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Utilizing Bentonite Clay as a Pozzolanic Material to Reduce Cement Consumption and Cost in Construction Industry

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Abstract

This research focuses on finding an alternative to expensive cement in the construction industry in Pakistan by utilizing pozzolanic materials, specifically volcanic ash/bentonite clay. By replacing a portion of the cement with bentonite (10%, 20%, 30%, and 40%), the study demonstrates the potential to reduce the net consumption and cost of cement while also contributing to more durable concrete and reducing energy consumption and greenhouse gas emissions. Physical properties such as setting time and fineness were studied, and the compressive, flexural, and split tensile strength of the mixes were compared at 7 and 28 days of curing. While the strength of the mixes decreased with the successive addition of bentonite, the rate of reduction was much lower at 28 days than at 7 days. The results validate the feasibility of developing low-cost concrete using bentonite as a partial replacement for cement.

Keywords: Bentonite clay; Pozzolanic material; Cement consumption; Construction industry

Abbreviations: SCM: Supplementary Cementitious Material; ARB: As-Received Bentonite; CB: Calcined Bentonite, PC: Portland Cement; EAs: Expansive Agents

Introduction

Cement is the most widely and ordinarily used binding material in the construction field, but with the passage of time the cost of cement has increased up to 150% in a short span of ten years. It is further divided into sodium bentonite and calcium bentonite which can be recommended as swelling bentonite and non-swelling bentonite. The properties of bentonite are worth having in its use in drilling mud for oil and gas wells as well as slurries used in grouting fissures in rocks [1].

Bentonite can be defined as hydrous aluminum silica containing small amounts of alkali and alkaline earth metals. The use of bentonite clays as supplementary cementitious material (SCM) is limited because of their low pozzolanic activity, high hydrophilicity, and dramatic swelling nature. In this study the bentonite clay was modified by silane treatment, and its pozzolanic activity was compared with as-received bentonite (ARB) and calcined bentonite (CB) clay [2]. Concrete is an important material that has been used extensively in construction and infrastructure devotement. Portland cement (PC) concrete is a structured, quasi-brittle, and heterogeneous material that can resist high compressive strength. Several researchers analyzed the self-healing performance of concrete with various admixtures such as fly ash, silica fume, expansive agents (EAs), and others [3]. Bentonite is a kind of clay with montmorillonite as the main mineral. The basic structure of montmorillonite crystal lattice consists of silica (tetrahedron) and alumina (octahedron) [4].

Bentonite is a clay rock, and China is one of the major bentonite producers in the world. Bentonite is abundant and inexpensive. Bentonite clays are aluminosilicates with montmorillonite group minerals as their major component. Structurally, due to three-layer packets made of an aluminum layer enclosed between two silica layers, bentonite has many peculiar properties, such as water absorption, thixotropy rheological property, adsorbability, and expandability. Currently, bentonite is mostly used as a binding agent, as an adsorbent (for drilling in mud), and as a filler in slurries in the foundry industry [5].

Indigenous clays have been widely mixed with bentonite (called bentonite-clay mixtures) as bottom barriers in waste disposal facilities in various countries owing to great adsorption properties, swelling capacity of bentonite leading to low hydraulic conductivity and cost-effectiveness [6].

Different investigations have shown that thermally treated calcium bentonite offers several advantages as a pozzolanic component in cement-based materials. At concentrations varying from 5% to 30% cement replacement, the authors reported improved resistance to chemical attack and enhanced long-term strength [7]. The effect of bentonite clay on properties of grout is studied by another researcher [8]. Similarly, the performance of activated soil-cement-bentonite clay can be found at another source [9]. One of the studies investigated the use of natural bentonite clay for the recovery of Gd3+ from real leachate of phosphogypsum. The clay was characterized and tested with synthetic Gd3+ solutions, as well as real PG leachate. The optimum pH for Gd3+ removal was found to be 6, and the Langmuir model was suitable for describing the adsorption isotherms. The maximum adsorption capacity was 121.5mg g^{-1} at pH 6. The adsorption process was spontaneous and involved ionic exchange, as indicated by the thermodynamic parameters. The fixed bed adsorption test showed that Gd3+ could be adsorbed for up to 200 minutes without regeneration. Regeneration tests showed that citric acid was effective in desorbing Gd3+ from the bentonite, with up to 8 cycles without efficiency loss. The study demonstrated that bentonite clay can selectively recover Gd3+ from real PG leachate, providing a promising method for Gd3+ recovery and reuse [10].

