Optimizing Compressive Strength of Concrete: A Study on The Impact of Fly Ash, Silica Fume, And Polypropylene Fibre

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Abstract- *A parametric experimental study was undertaken to examine the impact of fly ash, silica fume, and polypropylene fibre on the compressive strength of concrete cubes. A total of 6 trial sets, each measuring 150 x 150 x 150 mm and classified under grade M-70, were prepared with different proportions of fly ash, silica fume, and polypropylene fibre (PP Fibre), resulting in a total of 14 different trial mixes. The results suggest that the optimal combination of fly ash, silica fume, and PP fibre together is 12.5% fly ash, 5% silica fume, and 1% PP fibre.The inclusion of polypropylene fibre has significantly enhanced the durability of the concrete composite incorporating fly ash and silica fume.*

Keywords- Fly ash, Silica Fume, PP Fibre, Concrete.

I. INTRODUCTION

Due to its role in environmental pollution and the substantial storage expenses associated with it, the use of fly ash in concrete technology is indisputably beneficial for both mitigating pollution and bolstering a nation's economy. The fly ash concrete offers a holistic approach that can help us to achieve the goals of meeting the rising demands for concrete, enhancement of concrete durability with little or no increase in cost (in some instances reduced cost), and ecological disposal of large quantities of the solid waste products from coal-fired power plants[1, 2]. Numerous studies on concrete incorporating fly ash have consistently demonstrated outstanding mechanical strength and durability characteristics. Although fly ash offers significant advantages, practical challenges persist in its real-world application. Concrete with a high volume of fly ash as a partial cement substitute often exhibits lower strength in the early stages of aging compared to control concrete. This is attributed to the slow pozzolanic reaction of fly ash, with its contribution to strength development becoming noticeable only at later stages[3, 4, 5].

Silica fume, stemming from the silicon metal and ferro-silicon alloy industry, is no longer considered a waste product but rather a valuable by-product, with its utilization in concrete technology seeing a recent surge. Thanks to notable enhancements in the interfacial zone between cement paste and aggregate, silica fume is recognized for its capacity to enhance the early strength and durability of concrete, leading to the production of high-strength concrete[6]. Silica fume is commonly employed in two distinct manners: first, as a substitute for cement to diminish the cement content, typically for economic considerations; and secondly, as an additive to enhance concrete properties, encompassing both its fresh and hardened states[7]. Hence, to bolster the early strength of concrete incorporating fly ash, the concurrent use of silica fume alongside fly ash presents an intriguing alternative. Numerous researchers have undertaken recent investigations utilizing a combination of these two by-products[8, 9]. The amorphous silica colloidal particles found in silica fume possess the ability to adsorb dispersants present in the surrounding environment, resulting in the formation of a solvent layer. This process enhances the fluidity of the casting materials. Moreover, the secondary hydration products of calcium-silicate-hydrate (C-S-H) gel diminish the concentration of calcium hydroxide (Ca(OH)2) in the pore solution, thereby facilitating the continued hydration of cement[10, 11] Research indicates that as the proportion of amorphous silica (nSiO2) in the mixture rises, the pore structure undergoes refinement, resulting in outstanding mechanical properties[12]. Nevertheless, numerous research findings suggest that incorporating silica fume into concrete can lead to a more brittle structure. Enhancing ductility is a significant objective in concrete science and warrants careful consideration by researchers[13].

Polypropylene (PP) fibre is a synthetic fibre made from the polymer polypropylene. PP fibres are used in a wide range of construction applications due to their strength, durability, and resistance to chemicals and heat. **Error! Reference source not found.** represents the Image of PP Fibre. Historically, steel and polypropylene (PP) fibres have been integrated into cementitious composites to bolster building fire safety. This hybrid combination has proven effective in reducing excessive cracking, mitigating explosive spalling, and enhancing both the ambient and post-fire performance of the cementitious composite[14].

