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# Experimental Design Analysis of Ultra Fine Fly Ash, Lime Water, and Basalt Fibre in Mix Proportion of High Volume Fly Ash Concrete

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## ABSTRACT

This paper reports an analysis of three factors in mix proportion of high volume fly ash concrete to produce high strength concrete. The factors analyzed are type of fly ash, kind of mixing water and the utilization of basalt fibre. The type of fly ash factor comprises of the use of raw fly ash and ultra fine fly ash, whereas the kind of water consists of the use of lime water and tap water. The addition of basalt fibre to improve the ductility of high strength concrete is studied and also high strength concrete without basalt fibre is studied. To prepare the mix proportion and to analyze the compressive strength result, experimental design, a statistical method is used. In addition, the compressive strength of concrete is tested on concrete cylinder of ∅100 mm – height 200 mm at curing ages of 28 days and 56 days. The results show that the optimum mix proportion to produce high strength concrete is the mix proportion with the combination of high volume ultra fine fly ash and the use of lime water without the use of basalt fibre. Moreover, the optimum mix proportion meets the mix design of high strength concrete and has similar strength development as normal cement concrete at the age of 28 days.

*Keywords:* Fatigue life, composite materials, non-destructive technique

## INTRODUCTION

Based on ACI 363R-92 (1997), the ACI committee report that high strength concrete is concrete with a compressive strength greater than 6,000 psi (41 MPa) and it is widely used in many applications, including high-rise buildings, offshore structures, bridge elements, overlays, and pavements

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(Caldarone, 2009). It carries loads more efficiently than normal concrete, reduces the total amount of material needed and reduces overall cost of the structure (Portland Cement Association, 2008). Despite the benefit of using high strength concrete in construction, the increase of relative brittleness or the decrease of ductility of High Strength Concrete needs to be balanced by adding fibres in it (Taylor *et al.*, 1997). One of the types of fibres is basalt fibre that is made from basalt rocks and based on the previous research it shown that the fibre is a good alternative system for strengthening material in concrete, particularly when moderate structural strengthening and high resistance to fire are needed (Sim *et al.*, 2005).

Generally, high strength concrete is a mixture of strong aggregate, a higher Portland cement content, low water/binder ratio, and selected admixture (Nawy, 1996). One of mineral admixtures possible to use in concrete is fly ash, a by product of combustion of ground or powdered coal exhaust fumes of coal-fired power stations (Nawy, 1996). The use of fly ash as binder has proved to give many advantages for concrete properties, both in fresh concrete and hardened concrete (Oner *et al.*, 2005). The durability properties of concrete incorporated with fly ash is better than that of normal concrete as it can prevent the alkali silica reaction in concrete and has very low permeability (Nawy, 1996).

Significant increase of the use of fly ash in concrete will significantly reduce $CO_2$ emissions, a main contributor to the greenhouse effect and the global warming, it is necessary to support the use of large amounts of fly ash in concrete industry (Malhotra & Mehta, 2005). The term of high volume fly ash (HVFA) concrete was firstly introduced by Malhotra at CANMET in the 1980s, which means the concrete with at least 50% of its Portland cement by mass is replaced with ASTM class F or class C fly ash (Malhotra & Mehta, 2005). Although high volume fly ash concrete contains large amount of fly ash, the concrete produced demonstrates the attributes of high-performance concrete (Bilodeau & Malhotra, 2000).

Additionally, the increase of fly ash fineness is beneficial as one of the factors giving great influence in fly ash reactivity is the particle size (Obla *et al.*, 2003). Moreover Butler and Mearing in Xu (1997) found that fly ash particles in the range of 10 to 50 μm mainly act as void fillers in concrete, whereas the particles smaller than 10 microns are more reasonably classified as pozzolanic reactive.

Despite the advantages it has, fly ash concrete usually demonstrates lower strength at early ages although it shows higher strength at a longer period of time (Atis, 2003). One method to get same early age strength as normal portland cement is by using elevated curing temperature (Elsageer *et al.*, 2009).

As fly ash reaction mechanism needs $Ca(OH)_2$ to give a positive contribution in concrete properties (Oner *et al.*, 2005), the addition of lime in fly ash concrete gives significant improvement in concrete durability although there is no influence on concrete strength (Mira P., Papadakis, & Tsimas, 2002). The deployment of lime in treating concrete is also assured by ASTM which stated that lime water should be used as curing water for mortar cubes (ASTM, 2002).