The research problem addressed in the article is the need to find a cost-effective and sustainable alternative to cement in the construction industry in Pakistan. The study aims to investigate the potential of using volcanic ash/bentonite clay as a partial replacement for cement in concrete production, with the objective of reducing the net consumption and cost of cement while enhancing the durability of concrete and minimizing energy consumption and greenhouse gas emissions. The study seeks to determine the optimal replacement percentage of bentonite, as well as the effect of bentonite on the physical and mechanical properties of concrete, including setting time, fineness, compressive, flexural, and split tensile strength. The research problem aims to address the need for sustainable and low-cost construction materials in Pakistan, while also contributing to the global effort to reduce carbon emissions and mitigate the impact of climate change.

Research Methodology

The study involved performing various tests on both fresh and hardened concrete. This included determining the necessary amount of material based on the design mix, preparing specimens, and conducting standardized tests such as the sump test for fresh concrete, as well as compression tests on cubes and cylinders, split tensile tests on cylinders, and flexural tests on beams for hardened concrete. The testing of cylinders is performed according to ASTM C39, while slump test is performed according to ASTM C143. The flexure testing of beam is performed according to ASTM C78. This flow chart shows the steps that were followed during the project. Table 1 shows the use of different proportions and total number of samples.

Table 1: Total number and proportion of samples.

Sr.	Mixes	Binders		Fine Aggregate	Coarse Aggregate	w/c	Samples
	Replacement	Cement (%)	Bentonite (%)	(%)	(%)	-	-
1	Control mix	100	0	100	100	0.48	10
2	Be10	90	10	100	100	0.48	10
3	Be20	80	20	100	100	0.48	10
4	Be30	70	30	100	100	0.48	10
5	Be40	60	40	100	100	0.48	10
Total							50

Calculation for bentonite

Table 2 below shows the amount of Bentonite required for the mixes.

Total material required

The total material required for all 45 samples of concrete cubes, cylinders and beams are given below in table 3.

Two bags of type 1 ordinary Portland cement, which is commonly utilized for building construction, bridges, and pavements according to ASTM C-150, were obtained from the suppliers in Taxila Chowk. The coarse aggregate was collected from the quarry site of Margalla hills, while the fine aggregate was acquired from crush and sand suppliers in Taxila, sourced back to Margalla hills. The suppliers ordered the Bentonite clay from Lahore, which was sourced back to the Jahangira Bentonite quarry

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site shown in figure 1. Chemrite 303 SP super-plasticizer, which was purchased from Emporium Company Islamabad, was used to address the workability issue.

Table 2: Calculation for bentonite clay.

S.No.	Mixes	Proportion (%)	Sample Needed	Weight (kg)
1	C + Be	10	10	2.85
2	C + Be	20	10	5.69
3	C + Be	30	10	8.53
4	C + Be	40	10	11.33
Total			40	28.40

Table 3: Total calculation for procurement.

Name	Quantity (kg)
Cement	113.8
Fine Aggregates	226.3
Coarse Aggregates	451.2
Bentonite Clay	28.40
Total	819.7 kg

Figure 1: Bentonite clay.

Results and Discussion

Slump test

According to ASTM C125-15 the slump test was conducted on the concrete having different composition of bentonite replacement of cement for each mix design slump test was conducted to check the feasibility of concrete placing in mold and aftermath it's rodding temping intensity show figure 2.

