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EFFECTIVENESS OF BOTTOM ASH AS FINE AGGREGATE REPLACEMENT IN ENGINEERED CEMENTITIOUS COMPOSITES

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Abstract

Concrete productions have been revolutionized by replacing natural aggregate or cement with waste or recycled material as part of the concrete material. It has been used as material replacement partially or fully. This revolution of engineering practices is in line with the aim of a sustainable and economical design in construction. Industries have used steel fibres in pure concrete to improve the properties of concrete by reducing or stopping cracks from propagating further in concrete and reinforced concrete structures. Steel fibres at the same time also help to increase the strength of concrete and the strength of structures indirectly. On the other hand, bottom ash has been used as fine aggregate replacement in concrete. Bottom ash is part of the non-combustible residue of combustion in a power plant, boiler, furnace or incinerator. A total of 9 concrete cubes and 4 reinforced concrete beams were prepared for this project. 25% bottom ash was used as fine aggregate replacement, and 2% steel fibre was used as additional reinforcement in the concrete (BASF Concrete). The presence of bottom ash helps to develop long-term strength improvement while the presence of steel fibres has helped to improve the strength of concrete. The bottom ash was able to work well with the steel fibres in meeting the compression strength design requirement. The strength rose up to 32.84 MPa in average in a 42 day test. The presence of steel fibres has created a bridging affect in the beam structure and helped the BASF reinforced concrete beam to achieve an average ultimate load of 110.13 MPa compared to the SFRC beam which just achieved 89.68 MPa in flexural strength. In addition, the deflection was reduced by 22% in average for the BASF beam compared to the SFRC beam. These achievements have shown that BASF concrete has a higher potential to be commercialised in the construction industry which is in line with SDG goal 9. The usage of bottom ash may help to reduce the environmental issue by adopting waste products as part of the materials used in concrete.

Keywords: Bottom ash, Engineered cementitious composite, Fine aggregate replacement, Steel fibre, Sustainable materials.

1. Introduction

Bottom ash is a course, granular, non-combustible by-product of coal combustion that's collected from furnaces. Most bottom ash is created at coal-fired power plants which comes from coal combustion which contains traces of combustibles embedded in forming clinkers that sticks to the hot walls of a coal- burning chamber throughout its operation [1]. Once powdery coal is burned in a bottom boiler, most of the material is caught within the flue gas and captured as ash. Solely 10-20% of this ash is bottom ash [2]. This ash is dark grey in colour and is to the scale of sand. This waste is then deposited to the landfill as waste disposal or used as reusable material. Once BA is left dry it is often employed in several materials like concrete, bricks, and different useful material. This even have several environmental advantages such as alternative raw material, or as replacement for earth or sand or aggregates, as an example for buildings and in cement kilns [3].

Previous research has shown the cost reduction in construction by developing a green environment with bottom ash which proving to be an economical material in the engineering construction aspect [4]. On the other hand, steel fibres help to enhance the resistance of concrete against tension and impact loads with effective dosage of steel fibres with volume fractions varying between 1.0% and 2.0% [5]. Steel fibre contain in concrete also helps to hold the crack fragment on the surface from collapse and has possibly will withstand small crack from propagate further [5]. The combination of bottom ash as partial fine aggregate replacement materials in concrete may be able to produce variations in the characteristics of concrete in terms of compressive strength, durability, and workability of concrete [6].

Previous studies on addition of bottom ash to replace sand in the production of concrete show that the development of strength characteristics in bottom ash concrete were similar to conventional concrete and proves that bottom ash is an economical material [7, 8]. Although a lot of investigations had been made on bottom ash and steel fibres, but less research had been done on bottom ash in collaboration with steel fibre reinforced concrete in beam structures. Thus, this paper will focus on the effectiveness of bottom ash as fine aggregate replacement in steel fibre reinforced concrete beams. The idea of combining these two materials was based on the previous work which has shown the bottom ash is having a potential to be commercialize as part of concrete material.