However, although it is known that the use of lime in fly ash concrete improves the properties of concrete, there has not been any research on the use of lime water as mixing water in concrete. The use of lime in liquid form in this study is expected to produce better reactivity with ultra fine fly ash than that of powder form.

## RESEARCH SIGNIFICANCE

This research investigated the Experimental design of 3 factors in concrete mix proportion to find out the influence of those 3 factors to produce high strength concrete using high volume ultra fine fly ash. The factors analyzed are type of fly ash, kind of mixing water and the utilization of basalt fibre. Each factor comprises of 2 levels, low and high. The two levels of fly ash are the use of raw fly ash and the use of ultra fine fly ash. In addition, the two levels of mixing water are the use of tap water and the use of lime water. Moreover, the two levels of basalt fibre are the addition of basalt fibre in high strength concrete and high strength concrete without basalt fibre.

The mix proportion of concrete is based on proposed method of high performance concrete mix design (Aïtcin, 2004) for design compressive strength of 80 MPa at 28 days. The compressive strength of concrete was tested on 100 mm and 200 mm height cylinders at curing ages of 28 days and 56 days. All of the specimens were cured by immersing in a water tank with a temperature of 24$^{o}$C until the day of test.

Experimental design, a statistical method, was used to prepare concrete mix proportion and to analyze the experimental results. Furthermore based on the design experimental result, a mix proportion to produce highest strength of the concrete was tested and compared with normal cement concrete.

## MATERIALS

### *Fly ash*

Fly ash for this research comes from Tarong power plant and it is classified as Low calcium fly ash or ASTM class F fly ash (Sofi *et al.*, 2007), because the sum of $SiO_3$ + $Fe_2O_3$ + $Al_2O_3$ is more than 70%. The chemical properties of fly ash are given in Table 1.

TABLE 1
Chemical properties of Tarong fly ash (mass %)

| | Tarong | ASTM Class F* |
|---|---|---|
| $SiO_2$ | 65.9 | |
| $Al_2O_3$ | 28.89 | The sum of $SiO_3$ + $Al_2O_3$ + $Fe_2O_3$ min 70% |
| $Fe_2O_3$ | 0.38 | |
| $TiO_2$ | 1.97 | |
| MnO | 0 | |
| MgO | 0.15 | |
| CaO | 0.06 | |
| $Na_2O$ | 0.05 | |
| $K_2O$ | 0.26 | |
| $P_2O_5$ | 0.08 | |
| $SO_3$ | 0.03 | Max, 5% |
| LOI | 1.24 | Max, 6 % |

*ASTM, 2003

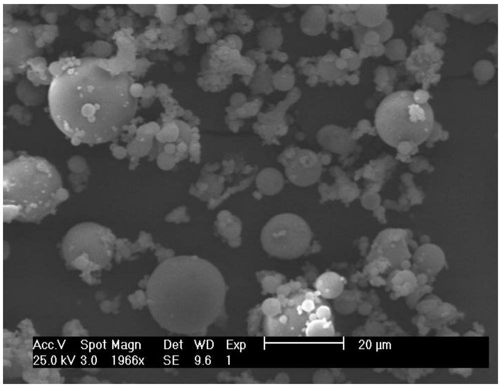
As this research investigates the influence of using raw fly ash and fine fly ash, to obtain the ultra fine fly ash the raw fly ash was ground in a Micronizer. The micronizer is a jet mill, using compressed air or gas to make high speed rotation of the particles in grinding chamber which further leads the material to have particle-on-particle impact. The micronizer can produce particle fineness ranging from 0.5 to 45 microns.

The increase of fineness of fly ash after the grinding was tested using Blaine test apparatus to find out the surface area of fly ash. The result showed that the surface area of fly ash increases from 364 $m^2$ /kg in raw fly ash to 525 $m^2$ /kg in ultra fine fly ash based on cement fineness. It means the fineness of fly ash increased by 40% after the grinding process using micronizer. Both pictures at Fig.1 show the difference between the raw fly ash and the ultra fine fly ash from Scanning Electron Microscopic (SEM) analysis. It proves that the particle size of ultra fine fly ash is smaller than that of the raw fly ash.

