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Durability Study on Concrete with Partial Replacement of Cement using Bentonite and Silica-Fume

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Abstract: Concrete, one of the most widely used construction materials globally, is known for its environmental impact due to the high carbon footprint associated with cement production. By looking at a partial replacement of cement with two extra components, bentonite and silica fume, this study investigates an environmentally beneficial option. Bentonite, a naturally occurring clay mineral, and silica fume, an industrial waste, both have the ability to improve the characteristics of concrete. In this study, a variety of concrete mixtures were created using different amounts of bentonite and silica fume in place of cement as a partial substitution by the weight of cement. To assess these concrete mixes mechanical, durability properties and environmental sustainability laboratory testing was done. The study evaluated variables like water absorption, flexural strength, compressive strength, and resistance to aggressive chemical attacks. The results of this study showed that concrete mixtures with improved mechanical strength and durability properties can be produced by partially replacing cement with bentonite and silica fume. By adding bentonite, the material became easier to work with, had less permeability, and was more resistant to attacks from sulphates and chlorides. On the other hand, silica fume resulted in decreased porosity and enhanced compressive and flexural strengths. In conclusion, a potential path to create environmentally friendly and sustainable concrete mixtures is the partial replacement of cement with bentonite and silica fume. These combinations have stronger mechanical characteristics and longer endurance while lowering the environmental impact of cement production. This research underscores the potential for eco-conscious construction practices and paves the way for the adoption of alternative materials in the quest for sustainable infrastructure development.

Index Terms: partial replacement by weight of cement, Bentonite, silica fume, durability test, chemical attacks

I. INTRODUCTION

Concrete is renowned for its adaptability, durability and versatility and is used extensively in the building sector, from modest residential projects to significant infrastructure expansions.

Bentonite is made from deposits of volcanic ash that have weathered and geologically changed over millions of years. Bentonite is a type of calcined clay that derives its characteristics from the main mineral montmorillonite. Calcined clay is defined as clay that has through a heat treatment to become powder form. Due to its widespread availability and affordable pricing, calcined clay appears to offer the most overall potential as a pozzolanic option for concrete. Its use as a partial replacement for some of the regular Portland cement has been discovered to have advantages for durability enhancement in addition to strength improvement.

Silica fume, also known as micro silica is a highly reactive pozzolanic substance produced as a byproduct in the manufacture of ferrosilicon alloys or silicon metal. It is made up of minor amounts of aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), and primarily of silicon dioxide (SiO_2). Silica fume has a variety of uses in different industries and has special qualities that make it particularly useful in the concrete and construction industries. Overall, silica fume is a useful substance that improves the qualities and functionality of concrete and other building materials. Due to its distinctive qualities, it is a crucial component in the creation of high-strength, long-lasting, and environmentally friendly construction solutions.

II. LITERATURE REVIEW

A. Effect Of Bentonite as Partial Replacement of Cement on Residual Properties of Concrete

Exposed to Elevated Temperatures *(Sardar Farhan Mushtaq, Ather Ali, Rao Arsalan Khushnood, Rana Faisal Tufail, Ali Majdi, Adnan Nawaz, Serdar Durdyev, Dumitru Doru Burduhos Nergis, And Jawad Ahmad)* Results were generated from this study on the behavior of concrete when incorporating different proportions of bentonite (5%, 10% and 15%) and were compared with the results for conventional concrete. Samples containing 10% bentonite showed better performance in terms of residual compressive strength at all targeted temperatures. It improved the pore structure of cementitious materials. Good resistance against acid attack. The durability of the concrete specimens improved significantly with increased bentonite content.

B. Utilization of Bentonite in Concrete: A Review *(M. Achyutha Kumar Reddy, V.Ranga Rao)* There is an improvement in durability of concrete was observed by bentonite addition. Bentonite can be utilized as supplementary material in concrete. Higher C-S of cement mortar were noticed by using 20% of bentonite (heated at 1500C for 3 hours) substitution to OPC. Concrete resistance is increased against sulphate by addition of bentonite around 20-30%. It also showed resistance against HCl

C. Fresh, Mechanical & Durability Properties Of Polypropylene Concrete Containing Bentonite & Silica Fume *(Inzimam Ul Haq, Ayub Elahi, Syed Aamir Qadeer Shah, Malik Ahmad Ghaffar)* This study investigated the partial replacement of cement by bentonite & silica fume on PPF concrete. Compressive strength was increased by addition of both Bentonite as well as SF mixes. PPF strengthened ternary mixes, containing PPF up to 0.5%, showed reduction in the coefficient permeability and showed greater resistance against acid attack like HCl, NaCl as compared to CC mix. Further addition of PPF increased the coefficient of permeability & ternary mix by 42% as compared with CC mix. The addition of PPF increased the durability characteristics.

