Performance of Straight Steel Fibres Reinforced Alkali Activated Concrete

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Abstract. This paper focuses on the performance of alkali activated concrete produced by using fly ash activated by sodium silicate and sodium hydroxide solutions. These alkali activated concrete were reinforced with straight steel fibres with different weight percentage starting from 0 % up to 5 %. Chemical composition of raw material in the production alkali activated concrete which is fly ash was first identified by using X-ray fluorescence. Results reveal there have an effect of straight steel fibres inclusion to the alkali activated concrete. Highest compressive strength of alkali activated concrete which is 67.72 MPa was obtained when 3 % of straight fibres were added. As well as flexural strength, highest flexural strength which is 6.78 MPa was obtained at 3 % of straight steel fibres inclusions.

1. Introduction
In most of country, the source of generation electricity is from the combustion of coal. This is proved by a report made by World coal Association where 41 % of global electricity is generated by the combustion of coal \cite{1}. In details, there are approximately 2 million of coal will be fired for a capacity of 100 Mega-Watt coal fired station and produce 230 000 tons of coal ash annually \cite{2}. This coal ash is a waste and may become harmful to the environment if not disposed properly. Nowadays, due to the most of coal ash is not consumed as alternative applications it become a waste product and normally disposed in landfill which can cause hazardous to the environmental \cite{3}. So, the usage of fly ash as a raw material in the production of alkali activator material is the alternative solution for this environmental issue.
In 1990, there are about 22.7 billion tons of carbon dioxide was released to the environment over the world. The value then increase in 2012 where 33.9 billion tones of CO$_2$ was released and currently the emission of CO$_2$ reported is over than 34.5 billion tons [4]. Unfortunately, a main contributor to the emission of CO$_2$ is claimed from the cement industry. In facts, the production of 1 tons of OPC will release about 1 tons of CO$_2$. Details of chemical reaction involved in the production of OPC where CO$_2$ was release to the environment as in equation (1):

$$5\text{CaCO}_3 + 2\text{SiO}_2 \rightarrow 3\text{CaO (SiO}_2\text{) + 2CaO}_2 \text{ (SiO}_2\text{) + 5CO}_2$$

(1)

People are very depending on this material (OPC) due to the using of OPC in the production of buildings. This may lead the increment of emission of CO$_2$ to the environment and brings into a global warming issue. Regarding to this issue, alkali activated concrete is the best alternative material to be used as a substitution of OPC in the production of cementitious binder with an excellent properties and proved to improves the greenness of OPC cement [5].

Steel fibres that normally used in OPC concrete have an ability to enhance the post cracking behavior and create a bridge between the crack spot with a sufficient amount of fibres [5]. The addition of steel fibres in OPC concrete proved to produce a better crack control [6-9] and improves tensile strength before and after cracking [7, 10]. Function of steel fibres in OPC concrete to influence the behavior of brittleness of normal concrete to ductile has been studied [7, 9, 11, 12]. Fatigue and dynamic resistance of OPC concrete also improved with high bond in steel fibres surface and cement paste that has been hydrated [13-16]. However, a drawback of steel fibres addition is same as any additions of other types fibres which is the workability of concrete is become lower [17]. Low workability leads to the increasing of bleed water at the top of concrete [18-20]. The effect of fibres additions have been extensively studied toward the OPC concrete. However there is still lack of data regarding to the using of steel fibres as reinforcement in alkali activated concrete. Therefore, the performance of alkali activated concrete with the additions of steel fibres need to be studied and discovered especially in terms of the mechanical properties.

2. Materials and Methodology

Alkali activated concrete was produced by using fly ash as raw material and mixed with alkaline activator. Fly ash was taken from electric power plant Manjung, Malaysia. Alkaline activator is composed of mixture between sodium silicate (Na$_2$SiO$_3$) and sodium hydroxide (NaOH). The Na$_2$SiO$_3$ is from South Pacific Chemicals Industry Sdn. Bhd. (SPCI), Malaysia with SiO/Na$_2$O ratio is 3.2 while the NaOH pellet is obtained from Formosa Plastic Corporation, Taiwan with concentration of 12 M after diluted with distilled water. Chemical composition of Fly ash was first characterized by using x-ray fluorescence (XRF). Ratio between fly ash to alkaline activator that has been used was 2.0. Meanwhile, ratio between Na$_2$SiO$_3$ to NaOH was 2.5.