2. Experimental Work

2.1. Materials

The materials used in trial mixes to prepare test specimens consist of Ordinary Portland Cement (OPC), coarse and fine aggregates, bottom ash, steel fibres, and water. Grade 30 Ordinary Portland Cement (OPC) is classified as Type 1 according to ASTM C150 with water cement ratio of 0.5. Coarse aggregates are sieved to a nominal size of 10 mm and 20 mm and sand is used as fine aggregates. Bottom ash is sourced from Tanjung Bin with at sizes of 0.075 mm – 20 mm and passed through a 4.75 mm sieve. Steel fibres for reinforcing concrete are defined as short, discrete lengths of steel fibres with an aspect ratio (ratio of length to diameter) from about 20 to 100, with different cross-sections, and that are sufficiently small to be randomly dispersed in an unhardened concrete mixture using the usual mixing procedures. T10 are used as the longitudinal bars, and R6 as shear links to an 85 mm spacing. Concrete mix design was computed according to the DOE method for Grade 30. 25% bottom ash was used as fine aggregate replacement and 2% of steel fibres calculated by weight of concrete were used for this project.

2.2. Sample test

In total, 18 samples of concrete cubes of 150 mm × 150 mm × 150 mm size were cast of concrete Grade 30 with 25% bottom ash as fine aggregates replacement [8] and 2% steel fibres [5] as additional material in the concrete (BASF). Whereas the beam samples consist of two (2) samples with 2% Steel Fibre Reinforced (SFRC) and the other two (2) samples consist of BASF. The beam samples have a design size of 150 mm × 150 mm × 750 mm . The cubes were then soaked in water for 7, 28 and 42 days for the curing process and the beams followed the normal curing procedure for structures. The cubes were tested for compression and the beams were tested for flexure. The cube test was prolonged to 42 days as bottom ash has a long term strength effect due to its slow pozzolanic reaction as bottom ash has a Class C classification with pozzolanic and cementitious properties [9]. Whereas the beams were put under the four point load test by incrementing the load until failure to determine the flexural strength at 42 days.

Table 1. Concrete mix proportion for concrete M30.

Detail	Content (kg)					
	Cement	Water	C. Agg	F. Agg	25% BA	2% SF
SFRC 1 (2% SF)	9.49	4.75	21.83	13.60	0	0.972
SFRC 2 (2% SF)	9.49	4.75	21.83	13.60	0	0.972
BASF 1 (2% SF + 25% BA)	9.49	4.75	21.83	12.63	0.953	0.953
BASF 2 (2% SF + 25% BA)	9.49	4.75	21.83	12.63	0.953	0.953

3. Test Result

3.1. Slump test

The slump test identifies the consistency and workability of fresh concrete before it sets and hardens into a solid form. Since the water cement ratio is the main factor affecting workability, the greater the water content in the concrete mixture, the greater the workability of fresh concrete. In this study, the range of slumps required falls between 60 mm to 180 mm as stated by the DOE method for Grade 30 concrete. Table 2 shows the slump value of each batch of concrete mix. From the slump results, it is concluded that each batch of concrete had medium workability with the corresponding water cement ratio.

Table 2. Slump test for each batch.

Slump Test	Height (mm)
BASF 1	100
BASF 2	90
SFRC	90

3.2. Compression test

Compression strength is one of the behaviours of concrete cubes determined under a compressive load. Loads are constantly applied to the concrete cubes until it cracks or fails to achieve the ultimate compressive strength. In total, 9 concrete cubes of Bottom Ash with Steel Fibres (BASF) and 9 concrete cubes of Steel Fibres concrete (SFRC) were prepared to a 150 mm x 150 mm x 150 mm size. The cubes were tested at 7, 28 and 42 days to reach the maturity of BASF as bottom ash has late age strength development [6, 10, 11]. The compression test for the BASF concrete cubes are about 6% higher compared to SFRC concrete at 42 days (refer to Table 3) and a trend can be seen in Fig. 2, where the strength was 2.11MPa higher compared to the control sample (Fig. 1). This shows that the addition of bottom ash worked well with steel fibres in concrete as potential materials to replace fine aggregates with its long team development strength. As is known, SFRC alone has shown good strength increment compared to normal concrete [5] and with this presence of bottom ash, the compressive strength of concrete has a better increment.

