Strength Characteristics of Glass Fiber Reinforced Bottom Ash based Self Compacting Concrete

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***Abstract*— Self-compacting concrete (SCC) is that concrete which has high flowing ability with no segregation. Usage of SCC will overcome the difficult casting conditions and reduce manpower required. Bottom ash is a hazardous by product from coal based thermal power plant. Wastes and by-products have been introduced into the concrete industry to conserve natural resources and environment as well as to reduce the cost of concrete. In this project fine aggregate in SCC mix had been replaced with bottom ash and glass fiber is additionally used to enhance the strength characteristics. The mix is prepared by the replacement of M sand with different proportions (0%,5%,10%,15%,20%,25%) of bottom ash and Glass fiber is added in 0.2%,0.4%,0.6% and 0.8% by weight of cement to the mix with optimum replacement level of fine aggregate. The laboratory tests for materials, fresh concrete properties, hardened concrete properties such as compressive strength, flexural strength and splitting tensile strength are conducted. The test results are analysed and it is found that up to 25% replacing bottom ash gives satisfactory strength hence M sand can be replaced up to 25%.adding glass fiber is found enhancing strength properties.**

Keywords*— *Self compacting concrete; bottom ash; glass fiber; compressive strength; flexural strength; splitting tensile strength.

I. INTRODUCTION

Self-compacting concrete (SCC) is that concrete which has high flowing ability with no segregation. It is considered to be one of the revolutionary developments in concrete technology in recent times. It reduces noise at sites, precast factory and neighborhood.

The mix proportions for self-compacting concrete were arrived at by performing mix design and then fine-tuning using EFNARC guidelines. It was first developed in 1988 by Professor Okamura in Japan.

SCC must satisfy the following workability performance criteria: 1) Flow ability: The ease of flow of fresh concrete when unconfined by formwork and/or reinforcement; 2) Viscosity: The resistance to flow of a material (e.g. SCC) once flow has started; 3) Passing ability: The ability of fresh concrete to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking; and 4) Stability: the ability of SCC to remain homogenous by resisting segregation, bleeding, and air popping during transport, placement, and after placement. Due to its characteristics, SCC provides several benefits, such as: greater freedom in shape design, easier pumping and placing, improved consolidation around reinforcement, higher bond strength with reinforcement, uniform and complete consolidation, better surface finishes, improved durability, reduced noise levels caused by absence of vibration, labor savings, faster construction and also more spacious and safe working environment. Those characteristics of SCC can be achieved by implementing following basic principles in the mix design process; 1) lower coarse aggregate content, 2) increasing paste content, 3) lower water/powder ratio, (powder is defined as cement added with filler, such as: fly ash, silica fume, etc.), and 4) the use of super plasticizer. Considering lower water-cement ratio and higher content of cementitious materials compared to conventional concrete, SCC should have improved durability and strength

Concrete is acknowledged to be a relatively brittle material when subjected to normal stresses and impact loads, where tensile strength is approximately just one tenth of its compressive strength. As a result for these characteristics, concrete flexural members could not support such loads that usually take place during their service life. Historically, concrete member reinforced with continuous reinforcing bars to withstand tensile stresses and compensate for the lack of ductility and strength. Furthermore, steel reinforcement is adopted to overcome high potentially tensile stresses and shear stresses at critical location in concrete member. Even though the addition of steel reinforcement significantly increases the strength of concrete, the development of micro cracks must be controlled to produce concrete with homogenous tensile properties. The introduction of fibers is brought in as a solution to develop concrete with enhanced flexural and tensile strength.

The term Fiber Reinforced Concrete (FRC) can be defined as a concrete structure having randomly oriented and dispersed fibers. Fibers can be defined as small wire-like reinforcements which are made of either steel or polymers having high ductility. The fibers are produced in a wide range of sizes and shapes, stiff or flexible etc. Addition of fibers into concrete improves the overall ductility of the concrete imparting toughness, greater tensile strength, and resistance to fatigue, impact, blast loading and abrasion. Fibers are added not only to improve the ductility of concrete but also, more importantly to control the cracking, by the bridging of the fibers across the cracks, which delay the propagation and widening of localized cracks. The use of glass fibers in SCC might bring together the advantages of both fibers and SCC. Glass fiber (also called fiberglass) is a material made from extremely fine fibers of glass. There are several types of glass fibers such as A-glass, E-glass, AE-glass, AR-glass etc. Glass Fiber Reinforced Self-Compacting Concrete (GFRSCC) combines the advantages of SCC in its fresh state and that of fibers in its hardened state.

