International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 07 July 2024, pp: 779-789 www.ijaem.net ISSN: 2395-5252

Strength Analysis of Concrete Utilizing Industrial Waste

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Date of Submission: 15-07-2024 Date of Acceptance: 25-07-2024

ABSTRACT
Marble has been a major decorative building material in recent years. Industrial by-products like fly ash (FA) and marble powder (MP) can be harmful to the environment and human health. Marble sawing, shaping, and polishing produce MP, but the burning of powdered coal leaves behind FA. The effects of partially substituting MP and FA for cement in different concrete mixtures are examined in this study. The percentage of marble dust used in concrete mixes to partially substitute Portland Pozzolana Cement (PPC) is the main variable.

The research concentrates on concrete of grade M30, with a consistent water-to-cement (w/c) ratio of 0.43. The percentages of MP that replace PPC vary from 5% to 20%, and the same ranges apply to FA. Additionally, the same percentages are used to evaluate MP and FA combinations with PPC. Reusing leftover resources is emphasised.

To evaluate the qualities of the concrete mixtures, a number of tests are carried out. Tests on fresh concrete, such as slump cone and compaction factor tests, determine workability; testing on hardened concrete, such as split tensile strength and compressive strength tests, determine mechanical qualities. The efficiency of MP and FA as partial cement substitutes is determined by analysing the data and drawing comparisons between various concrete mixes.

Key Words: Workability, Mechanical properties, Environmental impact, Fly ash, Cement, Partial replacement, and Concrete mixes.

I. INTRODUCTION

The demand and production of cement are escalating globally, with total cement output projected to surpass 3 billion tonnes in 2009 (Feiz et al., 2015) and reaching approximately 3.6 billion tonnes in 2012 (Rashad, 2015). Concrete, a ubiquitous construction material, comprises cement, fine aggregates, coarse aggregates, and water. Research has shown that mineral admixtures can be effectively and economically used to enhance certain fresh and hardened properties of concrete (Rashad, 2015). Marble Powder (MP), a by-product from marble processing plants involving sawing, polishing, and cutting, poses environmental and health challenges. Similarly, Fly Ash (FA), a waste product from coal combustion in thermal power plants, offers potential benefits for eco-friendly construction.

FA is extensively used as a partial replacement for cement, although it often reduces early strength due to its slow hydration process. Despite this, FA improves concrete workability. This study explores the impact of using MP and FA as partial replacements for cement, investigating the hardened properties of concrete. The experimental program involves replacing cement with MP and FA at levels of 5%, 10%, 15%, and 20%, followed by normal curing.

The research focuses on the physical and mechanical properties of various concrete mixes with different percentages of MP and FA replacements. Tests include fresh concrete assessments like slump cone and compaction factor tests for workability, as well as hardened concrete tests such as compressive and split tensile strength tests to evaluate mechanical properties. The results are analyzed and compared to draw conclusions on the effectiveness of MP and FA in enhancing concrete properties.

1.1 Objective of the Work

Industrial waste materials such as Fly Ash (FA) and Marble Powder (MP) have been utilized as partial replacements for Portland Pozzolana Cement (PPC) in M30 grade concrete. This study aims to evaluate both the fresh and hardened properties of the concrete mixes containing these industrial waste materials. The primary objective is to analyze how the incorporation of FA and MP impacts the workability, compressive strength, and tensile strength of the concrete.

a) To determine the optimal percentage of FA and MP that can be used as a replacement for PPC without compromising the concrete's performance.
b) To analyze the workability of the fresh concrete with varying percentages of FA and MP.
c) To assess the compressive strength and split tensile strength of the concrete at different curing periods.
d) To compare the performance of concrete mixes with FA and MP against conventional concrete mixes.

II. LITERATURE REVIEW

F.U.A. Shaikh (2016) [13] states the mechanical and durability properties of FA geopolymer concrete containing recycled coarse aggregates. This paper presents mechanical and durability properties of geo polymer concrete containing recycled coarse aggregate (RCA). The RCA is sourced from local construction and demolition (C&D) waste in Perth, Australia. The RCA is used as a partial replacement of natural coarse aggregate (NCA) in geopolymer concrete at 15%, 30% and 50% by wt. which corresponds to series two, three and four, respectively, while the geopolymer concrete containing 100% NCA is control and is considered as the first series.