D. Durability properties of concrete with silica fume and rice husk ash *(Smita Sahoo, Pravat Kumar Parhi)* Sulphuric acid attack resistance increases with an increase in SF or RHA content, which is due to a decrease in the content of calcium hydroxide upon use by SF or RHA in pozzolanic reaction. Hence, the SF-based and RHA-based concrete mixes can be utilized in the structures exposed to acidic environments. There is a positive effect on resistance to carbonation due to the inclusion of any content of SF and RHA. Water permeability, porosity and sorptivity of concrete decrease with increase in SF or RHA content, which is due to the increase in compactness of the SF based and RHA based concrete mixes.

E. Bentonite replacing part of cement concrete for resistance to chloride ion attack *(Jie Luo, Chuanchang Li, Yafei Ma and Lei Wang)* This paper demonstrated that mixes with bentonite was better than the control mix in resisting chloride ion attack. The mixes with low W/C have a stronger resistance to chloride attack compared with high W/C specimens. The value of the chloride ion diffusion coefficient of the mixes containing 10% bentonite is 42% of the control mix. This indicates that the diffusion rate of chloride ions is slowed by half.

F. Experimental Investigation on Silica Fume as partial Replacement of Cement in High Performance Concrete *(T.Shanmugapriya , Dr.R.N.Uma)* The compressive strength mainly depends on the percentage of silica fume because of its high pozzolanic nature to form more densely packed C-S-H gel. The flexural strength at the age of 28 days of silica fume concrete continuously increased with respect to controlled concrete and reached maximum value of 7.5% replacement level.

Conclusion: Bentonite and silica fume improves the pore structure of cementitious materials thereby reduces the water absorption. Concrete resistance is increased against sulphate by addition of bentonite around 20-30% Showed greater resistance against acid attack like HCl, NaCl as compared to conventional concrete mix. Durability of the specimen increases significantly. Water permeability, porosity and sorptivity of concrete decrease with increase in Silica fume. Bentonite in combination with Silica Fume can be used in structural concrete as a partial replacement, by weight of cement, to produce durable and reliable concrete. The literature review underscores the significant potential of metakaolin and silica fume as partial replacements for cement in concrete. It offers the opportunity to enhance strength, durability, and sustainability while posing challenges related to workability and mix design. The combined use of these materials has demonstrated synergistic benefits. Further research is needed to explore the optimal utilization of metakaolin and silica fume in various concrete applications, considering factors such as local materials and environmental considerations. Overall, these holds promise for advancing the field of high-performance and sustainable concrete technology.

IV. DURABILITY TEST

A. *Water absorption:* The water absorption test results provide information about the concrete's permeability and its ability to resist water penetration. Lower water absorption values indicate improved resistance to moisture ingress and better durability. This test is useful for assessing the quality and durability of concrete mixes.

B. *Sorptivity:* The sorptivity test provides a measurement of how quickly water is absorbed into the surface of concrete. The sorptivity value (S) is typically expressed in units of millimeters per minute (mm/min) and represents the rate of water absorption. Lower sorptivity values indicate lower permeability and better resistance to water penetration, which is desirable for concrete's durability and longevity.

C. *Acid attack:* The results of the acid attack test provide information about the concrete's resistance to chemical deterioration by acids. Lower mass loss values and slower rates of deterioration indicate better acid resistance. The test helps assess the suitability of the concrete mix for specific environments.

D. *Sulphate attack:* The results of the sulphate attack test provide information about the concrete's resistance to sulfate-induced deterioration. Lower mass loss values and slower rates of deterioration indicate better sulfate resistance.