Table 3. Compressive strength.

	COMPRESSIVE STRENGTH (MPA)		
DURATION	**Control Sample**	**SFRC**	**BASF**
7	19.18	19.71	19.80
28	33.50	30.16	30.23
42	32.11	32.20	34.22

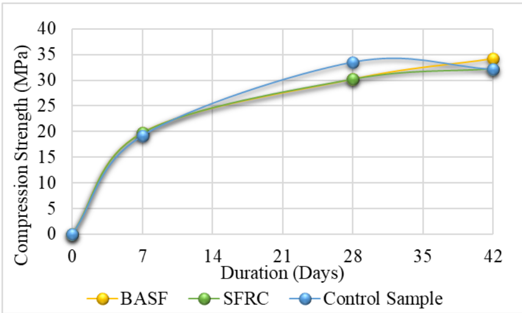


Fig. 1. Compressive strength of concrete cubes.

3.3. Flexural test

Flexural strengths of reinforced concrete beams were obtained using the four-point flexural test. Two samples of SFRC beams and two samples of BASF beams were prepared to a size of 150 x 150 x 750 mm. All samples were tested to failure with the Universal Testing Machine.

The BASF beams achieved the highest ultimate loads of 114.09 kN and 106 kN; and SFRC beams reached ultimate loads of 90.17 kN and 89.19 kN. Based on the result, BASF and SFRC beams achieved average higher flexural loads compared to the theoretical load being 120.26% and 79% higher respectively. It was also observed that BASF have the lowest deflection compared to SFRC. Thus, it shows that BASF beams were able to sustain higher loads with lower deflections compared to SFRC beams. The bottom ash has work well with SFRC in concrete and make the beams more durable and sustainable. Special character of bottom ash, it has very low strength progress within 14 days of curing after casting. However, the strength is started to have better improvement after 28 days. Bottom ash was started to react with calcium hydroxide for CSH gel and needle for a better strength performance [12]. With the present of steel fibre to react as scattered reinforcement in beam has help to improve back the bottom ash concrete as previous research has shown that the strength of concrete was low when bottom ash was using as fine aggregate replacement [9].

Table 4. Deflection of beams at ultimate load.

Sample	Theoretical Load Ptheory (kN)	Ultimate Load Pultimate (kN)	Deflection (mm)
BASF 1	50	114.09	15
BASF 2	50	106.17	13
SFRC 1	50	90.17	17
SFRC 2	50	89.19	19

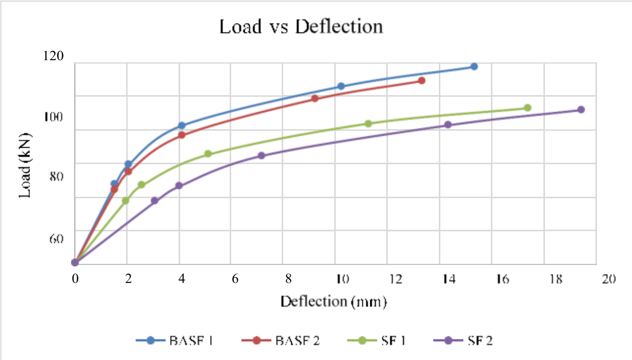


Fig. 2. Load vs. deflection of reinforced concrete beams.