Raharjo D. et al. (2013) [14] made a research on mixed concrete optimization using FA, silica fume and iron slag on the compressive strength. In this paper the ability, viscosity and segregation were conducted using slump cone, L-box and V-funnel. There were 33 variation of concrete mixture using 495 samples total mixture have been tested. Each composition contained various super plasticizer dosages from 0.5 to 1.8% of cementitious weight. The dosage of silica fume was also varied 0%, 10% and 20% of fly ash weight. The goal that expected from this study is to obtain the optimal material composition of the mixture that produces the maximum compressive strength but cheaper and competitive in price.

Gulden Cagin Ulubeyli et al. (2016) [15] made a study on the properties of hardened concrete produced by waste marble powder. As a result, the use of waste marble powder in conventional concrete mix, self-compacting concrete mix, and polymer concrete mix, was revealed. Consequently, it was found out that the use of waste marble in the conventional concrete mix as an admixture material or aggregate is suitable as it can improve some properties of the hardened concrete. However, the use of waste marble in the self-compacting and polymer concrete mixes as an admixture material or aggregate is not affected positively in terms of hardened properties of concrete.

2.1 Scope of the Work

a) To compare the workability and strength properties of concrete separately with varying proportions of MP and FA.
b) To evaluate the strength properties of concrete incorporating MP and FA.
c) To assess the combined effect of MP and FA when used as partial replacements for cement and evaluate their properties.
d) To contribute to eco-friendly construction through the utilization of these industrial waste products.

III. EXPERIMENTAL PROGRAMME

In concrete, MP and FA are substituted for various replacements with cement. All components are combined correctly in accordance with IS 10262 (2009). Tests for fresh concrete have been conducted, including slump cone and compaction factor tests. Different examples are made for various cement replacements of MP and FA. Concrete has been poured into cylinder and cube moulds. After a day, the mould was removed. Upon being taken out of the mould, specimens are properly labelled. Every specimen is removed in order to cure it for 7, 28, 56, and 90 days. Following the curing procedure, the compressive and split tensile strengths are measured.

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3.1 Mix Proportion for Conventional Concrete

Table 3.9: Mix Identity for MP Based Specimen

Concrete Mix Proportion	Mix Identity
Cement 100%+NFA100%+NCA100%	CM0F0
Cement 95%+NFA100%+NCA100%+MP5%	CM5F0
Cement 90%+NFA100%+NCA100%+MP10%	CM10F0
Cement 85%+NFA100%+NCA100%+MP15%	CM15F0
Cement 100%+NFA80%+NCA100%+MP 20%	CM20F0

Table 3.10: Mix Identity for FA Based Specimen

Concrete Mix Proportion	Mix Identity
Cement 100%+NFA100%+NCA100%	CM0F0
Cement 95%+NFA100%+NCA100%+FA5%	CM0F5
Cement 90%+NFA100%+NCA100%+FA10%	CM0F10
Cement 85%+NFA100%+NCA100%+FA15%	CM0F15
Cement 80%+NFA100%+NCA100%+FA20%	CM0F20

Table 3.11: Mix Identity for MP and FA Based Specimen

Concrete Mix Design	Mix Identity
Cement 100%+NFA100%+NCA100%	CM0F0
Cement 80%+NFA100%+NCA100%+MP5%+FA15%	CM5F15
Cement 80%+NFA100%+NCA100%+MP10%+FA10%	CM10F10
Cement 80%+NFA100%+NCA100%+MP15%+FA5%	CM15F5

3.2 Mixing

The concrete mixture machine is filled with all of the necessary materials, including PPC, NCA, NFA, MP, and FA, in the specified quantities. When everything was dry, the materials were evenly combined. Water has been gradually added in the required amount to achieve homogeneity.