E. *SEM analysis:* SEM reveals the microstructure of concrete, including the arrangement of aggregates, cementitious phases, and porosity. It can help assess the quality of concrete

F. *Energy Dispersive X-ray Spectroscopy (EDS):* In addition to imaging, SEM can be equipped with an EDS detector. EDS allows for the analysis of the elemental composition of different phases within the concrete. It can identify and quantify the presence of specific elements and minerals, helping to understand the concrete composition in detail.

V. MIX DESIGN

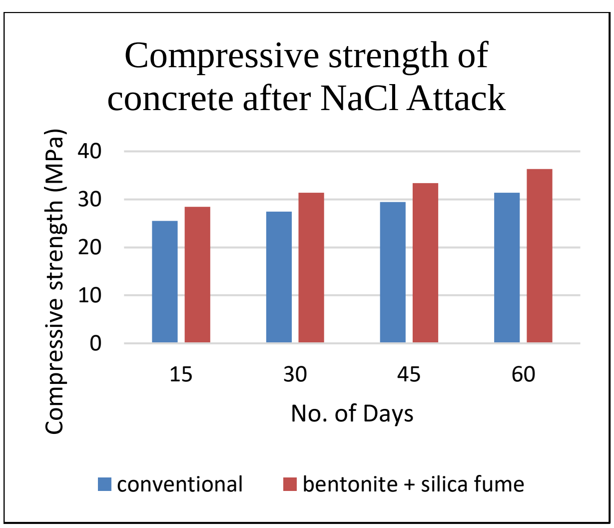
Grade of concrete: M20
Mix Ratio: 1:1.42:2.95
W/C Ratio: 0.54

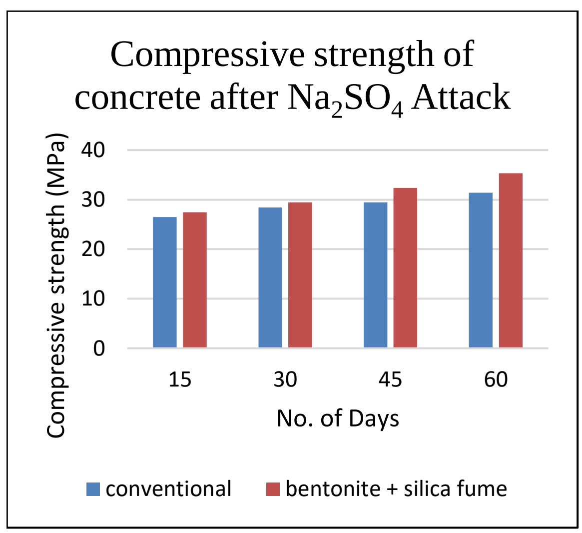
	Cement	Fine aggregate	Coarse aggregate
Quantity	325	465	960
Mix Ratio	1	1.42	2.95

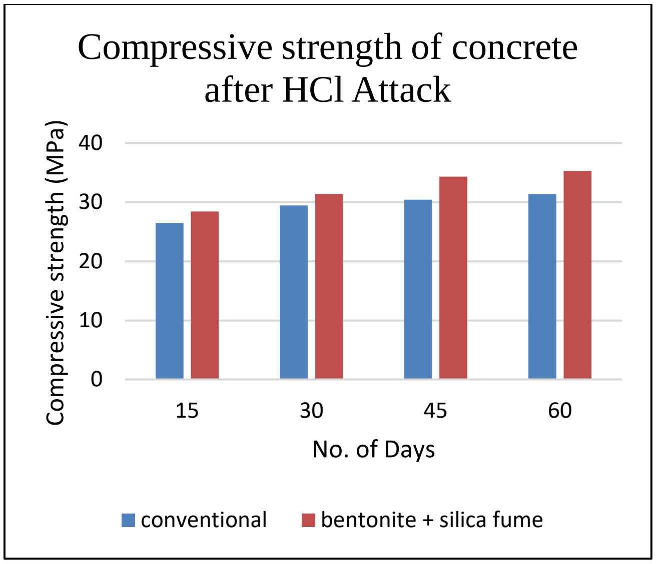
Dimensions of specimen
Cube mould – 100 x 100 x 100
Cylindrical mould – 100mm diameter and 50mm length