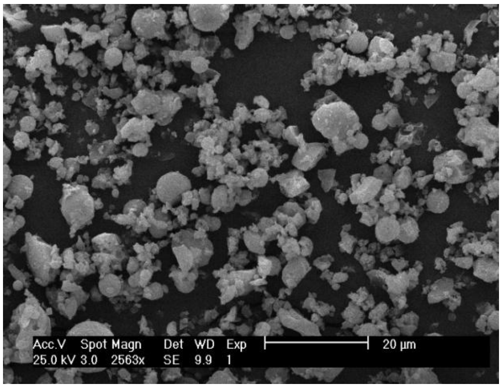
*Lime water*

There were two types of mixing water used in this experiment, tap water and saturated lime water. The saturated lime water was made by dissolving 3 grams of hydrated lime powder in 1 litre tap water. After being allowed to sediment for 24 hours, the top layer of the water was taken and used as mixing water while the solid hydrated lime was left on the bed. The saturated lime water has different properties compared to tap water as shown in Table 2.

The density of saturated lime water was slightly higher than that of tap water since some hydrated lime particles are dissolved in it (0.08%). Furthermore, the alkalinity of saturated lime water increased than that of the tap water. The increase of alkalinity in lime water resulted from $Ca(OH)_2$ (hydrated lime) which will be useful when reacting with pozzolanic material like fly ash. The use of lime water in fly ash concrete is in line with what is stated by Davidovits in 1999 that geopolymer concrete might be produced by making a reaction of alkaline liquid with silicon and the aluminium from by-product material (Vijai *et al.*, 2010). Unfortunately geopolymer concrete has a stiff consistency in fresh state. To reduce the effect, the concentration of 50% saturated lime water and 50% of tap water was used.




a) Raw fly ash




b) Ultra fine fly ash

Fig.1: Scanning Electron Microscopic analysis of fly ash

TABLE 2
Properties of lime water

| Water | Density | pH |
|---|---|---|
| Tap water | 0.9909 | 7.3 |
| Saturated lime water | 0.9917 | 11.4 |

## MIX PROPORTION

The design experiment in this research was created using 3 factors, which comprise of low level and high level. The factor and each level are shown in Table 3.

To find out how each factor had influence on the compressive strength of concrete, the experimental design, a statistical method was used. The method started by finding out the combination of mix proportion which should be prepared from those factors considered. The full factorial combination of 3 factors each of which consist of 2 levels will result in 8 combinations. However, considering the affordability of resources, this study uses one-half fraction by neglecting higher order interaction between factor and levels (Montgomery, 2009). The randomization of one-half fraction of $2^3$ designs using minitab software comes in four combination (½ x $2^3$ = 8) treatments as shown in Table 4.

TABLE 3
The factor and the level in this experimental design

| Factor | Low | High |
|---|---|---|
| Type of fly ash | Ultra fine fly ash (UFFA) | Raw fly ash |
| Kind of water | Lime water | Tap water |
| The used of fibre | Basalt fibre | No fibre |

TABLE 4
The randomization of a one-half fraction of $2^3$ designs

| Combination | Fly ash | Fibre | Mixing water |
|---|---|---|---|
| No 1 | UFFA | No Fibre | Tap water |
| No 2 | UFFA | Basalt fibre | Lime water |
| No 3 | Raw | Basalt fibre | Tap water |
| No 4 | Raw | No Fibre | Lime water |

Based on the randomization of those factors and proposed mix design of high strength concrete, the mix proportion in this research is shown in Table 5. The mix proportion is made with specific gravity of Portland cement 3.15, fine aggregate 2.60, coarse aggregate 2.89, raw fly ash 2.01 and ultra fine fly ash 2.18. The basalt fibre used was 1% by the volume of concrete.

The total binder in the mix proportion is 450 kg/m$^3$ with the water binder ratio of 0.3. As low w/b ratio was used, this mix proportion used HRWR sodium naphthalene formaldehyde sulphonate type with the specific gravity of 1.21. The Ultra fine fly ash need less HRWR in comparison to raw fly ash. As the HRWR is a liquid substance, the content of HRWR affected the amount of water use. The basalt fiber content was 1% of total concrete volume.

Each concrete mix proportion was batched in small mixer, then it is cast in 100 diameter x 200 mm cylinder mould and was compacted using vibrating table to get better density. After the concrete specimens are cast, on the following day the mould is opened and the specimens are cured by placing them in the water tank with temperature 24°C until the day of test.