3.3 Casting

For every concrete mix, cubes and cylinders were cast for 7, 28, 56, and 90 days. Make sure every mould is cleaned thoroughly. Inside the mould, lubricant (oil) has been applied. Using a scoop and trowel, the concrete sample should be added to the cube moulds in three levels, each about five centimeters deep. To guarantee an uneven distribution of the concrete inside the mould, the scoop must be rotated around the upper edge of the mould as each scoopful of concrete is placed. The vibration will condense each layer. Mould shall be compacted by not less than 25 strokes by tamping bar. Where voids are left by the tamping bar the sides of the mould shall be tapped to close the voids.

Table 3.12: Test Specimen Size Details

Tests	Sample Size	Number
7 Days Compressive Strength of Cube	(150×150×150) mm	3
28 Days Compressive Strength of Cube	(150×150×150) mm	3
56 Days Compressive Strength of Cube	(150×150×150) mm	3
90 Days Compressive Strength of Cube	(150×150×150) mm	3
7 Days Split Tensile Strength of Cylinder	(100 mm Diameter × 200 mm Height)	3

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28 Days Split Tensile Strength of Cylinder	(100 mm Diameter × 200 mm Height)	3
56 Days Split Tensile Strength of Cylinder	(100 mm Diameter × 200 mm Height)	3
90 Days Split Tensile Strength of Cylinder	(100 mm Diameter × 200 mm Height)	3


Figure3.6: Casting of Cube Specimen **Figure3.7: Casting of Cylinder Specimen**

IV. RESULT AND DISCUSSION

The test results for the hardened concrete and fresh concrete tests are included in this chapter. Different tests have been carried out for various blend identities. In order to assess the concrete's workability, new tests have been performed, including the slump cone and compaction factor tests. To assess the mechanical qualities of concrete, experiments on hardened concrete such as split tensile strength and compressive strength have been carried out.

Table 4.8: Summary of the MP Based Compressive Strength Test Result

Mix Identity	7 Days		28 Days		56 Days		90 Days	
	Avg. CS(N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0
CM0F0	26.5	0	32.3	0	44.26	0	49.24	0
CM5F0	29.33	2.83	33.38	1.08	45.06	0.8	50	0.76
CM10F0	25.16	-1.34	31	-1.3	41.03	-3.23	46.94	-2.3
CM15F0	25.03	-1.47	30.43	-1.87	39.4	-4.86	45	-4.24
CM20F0	19.1	-7.4	26	-6.3	34	-10.26	40	-9.24

The table above demonstrates that CM5F0 has the highest compressive strength rating after a 90-day curing time. Throughout the seven-day curing period, CM20F0 receives the lowest strength value. Comparing all other MP-based concrete mixes to CM0F0, the compressive strength decreases. Compressive strength rises with longer curing times. Concrete that has been cured has a higher compressive strength. In comparison to 7, 28, and 56 days of curing time, Figure 4.2 demonstrates that a specimen cured for 90 days yields the best compressive strength.

Table4.13: Summary of the FA Based CS Test Result

Mix Identity	7 Days		28 Days		56 Days		90 Days	
	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0

CM0F0	26.5	0	32.3	0	44.26	0	49.24	0
CM0F5	29.6	3.1	34.03	1.73	46.3	2.04	48.93	-0.31
CM0F10	27.63	1.13	30.26	-2.04	41.06	-3.2	44.06	-5.18
CM0F15	21.1	-5.4	28.4	-3.9	35.3	-8.96	38	-11.24
CM0F20	18.03	-8.47	25.23	-7.07	33.06	-11.2	36.06	-13.18

The comparison between the tests results are presented in the Table 4.13 shows that the concrete mix CM0F5 indicates highest strength value for 90 days of curing period and CM0F20 indicates lowest strength value for 7 days of curing period as compared to CM0F0. All other FA based concrete mix shows the reduction in the compressive strength as compared to primary specimen.

