Investigation of Glass Fiber Reinforced Concrete with Partial Replacement of Cement and Fine Aggregate using Coal Ash

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Abstract:
Concrete is a highly versatile, durable, and cost-effective construction material that is widely used worldwide. However, traditional concrete production has raised concerns regarding its environmental impact and the depletion of natural resources, primarily due to the substantial amounts of cement and sand required. This study aims to develop sustainable concrete by partially substituting cement and sand with fly ash and pond ash, respectively, while incorporating glass fiber. The replacement levels chosen are 20% for cement with fly ash and 40% for sand with pond ash. Additionally, a consistent proportion of 600 gm/m^3 of glass fiber is added to examine the combined effect on concrete properties. Experimental tests were conducted to assess both fresh concrete, focusing on workability, and hardened concrete, including compressive strength, flexural strength, and ultrasonic pulse velocity. The results demonstrate that a cement replacement of up to 40% with fly ash, coupled with a low volume of glass fiber, is recommended based on workability. In terms of durability, a replacement of 20% cement and 40% sand using fly ash and pond ash, along with glass fiber, is advised. Furthermore, considering the 28-day strength, the study suggests a maximum replacement of 20% cement and 40% sand with fly ash and pond ash, respectively, in conjunction with 600 gm/m^3 of glass fibers.

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1. Introduction

Concrete is the most widely used construction material globally due to its versatility, durability, and cost-effectiveness. However, the production of conventional concrete requires a substantial amount of cement and sand, which leads to environmental concerns and depletion of natural resources. To address these challenges and promote sustainable construction practices, researchers have been exploring alternative materials and methods to enhance the performance and reduce the environmental impact of concrete.

One approach is the partial replacement of cement and sand with supplementary materials like fly ash and pond ash, respectively. Fly ash is a byproduct of coal combustion in thermal power plants, while pond ash is obtained from ash ponds where fly ash is stored. These materials are commonly classified as pozzolanic materials and exhibit cementitious properties when combined with water and calcium hydroxide. By utilizing fly ash and pond ash in concrete, not only can the environmental impact of their disposal be minimized, but also the consumption of cement and sand can be reduced, leading to a more sustainable construction practice.

1.1 Application of Fly Ash in Concrete

Fly ash is a fine powder composed of spherical particles that are predominantly glassy in nature. It is rich in silicon dioxide (SiO_2), Aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3). Due to its pozzolanic properties, fly ash can react with calcium hydroxide, a byproduct of cement hydration, to form additional cementitious compounds.

In conclusion, the application of fly ash in concrete offers numerous benefits (Wang, K., & Huang, B., 2002; Malhotra, V. M., & Mehta, P. K. 2004; Thomas, M. D. A., & Gupta, R. C. 2004; Thomas, M. D. A., & Gupta, R. C. 2004). It enhances the workability, strength, and durability of concrete while reducing the environmental impact. The utilization of fly ash in concrete production has become a sustainable practice that supports the circular economy by effectively utilizing a byproduct of power generation (Wang, S., & Song, Y., 2007; Mollah, M. Y. A., & Shaikh, I. U. 2008; Thomas, M. D., & Ramaswamy, A. 2010; Sarkar, P., & Jha, S. 2018). As a result, the construction industry continues to embrace the use of fly ash as a valuable supplementary cementitious material for the development of durable and environmentally friendly concrete structures (Patil, N., & Pande, A., 2019).