TABLE 5
Mix proportion of concrete

| Mix proportion | Cement | Fly ash | Water | Agregate | | HRWR | Basalt Fibre |
|---|---|---|---|---|---|---|---|
| | | | | fine | Coarse | | |
| | (kg/m³) | (kg/m³) | (kg/m³) | (kg/m³) | (kg/m³) | (litre/m³) | (kg/m³) |
| UFFA without basalt fiber, tap water (No 1) | 225.0 | 225.0 | 141.0 | 835.0 | 994.0 | 7.0 | - |
| UFFA with basalt fiber, lime water (No 2) | 225.0 | 225.0 | 141.0 | 809.0 | 994.0 | 7.0 | 26.7 |
| Raw Fly Ash with basalt fibre, tap water (No 3) | 225.0 | 225.0 | 139.0 | 785.0 | 994.0 | 10.2 | 26.7 |
| Raw Fly Ash without basalt fibre, lime water (No 4) | 225.0 | 225.0 | 139.0 | 811.0 | 994.0 | 10.2 | - |

## COMPRESSIVE STRENGTH OF CONCRETE

MTS hydraulic compression test machine was used to find out the Compressive strength of concrete. Based on Australian standard the tests were conducted with loading rate of 157 kN/ minute and the compressive strength is calculated using maximum load divided by surface area of concrete cylinder (Australian Standard Comittee, 1999). The result of compression strength of concrete at 28 days and 56 days are shown in Table 6 and Fig.2.

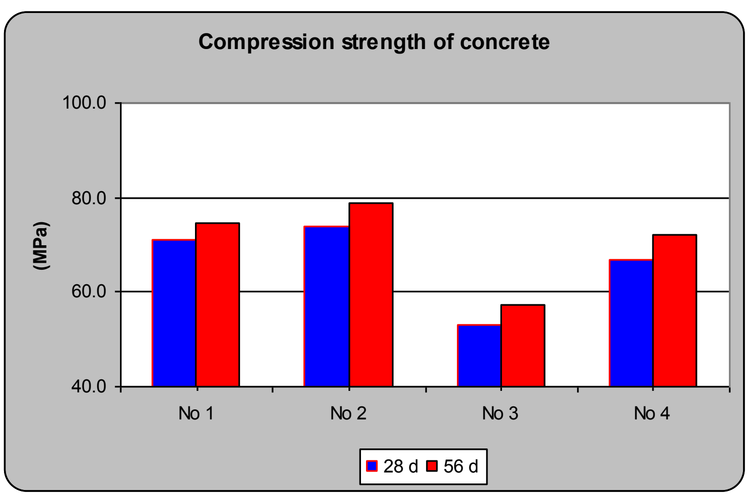



Fig.2: Compressive strength of concrete

The compressive strength result shows all the mix proportions did not meet the compressive strength design of 80 MPa at 28 days. However at 56 days the high volume ultra fine fly ash concrete with lime water and basalt fibre nearly has the same compressive strength as the design compressive strength. For all the mix proportion the longer the curing time the higher the strength of the high volume fly ash concrete. The increase of fly ash concrete compressive strength in correlation to the curing period is same as reported by some researchers (Oner *et al*., 2005), (Ramezanianpur & Malhotra, 1995) (Alvarez *et al.*, 1988). Furthermore the use of ultra fine fly ash significantly increases the compressive strength of high volume fly ash concrete in comparison to the use of raw fly ash. The contribution of ultra fine fly ash to increase compressive strength of concrete was also reported by Chindaprasirt (Chindaprasirt *et al.*, 2007).

TABLE 6
Compressive strength of the concrete

| | 28 d | 56 d |
|---|---|---|
| UFFA without basalt fiber, tap water (No 1) | 70.90 | 74.72 |
| UFFA with basalt fiber, lime water (No 2) | 73.78 | 78.84 |
| Raw Fly Ash with basalt fibre, tap water (No 3) | 52.97 | 57.23 |
| Raw Fly Ash without basalt fibre, lime water (No 4) | 66.69 | 71.97 |

## ANALYSIS OF FACTORS

To analyze how each factor influences the compressive strength of concrete, the main effect graph and size of effect are used. It is the analysis of the difference between the average response at the low level and the average response at high level. The main effect graph and the size of effect graph for the compressive strength of concrete which were used in this experiment are shown in Fig.3 and Fig.4.

Based on the Compressive strength size of effect, the type of fly ash as part of cement replacement is the most influential factor for the compressive strength of concrete in comparison to all factors studied. The higher compressive strength of concrete with the use of ultra fine fly ash in comparison to the use of raw fly ash is also supported by some researchers (Chindaprasirt *et al.*, 2004) (Kiattikomol *et al.*, 2001). In addition the use of lime water as mixing water becomes the second important factor to the compressive strength of high volume fly ash concrete and the contribution increases with increase of curing age.