Table 4.17: Summary of the MP and FA Based Compressive Strength Test Result

Mix Identity	7 Days		28 Days		56 Days		90 Days	
	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0	Avg. CS (N/mm^2)	% Change w.r.t CM0F0
CM0F0	26.5	0	32.3	0	44.26	0	49.24	0
CM5F15	33.33	6.83	34	1.7	35	-9.26	39	-10.24
CM10F10	27	1.5	33	0.7	36	-10.26	39	-10.24
CM15F5	22	-4.5	28	-4.3	32	-12.26	48	-1.24
CM20F0	19.1	-7.4	26	-6.3	34	-10.26	40	-9.24
CM0F20	18.03	-8.47	25.23	-7.07	33.06	-11.2	36.06	-13.18

Table 4.17 presents a comparison between the test findings. In comparison to CM0F0, it demonstrates that the concrete mix CM5F15 has the maximum strength after 90 days of curing, whereas CM0F20 has the lowest strength value. In comparison to CM0F0, the compressive strength ratings of all other concrete mixes based on MP exhibit a continual decrease in strength. Figure 4.6 illustrates that after 28 and 56 days of curing, CM20F0 and CM0F20 have almost the same value.

Table 4.23: Summary of MP Based STS Test Result

Mix Identity	7 Days		28 Days		56 Days		90 Days	
	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0
CM0F0	2.68	0	3.16	0	4.26	0	4.8	0
CM5F0	3	0.32	3.53	0.37	4.38	0.12	4.68	-0.12
CM10F0	2.7	0.02	3.1	-0.06	4.1	-0.16	4.7	-0.1
CM15F0	2.5	-0.18	3	-0.16	3.9	-0.36	4.5	-0.3
CM20F0	1.77	-0.91	2.6	-0.56	3.22	-1.04	3.5	-1.3

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Table 4.18-4.22 shows the split tensile strength test results for concrete based on MP and FA. When compared to CM0F0, the concrete mix CM5F0 shows the highest strength, according to the comparison of test results shown in Table 4.23. Comparing all other MP-based concrete mixes to CM0F0, the Split Tensile Strength is reduced. The amount of curing days grows along with the split tensile strength. Concrete that has been cured has a higher compressive strength. Fig. 4.8 shows a specimen that was cured for 90 days and had high split tensile strength values.

Table 4.28: Summary of the FA Based Split Tensile Strength Test Result

Mix Identity	7 Days		28 Days		56 Days		90 Days	
	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0
CM0F0	2.68	0	3.16	0	4.26	0	4.83	0
CM0F5	2.8	-0.08	3.6	0.44	4.5	0.24	5.2	-0.33
CM0F10	2.69	0.01	3	-0.16	3.9	-0.36	4.3	-0.53
CM0F15	2	-1.68	2.6	-0.56	3.48	-0.78	3.88	-0.95
CM0F20	1.7	-0.98	2.3	-0.86	3.27	-0.99	3.82	-1.01

The test result of split tensile strength for MP based concrete is represented in Table 4.24-4.27. The comparison between the tests results are presented in the Table 4.28 shows that the concrete mix CM0F5 indicates highest strength as compared to CM0F0.

All other MP based concrete mix shows the reduction in the compressive strength as compared to CM0F0 as shown in Fig 4.9.CM0F15 and CM0F20 having nearly same split tensile strength on 90 days of curing period as shown in Fig. 4.10.

Table 4.32: Summary of MP and FA based Split Tensile Strength Test Result

Mix Identity	7 Days		28 Days		56 Days		90 Days	
	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0	Avg. STS (N/mm^2)	% Change w.r.t CM0F0
CM0F0	2.68	0	3.16	0	4.26	0	4.83	0
CM5F15	3.22	0.54	3.34	0.18	3.52	-0.74	3.8	-1.03
CM10F10	2.7	0.02	3.29	0.13	3.65	-0.61	4	-1.83
CM15F5	2.2	-0.48	3.24	0.08	3.8	-0.46	4.12	-0.71
CM20F0	1.77	-0.91	2.6	-0.56	3.22	-1.04	3.5	-1.33
CM0F20	1.7	-0.98	2.3	-0.86	3.27	-0.99	3.82	-1.01

The test result of split tensile strength for MP and FA based concrete is represented in Table 4.29-4.31.The comparison between the tests results are presented in the Table 4.32 shows that the concrete mix CM5F15 indicates highest strength as compared to CM0F0. All other MP based concrete mix shows the reduction in the split tensile strength as compared to CM0F0 as shown in Figure 4.11.