3.4. Load comparison between BASF and SFRC

Table 5 shows the load comparison between BASF and SFRC beams. Cracks occurred when the BASF 1 and BASF 2 reached 81.29% and 82.17% of load increments respectively. As for SFRC 1 and SFRC 2, the cracks occurred at 79.50% and 76.87% respectively of the load increments. The occurrence of cracks in the two BASF beams started at 92.75 kN and 87.24 kN respectively while for SFRC these were formed at 71.69 kN and 27.05 kN. From Table 4, the load differences between ultimate load, $P_{ultimate}$ and crack load, P_{crack} for BASF is greater than for SFRC beams which shows that BASF is able to sustain more load before reaching its ultimate point after the sample started to crack. The present of bottom ash and steel fibre in concrete has help to sustain the beam structure longer. Both materials has help to absorb more energy while steel fibre also has help to distribute the energy evenly throughout the beam [5]. Thus, SFRC beams have slightly lower performance in restricting cracks and bonding in concrete. The presence of bottom ash in steel fiber concrete has helped the beam to sustain higher loads compared to steel fiber concrete due to the greater increment of C-S-H gel formation from the pozzolanic and cementitious properties in bottom ash that increases the strength of the concrete beam as the silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) components are greater than 50% [6].

Table 5. Load comparison between BASF and SFRC beams.

Sample	Pcrack (kN)	Pelastic (kN)	Ultimate load Pultimate (kN)	Theoretical load, Ptheory (kN)
BASF 1	92.75	36.24	114.09	50
BASF 2	87.24	33.85	106.17	50
SFRC 1	71.69	27.05	90.17	50
SFRC 2	68.56	25.78	89.19	50

3.5. Stress-strain relationship

Stress – strain curves for each reinforcement bar was developed with strain values obtained using a strain gauge on the concrete. It was observed that two strain gauges of the beams failed on the bottom bar on the same side. The strain gauges were observed to have negative strain values near the top bar of the beams. This can be seen from the trend of the stress-strain curves (refer to Figs. 3 to 6). Table 6 and Table 7 show the detail stress and strain results for each sample. The negative strain values obtained were due to the failure was subjected to compression. Thus, the length of the strain gauges decreased while its cross-sectional area increased. As the resistance of the strain gauge is proportional to its length and inversely proportional to its cross-sectional area, the resistance decreases with negative strain.

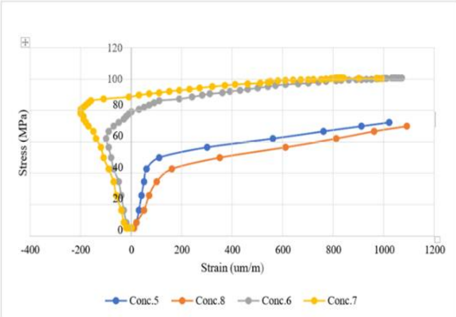
However, when the strain gauge is subjected to tension, its length increases, and its cross- sectional area decreases. The resistance of the strain gauge increased with the positive strain. Based on the data obtained, the average maximum deflection of the reinforcement bar in BASF was higher than SFRC as the BASF achieved a higher ultimate load compared to SFRC. It was observed that BASF was able to sustain more load with lower deflection. In short, BASF have performed better than SFRC beams. Table 6 shows the maximum deflections of the reinforcement bars in beams.

Table 6. Stress – strain value of reinforcement bar on beams.

Sample	Strain (u m/m)				Stress	Load
	Top (1)	Top (2)	Bottom (1)	Bottom (2)		
BASF 1	-80	-110	110	350	44.12	50
BASF 2	110	40	680	910	44.12	50
SFRC 1	-80	-100	1100	1210	44.12	50
SFRC 2	0	0	1390	1160	44.12	50

Table 7. Maximum deflection of reinforcement bars on beams.