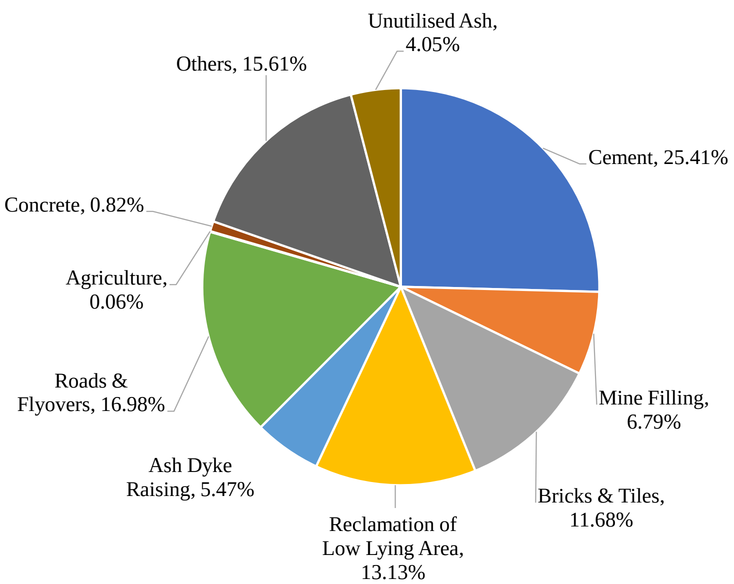

Fig. 1 Various mode of fly ash utilization

1.2 Application of Pond Ash in Concrete

Pond ash, also known as bottom ash or pulverized fuel ash, is a waste material obtained from the bottom of ash ponds in thermal power plants. It is a fine, siliceous material that possesses pozzolanic properties like fly ash. While fly ash has been extensively researched and used as a partial replacement for cement in concrete, pond ash has gained less attention despite its potential as a sustainable alternative to sand in concrete production.

Pond ash has properties that make it suitable for replacing sand in concrete mixtures (Kumar, V., & Devi, S. 2008; Prakash, A., & Srivastava, R. K. 2010; Jain, A., & Aggarwal, P. 2012; Nataraja, M. C., & Vishwas, B. K. 2012). It is a fine-grained material with a similar particle size distribution to sand, making it compatible with the existing concrete production processes. When used as a partial replacement for sand, pond ash contributes to improved workability and reduced water demand in concrete mixtures. This is beneficial for concrete placement and consolidation, facilitating easier construction practices.

In conclusion, the application of pond ash as a replacement for sand in concrete offers several benefits. It addresses the environmental concerns associated with the disposal of ash from thermal power plants, promotes sustainable waste management practices, and reduces the reliance on natural sand resources. The use of pond ash improves the workability, strength, and durability of concrete, making it a promising alternative material in concrete production (Sharma, P., & Siddique, R. 2016; Rokade, A. K., & Kachole, M. S. 2017). However, further research and development are necessary to optimize the utilization of pond ash in concrete mixtures and ensure consistent and reliable performance for a sustainable future.

1.3 Application of Glass Fiber in Concrete

The primary advantage of using glass fiber in concrete is its high tensile strength. Unlike traditional concrete, which is weak in tension, glass fiber reinforcement can effectively resist tensile forces and prevent crack formation and propagation. This property makes glass fiber-reinforced concrete (GFRC) ideal for applications where tensile strength is crucial, such as in thin structural elements, architectural panels, and precast elements.

In conclusion, the application of glass fiber in concrete offers numerous advantages. It enhances tensile strength, flexural strength, impact resistance, and durability (Naaman, A. E., & Reinhardt, H. W. 2001; Mobasher, B., et al. 2009; Li, V. C., & Wu, C. 2012; Zollo, R. F., et al. 2015; Caggiano, A., et al. 2019). The incorporation of glass fiber reinforcement allows for the design of structures with improved performance and longevity. As a sustainable alternative to traditional steel reinforcement, glass fiber reinforcement supports environmentally conscious construction practices. The utilization of glass fiber in combination with other materials, such as fly ash and pond ash, further enhances the potential for developing sustainable and high-performance concrete structures.

In the present study, an attempt has been made to prepare the sustainable concrete using partial replacement of cement and sand by fly ash and pond ash, respectively, with glass fiber. The cement and sand are replaced by 20% and 40% by fly ash and pond ash respectively. A constant proportion of fiber i.e., 600 gm/m^3 is added to evaluate the combined effect on properties of concrete. The experimental tests on fresh concrete and hardened concrete were performed to study the effect of partial replacement of coal ash into the concrete.

2. Material Used

2.1 Cement

The 53 grade Birla A-1 gold ordinary Portland cement was purchased from locally available cement supplier used for the present investigation. As per IS 4031-1988 the laboratory tests i.e., standard consistency of cement paste, initial and final setting time, compressive strength at the age of 3, 7 and 28 days and soundness of cement were carried out and Tabulated in Table 1. All the results on cement were used as per the results of ordinary Portland cement conforming to the IS 12269- 1987.