II. MATERIALS AND METHODS

The study utilized commercially available Ultratech ordinary Portland cement for its investigation The specific gravity of fine aggregates (FA) and coarse aggregates (CA) were recorded as 2.6 and 2.82, respectively. Class F fly ash was procured from the local market of Jabalpur for use in the study.According to ASTM-C618 standards, the fly ash was categorized as low calcium fly ash for the purposes of the study[15]. Class-F fly ash was deliberately selected due to its slow-reacting property, lower calcium oxide content, enhanced workability, and sustainability attributes. Additionally, a high-grade supplementary cementitious material (SCM) was introduced as a secondary pozzolanic material to expedite the rate of strength development [16]. The SF utilized had a specific gravity of 2.20, a specific surface area of 22 m²/g, and consisted of 91.5% SiO2. Additionally, the specific gravity of pink metakaolin (MK) used, with major ingredients SiO2 and Al2O3 at 51% and 43%. Customized polypropylene synthetic fibres with a unique triangular cross-section, measuring 12 mm in length and 36 µm in diameter, were employed in the study. Fresh, potable water devoid of biological and acid impurities was utilized for concrete mixing. The superplasticizer (SP) employed had a specific gravity of 1.2.*Figure 1* shows the Images of Study.

Figure 1 Casting and testing of cube.

Approach of the study:

A total of 6 trial sets, each measuring 150 x 150 x 150 mm and belonging to grade M-70, will be fabricated to determine the optimal High-Performance Fibre-Reinforced Concrete (HPFRC) mixture. Mix 1 is prepared without any mineral admixture. Mixes 2-6 involve cement replacements of 10%, 12.5%, 15%, 20 and 25% with fly ash (FA) to identify the optimal dosage of FA. Once the optimal dosage of FA is determined, the dosage is fixed, and the variable becomes silica fume (SF). Mixes 7-9 are cast to ascertain the optimum dosage of SF at replacement levels of 5%, 10%, and 15%. After establishing the optimal dosage of SF, a similar process is repeated to determine the optimal dosage of polypropylene (PP) fibresfor mixes 10-14 with replacement of 0.5, 0.75, 1.0, 1.25, 1.50% as

. Following these steps, the optimal HPFRC mix is finalized, and a total of 84 cubes are cast using this mix as specified in Table 2

Table 1Trial mixes

Trial mix (M70)	7 days	28 days	Total
Mix 1 Nominal Mix	**3**	**3**	**6**
Mix 2 FA 10%	**3**	**3**	**6**
Mix 3 FA 12.5%	**3**	**3**	**6**
Mix 4 FA 15 %	**3**	**3**	**6**
Mix 5 FA 20 %	**3**	**3**	**6**
Mix 6 FA 25 %	**3**	**3**	**6**
Mix 7 FA 12.5% + SF 05%	**3**	**3**	**6**
Mix 8 FA 12.5% + SF 10%	**3**	**3**	**6**
Mix 9 FA 12.5% + SF 15%	**3**	**3**	**6**
Mix 10 FA 12.5% + SF 5% + PP FIBRE 0.5 %	**3**	**3**	**6**
Mix 11 FA 12.5% + SF 5% + PP FIBRE 0.75 %	**3**	**3**	**6**
Mix 12 FA 12.5% + SF 5% + PP FIBRE 1.0 %	**3**	**3**	**6**
Mix 13 FA 12.5% + SF 5% + PP FIBRE 1.25 %	**3**	**3**	**6**
Mix 14 FA 12.5% + SF 5% + PP FIBRE 1.50 %	**3**	**3**	**6**

Table 2 Mix Design of trial mixes

Notation	Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)	Fly Ash (Kg/m^3)	Silica Fume (Kg/m^3)	PP fibre (Kg/m^3)
mix 1	523.5	685.04	1296	138	0	0	0
mix 2	471.14	648.23	1226.54	138	52.35	0	0
mix 3	458.05	646.52	1223.31	138	65.44	0	0
mix 4	444.97	644.82	1220.08	138	78.52	0	0
mix 5	418.79	641.4	1213.62	138	104.7	0	0
mix 6	392.62	637.99	1207.16	138	130.87	0	0
mix 7	431.8	643.1	1216.8	138	65.44	26.17	0
mix 8	405.7	639.69	1210.39	138	65.44	52.35	0
mix 9	379.53	636.28	1203.9	138	65.44	78.52	0
mix 10	431.8	640.85	1212.58	138	65.44	26.17	2.15
mix 11	431.8	639.7	1210.44	138	65.44	26.17	3.24
mix 12	431.8	638.59	1208.31	138	65.44	26.17	4.31
mix 13	431.8	637.46	1206.17	138	65.44	26.17	5.39
mix 14	431.8	636.33	1204.03	138	65.44	26.17	6.47

The inclusion of fibres significantly enhances the tensile strength, toughness, and fatigue life of concrete. To determine the optimal dosage of polypropylene (PP) fibre, a split tensile test is conducted. However, it's essential to note that the addition of fibres can lead to lump formation during the mixing process, and higher percentages of fibre can negatively impact the workability of concrete. Consequently, this may necessitate an increased demand for superplasticizer, ranging from 1.2% to 1.4%.