The least important factor to the compressive strength of concrete is the presence of basalt fibre in which the concrete without basalt fibre has higher compressive strength in comparison to the concrete with basalt fibre. Although previous researcher reported that the use of steel fibre did not reduce the compressive strength of concrete (Balendran *et al.*, 2002), the rapid loss of basalt fibre strength and the lower volumetric stability of basalt fibre in concrete alkali environment are the reason of concrete compressive strength decrease (Sim *et al*., 2005).

Based on the analysis of each factor used in this experiment, to produce highest compressive strength is mix proportion with the combination of high volume ultra fine fly ash and the use of lime water without the use of basalt fibre.

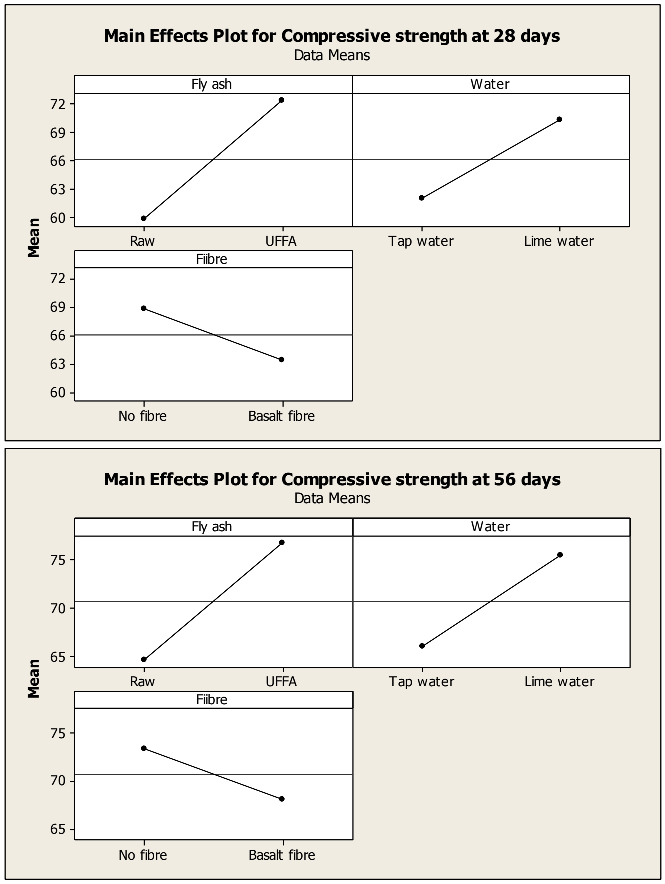



Fig.3: Main effect of compressive strength at 28 days and 56 days

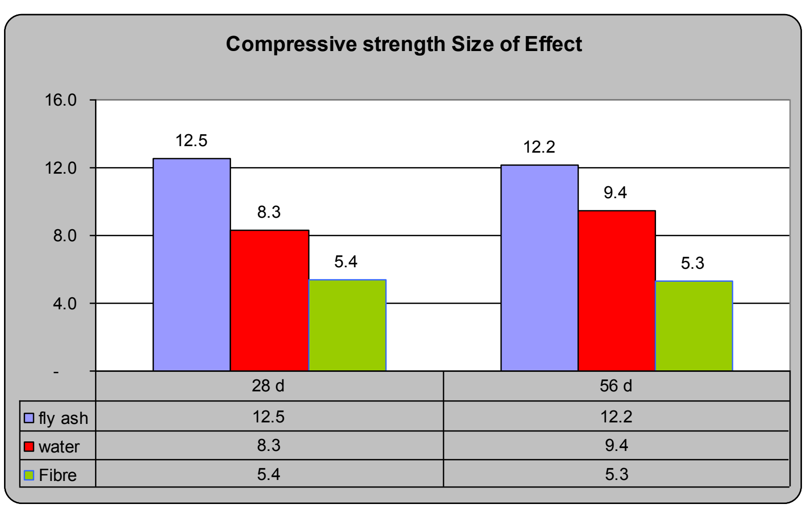



Fig.4: Compressive strength size of effect

TABLE 7
Verification of mix proportion and normal cement concrete

| Mix proportion | Cement | Fly ash | Water | Agregate | | HRWR | Basalt Fibre |
|---|---|---|---|---|---|---|---|
| | | | | fine | Coarse | | |
| | (kg/m3) | (kg/m$^3$) | (kg/m$^3$) | (kg/m$^3$) | (kg/m$^3$) | (litre/m$^3$) | (kg/m$^3$) |
| UFFA without basalt fiber, lime water (No 10) | 225.0 | 225.0 | 141.0 | 835.0 | 994.0 | 7.0 | - |
| Normal cement without basalt fibre, tap water (No 5) | 450.0 | - | 137.0 | 912.0 | 994.0 | 13.9 | - |

