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AN EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES OF HIGH PERFORMANCE CONCRETE USING NANO SILICA, SILICA FUMES AND GGBFS

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Abstract: The present study aims at developing the concrete mixture incorporating nano silica, silica fumes, and ground granulated blast furnace slag as partial replacement of cement. The aim is to study the mechanical properties of high performance concrete mixes using the local materials and to compare it with the control concrete mixes i.e. without any mineral admixture. Cement was replaced by nano silica with 2% and 3%, silica fumes with 5%, 7.5% and 10% and ground granulated blast furnace slag with 20% in the mixes respectively. The design mix was worked out as per ACI guidelines and various trials were performed to obtain the mix of desired grade (M70) at 28 days. In this study, the compressive strength, split tensile strength and flexural strength of HPC concrete mixtures for different percentage of replacement of cement with mineral admixtures are obtained at 7 and 28 days respectively. After analysis of test results it was seen that the performance of HPC mixes in terms of mechanical properties was better than their corresponding control mixes. Cube compressive strength of mixes showed 3% - 16% of increase in strength when compared with control mixes. Split tensile strength of mixes was found to be 6% - 8% of its cube compressive strength. Flexural strength of mixes was found to be 9% - 11.5% of its cube compressive strength. It is found that the maximum increase in compressive strength, split tensile strength and flexural strength is for concrete mix in which 2% nano silica, 7.5% silica fume and 20% ground granulated blast furnace slag is replaced with cement.

Keywords: High performance concrete, Nano Silica, Silica Fumes, Ground Granulated Blast Furnace Slag.

1. INTRODUCTION

Concrete is a widely used construction material in the construction industry worldwide. It is the second largest material consumed by the human being in the world next to water. It needs to be capable of withstanding the conditions for which it has been designed throughout the life of the structure as long term performance of structures has become vital to the economics of all nations. Large concrete structures such as high rise buildings, bridges, and structures under severe exposure conditions require high strength, workability and durability. As construction material cost escalates, demand has risen significantly for stronger and durable materials. This resulted in development of High Strength Concrete. In the 1980s, the high strength concrete was developed by reducing the water-cement ratio and adding water reducers and super plasticizers to concrete. This resulted in increase of cement content in the mix, which is the most expensive. The great heat of hydration developed due to the chemical reactions produces undesirable cracks and shrinkage in the concrete. Therefore, it is necessary to improve the strength and performance of concrete with suitable mineral and chemical admixtures to cater to the present need. A new class of concrete that exhibits greatly improved strength and durability properties has recently been developed and has been termed as High Performance Concrete.

High performance concrete refers to the type of concrete mixture which develops high strength, has adequate workability and posses excellent durability properties throughout its intended service life. In actual high performance concrete is not a special type of concrete. It comprises of the same materials as that of the conventional cement concrete. High performance concrete works out to be economical, even though its initial cost is higher than that of conventional concrete, because the use of high performance concrete in construction enhances the service life of the structure and the structure suffers less damage which would reduce overall costs.

The conventional cement concrete is found deficient in respect of durability in severe environment, energy absorption capacity and demand of repair & maintenance. From this, it has been increasingly realized that besides strength, there are other equally important criteria such as durability, workability and toughness etc. For producing high performance concrete (HPC), it is well recognized that the use of supplementary cementitious materials (SCMs), such as nano silica (NS), silica fumes (SF), fly ash (FA) are necessary. High-performance concretes are made with carefully selected high-quality ingredients and optimized mixture designs; these are batched, mixed, placed, compacted and cured to the highest standards. Typically, such concretes will have a low water-cementing materials ratio. Plasticizers are usually used to make these concretes fluid and workable. Hence high performance concrete can be considered as an economical material in terms of time and money.

2. EXPERIMENTAL PROGRAMME

The experimental program was planned to investigate the compressive strength, split tensile strength and flexural strength of concrete by partially replacing cement with nano silica, silica fumes and ground granulated blast furnace slag. This study has been divided into three parts, the first part of the study deals with procurement of materials and testing the materials in the laboratory. The physical properties of cement which were studied are fineness, soundness, standard consistency, initial and final setting time, compressive strength and specific gravity. The physical properties of fine and coarse aggregates which were studied are specific gravity, grading, water absorption, sieve analysis and bulk density. The second part of study deals with mix design of HPC mix by varying the proportions of admixtures and casting of test specimen. Cement was replaced by nano silica with 2% and 3%, silica fume with 5%, 7.5% and 10% and ground granulated blast furnace slag with 20% in the mixes respectively. The design mix was worked out as per American Concrete Institute (ACI) guidelines and various trials were performed to obtain the mix of desired grade (M70) at 28 days. The third part of the study deals with curing of test specimen for 7 days, 28 days, testing of specimen for mechanical properties and analysing the test results. The mix proportion adopted is given in Table 1.