In all tests conducted, it was observed that the slump value decreased as the amount of bentonite in the concrete mix increased. From this perspective, it can be clearly determined that the addition of more bentonite in the concrete reduces its workability. This occurs due to two reasons. Firstly, the usable form of bentonite soaks up more water in the concrete mix, thereby significantly reducing its amount. Secondly, the specific gravity of bentonite is much lower than sand, which results in low flow of concrete and a filler agent phenomenon in fresh concrete.

The graphical representation of slump value with bentonite percentage mainly tells us the trend of slump values on bentonite content figure 3.

Compressive strength

Different results were obtained for different types of molds for cubes/blocks at 10% replacement, where lower reduction in strengths was observed as compared to cylinders because compression test was performed on the sample having the same mix design.

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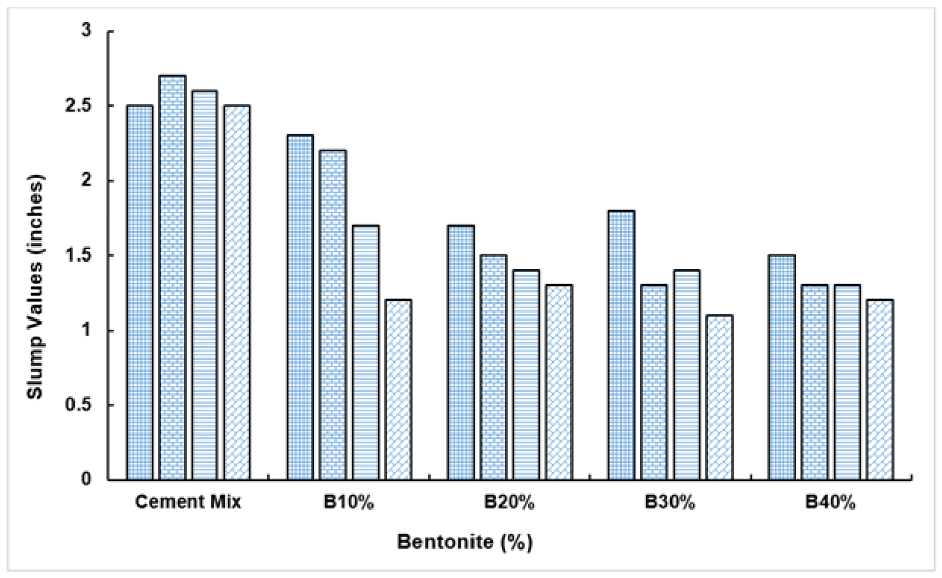

Figure 3: Slump vales at different % of bentonite clay.

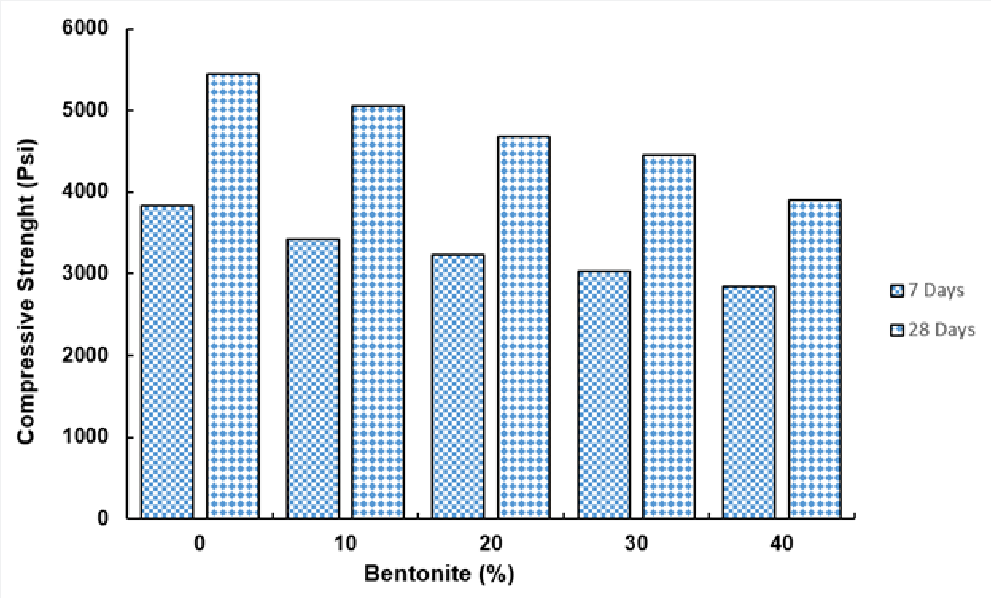

Figure 4: Compressive strength at different % of bentonite clay.