Table 1 Properties of Cement

S. No.	Property		Result	
			At initial stage	After one month
1	Standard Consistency		30.5%	30%
2	Initial setting Time		118min	120 min
3	Final setting Time		220 min	210 min
4	Fineness by Sieving (90 micron)		3%	3%
5	Specific Gravity		3.15	3.15
6	Soundness		2mm	2mm
7	Average compressive strength	3 Days	31.5 N/mm^2	31 N/mm^2
		7 Days	38.5 N/mm^2	38.5 N/mm^2
		28 Days	55 N/mm^2	54.75 N/mm^2

2.2 Coal Ash

Fly ash and pond ash was collected from the NSPCL plant, Bhilai, Chhattisgarh, India. The physical properties such as specific gravity and fineness were found and tabulated in Table 3.2. In present research the finer fly ash was used having average particle size less than average particle size of cement which improved the particle packing and reduced the voids in concrete. The specific gravity of the fly ash and pond ash observed as 2.15 and 2.00 respectively.

2.3 Coarse Aggregate

The 20 mm and 10 mm coarse aggregate separately collected from local supplier. While collecting it, insure regarding the coarse aggregate to be free from impurities, dust and clay particle etc. was done. According to IS 2386-1963, the various physical properties of aggregates such as sieve analysis, loose, rodded, and vibrated densities, percentage voids, specific gravity, water absorption, aggregate crushing and impact values were tested. The details of the physical properties are given in the Table 2. As per IS 383-2016 to achieve the final grading of coarse aggregate, 20 mm and 10 mm aggregates are combined 60% and 40% respectively.

Table 2 Physical Properties of 20 mm and 10 mm Coarse Aggregates

Properties	**Test Result**	
	20 mm aggregate	**10 mm aggregate**
Specific gravity	2.68	2.65
Water absorption (%)	0.4	0.60
Bulk density (Loose in kg/m^3)	1480.34	1520.36
Bulk density (Rodded in kg/ m^3)	1710	1730.14
Bulk density (Vibrated in kg/ m^3)	1780.52	1811
Percentage void (Loose)	45	43
Percentage void (Rodded)	36	35
Percentage void (Vibrated)	33.50	32
Impact Value (%)	9.71	6.57
Crushing Value (%)	22.57	17

2.4 Fine Aggregate

Locally available Kharun river sand was procured from local supplier and to protect it from dust it was stored in clean cement bags. According to 2386- I 963 the various physical properties of fine aggregate such as sieve analysis, loose, rodded, and vibrated bulk densities, percentage voids, specific gravity, water absorption and silt content were tested.

2.5 Glass Fiber

The nominal doses of glass fiber i.e. 600 gm/m^3 were decided on the basis of trials to reduced shrinkage value, cost, early age strength, and improve the durability of concrete. While mixing the glass fiber in cement, care was taken that glass fiber should be mixed uniformly without formation of balling. Based on datasheet available from distributor, the physical properties of fibers are tabulated in Table 3.

3. Concrete Mix Proportions

To understand the effect of fly ash as a partial replacement material for cement and pond ash for the partial replacement of the fine aggregate together with glass fiber, the mix design was prepared using 0.40 and 0.45 W/C ratios. Mix proportions are given in Table 4 and Table 5 for 0.40 and 0.45 W/C ratios respectively.

Table 3 Physical Properties of Glass Fiber

S.No.	Properties	Test result as per distributor
1	Length (mm)	12
2	Diameter (µm)	14
3	Specific Gravity	2.6

4	Tensile Strength (MPa)	1700
5	Modulus of Elasticity (Pa)	72

Table No 4 Concrete Mix Proportions for a 1m³ Concrete (0.40 W/C)

MIX	**Cement** (kg)	**Fly Ash** (kg)	**Pond Ash (kg)**	**Aggregate** (kg)	**Sand** (kg)	**Water** (kg)	**Fiber** (kg)	**Admixture** (kg)
CM	418.5	0	0	1102	732	167.40	0.0	4.18
CMF	418.5	0	0	1102	732	167.40	0.6	4.18
C20S0	368.4	92	0	1102	685	167.40	0.6	4.18
C40S0	276.5	184	0	1102	671	167.40	0.6	4.18
C0S20	418.5	0	150	1102	557	167.40	0.6	4.18
C0S40	418.5	0	293	1102	383	167.40	0.6	4.18
C20S20	368.4	92	150	1102	522	167.40	0.6	4.18
C40S20	276.5	184	150	1102	510	167.40	0.6	4.18
C20S40	368.4	92	293	1102	360	167.40	0.6	4.18
C40S40	276.5	184	293	1102	351	167.40	0.6	4.18

Note: CM- Control Mix
CMF- Control mix with glass fiber
CXFY- Cement (C) replaced by fly ash (X) in % and Sand (S) replaced by pond ash (Y) in %.