Table 1 Mix proportion for w/b ratio 0.26

W/B	**0.26**						
MIX	**WATER (kg/m^3)**	**CEMENT (kg/m^3)**	**FA (kg/m^3)**	**CA (kg/m^3)**	**NS (kg/m^3)**	**SF (kg/m^3)**	**GGBFS (kg/m^3)**
M0	150	577	632	1102	-	-	-
M1	150	421.21	632	1102	11.54	28.85	115.4
M2	150	406.79	632	1102	11.54	43.28	115.4
M3	150	392.40	632	1102	11.54	57.70	115.4
M4	150	415.44	632	1102	17.31	28.85	115.4
M5	150	401	632	1102	17.31	43.28	115.4
M6	150	386.60	632	1102	17.31	57.70	115.4

3. CASTING OF SPECIMENS

All the moulds were cleaned and oiled properly. They were properly tightened to correct dimensions before casting. Care was taken that there were no gaps left from where there could be any leakage of slurry. The quantities of cement, fine aggregates, coarse aggregates, nano silica, silica fumes, ground granulated blast furnace slag and water for each batch were weighed accurately. The 75% of the water was added to the mixture and mixed thoroughly in a rotating drum type mixture for not less than one minute. After that superplasticizer along with the remaining water was added to the mix and drum was rotated for few minutes. Then concrete was filled into the prepared moulds in three layers. Electric Table vibrator was used to compact the concrete. The surface of the concrete was finished level with the top of the mould using a trowel. The finished specimens were left to harden in the moulds for 24 hours. The specimens were removed from the mould after 24 hours. They were properly marked and placed in the curing tank for next 28 days.

4. ANALYSIS OF RESULTS

4.1 Cube Compressive Strength

Table 2 shows the summary of the test results of cube compressive strengths and Fig 1 shows the strength gain for mixe, cast using varying proportions of the binder in the mix.

Table 2 Summary of Cube Compressive Strength

W/B	0.26							
MIX	NS (%)	SF (%)	GGBFS (%)	7 days MPa	%age increase	28 days MPa	%age increase	F_C (7)/ F_C (28)
M0	-	-	-	48.40	-	71.88	-	0.67
M1	2	5	20	53.87	11.30	78.34	8.99	0.69
M2	2	7.5	20	55.97	15.65	82.03	14.12	0.68
M3	2	10	20	54.67	12.95	79.72	10.90	0.69
M4	3	5	20	50.42	4.20	77.57	7.92	0.65
M5	3	7.5	20	52.96	9.42	79.19	10.17	0.67
M6	3	10	20	49.42	3.14	74.90	5.20	0.66

