Flexural Strength Performance of Glass Fibre Reinforced Concrete (GFRC) Beam with Bottom Ash as Fine Aggregate Replacement

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Abstract: Today, there are numerous newly invented concretes produced involving material replacement. Most of the new products prefer natural aggregates or cement waste material for a more sustainable and economical design. In line with these objectives, this project used glass fibre as part of material replacement in plain concrete in order to enhance concrete properties. The presence of glass fibre may help to reduce cracks and at the same time may help to increase the strength of concrete. This condition may help to produce higher flexural strength when the concrete is used in a concrete structure. As the new direction of concrete innovation work is now looking forward on engineered composite concrete (ECC) which had go towards the invention of a composite concrete, thus this project had also used bottom ash as fine aggregate replacement. This may help to minimize the environmental burden and reduce construction cost in production. Thus, this study is focused on the combination of bottom ash and glass fibre to determine the performance between these two particular materials in concrete. 25% of bottom ash content as fine aggregate replacement by weight had been used in 1% of glass fibre reinforced concrete (GFRC) beam. The performance of GFRC beam was compared and analysed to Glass Fibre Reinforced Concrete with bottom ash (GFBA) beam in this study for future utilization in the construction industry. The presence of glass fibres has help to improve the strength characteristics of concrete while the presence of bottom ash helps to develop long term strength development and produce an economical concrete. In this study, concrete beam was designed for Grade 30. A total of eight (8) concrete cubes and four (4) reinforced concrete beam specimens had been prepared. The curing stages for concretes had been divided into 7, 14, 28 and 42 days before proceed to the destructive test for determination of its compression and flexural strengths. Based on the compression test result, 25% bottom ash content able to develop a long term strength effect with 1% glass fibres concrete. The result of compressive strength at 42 days has shown an increment of 5.57% when compared with the compressive strength at 28 days with the presence of bottom ash in GFRC. However, GFRC beams have showed greater flexural performance than GFBA beams at an average of 31.88% higher when subjected to the theoretical design performance.

Keywords: Bottom Ash, Glass Fibres, Sustainable Concrete, Compressive Strength, Flexural Strength

Introduction

Nowadays, researchers are more focused on creating new innovative concretes which have higher strength and more durable. Main focus had been given to the material replacement in concrete such as aggregate or cement replacement by waste material. In line with the direction of the Sustainable Development Goal (SDG) blueprint by United Nations member states in 2015, this research direction has helped to reduce wastage by industries or households. It also help to enhance concrete properties and produce economical designs. Bottom ash is one of the industrial waste materials that can be utilized in concrete. Generally, bottom ash has been used as fine aggregate replacement for natural aggregate especially fine aggregate. This invention is considered as timely since the cost of natural aggregate is found to be inflated due to the long transportation cost and due to high clay content. Bottom ash is classified as a solid combustion residue and is normally dumped as waste. The bottom ash as partial fine aggregate replacement able to reduce the environmental pollution impact as it is a hazardous by-products produced from coal thermal power plants. Cost reduction in construction by developing a green environment with bottom ash was prove to be an economical material in engineering (Dilip et.al, 2014). Bottom ash possesses 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 may be able to produce the various characteristic of concrete in term of compressive strength, durability and workability (Abdullah et.al, 2019).

Plain cement concrete exhibits limited ductility, low tensile strength and low resistance to cracking. Propagation of internal micro cracks are inherent in concrete which result in poor tensile strength. However, the addition of a certain fibre percentage is able to resolve these problems. The presence of fibre in concrete was proven to help increase the strain properties of concrete such as its flexure strength, crack resistance, toughness and ductility (Nurharniza et.al, 2012; Deshmukh et.al, 2012). The presence of glass fibre in concrete has helped to decrease cracking and failure of concrete and at the same time has helped to improve the compressive and flexural strength of reinforced concrete beams (Deshmukh et.al, 2012). The advantages of Glass Fibre Reinforced Concrete (GFRC) is its light weight but also with a higher tensile strength in concrete compared to conventional concrete.