III. DISCUSSION OF THE FINDINGS:

Cubes underwent uniaxial compression testing using a 3000kN capacity compressive testing machine. The test results, detailed inTable 3, were obtained by casting and testing cubes with varying fly ash dosages. The objective was to determine the optimal fly ash dosages through compressive load assessments. Figure 2represents the graphical representation of strength of cubes with flyash.

Table 3Compressive strength of cube

Fly Ash	7 days strength	28 days strength
10 %	40.12	62.67
12.5 %	45.64	67.41
15%	34.5	53.63
20%	32.21	52.15
25%	30.12	48.15

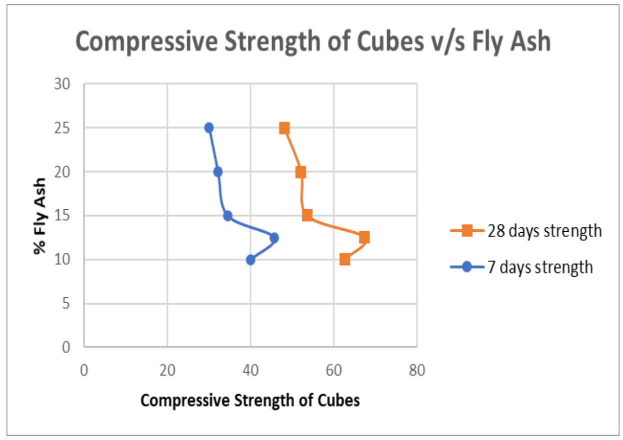

Figure 2 strength with fly ash

Cubes, each featuring distinct silica fume quantities alongside consistent fly ash dosages, were cast and subjected to compressive load testing. The aim was to identify the optimal combination dosages of silica fume and fly ash through the evaluation of compressive strength. Table 4represents the compressive strength of cube for optimum dosage of Silica Fume while Figure 3shows the graphical representation for the same.

Table 4 compressive strength of cube for optimum dosage of SF

Fly Ash 12.5 % + SF	7 Days strength (Mpa)	28 Days strength (Mpa)
5%	56	81.35
10%	52.1	75.41
15%	48.25	71.48

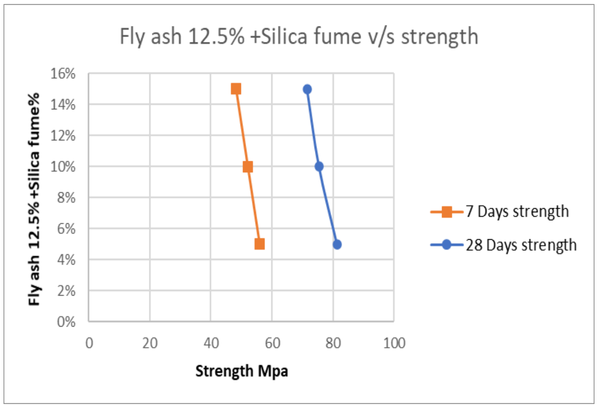

Figure 3strength with silica fume

Polypropylene (PP) fibres are incorporated to enhance the cyclic behaviour of concrete, simultaneously improving its shrinkage and permeability coefficients[17]. The determination of optimal dosages is based on assessing parameters such as compressive strength and split tensile strength in the concrete.

represents the strength for optimum dosage of PP fibre while Figure 4shows the graphical representation for the same.

Table 5 Strength with PP Fibre

PP Fibre Dosage (%)	**Split tensile strength**	**Cube compressive strength**
0.5	6.85	78.41
0.75	6.92	79.11
1.0	6.94	77.11
1.25	7.05	70.96
1.50	6.50	68.89

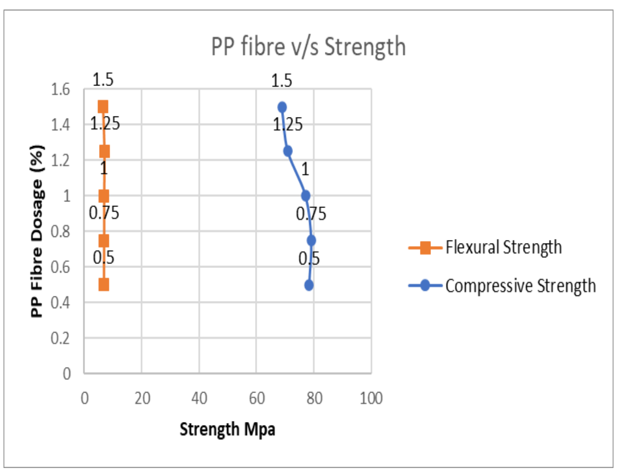

Figure 4Strength with PP fibre

V. CONCLUSIONS

Within the constraints of the current study, the following conclusions are drawn.