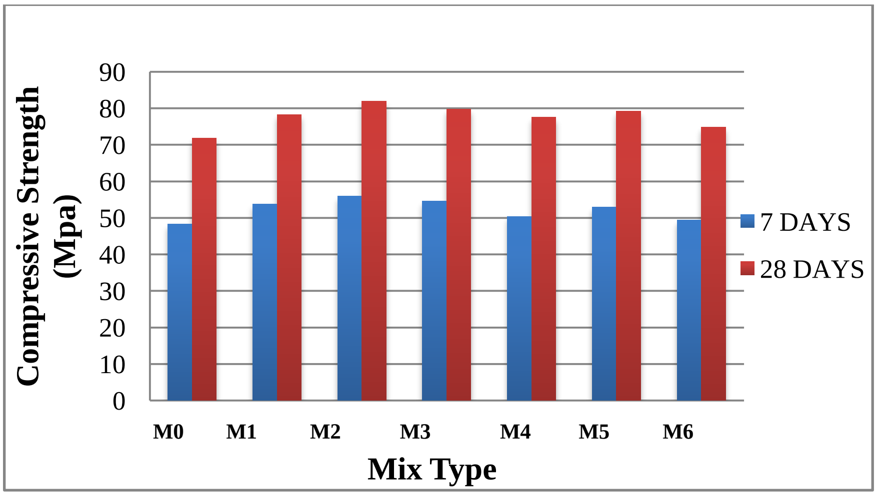

Fig 1 Variation in Compressive Strength for various mixes

Fig 1 shows the variation in compressive strength values for different mixes cast keeping the water-binder ratio fixed at 0.26. The cube compressive strength of the control mix M0 at 7 days was found to be 0.67 times its 28 days strength of 71.88 MPa. The cube compressive strength of the mix M1 at 7 days was found to be 0.69 times its 28 days strength of 78.34 MPa. When compared with control mix there was an increase of 11.30% in strength at 7 days and 8.99% in strength at 28 days. The cube compressive strength of mix M2 at 7 days was found to be 0.68 times its 28 days strength of 82.03 MPa. When compared with control mix there was an increase of 15.65% in strength at 7 days and 14.12% in strength at 28 days. The cube compressive strength of mix M3 at 7 days was found to be 0.69 times its 28 days strength of 79.72 MPa. When compared with control mix there was an increase of 12.95% in strength at 7 days and 10.90% in strength at 28 days. The cube compressive strength of mix M4 at 7 days was found to be 0.65 times its 28 days strength of 77.52 MPa. When compared with control mix there was an increase of 4.20% in strength at 7 days and 7.92% in strength at 28 days. The cube compressive strength of mix M5 at 7 days was found to be 0.67 times its 28 days strength of 79.19 MPa. When compared with control mix there was an increase of 9.42% in strength at 7 days and 10.17% in strength at 28 days. The cube compressive strength of mix M6 at 7 days was found to be 0.66 times its 28 days strength of 74.90 MPa. When compared with control mix there was an increase of 3.14% in strength at 7 days and 5.20% in strength at 28 days.

From the above observations it can be seen that, when compared with CM the mix containing nano silica 2%, silica fumes 7.5% and ground granulated blast furnace slag 20% (i.e. M2) showed best results among other mixes. Mix M2 had maximum compressive strength at 7 and 28 days when compared to other mixes. Only M2 mix achieved the value above 80 MPa after 28 days curing. The cement replacing pozzollans in the concrete produces C-S-H gel during the pozzolanic reaction with the calcium hydroxide formed by cement hydration, which in turn results in higher strength. The increase in early age strength was observed for all mixes. The increase in early age compressive strength may be due to early hydration process, which may be attributed to the very high surface area of nano silica and silica fume particles, which act as nucleation sites for the hydration reactions.

4.2 Split Tensile Strength

Table 3 shows the summary of the test results of split tensile strengths and Fig 2 shows the strength gain for different mixes, cast using varying proportions of the binder in the mix.

Table 3 Summary of Split Tensile Strength

W/B	0.26							
MIX	NS (%)	SF (%)	GGBFS (%)	7 days MPa	%age increase	28 days MPa	%age increase	F_{ct} (7)/ F_{ct} (28)
M0	-	-	-	3.77	-	4.48	-	0.84
M1	2	5	20	4.83	29.69	5.25	17.18	0.92
M2	2	7.5	20	5.05	32.91	5.61	25.22	0.90
M3	2	10	20	4.79	27.05	5.36	19.64	0.89
M4	3	5	20	4.54	20.42	5.04	12.50	0.90
M5	3	7.5	20	4.82	27.85	5.38	20.08	0.89
M6	3	10	20	3.98	5.57	4.83	7.82	0.82