Previous studies had proven that with the combination of fibre and ash implemented as fine aggregates replacement, concrete exhibits greater performance in terms of strength characteristics compared to conventional concrete. For instance, replacement of fine aggregate with 0.3% of glass fibre and different volume fractions with 25% and 40% fly ash in the concrete mix have help to provide better strength resistance compared to the control samples (Deshmukh et.al., 2012). Apart from that, glass fibre has been proven to enhance the compressive strength by adding it into the fly ash concrete mixture at 28 days as shown in previous research work (Rama et.al, 2010). Furthermore, 1% polypropylene fibre with 30% bottom ash exhibited higher flexural, and compressive strengths and a higher modulus of elasticity compared to the control specimen (Sathya & Rajasekar, 2015). Based on a previous study, bottom ash exhibited fused properties, glassy texture, and high recycling rate to be proven as the best replacement for natural fine aggregates (Arenas et.al, 2011). It is also suitable to be use in lightweight concrete as bottom ash has a lower density compared to natural fine aggregate (Aggarwal et al., 2007).

Methodology

Materials Used

The materials used in the trial mix specimens consisted of Ordinary Portland Cement (OPC) Type 1 according to ASTM C150, coarse and fine aggregates, bottom ash, glass fibre, and to a certain water cement ratio. Concrete was design for Grade 30 with coarse aggregates sieved to a nominal sizing of 20 mm and fine aggregates. The concrete mixture consist of 25% bottom ash and 1% glass fibres (BAGF) content by weight was implemented for fine aggregate replacement. The bottom ash used was from Tanjung Bin with sizes of 0.075mm - 20mm and sieved by passing through 4.75mm sieve. On the other hand, glass fibres was from the alkali resistant (AR) glass fibres with Cem-Fil Anti Crack and HD – 12 mm.

While the beam samples used steel reinforcement T8 as longitudinal bars and R6 as shear links with 85mm of spacing. The cubes were made of size 150mm x 150mm x 150mm using 25% bottom ash and 1% glass fibre as fine aggregates replacement or known as Bottom Ash Glass Fibre (BAGF) concrete. Whereas the beam were divided inti two sets of samples; two (2) samples were made with 1% Glass Fibre Reinforced (GFRC) and two (2) were made with 25% of bottom ash added with 1% of Glass Fibre Reinforced Concrete (BGRC RC). Beam samples were designed to size 150mm x 150mm x 750mm. The concrete cubes were set for curing durations of 7, 14, 28 and 42 days as the previous study had shown the potential for long term strength of bottom ash concrete (Gerry, 2020).

Test on Concrete

Destructive test such as compression test and tensile test will be carried out to determine the compression and flexural strengths of concrete. Concrete cubes were tested at 7, 14, 28 and 42 days since the compressive strength of concrete is gained at different periods of time and with the later age strength development of bottom ash, whereas beams were tested under a four point load by applying an increasing load until failure in order to determine the flexural strength at 42 days only.

Results and Discussions

Slump Test

Slump tests are done to identify the consistency and workability of fresh concrete before setting and hardening into a solid form. Thus, water cement ratio is the main factor that affect the workability, in which the greater the water content in a concrete mixture, the greater the workability of fresh concrete. In this study, the range of slump is required to fall in between 60mm to 180mm as stated by the DOE method for Grade 30 concrete. Table 1 shows the slump height for each batch for the entire slump test. From the consistent slump results, it can be concluded that each batch of concrete had medium workability corresponding to the water cement ratios. Meanwhile, the workability of the 1st batch and 2nd batch were lower than the 3rd batch of concrete. It is due to the comparatively high water absorption characteristic of bottom ash. Bottom ash was prepared in a saturated surface dry condition to prevent an additional variable in water cement ratio during concrete mixing. However, the slump result of the 1st batch and 2nd batch have shown that the fresh concrete workability was still affected and reduced by the water absorption capability of bottom ash. This might be caused by the insufficient immersion duration of bottom ash in water or too lengthy drying process when striving to achieve a dry surface.