River sand was used as fine aggregate with a maximum size of 4.75 mm. Meanwhile, limestone was used as coarse aggregate with a maximum size of 20 mm. Fibres used in this research was high quality of low carbon steel with type of straight end. Dimension of straight steel fibres used in this experiment was 0.13 mm in diameter and 5 mm in length. Amount of steel fibres additions were 0 %, 1 %, 3 %, and 5 % from the total weight of concrete.

Sample cube of dimension 100 x 100 x 100 mm were cast for compression test of alkali activated concrete. Meanwhile, beam with dimension of 100 x 100 x 500 mm were cast for flexural test. Every samples from compression and flexural were demoulded after 24 hours and cure at room temperature.

After 28 days, all samples were tested for compression and flexural by using universal testing machine. Four point bending was applied in flexural test as determined by ASTM C1018.
3. Results and Discussion

Table 1 shows XRF result for chemical analysis of fly ash. According to the result from Table 1, the total SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$ value of the fly ash is 72.98% while the total of CaO is 18.10. Since the chemical content of CaO is lower than 20% therefore this fly ash is classified as Class F according to ASTM C618 [21]. The ratio between silica and alumina (SiO$_2$/Al$_2$O$_3$) in raw material of fly ash is 2.64.

| Component | Percentage (%) |
|-----------|----------------|
| SiO$_2$   | 38.80          |
| Al$_2$O$_3$ | 14.70         |
| Fe$_2$O$_3$ | 19.48         |
| TiO$_2$   | 1.02           |
| CaO       | 18.10          |
| MgO       | 3.30           |
| SO$_3$    | 1.50           |
| K$_2$O    | 1.79           |
| MnO       | 0.16           |
| BaO       | 0.27           |
| SrO       | 0.11           |

The effect of steel fibres additions which are 0%, 1%, 3% and 5% to the compressive strength of alkali activated concrete was plotted in a graph as in Figure 1. From the graph, 3% of steel fibres addition shows the highest value of compressive strength which is 67.72 MPa, followed by 1% of steel fibres (62.27 MPa), 5% of steel fibres (60.21 MPa), and the lowest is with 0% of steel fibres (57.92 MPa). This result showed the function of steel fibres addition in order to improve the compressive strength of alkali activated concrete. From the graph, the increasing of steel fibres additions will slightly increase the compressive strength of alkali activated concrete until at 3% which is at the optimum value.

However, steel fibres addition more than 3% shows a reduction in terms of compressive strength. The increasing of compressive strength is due to the contribution of steel fibres inclusion to enhanced post cracking behaviour. This is supported by the previous researchers where Cuenca et al. mentioned steel fibres functioned to bridge the crack spot if the total amount of steel fibres is sufficient [22]. The inclusion of steel fibres in alkali activated concrete give minor effect to the improvement of alkali activated concrete which is 16.91% increment at 3% steel fibres additions (optimum).

Meanwhile, Figure 2 shows the flexural strength (4 point bending) of alkali activated concrete on 28 days related to the steel fibres additions starting from 0%, 1%, 3%, and 5%. From the graph, addition of 3% steel fibres shows the highest flexural strength which is 6.78 MPa, followed by 5% steel fibres content (6.15 MPa), 1% steel fibres content (5.88 MPa), and the lowest value is 0% steel fibres content which is 4.3 MPa. This graph result shows the importance of steel fibres in order to improve the flexural strength of alkali activated concrete. From the graph, the increasing of steel fibres content from 0% to 3% shows the increasing of flexural strength until maximum at 3% steel fibres content.
Figure 1. The effect of steel fibres addition on 28-day to the compressive strength of alkali activated concrete.

Figure 2. The effect of steel fibres addition on 28-day to the flexural strength of alkali activated concrete.

However, the flexural strength of alkali activated concrete slightly dropped when steel fibres additions over than 3 %. Increasing of flexural strength is due to the functions of steel fibres to change the properties of concrete from brittle to ductile behaviour. Generally, main function of steel fibres is excellent resistance to cracking and crack propagation. Hence, extensibility and tensile strength, both at first crack and at ultimate, specifically under flexural loading; and the fibres are able to hold the matrix together even after extensive cracking.

4. Conclusion

The additions of steel fibres in alkali activated concrete give impact to the mechanical properties which are compressive and flexural strength. The additions of steel fibres will enhance the compressive strength until at optimum content which is at 3 % and over than that, the value slightly getting lower. Meanwhile, the inclusions of steel fibres give significant effect to the flexural strength which is about 57.67% increase (maximum) at 3 % of fibres
additions compare to the compressive strength which is 16.91 % (maximum) at 3 % of fibres additions. This is shown the functions of steel fibres additions to increase the compressive strength and mainly to increase the flexural strength.

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