CM20F20 and CM0F20 having nearly same tensile strength at 7 and 56 days of curing period. CM5F15 and CM0F20 having nearly same tensile strength at 90 days of curing. CM5F15 and

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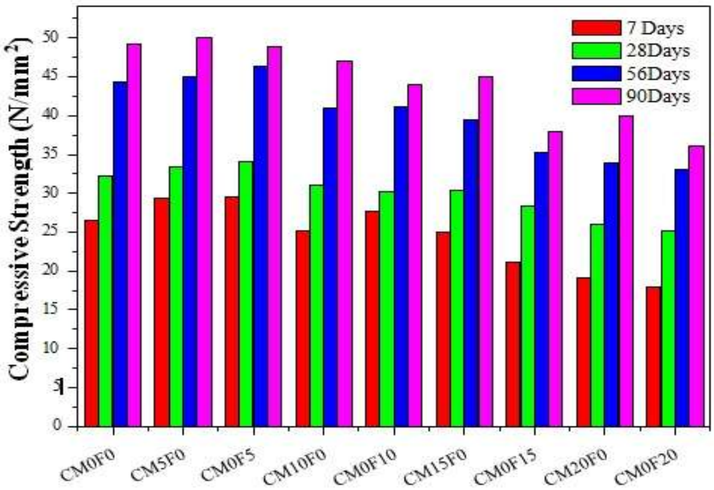
CM10F10 having nearly same tensile strength at 28 days of curing period as shown in Figure 4.12. Split tensile strength increases during the number of curing age's increases.

4.1 Compression of Test Results

Comparison results of M30 grade of PPC concrete replaced with various proportions of MP and FA for compressive strength and split tensile strength are shown below.

4.1.1 Compressive Strength Results

The data regarding the compressive strength with respect to replacement of MP and FA based concrete are shown in the Figure 4.13.



Compression between Different Combinations of MP and FA Based Concrete
Figure 4.13: CS between Different Combinations of MP and FA Based Concrete

The compressive strengths of concrete mixes with varying proportions of marble powder (MP), fly ash (FA), and M30 grade concrete are illustrated in Figure 4.13. The results indicate that after a 90-day curing period, CM5F0 exhibited the highest strength, while CM0F20 had the lowest. After 56 days of curing, CM0F5 showed the maximum strength, with CM0F20 remaining the weakest. Similarly, for the 28-day curing period, CM5F0 had the highest strength and CM0F20 the lowest. At the 7-day mark, CM0F5 achieved the highest strength, whereas CM0F20 again had the lowest. Notably, CM0F10 had the maximum strength according to Figure 4.13.

Figure 4.14 presents the compressive strength data for various combinations of MP and FA in concrete. A comparison with M30 grade concrete reveals that, after 90 days of curing, CM0F0 had the highest strength, while CM0F20 had the lowest. This pattern was consistent for the 56-day curing period. For the 28-day curing period, CM5F15 had the highest strength, with CM0F20 again having the lowest. Similarly, for the 7-day curing period, CM5F15 exhibited the highest strength, and CM0F20 the lowest. Additionally, CM0F10 showed the highest strength in Figure 4.13, while CM5F15 had the highest strength, followed by CM10F10 in Figure 4.14.

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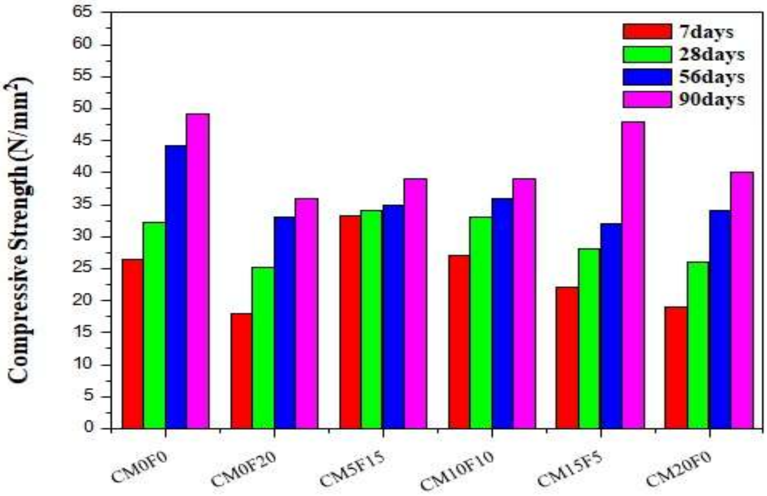