Table 1: Slump Test Result for Each Batch

Detail Sample	**Height (mm)**
1st batch : Cube (25% Bottom Ash + 1% Glass Fibre)	61
2nd batch : Beam (25% Bottom Ash + 1% Glass Fibre)	63
3rd batch : Beam (0% Bottom Ash + 1% Glass Fibre)	70

Compression Test

Compression strength is one of the behavior of concrete cubes which is determined under a compressive load. Loading was constantly applied to the concrete cubes until cracks start to penetrate the sample up to failure in order to achieve ultimate compression strength. A total of 8 concrete cubes with of 25% Bottom Ash and 1% Glass Fibres (BAGF) were used as replacement of fine aggregate. The concrete cubes were tested at 7, 14, 28 and 42 days with the compression strength test. The compressive strength test was conducted up to 42 days as the previous study by Gerry (2020) found that bottom ash concrete showed a great increment at a later age or long term strength development. Table 2 shows the results of the compression strength tests for BAGF concrete cubes at 7, 14, 28 and 42 days. Basically, 99% of the strength for this standard grade of concrete was gained after 28 days as the strength increment rate slowed after 28 days. Thus, the target strength gained at 7, 14 days and 28 days were 65%, 90% and 99% respectively according to BS 1881 – 116: Method for determination of compressive strength of concrete cubes. However, in this study the strength was prolong up to 42 days in order to observe and determine the potential trend of concrete strength rate at a later age for long term strength development due to the properties of bottom ash in concrete (Gerry, 2020).

Table 2 and Figure 1 shows that concrete strength developed gradually from 7 days to 42 days. The average compressive strength at 7 days was 23.56 MPa which is 78.53% of the target minimum strength for normal concrete Grade 30. Nevertheless, the concrete cubes had obtained an average compressive strength value which was 6.30% greater than the target strength at the age of 14 days with 28.89 MPa. At 28 days the compressive strength was 31.89 MPa which is 6.3% higher than normal compressive strength for concrete grade 30. Last but not least, an average compressive strength for BAGF concrete at 42 days was 33.56 MPa which is 11.87% higher than normal concrete grade 30. For the analysis of later strength development, the age of concrete beyond 28 days was considered as later age or long term strength growth. Figure 1 shows that the strength was increased gradually after 28 days about 1.67 MPa higher or 11.87% higher than the compressive strength of concrete grade 30. It shows the pozzolanic activity of bottom ash after 28 days, which has proven the potential of tremendous strength increment for long term development strength.

Table 2: Compression Strength of Bottom Ash Glass Fibres Concrete (BAGF)

Cube (Days)	**Specimen (MPa)**		**Average (MPa)**
	1	**2**	
7	22.7	24.4	23.56
14	31.11	26.67	28.89
28	32.2	31.6	31.89
42	32.00	35.11	33.56

