Effect of silica fume and fly ash on compressive strength of concrete exposed to marine environment

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***Abstract*— The experimental investigation is carried out to determine the compressive strength capability of concrete containing silica fume and fly ash as supplementary cementitious materials which is submerged in artificial marine environment which majorly contains sulphate and chlorides ions in it. Cube size of 150mm is used to determine the compressive strength of concrete and comparative study of compressive strength of concrete cured in potable water and concrete submerged in marine environment is done. Total of 6 design mixes are prepared with 4 percent increment of each cementitous materials as a replacement of cement. Workability of each design mix is observed and how the compressive strength affects on concrete specimen submerged in marine environment is found out.**

Key words: Silica Fume, Fly Ash, M50 concrete, durability, Chloride attack, Sulphate attack.

I. INTRODUCTION

Concrete is a widely used construction material known for its strength and durability. However, it is susceptible to various types of deterioration, including chloride and sulphate attack, which can significantly reduce its lifespan. To enhance the durability of concrete, the combination of silica fume and fly ash has been explored as an effective solution.

When silica fume and fly ash are combined in concrete, they act synergistically to improve its durability against chloride and sulphate attack. The combination of these two materials can result in denser concrete with reduced permeability. This densification limits the ingress of chloride and sulphate ions into the concrete, thereby minimizing the potential for chemical reactions that cause deterioration. In conclusion, the combination of silica fume and fly ash in concrete offers a promising approach to enhance the durability of M50 concrete against chloride and sulphate attack. By reducing permeability and improving the overall microstructure of the concrete, this combination can mitigate the ingress of aggressive ions and prolong the service life of concrete structures. It is essential to conduct further research and testing to optimize the mix design and validate the performance of concrete prepared with silica fume and fly ash for specific applications.

II. LITERATURE REVIEW

A. Review Stage

Dhir and Jones [1] investigated the effects of incorporating fly ash into concrete mixes to enhance chloride resistance. Discussed the effect of low lime concrete in the production of chloride resistant concrete by conducting laboratory experiments and evaluating various mix designs and proportions of fly ash in concrete. Suggested that the addition of fly ash to concrete can help reduce chloride ion penetration, as the pozzolanic reactions lead to denser and less permeable concrete. Rui Luo et.al. [2] focused on the behavior of chloride ions in concrete mixtures containing GGBS as an additional cementitious material. GGBS significantly increased the chloride-binding capacity, regardless of internal or external chlorine, and sulphate significantly decreased the chlorine-binding capacity of GGBS.

Mathias Maes, Nele De Belie [3] determined the performance of concrete and mortar when exposed to the simultaneous presence of chloride and sodium sulphate Md. Safiuddin, M.F.M. Zain [4] examined how the inclusion of silica fume and fly ash as supplementary cementitious materials affects the performance of high performance concrete