Popularity of using self-compacting concrete (SCC) in concrete construction has increased in many countries, since SCC is effectively applied for improving durability and increasing reliability of structures while reducing the need of skilled workers at the construction site. However, its use is still limited in Thailand due its high cost as the main reason. In general, the cost of SCC is 20-40 % higher than that of conventional concrete.

Wastes and by-products have been introduced into Thai concrete industry to conserve natural resources and environment as well as to reduce the cost of concrete. The idea of using by-products to replace natural aggregates is another alternative solution to achieve environmental conservation as well as to obtain a reasonable concrete cost. Bottom ash is the companion to fly ash in process of coal-burning with an approximate amount of 20 % by volume of the total ash, depending on the type of boiler, dust collection system, burning temperature and the type of coal. Its particle is porous, irregular, and coarser than that of fly ash but its chemical composition is not much different

These wastes are either deposited on the landfill or dump in the pond. Either way, a larger deposited area and pond are required. However, dumping these waste in the landfill and properly manage the wastes are not the best sustainable solution. Alternatively, a better approach in solving and handling of coal combustion by-product should be explored. The study focused on the strength development of the concrete with glass fiber and bottom ash including compressive strength, splitting tensile strength and flexural strength. The study on the workability of glass fiber reinforced bottom ash based self compacting concrete was also conducted.

II. MATERIALS USED

A. Cement

53 grade Ordinary Portland cement of RAMCO, from local market is used. The properties of cement are given in Table 1.

TABLE 1 PROPERTIES OF CEMENT

Properties	Observed Value
Specific gravity	3
Fineness modulus	2%
Initial setting time	33 min.
Final setting time	360 min.
consistency	32%

B. Fine Aggregate

M sand conforming to zone II was used and its properties are given in table 2:

TABLE 2 PROPERTIES OF FINE AGGREGATE

Property	Value
Fineness modulus	2.624
Specific gravity	2.6
Moisture content (%)	2.4
Water absorption(%)	2

C. Coarse Aggregate

Aggregate of size of 10 mm was used and its properties are given in table 3.

TABLE 3 PROPERTIES OF COARSE AGGREGATE

Property	**Value**
Fineness modulus	3.61
Specific gravity	2.8
Moisture content (%)	0.23
Water absorption (%)	0.5

D. Bottom Ash

Bottom ash is agglomerated ash particles, formed in pulverized coal furnaces, which are too large to be carried in the flue gases and impinge on the furnace walls or fall through open grates to an ash hopper at the bottom of the furnace. Physically, bottom ash is typically grey to black in color, is quite angular, and has a porous surface structure. The bottom ash was screened to remove oversized particles and the material passing through 4.75mm sieve was used in manufacturing of SCC. The bottom ash was collected from Hindustan News Print, Kottayam, India. The properties of bottom ash are given in table 4.

TABLE 4 PROPERTIES OF BOTTOM ASH

Property	Value
Fineness modulus	4.38
Specific gravity	2.45
Water absorption(%)	14.10

E. Fly Ash

Fly ash is obtained from Hindustan News Print Limited Kottayam, India. The physical and chemical properties of fly ash are given in table 5 and table 6 respectively.

TABLE 5 PHYSICAL PROPERTIES OF FLY ASH

Physical Properties of Fly Ash	Test Results
Colour	brownish
Specific Gravity	2.4

TABLE 6 CHEMICAL PROPERTIES OF FLY ASH

Parameters	**Results (%)**
Silicon dioxide (SiO2)	57.6
Magnesium oxide (MgO)	1.63
Total sulphur as sulphur trioxide(SO3)	0.07
Available alkalis as sodium oxide (Na 2O)	1.2
Loss on ignition	2.17

F. Glass Fibre

The fibre used in this study is the E- Glass fibre and its properties are given in table 7.

TABLE 7 PROPERTIES OF GLASS FIBRE

Properties	Value
Length(mm)	13
Diameter(mm)	0.034
Aspect Ratio	928.5
Fraction volume (%)	1%
Density(kg/m3)	2600

G. Water and Super Plasticizer

The drinking tap water has been used for both mixing and curing of concrete. A chemical admixture based on modified poly carboxylic ether, which is known commercially (Glenium 51) used as a super plasticizer.