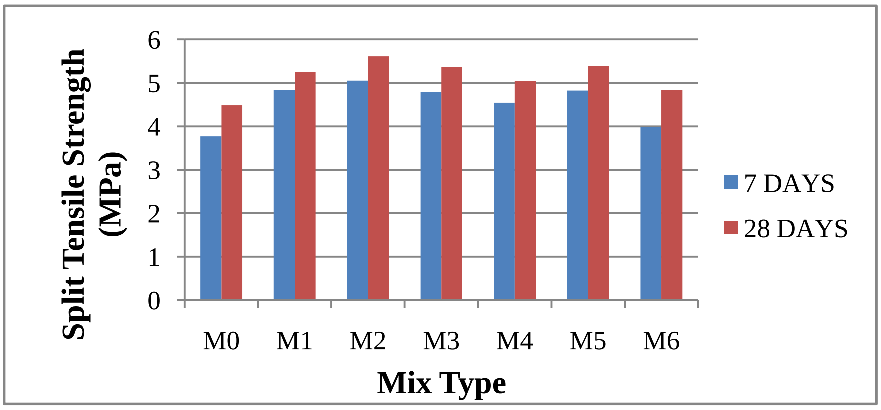

Fig 2 Variation in Split Tensile Strength for various mixes

The Fig 2 shows the variation in split tensile strength values for different mixes cast keeping the water-binder ratio fixed at 0.26. The split tensile strength of the control mix M0 at 7 days was found to be 0.84 times its 28 days strength. The split tensile strength of mix M1 at 7 days was found to be 0.92 times its 28 days strength. When compared with control mix there was an increase of 29.69% in strength at 7 days and 17.18% in strength at 28 days. The split tensile strength of mix M2 at 7 days was found to be 0.90 times its 28 days strength. When compared with control mix there was an increase of 32.91% in strength at 7 days and 25.22% in strength at 28 days. The split tensile strength of mix M3 at 7 days was found to be 0.89 times its 28 days strength. When compared with control mix there was an increase of 27.05% in strength at 7 days and 19.64% in strength at 28 days. The split tensile strength of mix M4 at 7 days was found to be 0.90 times its 28 days strength. When compared with control mix there was an increase of 20.42% in strength at 7 days and 12.50% in strength at 28 days. The split tensile strength of mix M5 at 7 days was found to be 0.89 times its 28 days strength. When compared with control mix there was an increase of 27.85% in strength at 7 days and 20.08% in strength at 28 days. The split tensile strength of mix M6 at 7 days was found to be 0.82 times its 28 days strength. When compared with control mix there was an increase of 5.57% in strength at 7 days and 7.82% in strength at 28 days.

From the above observations it can be seen that, when compared with CM the mix M2 showed best results among other mixes. Mix M2 had maximum split tensile strength at 7 and 28 days when compared to other mixes. This was closely followed by mixes M5 which contained same amount of silica fumes and ground granulated blast furnace slag but higher content of nano silica in it. The observed increase in the tensile strength can be attributed to the enhanced bond between the hydrated cement matrix and the aggregates. This enhanced bond is the result of the conversion of calcium hydroxide to calcium silicate hydrates in the presence of silica. Thus, it can be said that by using varying combinations of the binder ingredients, it is possible to produce a mix with 28 days split tensile strength more than 5 MPa at a w/b ratio of 0.26.

4.3 Flexural Strength

Table 4 shows the summary of the test results of split tensile strengths and Fig 3 shows the strength gain for different mixes, cast using varying proportions of the binder in the mix.

Table 4 Summary of Flexural Strength

W/B	0.26							
MIX	NS (%)	SF (%)	GGBFS (%)	7 days MPa	%age increase	28 days MPa	%age increase	F_b (7)/ F_b (28)
M0	-	-	-	5.08	-	6.48	-	0.78
M1	2	5	20	5.52	8.66	7.28	12.34	0.75
M2	2	7.5	20	5.72	12.59	7.60	17.28	0.75
M3	2	10	20	5.48	7.87	7.40	14.19	0.74
M4	3	5	20	5.40	6.29	7.20	11.11	0.75
M5	3	7.5	20	5.60	10.23	7.32	12.96	0.76
M6	3	10	20	5.28	3.93	7.08	9.25	0.74

The Fig 3 shows the variation in flexural strength values for different mixes cast keeping the water-binder ratio fixed at 0.26. The increase in flexural strength due to presence of SCMs in the mix was significant. The flexural strength of M0 mix at 28 days was 6.48 MPa. The flexural strength of M1 mix at 28 days was 7.28 MPa and after 28 days the increase in strength was about 12.34%. The flexural strength of M2 mix at 28 days was 7.60 MPa and after 28 days the increase in strength was about 17.28%. The flexural strength of M3 mix at 28 days was 7.40 MPa and after 28 days the increase in strength was about 14.19%. The flexural strength of M4 mix at 28 days was 7.20 MPa and after 28 days the increase in strength was about 11.11%. The flexural strength of M5 mix at 28 days was 7.32 MPa and after 28 days the increase in strength was about 12.96%. The flexural strength of M6 mix at 28 days was 7.08 MPa and after 28 days the increase in strength was about 9.25%.