## VERIFICATION OF MIX PROPORTION

From the experimental design result the mix proportion of high volume ultra fine fly ash concrete with lime water was prepared. The mix proportion is same as the mix proportion No 1, but the mixing water is lime water. The normal concrete as control mix proportion is also prepared. After the concrete specimens are prepared and then continued with curing stage until the test is conducted at 28 days and 56 days.

Fig.5 shows the compressive strength development of high volume ultra fine fly ash concrete with lime water and normal concrete. Both of the mix proportions satisfy the mix design of 80 MPa at 28 days. In addition the high volume ultra fine fly ash concrete with lime water has the same strength development as high strength normal concrete starting at 28 days and beyond.

In addition, the use of lime water is very useful in increasing compressive strength of high volume ultra fine fly ash concrete to be similar strength as normal cement concrete even

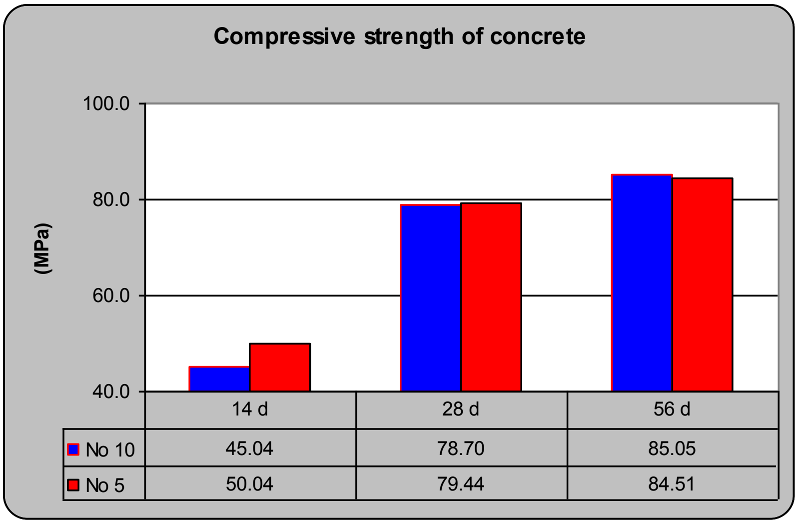



Fig.5: Compressive strength development of optimum mix proportion and normal cement concrete

though the amount of ultra fine fly ash used is up to 50% as cement replacement. This result is noteworthy, as previous research using high volume fine fly ash reduced the compressive strength of concrete at the curing age of 56 days by 15% to 19.0% in comparison to the normal cement (Sengul *et al.*, 2005) (Sengul & Tasdemir, 2009).

Moreover it proves that the use of lime water in high volume ultra fine fly ash concrete produce better reaction with silica in ultra fine fly ash in comparison to the use of hydrated lime to give same compressive strength as normal concrete. The similar research also reported about the utilization of hydrated lime in increasing compressive strength of high volume fly ash concrete, however the compressive strength did not compare to normal concrete (Barbhuiya *et al.*, 2009).

## CONCLUSION

Based on the data presented, the use of ultra fine fly ash and the use of lime water respectively become important factors to increase compressive strength of high volume fly ash concrete. Moreover the use of basalt fibre decreases the compressive strength of concrete due to the basalt fibre lower volumetric stability in alkali environment.

The use of lime water is useful to increase the compressive strength of high volume ultra fine fly ash concrete to be similar to normal cement starting at the age of concrete of 28 days and beyond. This finding is noteworthy, as high volume fine fly ash concrete from previous research has lower compressive strength in comparison to normal cement concrete. In addition the use of lime water in high volume ultra fine fly ash improved concrete compressive strength result in comparison to the use of hydrated lime in high volume fly ash concrete from precious research, as the liquid give better reaction to the silica in fly ash.

Further research should be conducted on the concentration of lime water used and the quantity of high volume ultra fine fly ash to produce optimum high strength concrete.

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