III. METHODOLOGY

A concrete mix of M30 grade is considered for the experimental work. The investigation is proposed to be carried out by adding 0.2%, 0.4%, 0.6%, and 0.8 % (by the weight of cement) of glass fibre and by replacing sand with bottom ash (0% , 5%,10%,15% 20%, 25%). Bottom ash obtained from Hindustan News Print Kottayam, and glass fiber from local market. Minimum of two test specimen will be taken for each analysis. The following tests were conducted on the hardened concrete:

1. Splitting Tensile Strength on cylinder
2. Flexural Strength on beam
3. Compressive Strength on cube

A. Mix Design

The SCC mix having a characteristic compressive strength of 30 MPa and water-cement ratio 0.38 was designed according to EFNARC guidelines. The concrete mix is given in table 8.

TABLE 8 MIX PROPORTION OF SCC WITH BOTTOM ASH

Bottom ash content(%)	Fine aggregate (Kg)	Coarse aggregate (kg)	Cement (kg)	Bottom ash(kg)	Fly ash(kg)	Water
0% (SCC0)	30.088	24.04	17.691	0	9.73	6.716
5% (SCC5)	28.58	24.04	17.691	1.504	9.73	6.716
10%(SCC10)	27.07	24.04	17.691	3.0088	9.73	6.716
15%(SCC15)	25.57	24.04	17.691	4.5132	9.73	6.716
20%(SCC20)	24.07	24.04	17.691	6.0176	9.73	6.716
25%(SCC25)	22.566	24.4	17.691	7.522	9.73	6.716

IV. RESULTS AND DISCUSSIONS

B. Fresh Properties of Bottom Ash based SCC

The fresh properties of bottom ash based SCC are presented in table 9. They are Flow ability (Slump Flow Test), Viscosity (T 500 Slump- Flow Test or V Funnel Test) and Passing ability (L Box Test).It shows that, the slump flow values for all mixes are in the range of 650-715mm. The European Guideline for Self-compacting Concrete has suggested that the slump flow range value should range from 650 to 800 mm. The sample without bottom ash (BA0) shows the highest value of slump flow with 750mm diameter followed by BA10 and BA15. The value decreased gradually with the increase of bottom ash up to 20% to 25%.

The reduction in the flow demonstrates that the presence of bottom ash influence the workability of self compacting concrete.T500 value increased with the increase of bottom ash in the mixture. The longest T500 was considered to be due to inter-particle friction among aggregates, and the irregular shape and rough texture of the bottom ash.

The value of passing ability of SCC was measured by using L-box test. The passing ability ratio was observed to be decreased as the percentage replacement of bottom ash increased. Mixture without bottom ash (BA0) shows the lowest passing ability ratio followed by BA5 and BA10. V - Funnel test measures the ease of flow of the concrete; shorter flow time indicates greater flow ability .For SCC flow time of 10 seconds was considered as appropriate, flow time increased with the increase in the percentage of bottom ash.

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TABLE 9 FRSH PROPERTIES OF SCC

Tests	**(BA0) SCC- 0%**	**(BA5) SCC – 5%**	**(BA10) SCC – 10%**	**(BA15) SCC – 15%**	**(BA20) SCC- 20%**	**(BA25) SCC- 25%**
Slump flow test(mm)	750	715	700	680	675	650
T500(sec)	2	2	3.5	4	4.5	5
Passing ratio	0.90	0.87	0.85	0.83	0.81	0.8
V- Funnel(sec)	6.5	7	7	7.5	9	11

C. Hardened Properties of Bottom Ash based SCC

The hardened properties of bottom ash based SCC are shown in table 10.

TABLE 10 HARDENED PROPERTIES OF BOTTOM ASH BASED SCC

Mix proportion	Compressive strength(MPa)		Split tensile strength(MPa)		Flexural strength (MPa)	
	7 day	*28 day*	*7 day*	*28 day*	*7 day*	*28 day*
0%	35.5	40.6	2.75	2.96	1.42	1.95
5%	31.8	36.8	2.18	2.73	1.15	1.76
10%	32.1	34.7	2.03	2.68	1.21	1.53
15%	32.7	35.3	2.23	2.63	1.27	1.46
20%	28.3	31.6	1.96	2.44	1.33	1.30
25%	26.7	30.05	1.63	2.21	1.21	1.25

Results show that the compressive strength of the specimens gradually decrease with the increase in the percentage of replacement of bottom ash. Flexural strength and split tensile strength exhibit the same behaviour as compressive strength. Even if there is a decrease in strength, each mix meets its target value. Hence replacement of sand with bottom ash can be done up to 25%.15% replacement of sand with bottom ash gives better results. Hence addition of glass fiber can be done at this replacement level. Figure 1 shows the variation of compressive strength with percentage of bottom ash.