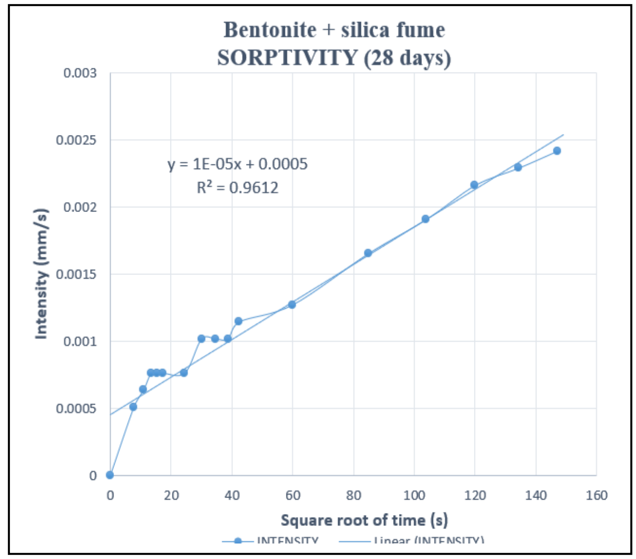
VI. RESULTS AND DISCUSSION

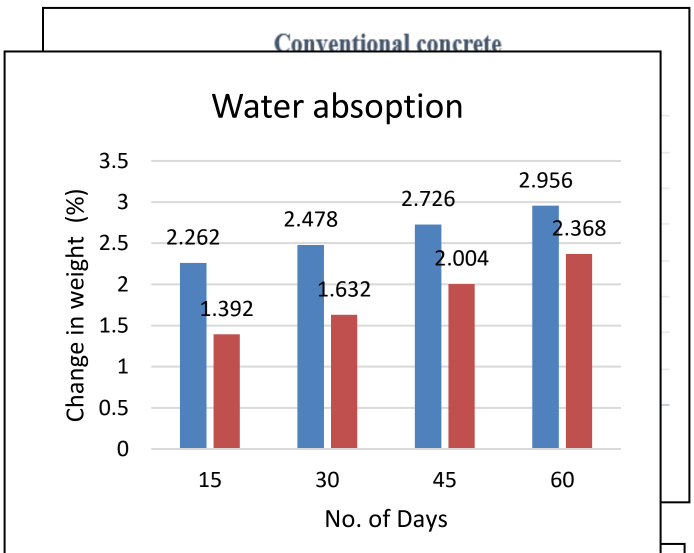
SPECIMEN	NO. OF DAYS	WEIGHT BEFORE ATTACK (kg)	WEIGHT AFTER ATTACK (kg)	% LOSS OF WEIGHT	COMPRESSIVE STRENGTH BEFORE ATTACK (MPa)	COMPRESSIVE STRENGTH AFTER ATTACK (MPa)	AVERAGE LOSS OF STRENGTH (%)
NaCl attack							
Conventional	15	2.502	2.576	2.942	27.468	25.506	7.143
	30	2.516	2.590	2.98	30.411	27.468	9.677
	45	2.496	2.574	3.142	32.373	29.43	9.091
	60	2.522	2.621	3.96	33.354	31.392	5.882
Bentonite + Silica Fume	15	2.488	2.519	1.246	29.43	28.449	3.333
	30	2.494	2.531	1.508	33.354	31.392	5.882
	45	2.502	2.542	1.62	36.297	33.354	8.108
	60	2.522	2.564	1.694	37.278	36.297	2.632
Na_2SO_4 attack							
Conventional	15	2.504	2.577	2.928	27.468	26.487	3.571
	30	2.488	2.563	3.002	30.411	28.449	6.451
	45	2.512	2.591	3.126	32.373	29.43	9.091
	60	2.496	2.577	3.248	33.354	31.392	5.882
Bentonite + Silica Fume	15	2.518	2.589	2.82	29.43	27.468	6.667
	30	2.506	2.579	2.912	33.354	29.43	11.764
	45	2.488	2.562	2.978	36.297	32.373	10.810
	60	2.494	2.568	3.002	37.278	35.316	5.263
HCl acid resistance							
Conventional	15	2.502	2.559	2.28	27.468	26.487	3.571
	30	2.488	2.550	2.496	30.411	29.43	3.225
	45	2.512	2.581	2.748	32.373	30.411	6.061
	60	2.492	2.567	2.996	33.354	31.392	5.882
Bentonite + Silica Fume	15	2.522	2.550	1.126	29.43	28.449	3.333
	30	2.496	2.530	1.382	33.354	31.392	5.882
	45	2.5	2.540	1.624	36.297	34.335	5.405
	60	2.508	2.556	1.942	37.278	35.316	5.263