Figure 4.14: Compressive Strength Regarding Different Combinations of MP and FA Based Concrete

4.1.2 Split Tensile Strength Results

Figure 4.15 displays the split tensile strength data for the substitution of MP and FA-based concrete. The graph displays the split tensile strength of concrete with an M30 grade, concrete based on MP, and concrete based on FA. CM0F5 has the maximum strength and CM0F20 has the lowest strength after a 90-day curing time. CM0F5 has the maximum strength after 56 days of cure, whereas CM20F0 has the lowest strength. CM0F5 has the most strength over the 28-day curing period, whereas CM20F0 displays the lowest strength. CM5F0 has the maximum strength after a 7-day curing time, whereas CM0F20 has the lowest strength. The strongest component in Figure 4.15 is CM0F15.

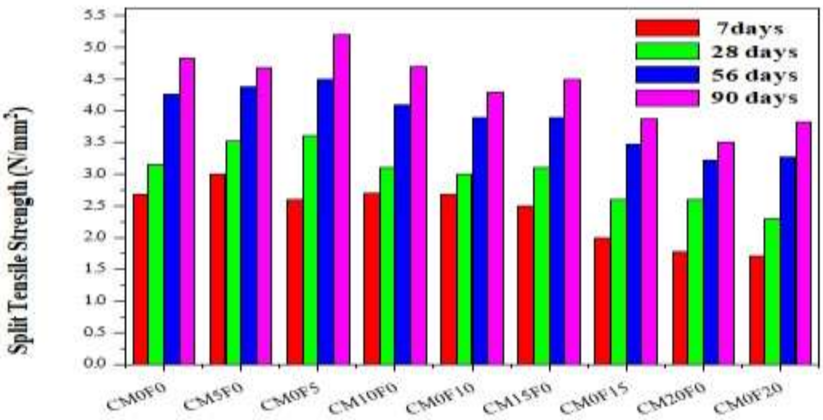

Figure 4.15: Tensile Strength of MP and FA Based Concrete

The data regarding the split tensile strength with respect to different combinations of MP and FA based concrete are shown in the Figure 4.16.

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Volume 6, Issue 07 July 2024, pp: 779-789 www.ijaem.net ISSN: 2395-5252

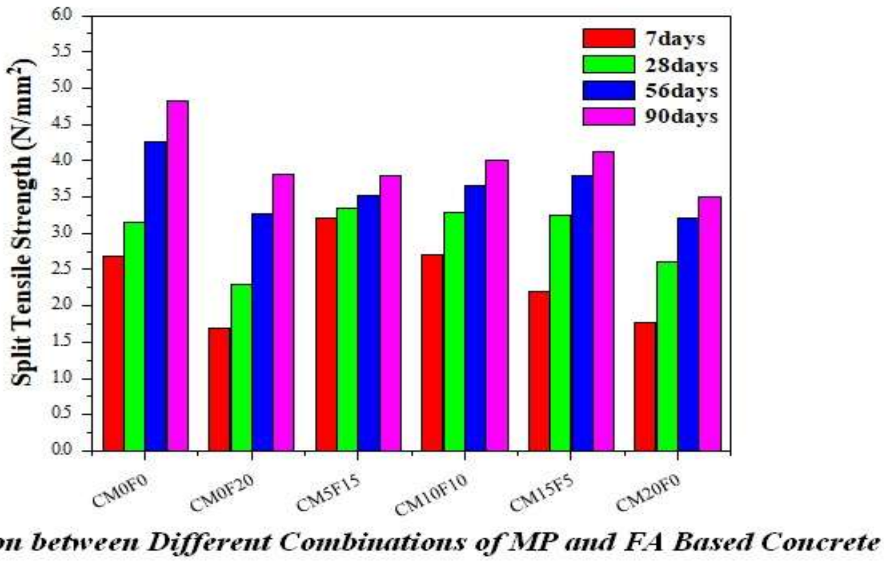

Figure 4.16: Split Tensile Strength Regarding Different Combinations of MP And FA Based Concrete