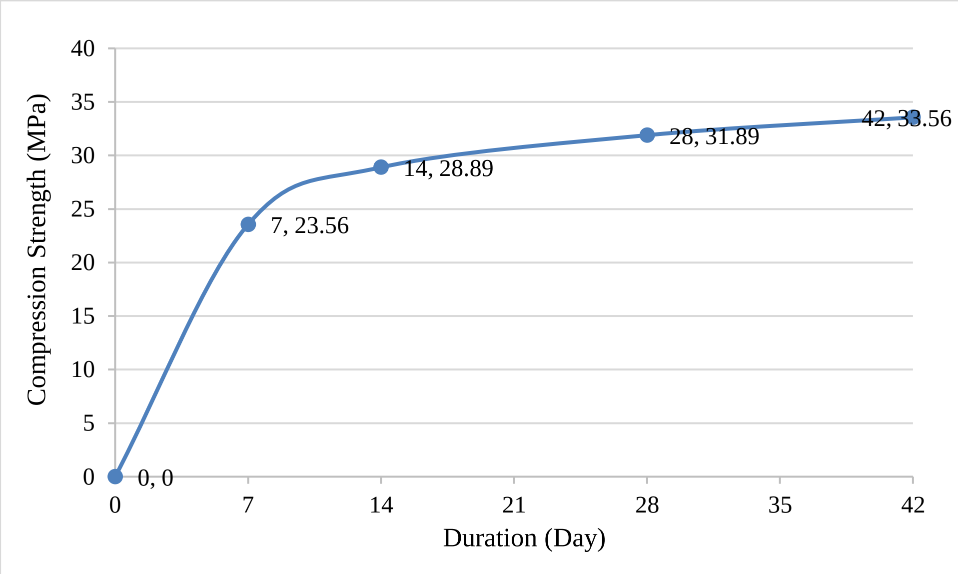


Figure 1: Average Compression Strength of Bottom Ash Glass Fibres Concrete (BAGF)

Flexural Test

Flexural strength of reinforced concrete beam was obtained by flexural test. In this study, two beams made from 1% Glass Fibres Reinforced Concrete (GFRC) beams and another two beams were made from Bottom Ash Glass Fibres Concrete (BAGF RC) with sizes of 150 x 150 x 750mm. The beam samples were tested under a four point load by applying an increasing load until failure in order to determine the flexural strength at 42 days.

- **Displacement of Beam**

Table 3 shows the detail displacements of the beams at ultimate load increments, $P_{ultimate}$. According to Table 3 and Figure 2, all beam specimens had met the theoretical design load. In this study, GFRC beams achieved the highest ultimate loads at 73.98kN and 71.74kN with an average load of 72.86kN. Whereas, BAGF RC beams reached ultimate loads at 61.28kN and 52.56kN with an average of 56.92kN. Based on the average load of beams, GFRC beam and BAGF RC beam were higher than the theoretical load at 45.72% and 13.84% higher respectively.

Furthermore, it was observed that GFRC beams had obtained lower displacements compared to BAGF RC beams. GFRC beams were able to sustain higher load with lower displacements and were more sustainable than BGRC beams. Thus, the presence of glass fibres has effectively reduced the bending and displacement of beams, whereas bottom ash was weaker as its high permeability and porosity characteristics could slightly reduce the concrete strength. The high water absorbability of bottom ash has indirectly reduced the water content in concrete for pozzolanic activity.

Table 3: Displacement of Beams at Ultimate Load

Sample	Theoretical load, P_{theory} (kN)	Ultimate load, $P_{ultimate}$ (kN)	Displacement (mm)
GFRC - K(1)	50	73.98	16
GFRC - K(1)	50	71.74	11
BAGFRC - K(2)	50	61.28	12
BAGFRC - K(2)	50	52.56	18

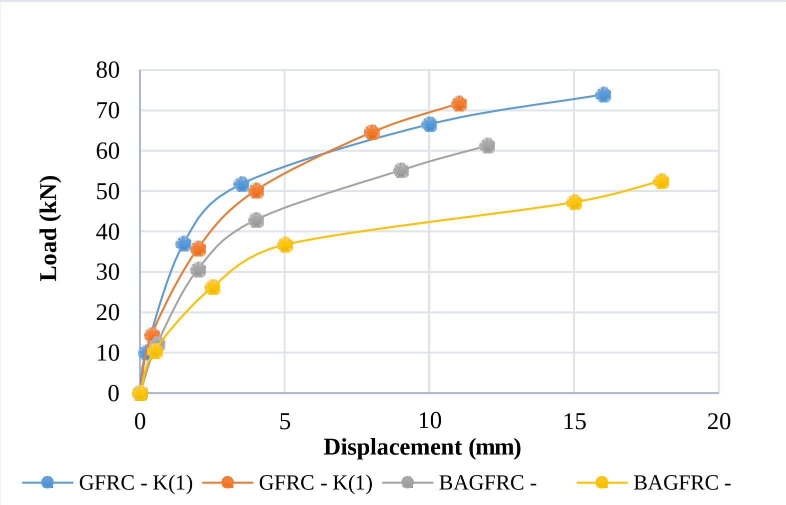


Figure 2: Load versus Displacement of 4 Reinforced Concrete Beams

- **Load Comparison between Glass Fibre Reinforced Concrete (GFRC) and Bottom Ash Glass Fibre Reinforced Concrete (BAGF RC) Beams**