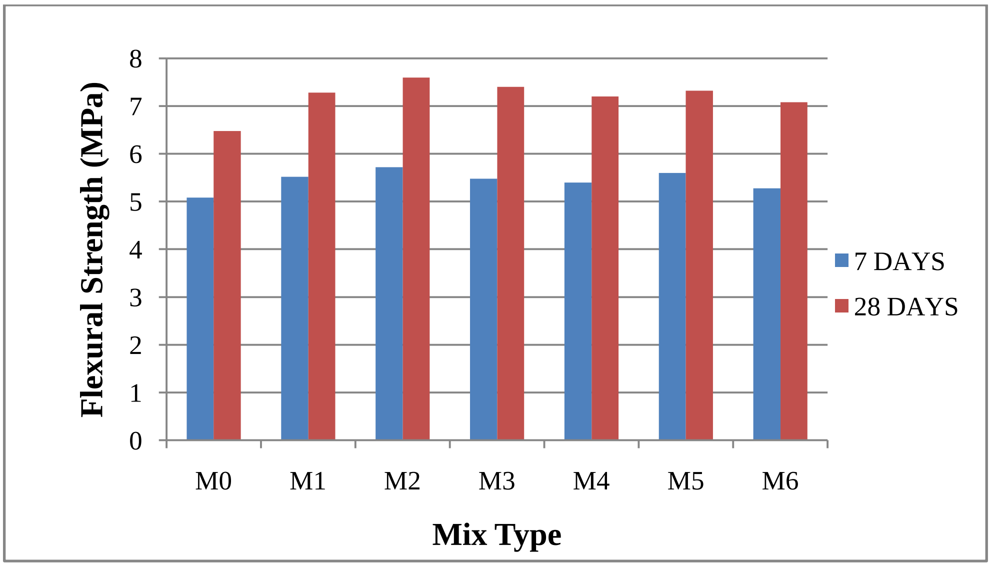

Fig 2 Variation in Flexural Strength for various mixes

From the above observations it can be seen that, mix M2 showed best results among other mixes. Mix M2 had maximum flexural strength at 7 and 28 days when compared to other mixes. This was closely followed by mixes M5 and M3. Thus, it can be said that by using varying combinations of the binder ingredients, it is possible to produce a mix with 28 days flexural strength more than 7 MPa at a w/b ratio of 0.26. The mix M2 indicates that the optimum percentage of nano silica, silica fume and slag are mandatory for the development of HPC, as the microstructure of concrete gets modified even with slight variations in the same.

5. Conclusions

The present study was undertaken to design the mix proportions for high performance concrete (HPC) to study the mechanical behavior. Experimental investigations were carried out to study the effect of partial replacement of cement with nano silica, silica fume and ground granulated blast furnace slag on compressive strength, split tensile strength and flexural strength of concrete.The results were compared with that of control mixes (containing no mineral admixtures). HPC mixes were tested for cube compressive strength, split tensile strength and flexural strength at 7 and 28 days. Based on the study it was seen that the performance of HPC mixes in terms of mechanical properties were better than their control mixes. The following conclusions and recommendations have been discussed in the succeeding sections.

1. Cube compressive strength at 7 and 28 days for all mixes was greater than the control mixes. The gain in compressive strength was in the range of 3% to 16% for all the mixes when compared to control mixes.
2. It is possible to produce mixes with a compressive strength of nearly 80 MPa, after 28 days curing, with a w/b ratio of 0.26, with an optimized mix of nano silica, silica fume and ground granulated blast furnace slag as supplementary cementitious materials.
3. Split tensile strength of mixes was found to be 6% - 8% of its cube compressive strength.
4. It is possible to produce mixes with a split tensile strength of nearly 5.6 MPa after 28 days curing with a w/b ratio of 0.26 and 6.1 MPa after 28 days curing with a w/b ratio of 0.24 with an optimized mix of nano silica, silica fume and ggbs as supplementary cementitious materials.
5. Flexural strength of mixes was found to be 9% - 11.5% of its cube compressive strength.
6. It is possible to produce mixes with a flexural strength of nearly 7.08 MPa after 28 days curing with a w/b ratio of 0.26
7. The optimum concentration of HPC mixes at 7 as well as 28 days curing was 2% nano silica, 7.5% silica fume and 20% ground granulated blast furnace slag.

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