1. The findings suggest that optimal strength and structural stability are exhibited by 5% of SF, 12.5% of FA, and 1% of PP fibre across the various trials conducted.
2. The concrete's tensile strength has experienced an increase of over 4%.
3. The early age compressive strength of HPFRC has risen by approximately 15% compared to the nominal concrete mix

REFERENCES

[1] E. Berry and V. Malhotra, "Fly ash for use in concrete-a critical review," ACI Mater J, pp. 59-73, 1990.

[2] V. M. Malhotra, "Durability of concrete incorporating high-volume of low calcium (ASTM class F) fly ash," Cem Concr Compos 12(4), p. 487–93, 1990.

[3] V. M. Malhotra, M.-H. Zhang, P. H. Read and J. Ryell, "Long-term mechanical properties and durability characteristics of high-strength high-performance concrete incorporating supplementary cementing materials under outdoor exposure conditions," ACI Mater J,97(5), 2000.

[4] R. Swamy, S. Ali and D. Theodorakopulos, "Early strength fly ash concrete for structural applications," ACI Mater J, pp. 414-423, 1983.

[5] S. A. Barbhuiya, J. K. Gbagbo, M. Russell and P. A. M. Basheer, "Properties of fly ash concrete modified with hydrated lime and silica fume. Constr Build Mater," Constr Build Mater, 2009.

[6] S.-T. Lee and S.-H. Lee, "Mechanical properties and durability of cement concrete incorporating silica fume," Journal of the Korean Ceramic Society, p. 412–418, 2010.

[7] T. Nochaiya, W. Wongkeo and A. Chaipanich, "Utilization of fly ash with silica fume and properties of Portland cement–fly ash–silica fume concrete.," Fuel (Guildford), pp. 769-774, 2010.

[8] Ş. Erdoğdu, C. Arslantürk and Ş. Kurbetci, "Influence of fly ash and silica fume on the consistency retention and compressive strength of concrete subjected to prolonged agitating," Construction & Building Materials, pp. 1277-1281, 2011.

[9] P. Zhang, Q. Li and H. Zhang, "Combined effect of polypropylene fiber and silica fume on mechanical properties of concrete composite containing fly ash.," Journal of Reinforced Plastics and Composites, p. 1349–1358, 2010.

[10] M. Khan and M. Ali, "Improvement in concrete behavior with fly ash, silica-fume and coconut fibres.," Construction & Building Materials, p. 174–187, 2019.
[11] D. A. Figueiredo and M. R. Ceccato, "Workability analysis of steel fiber reinforced concrete using SLUMP and VE-BE Test," Materials Research (São Carlos. Impresso), 18(6), p. 1284–1290, 2015.
[12] M. Ibrahim, M. A. M. Johari, S. R. Hussaini, M. K. Rehman and M. Maslehuddin, "Influence of pore structure on the properties of green concrete derived from natural pozzolan and nanosilica," J. Sustain. Cem. -Based Mater, pp. 233-257, 2020.
[13] P. Zhang, Q. Li and Z. Sun, "Influence of silica fume and polypropylene fiber on fracture properties of concrete composite containing fly ash," Journal of Reinforced Plastics and Composites (Print), pp. 1977-1988, 2011.
[14] Y. Li, K. H. Tan and E. H. Yang, "Synergistic effects of hybrid polypropylene and steel fibers on explosive spalling prevention of ultra-high performance concrete at elevated temperature," Cement & Concrete Composites, pp. 174-181, 2019.
[15] "C618, ASTM Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete," American society for testing and materials,, West Conshohocken, PA , USA, 2003.
[16] S. W. Alalouh, M. A. Musarat, S. Haruna, K. Law, B. A. Tayeh, W. Rafiq and S. Ayub, "Mechanical properties of silica fume modified High-Volume fly ash rubberized Self-Compacting concrete," Sustainability, 13(10), 5571, 2021.
[17] D. Saje, B. Bandelj, S. Jakob, J. Lopatic and F. Saje, "Shrinkage of polypropylene Fiber-Reinforced High-Performance concrete.," Journal of Materials in Civil Engineering, 23(7), pp. 941-952, 2011.