Sample	Maximum deflection (mm)				Average Top (mm)	Average Bottom (mm)
	Top (1)	Top (2)	Bottom (1)	Bottom (2)		
BASF 1	0.0197	0.0123	0.00983	0.0273	0.016	0.018
BASF 2	0.0197	0.0197	0.0605	0.138	0.019	0.099
SFRC 1	0.0295	0.0295	0.0262	0.0262	0.029	0.026
SFRC 2	0.00843	0.0084	0.0393	0.0393	0.008	0.039



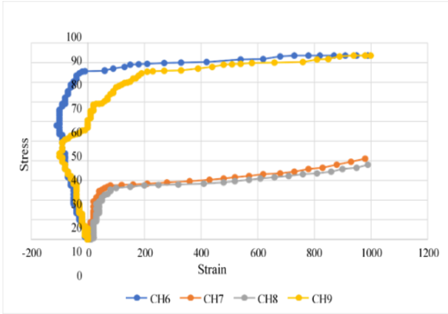
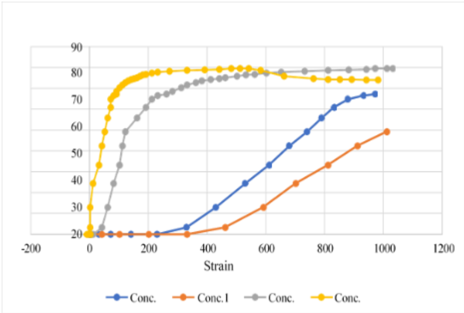


Fig. 3. Stress-strain curves of BASF Sample 1.

Fig. 4. Stress -strain curves of BASF Sample 2.



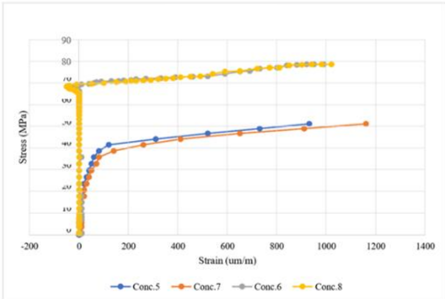


Fig. 5 Stress-strain curves of SFRC Sample 1.

Fig. 6. Stress-strain curves of SFRC Sample 2.

Thus, as the bottom ash is classified as solid combustion residues and normally had been dumped as waste disposal. The replacement of bottom ash as partial fine aggregate able to reduce the environmental pollution impact as it is a hazardous by products produced from coal thermal power plants. It has been proved to be an economical material in engineering construction aspect which mean it will help to reduce the cost of construction [4]. Moreover, as bottom ash possessed fused properties, glassy texture, and high recycling rate as well as similar particle size distribution permeability compared to clean sands or gravel, thus, the combination of bottom ash as partial fine aggregate replacement materials in concrete has able to produce the variations of the characteristic of concrete in term of compressive strength, durability and workability of concrete has been proven through the outcome of this research project [6].

4. Conclusions

This study was conducted to determine the flexural strength of Steel Fiber Reinforced Concrete Beam, and the effectiveness of bottom ash in Steel Fiber Concrete in terms of compressive and flexural strengths. The following points conclude the results of this study:

- In the beginning there was no occurrence of slow pozzolanic reaction in the development of concrete cubes. This is because bottom ash has a Class C classification which exhibits pozzolanic and cementitious properties.
- At the 28th day, the compressive strengths of bottom ash and steel fibre concrete cubes were greater than the specified characteristic strength of M30 concrete by 8.33%. As for the other cubes, the result also shows that all the cubes have compressive strengths greater than the specified characteristic strength of M30 concrete.
- As seen from the compression test result, replacement of fine aggregates with 25% of bottom ash and 2% of steel fibre had resulted in the long-term strength development of concrete compared to the control sample.
- Based on the flexural test result, BASFB showed greater flexural strength with lower displacement compared to SFRC.
- The formation of hairline cracks in BASFB due to rapid depletion of water in the concrete's plastic state caused by the high-water absorption characteristic of bottom ash.
- Partial replacement of fine aggregates with 25% bottom ash and 2% steel fibre in reinforced concrete has the potential to enhance green construction environment by reducing hazardous by-products and generating good concrete properties which in line with SDG 9 Industry, Innovation, and Infrastructure and SDG11 Sustainable Cities and Communities.

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