Experimental investigation conducted to evaluate the effects of silica fume and fly ash on various aspects of high-performance concrete. D. Ramachandran et.al. [5] focused on evaluating the strength and durability characteristics of concrete containing fly ash when exposed to sea water environments. M. Santhanam M. Otieno [6] discussed various degradation mechanisms such as chloride ingress, sulphate attack, carbonation, and the impact of wave action, tidal exposure, and seawater aggressiveness. Experimentally found out that durability of concrete in any service environment is primarily controlled by the permeability characteristics of concrete, or more generally the penetrability of the concrete. Md. Moinul Islam et.al. [7] investigated the performance of fly ash concrete exposed to artificially created seawater. Agus maryoto [8] studies the tightness of the concrete so that the different ions should not be penetrated in the concrete to deteriorate the concrete. Jun Liu et.al. [9] investigated the impact of incorporating fly ash, a supplementary cementitious material, on the chloride transport properties of concrete. It examines how fly ash affects the penetration and diffusion of chloride ions into the concrete matrix. E.G. Moffatt [10] carried out laboratory experiments, field investigations, or a combination of both to assess the performance of high-volume fly ash concrete in marine conditions. E.G. Moffatt [11] published the long-term durability performance of semi-lightweight concrete containing different levels of supplementary cementitious materials (SCM) and steel fibers when exposed to harsh marine environments for up to 25 years. Prinya Chindaprasirt et.al. [12] mechanical properties, chloride resistance and microstructure of portland ash cement concrete containing large amounts of bagasse ash (BA) were studied. Sajjad Ali Mangi et.al. [13] conducted a study considering the effect of natural seawater on the properties of concrete. However, this research aims to summarize and analyze previous findings and suggestions. Yong Yi et.al. [14] it shows that the salinity of sea water varies in different places, but the types and proportions of ions are the same. Because of this variability, laboratory studies must use artificial seawater specifically to simulate field conditions. A. Fuzail Hashmi et.al. [15] presented a methodology for the optimization of fly ash concrete mix using the data obtained through the planned test plan. Concrete containing ultrafine fly ash and superplasticizer has low permeability, good resistance to freeze-thaw and reduced drying. Fly ash extends the settling time and solidifies approximately 91 and 365 days.

III. EXPERIMENTAL PROGRAM

3.1 Mix proportions:

Primarily the ordinary concrete without any cementitious material of grade M50 is prepared (M0). Then further cementitious material (4% FA + 4%SF) is used as replacement of cement (M1). Similarly (8% FA + 8%SF) – (M2), (12% FA + 12%SF) – (M3), (16% FA + 16%SF) – (M4), (20% FA + 20%SF) – (M5) these combinations are taken into consideration while preparing the concrete to determine the chloride and sulphate attack resistance of concrete.

Table 3.1 : Mix design results:

Mix design results							
Sr. No.		Cement	Fly ash	Silica fume	Fine agg.	Coarse agg.	Water
1	M0	508.800	-	-	763.742	1052.030	157.728
2	M1	468.096	20.352	20.352	757.347	1043.220	157.728
3	M2	427.392	40.704	40.704	750.953	1034.420	157.728
4	M3	386.688	61.056	61.056	744.559	1025.610	157.728
5	M4	345.984	81.408	81.408	738.165	1016.800	157.728
6	M5	305.280	101.760	101.760	731.770	1007.990	157.728

3.2 Specimen preparation:

Concrete cubes of size 150mm each side is prepared using above concrete mix proportions. Since the specimens are casted and cured for 7 and 28 days respectively they must be tested for compressive strength test. Since chloride and sulphate attack adversely affects on concrete the weight loss as well as the volume loss of the specimen was observed. Ponding effect was created and much higher concentration of chloride and sulphate ions was prepared so as to get accelerated effects on concrete to determine the deterioration at early age of concrete. A compression test was conducted to determine the compressive strength of ordinary concrete prepared without using any cementitious material as well as on the concrete containing cementitious materials to compare its behaviour using 150 mm x 150 mm x 150 mm cubic test specimens. IS 516: 1959 was taken into consideration for the testing process of specimen. Fig 3.1 shows the arrangement where load Pc is applied on the specimen having cross sectional area A.

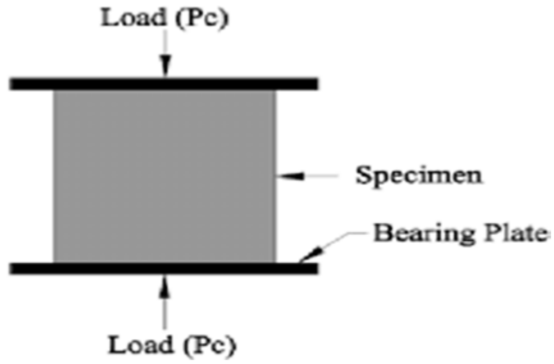


Fig 3.1: Compressive strength test arrangement:

IV. RESULTS AND DISCUSSION

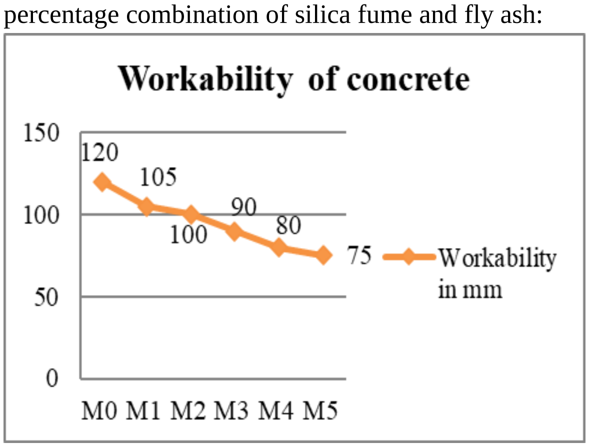
4.1 Workability of concrete:

It referred to the ease with which freshly mixed concrete could be handled, placed, and compacted without segregation or excessive bleeding. For the different design mixes workability of concrete is examined and arranged in tabular form in table 4.1 whereas as the silica fume and fly ash content increases in design mix the workability is observed to be decreased which is shown in graphical form in graph 4.1.

Table 4.1: Workability by Slump test:

Workability of concrete			
Sr. No.	Mix Design	(SF+FA)	Workability (mm)
1	M0	(0+0)	120
2	M1	(4+4)	105
3	M2	(8+8)	100
4	M3	(12+12)	90
5	M4	(16+16)	80
6	M5	(20+20)	75

Graph 4.1: Variation of slump with respect to percentage combination of silica fume and fly ash:



4.2 Compressive strength test results:

Compressive strength is an important parameter to check for the quality of the concrete. As the concrete's compressive strength is expected to be remain unaffected in harsh exposure condition it was necessary to use cementitious materials like silica fume and fly ash so as to maintain the compressive strength of concrete. Following are the tables showing the 7 and 28 days compressive strength of concrete. Compressive strength of concrete for 7 days and 28 days with different design mixes is indicated in table 4.2 and table 4.3 respectively:

Table 4.2: Compressive strength of concrete for 7 days:

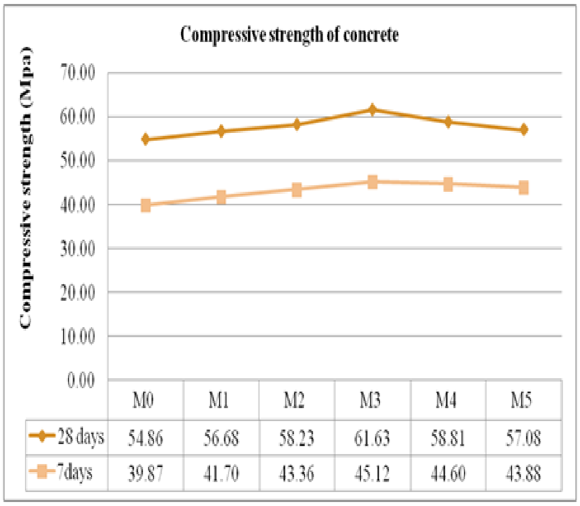
Sr. No.	Mix design	SF+ FA	Avg. comp. load(Pc)	Avg. comp. strength (Fcu)
	M50			
1	M0	(0+0)	897	39.87
2	M1	(4+4)	938.32	41.7
3	M2	(8+8)	975.64	43.36
4	M3	(12+12)	1015.23	45.12
5	M4	(16+16)	1003.47	44.6
6	M5	(20+20)	987.26	43.88

Table 4.3: Compressive strength of concrete for 28 days:

Sr. No.	Mix design	SF + FA	Avg. comp. load(Pc)	Avg. comp. strength (Fcu)
	M50			
1	M0	(0+0)	1234.42	54.86
2	M1	(4+4)	1275.34	56.68
3	M2	(8+8)	1310.23	58.23
4	M3	(12+12)	1386.74	61.63
5	M4	(16+16)	1323.15	58.81
6	M5	(20+20)	1284.33	57.08

Compressive strength test results are compared for 7 and 28 days and in graph 4.3 it was observed that the percentage increase in compressive strength of concrete is indicated in the form of line graph where the M3 design mix gives best results for percentage in compressive strength.