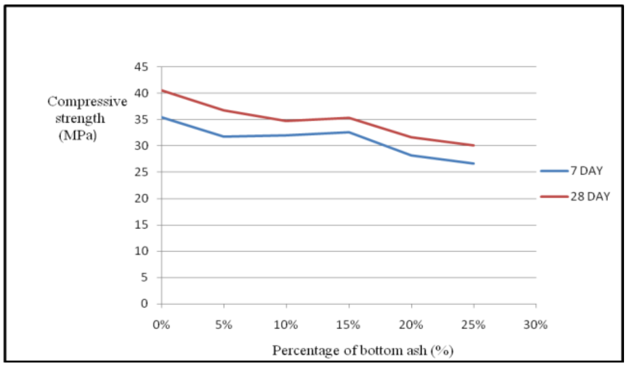

Fig. 1. Compressive strength of SCC with bottom ash

The results of splitting tensile strength of hardened bottom ash based concrete measured at 7 and 28 days. It is observed that the splitting tensile strength of concrete have the same pattern of compressive strength results. The tensile strength of the specimens decrease as the amount of bottom ash replacement level increase. The results suggested that the bonding between aggregate and cement paste are the most important factor in affecting the strength of concrete especially the tensile strength. The increment in the replacement level of bottom ash had produced more porous concrete with more pores distributed around the bottom ash surface, hence reducing its strength. Figure 2 shows the variation of split tensile strength with percentage of bottom ash.

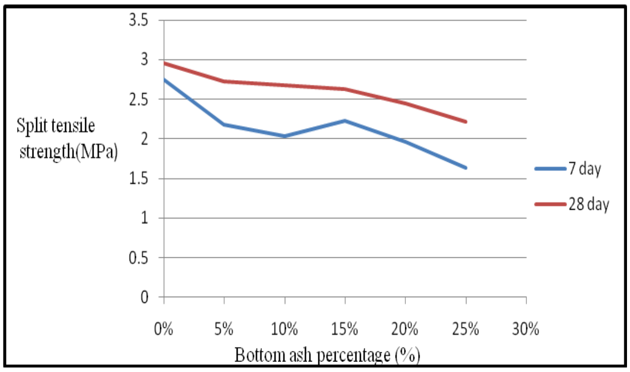

Fig. 2. Split tensile strength of SCC with bottom ash

The flexural strength of all specimens was observed to exhibit the same behavior as compressive strength and splitting tensile strength. It is evident that flexural strength of bottom ash concrete (5% to 25% replacement) is comparatively lower than control specimen. Flexural strength of bottom ash concrete with 15% replacement is higher compared to other bottom ash concrete mixes. The decreased flexural strength of the specimen, with the increase in the percentage of bottom ash is believed due to the poor interlocking between the aggregate, as bottom ash particles are spherical in nature. Figure 3 shows the variation of flexural strength with percentage of bottom ash.

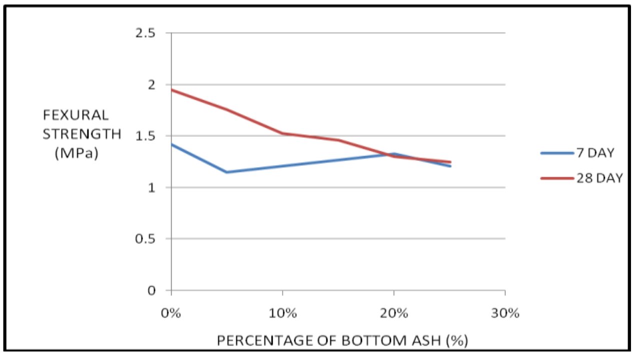

Fig. 3. Flexural strength of SCC with bottom ash

From the above results it was observed that 15% of sand replacement with bottom ash was the optimum percentage replacement. Fibers were added in quantities ranging from 0.2 to 0.8 % by weight of cement at this replacement level. Fibers were fed into mixer by hand to ensure that clumping and clustering effects were minimized. Then the above testes were repeated again.