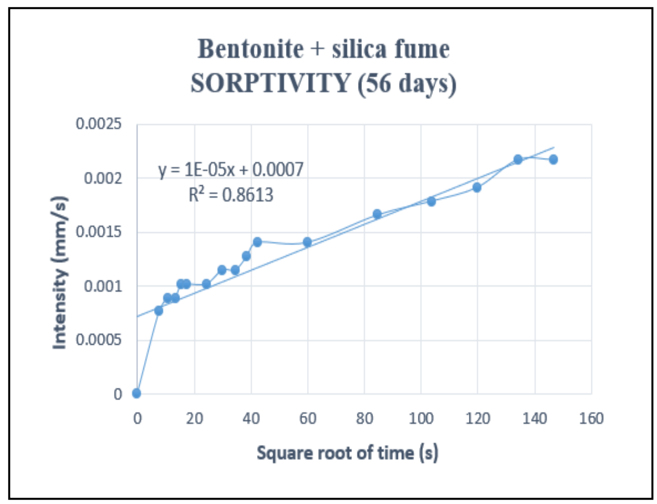


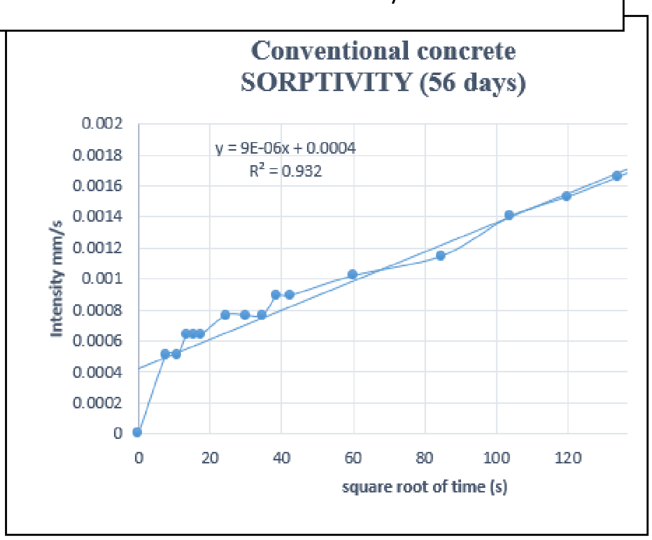












SPECIMEN	NO. OF DAYS	WEIGHT BEFORE ABSORPTION (kg)	WEIGHT AFTER ABSORPTION (kg)	CHANGE IN WEIGHT (%)
Water absorption				
Conventional	15	2.498	2.554	2.262
	30	2.486	2.547	2.478
	45	2.502	2.570	2.726
	60	2.516	2.590	2.956
Bentonite + silica fume	15	2.434	2.467	1.392
	30	2.498	2.538	1.632
	45	2.502	2.552	2.004
	60	2.486	2.544	2.368

Name of specimen	First crack load (kN)	Mid span deflection (mm)	Ultimate load (kN)	Flexural Strength (Mpa)
CONVENTIONAL CONCRETE				
CC 1				
CC 2				
15% BENTONITE + 10% SILICA FUME				
BS 1				
BS 2				

VI. CONCLUSION

From the investigation, rate of water absorption of conventional mix was found to be higher than the 15% bentonite + 10% silica fume replacement by weight of cement.

From the table, the average acid attack and chloride attack % loss in compressive strength of conventional mix was found to be more than 15% bentonite + 10% silica fume replacement by weight of cement.

Sorptivity investigation was also done and it showed better results.

Thus, the optimum percentage of 15% bentonite + 10% silica fume replacement by weight of cement was found to be effective in both mechanical and durability properties.

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