Table 5 Concrete Mix Proportions for a 1m³ Concrete (0.45 W/C)

MIX	**Cement** (kg)	**Fly Ash** (kg)	**Pond Ash (kg)**	**Aggregate** (kg)	**Sand** (kg)	**Water** (kg)	**Fiber** (kg)	**Admixture** (kg)
CM	372.11	0	0	1144.50	729	167.45	0.0	3.72
CMF	372.11	0	0	1144.50	729	167.45	0.6	3.72
C20S0	327.50	82.00	0	1144.50	703.50	167.45	0.6	3.72
C40S0	245.50	163.80	0	1144.50	703.50	167.45	0.6	3.72
C0S20	372.11	0	145.25	1144.50	555.50	167.45	0.6	3.72
C0S40	372.11	0	291.50	I 144.50	381.70	167.45	0.6	3.72
C20S20	327.50	82.00	145.25	I 144.50	528.50	167.45	0.6	3.72
C40S20	245.60	163.80	145.25	1144.50	535.5	167.45	0.6	3.72
C20S40	327.50	82.00	291.50	1144.50	368.00	167.45	0.6	3.72

C40S40	245.60	163.80	291.50	1144.50	426.60	167.45	0.6	3.72

4. Methodology

Laboratory tests were conducted on all the mix proportions to evaluate the properties of fresh and hardened concrete using slump cone test, compressive strength, flexural strength, and Ultrasonic pulse velocity test. The IS code recommended to conduct the various tests are presented in Table 6.

Table 6 Standard code followed for various tests

S. No.	Name of Test	Standard Code followed
1	Slump Cone Test	IS1199 (1959) and IS 456 (2000)
2	Compressive Strength	IS 516: 1959 and IS:456-2000
3	Flexural Strength	IS 516: 1959
4	Ultrasonic Pulse Velocity	IS 13311:1992

5. Results and Discussions

In the present study, fly ash and pond ash was used as a partial replacement of cement and sand respectively along with glass fiber for the development of sustainable and durable concrete. The results obtained from the test conducted on fresh and hardened concrete are presented in the below sections.

5.1 Fresh Concrete

The properties of fresh concrete, mainly workability, is determined by conducting slump cone test on all the mix proportions as 0.4 and 0.45 W/C ratio. The test results of slump cone test for all the mix proportions at W/C ratio of 0.4 and 0.45 are presented in Table 7. Test result noted that concrete made with 600 gm/m^3 of glass fiber without any replacement, the drop in slump observed as 6.12 % and 8.92 % for 0.40 and 0.45 W/C ratios respectively than control concrete. For replacement of 20% and 40% of cement by fly ash together with glass fiber, the slump value increased by 8.16 % and 18.37% for 0.40 W/C ratio and 10.71 % and 23.21 % for 0.45 W/C ratio respectively over control concrete. When 20% sand is replaced by pond ash together with glass fiber, nearly equal or slightly greater slump value is observed. As replacement of sand increased by 40%, the drop in slump is observed for all W/C ratio. It is observed that addition of glass fiber in the mix decreased the workability of concrete for all W/C ratios as compared to the control mix. Glass fiber due to small diameter and large length has very high surface area. Due to large surface area and micron thickness of glass fiber, water demand in concrete increased and hence workability decreased. In combined replacement it is observed that the slump was more for higher replacement of cement by fly ash (i.e. 40%) and lower replacement of sand by fly ash (i.e. 20%). In combine replacement of 20% cement and 20% sand by fly ash and pond ash respectively, better workability compares to control mix and mix with glass fiber is observed.

Table 7 Slump value (mm) at W/C of 0.40.

Mix		CM	CMF	C20S0	C40S0	C0S20	C0S40	C20S20	C40S20	C20S40	C40S40
Slump height (mm)	0.4 (W/C)	49	46	53	58	49	42	51	56	43	37
	0.45 (W/C)	56	51	62	69	57	47	60	64	48	41

5.2 Hardened Concrete

5.2.1 Compressive strength

Table 8 represent the compressive strength of concrete at W/C ratio of 0.4 and 0.45.