D. Fresh Properties of Bottom Ash based Glass Fibre Reinforced SCC

Self compactability cannot be assessed using a single test method, usually requiring more than one method, The present investigation evaluated the self compactability of the designed mix by Slump flow studies for flow ability, L box and V funnel for passing ability. It is well know that fiber affects the characteristics of SCC in the fresh state. In order to reduce the effect of fibers on fresh properties, careful placement of fibers need to be adopted. Tests results were shown in table 11.

TABLE 11 FRESH PROPERTIES OF BOTTOM ASH BASED GLASS FIBRE REINFORCED SCC

Tests	SCC- 0.2% (GF 0.2)	SCC – 0.4% (GF 0.4)	SCC – 0.6% (GF 0.6)	SCC – 0.8% (GF 0.8)
Slump flow test(mm)	675	670	667	660
T500(sec)	4	4	4	4.5
L- Box	0.8	0.8	0.8	0.8
V- Funnel(sec)	9sec	9sec	10sec	12sec

The mix without fibers gives a spread diameter of 680mm and with fibers in the range of 675-660mm Even though the flow diameter was slightly reduced with the incorporation of fibers, these values are in the range specified by EFNARC. The reason behind the decrease in flow diameter of mixes with glass fibres can be explained in such a way that, fibres are needle like particles which will enhance the resistance to flow and contribute to an internal structure in the fresh state and also due to the elongated shape of the fibre, which creates a higher surface area at the same volume. During the time of test, it was observed that mix with 0.8% glass fiber showed a very slight indication of segregation. L-box and V-funnel test was conducted to assess the passing ability. All the mixes with fibers indicates a fair passing ability. This is due to the fact that, since the mixes employed higher paste content, the aggregates had enough space to disperse effectively thereby avoiding the congestion at the reinforcements.

E. Hardened Properties of Bottom Ash based Glass Fibre Reinforced SCC

In the context of hardened properties, the present investigation focused mainly on compression, split tensile strength and flexural strength. All experiments were performed on three replicates, and the optimum values are taken for the discussion of test results. Hardened properties was analysed at 7 and 28days. The hardened properties of bottom ash based glass fibre reinforced SCC was shown in table 12.

TABLE 12 HARDENED PROPERTIES OF BOTTOM ASH BASED GLASS FIBER REINFORCED SCC

Mix Proportion	**Compressive Strength(MPa)**		**Split Tensile Strength(MPa)**		**Flexural Strength(MPa)**	
	7 day	28 day	7 day	28 day	7 day	28 day
0.2%	34.7	37.9	2.43	2.69	1.35	1.52
0.4%	35.3	38.6	2.5	2.92	1.43	1.61
0.6%	36.8	39.07	2.68	3.01	1.48	1.67
0.8%	37.2	41.44	2.70	3.11	1.58	1.72

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1) Compressive strength

The compressive strength is one of the most important properties of hardened concrete. Figure 4 shows the average results of the compressive strength tests at 7, and 28 days. The results indicate that all specimens exhibited a continuous increase in compressive strength with progress in age and also compressive strength increased by glass fiber introduction. The improvement in the compressive strengths of the glass fiber reinforced SCC refer to the control of cracking. It was noted that substantial increment in compressive strength occurred with the increase of volume of fibers.

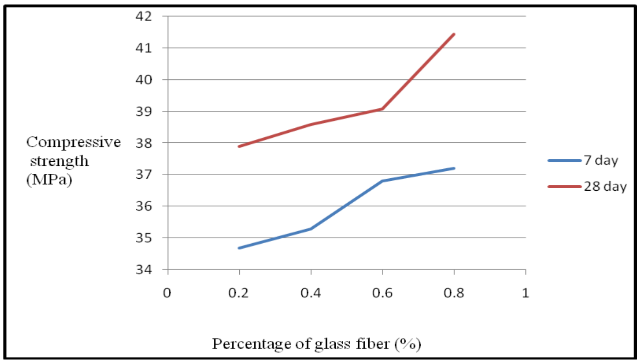

Fig. 4. Compressive strength of bottom ash based SCC with glass fiber

2) Split tensile strength

The results indicate that all specimens exhibit a continuous increase in splitting tensile strength with progress in age, and also splitting tensile strength increases with glass fiber content. The strength increase due to inclusion of glass fibers is attributed to the mechanism of fibers in arresting crack progression. Where, the presence of fibers in concrete restrains the development of internal micro cracks and thus contributes to an increased tensile strength. Accordingly, the increase in fiber content leads to an increase in the tensile strength of concrete. Figure 5 shows average results of split tensile strength tests at 7, and 28 days.