Table 4 shows the load comparison between GFRC and BAGF RC Beams. Cracks occurred when the stress in the beam exceeded its strength. The cracks were observed in two GFRC beams at loads of 58.79kN and 56.30kN while BAGF RC beams cracks were observed at the 47.08kN and 42.6kN loads. According to Table 4, GFRC beam load differences between the ultimate load, $P_{ultimate}$ and the crack load, P_{crack} is greater than BAGF RC beams which have shown that GFRC beams are able to sustain more load to reach its ultimate point when the sample starts to crack. Thus, BAGF RC beams are weaker at restricting cracks and bonding in concrete.

Table 4: Load Comparison between Glass Fibre Reinforced Concrete (GFRC) and Bottom Ash Glass Fibre Reinforced Concrete (BAGF RC) Beams

Sample	P_{crack} (kN)	$P_{elastic}$ (kN)	Ultimate load, $P_{ultimate}$ (kN)	Theoretical load, P_{theory} (kN)
GFRC - K(1)	58.79	32.383	73.98	50
GFRC - K(1)	56.3	21.1735	71.74	50
BAGF RC - K(2)	47.08	22.419	61.28	50
BAGF RC - K(2)	42.6	5.2311	52.56	50

- **Stress - Strain Relationship**

Stress – Strain curves for the reinforcement bars were developed with strain values obtained from strain gauges in concrete. The beams started to crack when the strain gauges had failed. In this study, it was observed that two strain gauges of the beams failed at the bottom bars primarily at the same angles and surfaces. It was observed that the strains at the theoretical load of 50kN for BAGF RC beams were greater than for GFRC beams for the same stress (refer Table 5). The strain for the top bar on the other hand for BAGF RC beams were higher compared to GFRC beams with one of the BAGF RC beams starting to fail at the left side of the top bar which showed that BAGF RC beams have lower flexural strength. The stress – strain diagram of GFRC beams is shown in Figure 3, while the stress – strain diagram of BAGF RC beams is shown in Figure 4.

Based on the obtained data from all six (6) strain gauges in the reinforced concrete beams, the average maximum deflections of the reinforcement bars in GFRC beams were lower than for the BAGF RC beams. GFRC beams were also subjected to higher ultimate loads compared to BAGF RC beams. Thus, GFRC beams are able to sustain more loads with lower deflections. In short, GFRC beams have performed better than BAGF RC beams with the presence of glass fibres. This shows that the glass fibres had acted as distributed reinforcement in beams by transmitting the load from concrete to fibers through interfacial shear stress and longitudinal tensile stress between aggregate cement paste bonds that enhances its flexural bearing capacity. However, BAGF RC beams have more pores as a result of the bottom ash, thus, glass fibres are needed to resist the increase in ruptures and porosity between the concrete bonds compared to GFRC beams. Table 6 shows the maximum deflections of reinforcement in the beams.

Table 5: Comparison of Stress - Strain Values at Theoretical Load

Sample	Strain (u m/m)						Stress (MPa)
	Top (1)	Top (2)	Bottom (1)	Bottom (1)	Bottom (2)	Bottom (2)	
GFRC - K(1)	-180	-110	1020	1090	980	860	44.12
GFRC - K(1)	-240	-160	1500	1520	1320	1210	44.12
BAGF RC - K(2)	460	250	1870	2010	1300	-	44.12
BAGF RC - K(2)	1030	540	1830	14350	5320	2060	44.12