Table 8 Variation in compressive strength of concrete at W/C 0.40

Mix	Compressive strength (N/mm^2)					
	0.40 (W/C)			0.45 (W/C)		
	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days
CM	31.78	39.11	47.57	27.64	34.82	41.34
CMF	33.13	41.12	50.67	28.73	36.24	43.53
C20S0	29.86	43.67	53.46	26.16	38.73	45.24
C40S0	24.84	34.14	39.15	19.48	27.83	33.14
C0S20	33.18	46.21	53.18	28.71	39.32	46.00
C0S40	37.14	50.53	59.24	31.74	43.23	50.14
C20S20	35.59	48.72	56.23	29.48	41.23	48.37
C40S20	25.73	36.16	42.31	20.84	30.54	35.18
C20S40	39. 13	53.32	61.15	31.31	45.18	52.31
C40S40	23.38	31.94	36.18	18.27	25.68	29.86

It is observed that when 20% cement replaced by fly ash, the 7 days compressive strength slightly reduced for 0.40 and 0.45 W/C ratio when compare to control concrete. After 7 days the strength developed at elevated rate than control concrete and concrete with glass fiber for all W/C ratios. The 28 days the strength improved by 11.66% and 11.23% for 0.40 and 0.45 W/C ratio respectively over control concrete.

As the replacement of cement increased 40% by fly ash the compressive strength decreased when compared to control concrete. But even at 40% cement replacement by fly ash together with glass fiber the 56 days strength of mix, nearly equal to 28 days strength of control mix. From the test result it is observed that it is possible to achieve 28 days strength of control concrete at 56 days for the same W/C ratios even at 40% cement replacement by fly ash together with low doses of glass fiber, which reduced nearly 153 kg/m^3 of cement and consume higher amount of fly ash and makes the concrete more sustainable by using proposed method.

For combined replacement when 20% of cement and 40% of sand replaced by fly ash and pond ash together with glass fiber, best result is obtained than all the other mixes for all W/C ratios at all curing ages. The increase in strength observed as 36.33% and 29.75% for 0.40 and 0.45 W/C ratio respectively at the age of 28 days when compared to control concrete. On the other hand, when 40% cement and 20% sand replaced by fly ash and pond ash respectively, the reduction in strength observed over control concrete at all curing period for all W/C ratio. Hence for achieving better strength, the combined replacement up to 20% cement on weight basis and up to 40% fine aggregate on volume basis with fly ash and pond ash respectively together with small dosages of glass fiber can be used in practices.

5.2.2 Flexural Strength

The test results of the flexural strength of all mix proportions are tabulated in Table 9 at W/C ratio of 0.4 and 0.45.

Table 9 Flexural Strength of all Concrete mix

Mix	Flexural strength (MPa)			
	0.40 (W/C)		0.45 (W/C)	
	28 Days	56 Days	28 Days	56 Days
CM	3.92	4.60	3.34	4.00
CMF	4.28	5.12	3.68	4.38
C20S0	4.12	5.24	3.53	4.46
C40S0	3.32	4	2.70	3.28
C0S20	4.38	5.41	3.72	4.63
C0S40	4.70	5.67	3.78	4.64
C20S20	4.54	5.52	3.86	4.72
C40S20	3.37	4.10	2.80	3.45
C20S40	5.12	6.23	4.42	5.35
C40S40	3.10	3.80	2.64	3.21

The addition of glass fiber increases the flexural strength by 9.18% &10.17% at 28 days and 11.30% & 9.50& at 56 days at 0.40 & 0.45 W/C ratio respectively. When 20% of cement was replaced by fly ash together with glass fiber, the flexural strength increased by 13.91% and 11.50% for 0.40 and 0.45 W/C ratio respectively over control concrete at 56 days.

However, when, 40% cement replaced by fly ash, the flexural strength decreased. Even at 40% cement replacement by fly ash together with glass fiber, it is possible to achieve 28 days flexural strength of control concrete at 56 days for the same W/C ratio.