This comparison shows the various mixes of MP and FA-based concrete with M30 grade concrete. CM0F0 has the maximum strength and CM20F0 has the lowest strength after a 90-day curing time. CM0F0 exhibited the most strength throughout the 56-day curing period, whereas CM20F0 displayed the lowest strength. CM5F15 has the maximum strength while CM0F20 has the lowest strength after a 28-day curing period. CM5F15 has the maximum strength after a 7-day curing time, whereas CM0F20 has the lowest strength. In Figure 4.16, CM5F15 has the maximum strength. Figure 4.16 show that CM10F10 has the second-highest strength.

4.2 Summary

The test results for both fresh and hardened concrete have been reported in this chapter. The table shows the results of the compaction factor and slump cone tests. The diagrams illustrate the differences between split tensile and compressive strengths. Plotted graphs compare the strength of the various replacement concrete samples with the control specimen concrete based on the results of the compressive and split tensile strength tests, which are tabulated. This chapter includes a detailed description of the test results.

V. CONCLUSION AND FUTURE WORK

5.1 Conclusions

The current study investigates the creation of concrete using MP and FA in place of PPC. Both fresh and cured concrete have been subjected to a variety of tests. The evaluation of split and compressive tensile strengths was conducted for various concrete replacements based on MP and FA. All test findings were examined, contrasted, and a conclusion was reached.
After the experimental study the following conclusions can be made from this study.

- The slump value of concrete decreases as the percentage of MP and FA replacing PPC increases.
- The workability of concrete improves with an increase in the percentage of MP.
- After 7 days, both compressive and split tensile strength tests show that replacing 5% of PPC with MP or FA results in higher strength compared to the control specimen.
- At 28 days, replacing 20% of PPC with either MP or FA achieves nearly the same strength.
- The lowest strength at 28 days is observed with a 20% FA replacement of PPC.
- At 56 and 90 days, the highest strength is achieved with a 5% replacement of PPC with MP, surpassing the control specimen.
- For MP-based concrete, the maximum compressive strength of 50 N/mm² is achieved with a 5% replacement of PPC. This is 1.55% higher than the control specimen (CM5F0) after 90 days of curing.
- For FA-based concrete, the maximum compressive strength of 48.93 N/mm² is obtained with a 5% replacement of PPC. This

strength is 0.31% lower than the control specimen (CM0F5) after 90 days.

- In MP and FA combined concrete, the highest compressive strength is obtained with a 15% MP and 5% FA replacement of PPC, which is 1.24% lower than the control specimen (CM15F5) after 90 days.
- The maximum split tensile strength of 4.7 N/mm² is achieved with a 5% MP replacement in MP-based concrete. This is 0.13% lower than the control specimen (CM5F0) after 90 days.
- For FA-based concrete, the maximum split tensile strength of 5.2 N/mm² is achieved with a 5% FA replacement, which is 0.37% higher than the control specimen (CM0F5) after 90 days.
- In MP and FA combined concrete, the highest split tensile strength of 4.12 N/mm² is obtained with a 15% MP and 5% FA replacement of PPC, which is 0.71% lower than the control specimen (CM15F5) after 90 days.
- The compressive strength of MP-based concrete is 1.07% higher than that of FA-based concrete.
- The tensile strength of FA-based concrete is 0.5% higher than that of MP-based concrete.
- For concrete requiring higher compressive strength, the CM5F0 mix is recommended.

5.2 Future Scope of Work

- For further analysis, additional tests can be conducted, such as flexural tests, acid resistance tests, micro structural analysis, and ultra pulse velocity tests.
- As a future scope, the combination of MP and FA in concrete as a partial replacement for cement can be further developed to enhance the strength and durability of concrete for construction purposes.
- In future work, the developed concrete mix can be analyzed using software like ANSYS, and the results can be compared with the experimental values.

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