Table 6: Maximum Deflection of Reinforcement Bars

Sample	$P_{ultimate}$ (kN)	Maximum deflection (mm)						Average (mm)
		Top (1)	Top (2)	Bottom (1)	Bottom (1)	Bottom (2)	Bottom (2)	
GFRC - K(1)	73.98	0.051	0.051	0.028	0.030	0.058	0.062	0.047
GFRC - K(1)	71.74	0.055	0.086	0.086	0.055	0.042	0.025	0.058
BGRC - K(2)	61.28	0.036	0.048	0.039	0.067	0.034	-	0.045
BGRC - K(2)	52.56	0.103	0.052	0.177	0.177	0.078	0.138	0.121

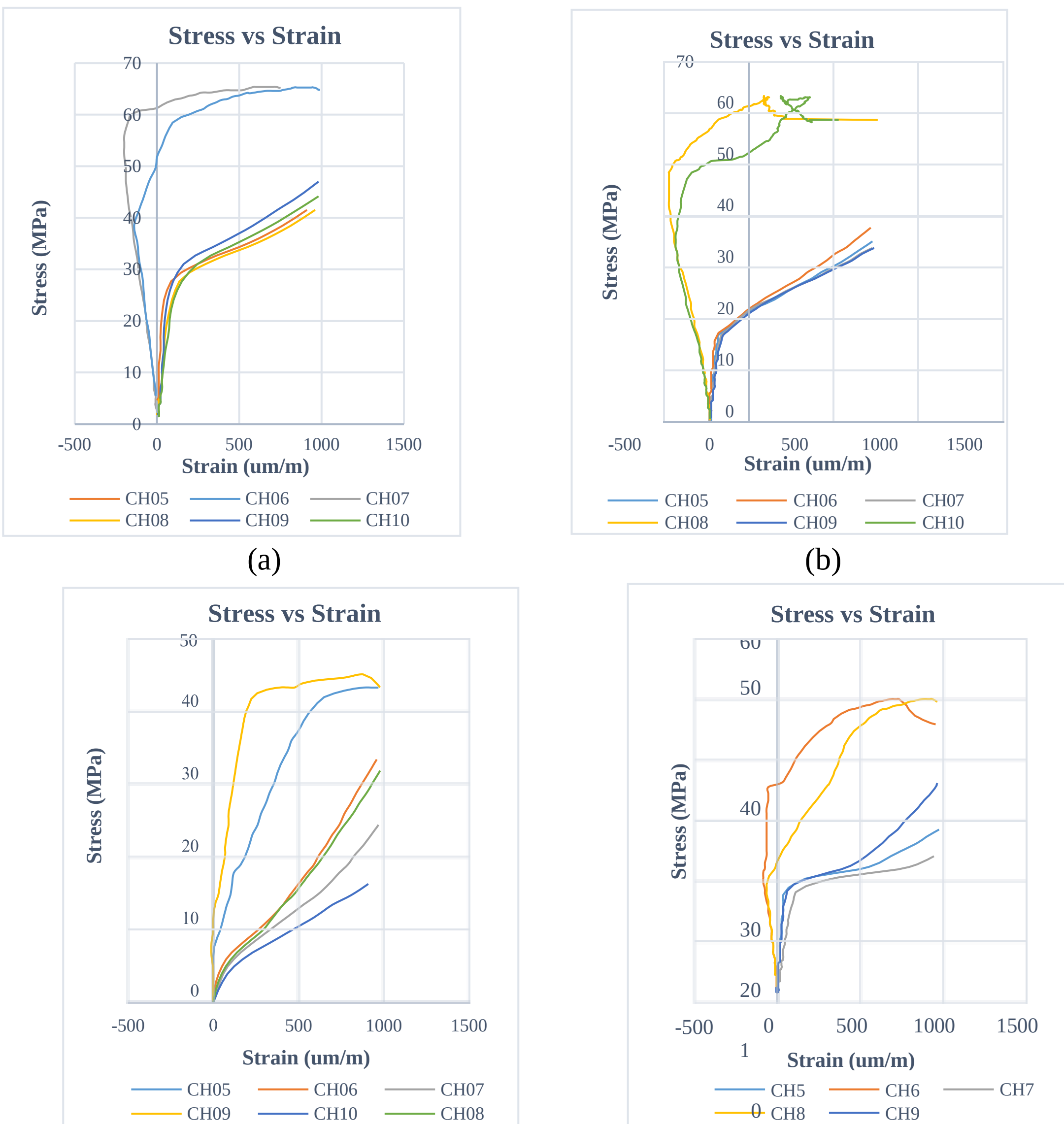
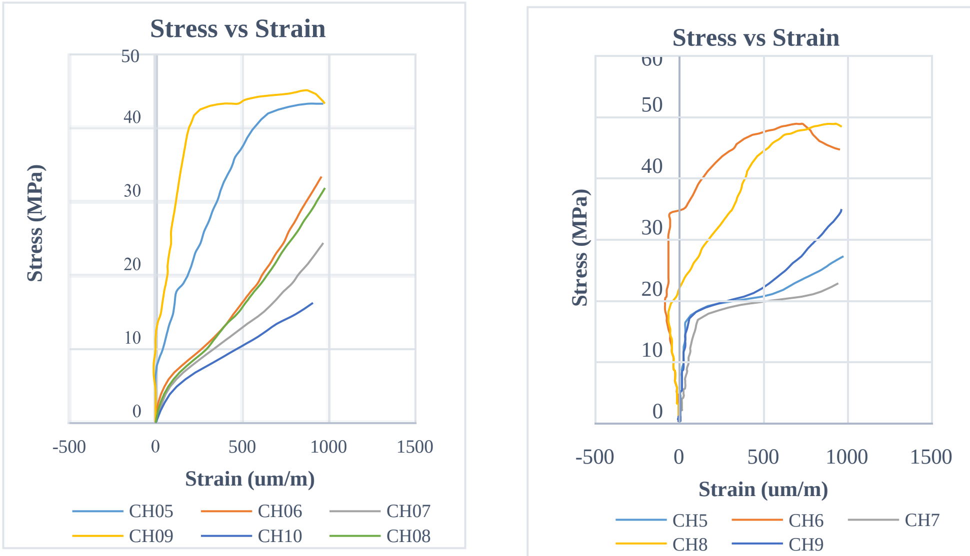