From present result it is observed that as the percentage of sand replacement by pond ash increased, the flexural strength also increased. For 20% sand replacement the increment in flexural strength observed up to 17.60% and 15.75% for 0.40 and 0.45 W/C ratio respectively at 56 days. With the increase in pond ash percentages, the flexural strength continued to increase at all ages, and there was considerable increase in strength with that of control concrete and concrete with glass fiber. This is due to the great pozzolanic reaction and the higher content of calcium silicate hydrate due to reaction of CH produced from cement hydration with active silica of pond ash.

In combine replacement when 20% cement and 20% sand replaced by fly ash and pond ash together with glass fiber, the flexural strength ranges in between 18.20 to 26.35% more than control mixes at all ages and all W/c ratios. While the mix C20S40 achieved highest flexural strength (34 to 38%) when compared to control mix for all W/C ratios at all curing periods.

5.2.3 Ultrasonic Pulse Velocity

The UPV test results of all the samples at W/C of 0.4 and 0.45 is presented in Table 10.

Table 10 UPV value of concrete mix proportion at W/C of 0.4 & 0.45

Mix	Ultrasonic Pulse Velocity (km/s)					
	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days
CM	4.95	5.04	5.06	4.95	5.04	5.06
CMF	5.00	5.08	5.11	5.00	5.08	5.11
C20S0	5.07	5.11	5.17	5.07	5.11	5.17
C40S0	5.08	5.14	5.22	5.08	5.14	5.22
C0S20	5.05	5.13	5.18	5.05	5.13	5.18
C0S40	5.15	5.23	5.32	5.15	5.23	5.32
C20S20	5.07	5.17	5.25	5.07	5.17	5.25

C40S20	5.16	5.25	5.35	5.16	5.25	5.35
C20S40	5.15	5.31	5.42	5.15	5.31	5.42
C40S40	5.14	5.27	5.38	5.14	5.27	5.38

Addition of 600 gm/m^3 of glass fiber in concrete improve the UPV values by 0.98% and 0.79% for 0.40 and 0.45 W/C ratios respectively over control concrete at the curing period of 28 days. Inclusion of glass fiber in concrete arrest the shrinkage cracks resulting in improvement in UPV values. From experimental investigation it is seen that as percentage of cement replacement by fly ash increases, the UPV values also increases compared to control concrete and concrete with glass fiber. Fly ash in concrete improves the microstructure which can be clearly seen from SEM images. Fly ash produced extra C-S-H gel which fills the voids inside the concrete. Also, finer fly ash improves the particles packing than cement particles due to which UPV increases as cement replacement by fly ash increases.

The effect of pond ash as sand replacement together with glass fiber on UPV values found to be more than control mixes at all ages and for all W/C ratios. It is observed that when 20% sand replaced by pond ash together with glass fiber the UPV values increased. The UPV values of sand replacement mixes for all W/C ratios at all curing periods are found to be slightly more than cement replacement mixes. When sand is replaced by pond ash together with glass fiber, the UPV values increased because of availability of additional finer material in mix.

On combine replacement of cement and sand by fly ash and pond ash together with glass fiber, the UPV values increased over control concrete and concrete with glass fiber. When 20% cement and 20% sand replaced by fly ash together with glass fiber, the UPV values increased. For mix C20S40, the UPV values slightly increased than mix C40S20. In combine replacement, the quantity of finer material increased which increased packing density of concrete. In mix C20S40, the reduction of coarser material (sand) was more than mix C40S20 which improve the particles packing density due to inclusion of finer fly ash. Also, the formation of CSH gel is more in mix C20S40 than mix C40S20. The voids in between cement and sand particles in control concrete reduces due to addition of pond ash for sand replacement, hence microstructure of concrete improves which improve the UPV values than other mixes.

6. Conclusion

Based on the test results of the present study, following conclusions are drawn:

- It is observed that as a replacement of cement increases, the workability of concrete also increases and found to be 23.22% for higher replacement (40%) and higher W/C ratio (0.45) than control concrete.
- Cement replacement up to 40% by fly ash and sand replacement up to 20% by pond ash increased the slump height. The loss of slump height due to the inclusion of glass fiber can be compensated due to addition of fly ash and pond ash.
- When replacement of sand is increased by 40%, the drop in workability is observed due to additional volume fraction of small particles. For combine replacement of 40% cement

and 40% sand by fly ash, the higher reduction in workability is observed than for all the other mixes.