Graph 4.3: Variation of compressive strength at varying concrete mixes at the age of 7 and 28 days respectively

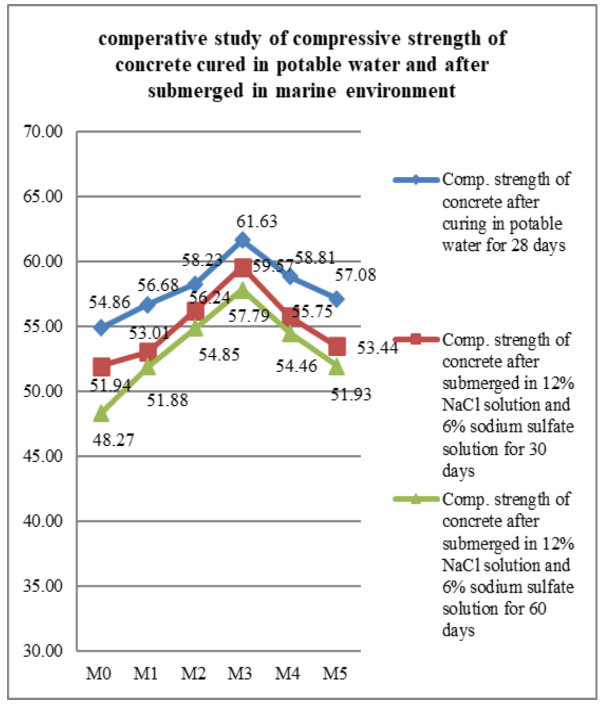


from above graph it can be concluded that compressive strength value increases up to M3 design mix and slightly decreases further. Now we will be examining the compressive strength results of concrete specimen kept in marine environment and will further compare it with compressive strength of normal concrete cube so as to get the best results for compressive strength without getting hampered by sulphate and chloride ions much. Table 4.4 gives the comparative study of compressive strength of concrete with concrete specimens kept submerged in marine environment and graphical representation of it is shown in graph 4.4:

Table 4.4: Comparative study of compressive strength testing results of cubes submerged in marine environment with potable water cured concrete specimens:

Sr. No	Mix design	Avg. comp. strength (Fcu)	Avg. comp. strength (Fcu) for submergence (30 days)	Avg. comp. strength (Fcu) For submergence (60 days)
		M50		
1	M0	54.86	51.94	48.27
2	M1	56.68	53.01	51.88
3	M2	58.23	56.24	54.85
4	M3	61.63	59.57	57.79
5	M4	58.81	55.75	54.46
6	M5	57.08	53.44	51.93

Graph 4.4: Comparative study of compressive strength of concrete exposed to marine environment and cured in potable water:



V. CONCLUSION

1) After replacing a cement with cementitious material (fly ash and silica fume) with 4 percent increment of each for every design mix workability of concrete was observed to be reduced but was satisfactory.

2) Comparative study of compressive strength of concrete is done and it was observed to be reduced after the cube specimens are kept in marine environment but still the compressive strength of concrete was inspected to be comparable to concrete mix design and hence the 12 percent replacement of fly ash and silica fume each as a cementitious material gives best results to prevent the ingression of chloride and sulphate ions to maintain the compressive strength of the concrete.

3) Addition of silica fume and fly ash is necessary to improve the strength of concrete as well as it also improves the pore structure of the concrete and hence voids in the concrete are reduced.

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