strength if compared with plain concrete and specimens with 20% and 40% of fly ash as cement replacements. This indicates that the optimum percentage of fly ash that can be used in design concrete mix by using BS method was 30%.
- 2) The specimen having lower value of bearing capacity experiencing much more deformation. Concrete block specimen containing fly ash have the tendency to reduce the deformation of the concrete specimen by half compared to plain concrete.
- 3) The type of failure modes that have been observed during the experimental testing is in the forms of localized damage especially at the outer edge of the contact area
- 4) All concrete block specimens demonstrate that failure of the concrete goes with the same phase and pattern. It starts with the crack in vertical and then produce splitting wedge, inverted pyramid shape, brittle and lastly, in the form of conical shape failure. The same pattern been observed for all specimens due to the reason that no reinforcing bar to hold the failure when the concrete specimen reaches its limiting value.

Acknowledgements

The authors gratefully acknowledge the financial supports by Ministry of Higher Education under Research Acculturation Grant Scheme (RAGS) (RAGS/1/2015/TK01/UITM/03/1) and also thankful to all staff in Concrete, Fabrication and Heavy Structures laboratories, Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam for their assistance in completing these experimental works.

References

- [1] Ahmad, Z., Saman, H. M. and Tahir, P. M. 2010. Oil Palm Trunk Fiber As A Bio-Waste Resource For Concrete Reinforcement. International Journal of Mechanical and Materials Engineering (IJMME), Vol.5 No.2, pp 199-207
- [2] Ahmed, T., Burley, E., & Rigden, S. 1998. Bearing capacity of plain and reinforced concrete

- loaded over a limited area. *ACI Structural Journal*, 330-340.
- [3] ACI Committee, Structural Building Code, & ACI Committee 318 2005. *Building code requirements for structural concrete (ACI 318-05) and commentary (ACI 318R-05)*, 2nd Edition, Farmington Hills, MI:American Concrete Institute.
- [4] Al-Sahawneh, E.I., Amjad, A.Y., Hassan, R.H., & Khair Al-Deen, B. 2013. A proposed model at failure stage to assess the bearing stress of normal weight concrete. *International Journal of Engineering Research and Application*, 3, 793-802.
- [5] Al-Ta'an, S.A. 2005. Bearing capacity of steel fibrous concrete. Civil Engineering Department, Mosul University, Mosul.
- [6] Au, T., & Baird, D.L. 1960. Bearing capacity of concrete blocks. *Journal of the American Concrete Institute*. 56, 869 – 880.
- [7] Australian Standard. 2001. Committee BD-002. Concrete Structures AS3600-2001.
- [8] Baushinger, J. 1876. Tests with Blocks of Natural Stone. *Mechanisch und Technischen Laboratorium der Kgl. Technischen Hochschule*, Munich, 6, 13.
- [9] DeWolf J.T. 1978. Axially Loaded Column Base Plates. *Journal of the Structural Division ASCE*, Vol. 104. No. ST4, pp. 781-794.
- [10] Escobar-Sandoval, D., Andren, S.W., & Gary, F.D. 2006. Concentrically loaded circular steel plates bearing on plain concrete. *Journal of Structure Engineering*, 132(11), 1784-1792.
- [11] Haagsma, T. 1969. The Ultimate Strength of Unreinforced Concrete Specimens subjected to Concentrated Load. Delft, Netherlands.
- [12] Hawkins, N.M. 1968. The bearing strength of concrete loaded through flexible plates. *Magazine of Concrete Research*, 20(63), 95-102.
- [13] Ince, R., & Arici, E. (2004). Size effect in bearing strength of concrete cubes. *Construction and Building Materials*, 18, 603-609.
- [14] Kameswara Rao, C.V.S., & Swamy, R.N. 1974. Bearing strength of steel fibre reinforced concrete. *Build. Sci.*, 9, 263-268.
- [15] Mohd Raizamzamani M.Z., Norrul Azmi, Y. 2017. Experimental Study on Bearing Strength of Concrete Blocks under Concentric Compression Load. *Pertanika J. Sci. & Technol.* Vol. 25 (S). pp. 67 – 76.
- [16] Meyerhof, G.G. 1953. The bearing capacity of concrete and rock. *Magazine of Concrete Research*, 107-116.
- [17] Ramli, M. and Dawood, E. T. 2010. Effects of Palm Fiber on the Mechanical Properties of Lightweight Concrete Crushed Brick. *American J. of Engineering and Applied Sciences*, Vol 3 (2), pp 489-493
- [18] Ravindrarajah, R. S., & Reinaldy, R. 2010. Bearing Strength of CFRP Confined Concrete. The 5th International Conference on FRP Composites in Civil Engineering, Beijing, China.
- [19] Ravindrarajah, R. S. 1999. Bearing Strength of Concrete Containing Polystyrene Aggregate. Centre for Built Infrastructure Research, Faculty of Engineering, University of Technology, Sydney, Australia. Pp 505 – 514.
- [20] Shelson, W. 1957. Bearing capacity of concrete. *Journal of the American Concrete Institute*, 54(5), 405-414.
- [21] Worrell, E., Martin, M., & Price, L. 1999. Energy Efficiency and Carbon Dioxide Emission Reduction Opportunities In The U.S. Iron And Steel Sector. Lawrence Berkeley National Laboratory, University of California.
- [22] Yahya, N. A., & Dhanasekar, M. 2014. Explicit finite element modelling of bridge girder bearing pedestals. In Smith, Scott T. (Ed.). *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, Southern Cross University, Byron Bay, Australia, 849-853.
- [23] Zhou, W., Hu, H., & Zheng, W. 2013. Bearing capacity of reactive powder concrete reinforced by steel fibers. *Construction and Building Materials*, 1179-1186.