The reduction in strength is primarily attributable to two factors. Firstly, the percentage of bentonite, which is added to replace the cement, and secondly, more importantly, the mix design of concrete. In our case, the mix design was kept (1:1.5:3) because this design comprises more cement than other mixes such as 1:2:4; 1:4:8, etc. If it had 1 part of cement with 1.5 parts of sand and 3 parts of coarse aggregate, in our case, it was primarily concerned with more reduction in compressive strengths. In this context, the strength reduction of blocks and cylinders was also measured for control mixes and for the sample where cement was replaced with bentonite. It was noted that strength of concrete also depended on the geometry or more precisely, the cross-section geometry of the specimen that was taken under observation.

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Blocks have firm edges usually considered at the common angle of 90 degrees; therefore, they resist the load applied along their common axis (from all sides). Whereas the cylinder has circular cross-section, which is not as stable towards aerial loading as compared to cuboids or blocks. The block's cross-sectional geometry makes it stronger to resist or bear vertical loading. The result is presented in figure 4.

Flexural strength

The reduction in beam flexure strength was caused by bentonite replacement in ordinary cement concrete beams. The pozzolanic bonding properties of bentonite as compared to cement are the reason behind this reduction. The result for cement flexural test of bentonite concrete can be effectively studied from the following graph.

On the positive side, in the presence of reinforcement, bentonite concrete gave better results as compared to ordinary concrete. This is because bentonite provides more time before failure than ordinary concrete having only cement. The failure in the presence of bentonite is much more elastic than in concrete. This can be better understood by the following graphical presentation. Therefore, by providing bentonite flexural member (meeting the design requirement), a safer and structurally economic building or structural member can be provided. The result is shown in figure 5.

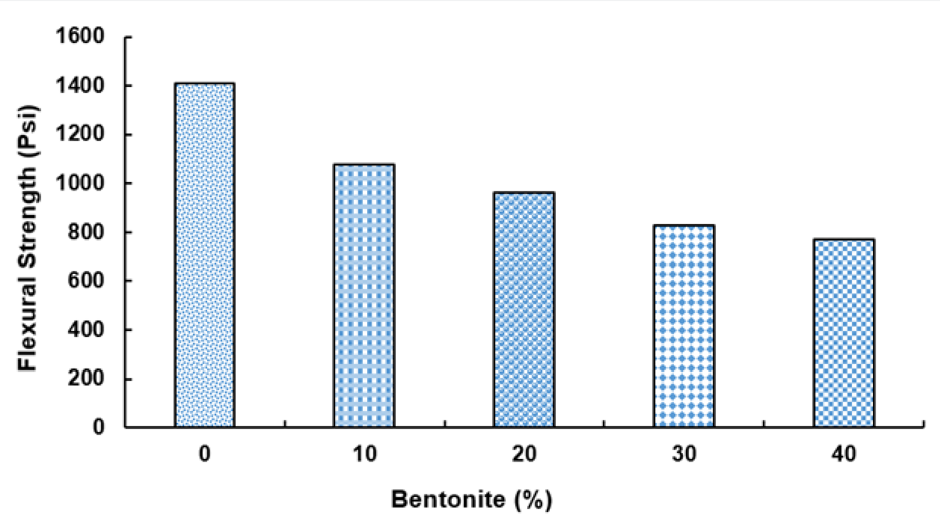

Figure 5: Flexure strength at different % of bentonite clay.