Figure 3: Stress – Strain Curve of GFRC Beams; (a) Sample 1, (b) Sample 2



(a) (b)

Figure 4: Stress – Strain Curve of BGRC Beams; ; (a) Sample 1, (b) Sample 2

Conclusions

This study was conducted to determine the flexural strengths of Glass Fibre Reinforced Concrete (GFRC) Beams and the effectiveness of bottom ash in Glass Fibre Concrete (BAGF RC) Beam in terms of compressive and flexural strength. The following points were concluded from the results of this study.

1. In the early strength development of the concrete cubes, there was no occurrence of slow pozzolanic reaction as the bottom ash is classified as Class C which exhibits pozzolanic and cementitious properties.
2. Compressive strengths of theconcrete cubes at 28 days was higher than the specified characteristic strength of M30 concrete at 6.3%. The working mechanism between the porosity caused by bottom ash and the reduction of pores by the glass fibres was achieved.
3. From the compression test result, replacement of fine aggregate with 25% of bottom ash and 1% of glass fibre had developed a long term strength for the concrete. There was an increase in compressive strength of 5.57% from the 28th day to the 42nd day.
4. Based on the flexural test result, GFRC beams showed greater flexural strengths with lower displacements compared to the BAGF RC beams due to the higher porosity of the BGRC beams.
5. According to (Deshmukh et al., 2012), the presence of glass fibres provide crack resistance and crack control to reduce crack propagation and failure of concrete. The crack patterns of the GFRC beams showed flexural cracks with reduced crack widths.
6. The formation of hairline cracks in BAGF RC beams was due to the rapid depletion of water in the concrete plastic state caused by the high water absorption characteristic of the bottom ash.

7. Partial replacement of fine aggregates with 25% bottom ash and 1% glass fibre in reinforced concrete has the potential to enhance green construction environment by reducing hazardous by-products but a with good concrete properties.

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