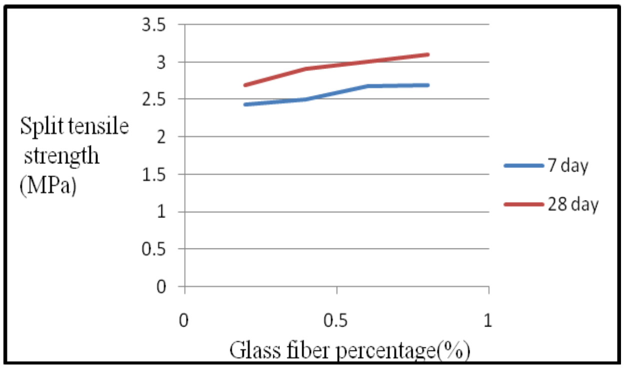

Fig. 5. Split tensile strength of bottom ash based SCC with glass fiber

3) Flexural strength

The flexural strength of all specimens was observed to exhibit the same behaviour as splitting tensile strength. From the results it is evident that flexural strength of glass fiber reinforced SCC increased with the increase in fiber content and progress in age. Figure 6 shows average results of flexural strength tests at 7, and 28 days.

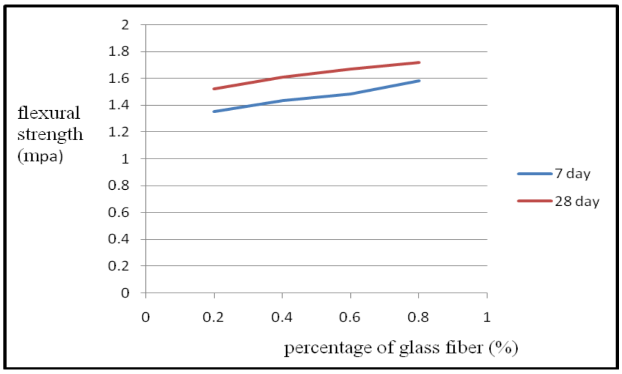

Fig. 6. Flexural strength of bottom ash based SCC with glass fiber

Glass fibres had marginal increments in compressive strength; all glass fibre mix demonstrated a higher splitting tensile strength and flexural strength relative to bottom ash based concrete. Strength increment is directly proportional to the amount of fibre content and age of curing. Fibres can arrest the propagation of macro cracks. Crack control plays a crucial role in the performance of concrete in service. The loads may overstress hardened concrete which leads to cracking then substantial failure of concrete. Thus, incorporation of discrete fibres in concrete is useful and effective. The resulting fibre-reinforced concrete exhibits satisfactory resistance to crack formation and propagation.

V. CONCLUSIONS

- From the testing results on the fresh properties of SCC mixture with bottom ash, it can be conclude that the presence of bottom ash in the concrete mixture decreased the workability of the fresh concrete; it is possible to design SCC with bottom ash on various percentages. Though serious consideration should be made in deciding the water-to-powder ratio, since bottom ash tends to absorb water during the mixing. Otherwise, the addition of super plasticizer is required to improve fresh concrete workability.
- By varying the quantity of bottom ash compressive strength, splitting tensile strength and flexural strength of bottom ash based SCC decreased with the increased bottom ash content but the mix meet the requirement hence it can be suggest for replacement purpose.
- Since durability tests do not conduct, journals suggest that durability of bottom ash replaced concrete is very low.
- 15% sand replacement with bottom ash (BA15) showed better results for compressive strength, flexural strength and splitting tensile strength compared to other bottom ash based mixes. Bottom ash used as fine aggregate replacement enables the large utilization of waste product.
- Glass fibre added at 15% sand replaced mix(BA15).Experimental results showed that addition of glass fibre increase the compressive, tensile and flexural strength of SCC.

- Flow ability of mixtures decreased in parallel with an increment of glass fibre content, all mixes shows satisfactory passing ability values of the EFNARC recommendation.
- The highest glass fibre content 0.8% (by weight of cement) had best effect on hardened properties but the worst on fresh properties of SCC.

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