Cost comparison

In May 2020, the cost of 1 ton of bentonite was PKR 1200, while cement cost PKR 12,600 per ton. If bentonite were successfully used as a partial replacement for cement, significant savings could be achieved, especially in high-volume applications such as commercial building construction where thousands of tons of cement are typically used. For instance, if 50,000 cubic meters of concrete are required for a proposed construction project with a ratio of 1:1.5:3 (by weight), substituting 20% of cement with volcanic ash could save considerable costs (Figure 6).

Based on comparative cost analysis, it is estimated that 350kg of cement would be required per cubic meter of concrete using only cement, whereas a 20% reduction in cement usage (i.e., 70kg) can be achieved by adding bentonite. Thus, the cost of bentonite per cubic meter of concrete would be PKR 84, while the cost of cement per cubic meter of concrete (1:1.5:3) would be PKR 4410. As a result, PKR 798 could be saved per cubic meter of concrete. Therefore, the total saved cost for 50,000 cubic meters of concrete would be PKR 39,810,000.

Conclusion

As the content of bentonite increased, the slump of the concrete decreased while the WRA increased. When more than 20% of bentonite was substituted, the compressive strength decreased beyond the required limit. This is because the weaker Pozzolanic properties of bentonite clay tried to influence the binding power of cement, resulting in weaker bonding with other constituents of concrete. The compressive strength of concrete containing bentonite was lower than that of the control mix (100% OPC) at 7 days. The strength decreased progressively as the substitution level increased. However, after 28 days, the decrease in compressive strength was much lower than that at 7 days. Therefore, these values may be considered satisfactory for low-cost construction. The substitution of cement with pozzolana is only suitable for rich mixes as the compressive strength is not satisfactory for lean mixes. The flexural strength tended to increase as the percentage of bentonite clay increased.

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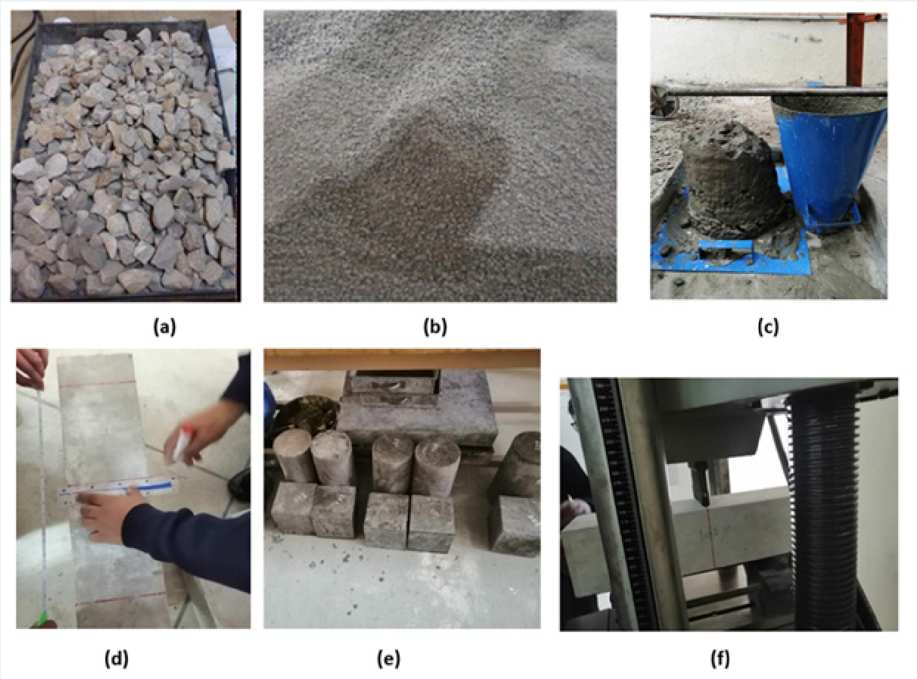

Figure 6: Experimental program (a) Aggregate used (b) Bentonite clay (c) Slump measurement (d) Beam for flexure testing (e) Cubes and cylinders (f) Flexure testing of beam.

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