- At 20% of cement and 40% of sand replaced by fly ash and pond ash together with glass fiber, best result is obtained than all the other mixes for all W/C ratios at all curing ages.
- The mix C20S40 achieved highest flexural strength (34 to 38%) when compared to control mix for all W/C ratios at all curing periods. For 40% cement and 40% sand replacement mix C40S40, the reduction in strength observed.
- In combine replacement, the quantity of finer material increased which increased packing density of concrete. In mix C20S40, the reduction of coarser material (sand) was more than mix C40S20 which improve the particles packing density due to inclusion of finer fly ash.

REFERENCES

1. Naaman, A. E., & Reinhardt, H. W. (2001). High-performance fiber-reinforced cement composites (HPFRCC): State-of-the-art review. Journal of Advanced Concrete Technology, 10(3), 77-90.
2. Wang, K., & Huang, B. (2002). Effects of fly ash on mechanical properties of high-strength concrete. Cement and Concrete Research, 32(3), 407-411.
3. Malhotra, V. M., & Mehta, P. K. (2004). Use of fly ash in concrete: a review. Journal of Civil Engineering and Management, 10(4), 269-275.
4. Thomas, M. D. A., & Gupta, R. C. (2004). Effect of fly ash fineness on the mechanical properties of concrete. Cement and Concrete Research, 34(6), 1049-1057.
5. Kumar, A., & Kumar, V. (2006). Effect of fly ash on fresh properties of self-compacting concrete. Construction and Building Materials, 20(4), 230-236.
6. Wang, S., & Song, Y. (2007). Effects of fly ash and silica fume on the compressive and flexural strength of concrete. Cement and Concrete Composites, 29(6), 448-453.
7. Kumar, V., & Devi, S. (2008). Utilization of pond ash as partial replacement of fine aggregate in concrete. Journal of Materials in Civil Engineering, 20(4), 291-298.
8. Mollah, M. Y. A., & Shaikh, I. U. (2008). Influence of fly ash on strength and pore structure development of high-volume fly ash cement mortar. Cement and Concrete Composites, 30(5), 371-376.
9. Mobasher, B., et al. (2009). Review of strain hardening fiber-reinforced concrete in the new millennium. ACI Materials Journal, 106(6), 611-620.
10. Prakash, A., & Srivastava, R. K. (2010). Utilization of pond ash as partial replacement of fine aggregate in concrete. International Journal of Earth Sciences and Engineering, 3(2), 439-442.
11. Thomas, M. D., & Ramaswamy, A. (2010). Influence of fly ash as fine aggregate on the properties of mortar. Construction and Building Materials, 24(8), 1411-1418.
12. Jain, A., & Aggarwal, P. (2012). Effect of pond ash as partial replacement of fine aggregate in concrete. International Journal of Engineering Research & Technology, 1(7), 1-5.
13. Li, V. C., & Wu, C. (2012). Tension hardening response of strain-hardening cementitious composites (SHCC). Materials and Structures, 45(4), 493-502.

14. Nataraja, M. C., & Vishwas, B. K. (2012). Experimental study on use of pond ash as partial replacement of fine aggregate in concrete. International Journal of Engineering Research and Development, 2(3), 40-45.
15. Zollo, R. F., et al. (2015). Steel fiber-reinforced concrete: Behavior, modeling, and design. Journal of Materials in Civil Engineering, 27(7), 04014207.
16. Sharma, P., & Siddique, R. (2016). Performance of pond ash as partial replacement of fine aggregate in concrete. Construction and Building Materials, 111, 319-325.
17. Rokade, A. K., & Kachole, M. S. (2017). Experimental investigation on the properties of concrete with pond ash as partial replacement of fine aggregate. International Journal of Engineering Sciences & Research Technology, 6(1), 567-573.
18. Sarkar, P., & Jha, S. (2018). Effect of fly ash and silica fume on fresh and hardened properties of self-compacting concrete. Construction and Building Materials, 181, 527-536.
19. Caggiano, A., et al. (2019). Fiber-reinforced concrete: A review of the mechanical performance. Materials, 12(10), 1706.
20. Patil, N., & Pande, A. (2019). Utilization of high-volume fly ash in self-compacting concrete: A review. Journal of Cleaner Production, 210, 865-880.