EXPERIMENTING BENTONITE EMULSIFIED SUSTAINABLE CONCRETE: ANALYSIS OF MECHANICAL AND MICRO STRUCTURAL PROPERTIES

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Abstract

Bentonite is a type of clay with a very high proportion of clay mineral montmorillonite, resulting from the decomposition of volcanic ash. Bentonite is highly water-absorbent and has high shrinkage and swelling characteristics. In this study, the partial replacement of Cement with Bentonite (source: Nizampur) at 5%, 10%, 15% and 20% mixes were prepared, and their compressive strength was compared with the control mix. The workability of the bentonite mixes is comparatively lower than that of the control mix because Bentonite is much more water-absorbent. The comparative compressive strength analysis indicated that at the age of 7 days of testing, the mixes containing Bentonite showed lower strength than the control mix, while at the age of 28 days of testing, the mixes having different percentages of Bentonite showed good strength when compared to the control mix. The main conclusion drawn from this research work is that Bentonite can be used where later-stage strength is required. The durability of the Bentonite concrete was measured in terms of resistance to the penetration of sulphate ions. It was seen from the results that the bentonite result was poor in the early stage and later stages. Compressive strength was reasonable when compared with Control samples. Although the strength of bentonite mixes was not higher than the control mix, as the percent of bentonite increases, the strength of concrete increases. The later age strength of 5% and 10% bentonite concrete was higher than the 15% and 20% bentonite mix, respectively. The strength of 5% and 10% bentonite was approximately equal to the control mix. For chemical analysis, the X-ray fluorescence test is performed on cylinder specimens. From the results, we obtain that three dominant compounds, i.e. SiO_2, Al_2O_3, Fe_2O_3 and their occurrence in abundance are responsible for the strength factor of bentonite mixes. At the same time, other minerals are present in small amounts. The XRF test was performed to know the chemical compositions of the minerals in the clay. The XRD test was performed on different bentonite mixes to determine mineral composition.

Keywords: Bentonite, Concrete, XRD, XRF, Microstructure.

1. Introduction

In recent years, the use of hydraulic Cement in concrete has increased significantly. Approximately 7% of global CO2 emissions are attributed to the cement industry, mainly to the manufacturing of clinker [1]. Reducing the amount of Cement used in concrete was necessary to reduce the amount of CO2 released into the atmosphere. Concrete made with pozzolanic elements will need less hydraulic Cement. Concrete will use less Cement if industrial byproducts like fly ash, GGBS, silica fume, etc., are used as a substitute for Cement [2]. Using fly ash in concrete has become a popular technique these days. Fly ash is mainly produced by thermal power stations that run on coal [3]. The cost of producing electricity using thermal power plants is relatively high compared to other sources (renewable-energysources.com). Thermal power facilities release significant CO2 into the atmosphere [4]. Supplementary cementitious materials (SCMs) can improve concrete's qualities and lessen CO2 emissions and strain on natural resources. According to the environmental impact analysis, B.C. and S.F. can cut carbon emissions by around 23% compared to the control mix.

Decades of research have been conducted on the properties and appropriate use of clays as cement substitutes in concrete [5]. Previously, a variety of compounds, including fly ash [9], metakaolin [10], carbon nanotubes [8], steel fibres [7], polypropylene fibres [6], and fly ash [7], were utilized to enhance the general behaviour of concrete subjected to increased temperatures. These resources aren't widely accessible, or they are pricey. As a result, Bentonite is used in this study to substitute Cement for concrete partially. At Pakistan's Khyber Pakhtunkhwa, Bentonite is widely accessible at Jahangira [11] and Karak [12]. Bentonite is a mineral clay with pozzolanic qualities.

Typical Cement, because concrete deteriorates before reaching its full-service life, requires many repairs over its lifetime. Four primary environmental phenomena influence concrete. These include the interaction between alkali and aggregates, concrete freezing and thawing, reinforcing corrosive action, and sulphate attack [13]. In every instance, toxic solutions seep into the concrete and cause harm. Structures built using high-performance concrete (HPC) have increased strength and resilience, making them cost-effective and durable. Because HPC is less porous, it can withstand the porous nature of harsh solutions, increasing the durability of concrete. When used as cementitious materials, pozzolanic materials provide high compressive strengths exceeding 40 MPa (6000 psi) [14]. The term "sulphate attack" refers to a sequence of chemical processes in solid concrete when sulphate ions are present. The product achieved from these reactions holds a larger volume than the reactants, thus causing internal stresses in the concrete. These stresses lead to cracks in the concrete and reduce the life span of the concrete structure. Exposure circumstances are one of the parameters that determine how much deterioration is induced by a sulphate assault. There are three possible exposure scenarios: partial immersion with evaporation, exposure to cyclic wetting and drying, and continuous immersion in a sulphate environment.

Researchers have examined the qualities and appropriate applications of clays and nutrients as cement substitutes in concrete for many years. At 91 days, blended Cement with a greater concentration of natural pozzolans can decrease alkali-silica expansion, yielding a similar strength to Portland cement [15]. Research has also been done on the mechanical and durability characteristics of concretes made using silica fume and metakaolin clay. Met kaolinite-clay concrete has comparable resistance to chlorides and better strength development than silica-fume concrete. It has also been studied how metakaolin clay, which replaces Cement, affects the resistance of concrete to sulphate assault. The investigation results indicated that using metakaolin instead of Cement improved the concrete's sulphate resistance. As the replacement amount of metakaoline in the concrete grew, so did its sulphate resistance.

When the weight-to-cement ratio is 0.5, metakaoline concrete has a higher sulphate resistance than when it is 0.6 [16]. Studies have also been conducted on the substitution of bentonite clay for Cement. Khan and Riaz (2003) found the reactivity index of mortar cubes containing Jehangira bentonite as a replacement for Cement. He concluded that 40 percent replacement of Bentonite in mortar and 25 percent replacement in concrete yielded satisfactory results when used as such (without any heat treatment) [17]. Badshah (2003) found the optimum replacement of Jehangira bentonite as pozzolan based on XRD diffraction analysis and compressive strength results. He also studied the sulphate resistance of concrete utilizing Jehangira bentonite. He concluded that 20 percent of bentonite replacement in concrete yields satisfactory results, but any further addition drastically reduces strength—concrete's sulphate resistance increases as the pozzolan replacement rises [18]. The chemistry of intercalation is a research area that has been widely investigated and plays an essential part in

applications in many academic and technological fields, such as those related to ion exchange reactions and supports for catalytic methods [19].
Knight first proposed the term bentonite in 1898. It is a natural pozzolan in many different areas of Khyber Pakhtunkhwa province of Pakistan. One of the Bentonites, originating from Jehangira, occurs at 335905600 latitudes and 721204700 longitudes in the survey of Pakistan topographic sheet 43C/1. Several preliminary studies evaluated the feasibility of utilizing industrial wastes in Pakistan. The different types of Bentonite are each named after the respective dominant elements, such as potassium (K), sodium (Na), calcium (Ca), and aluminum (Al). Experts debate several nomenclatorial problems with the classification of bentonite clays. Bentonite usually forms from the weathering of volcanic ash, most often in the presence of water. However, the term bentonite and similar clay called tonstein have been used to describe clay beds of uncertain origin. For industrial purposes, two main classes of Bentonite exist sodium and calcium bentonite. In stratigraphy and tephrochronology, completely devitrified (weathered volcanic glass) ash-fall beds are called K-bentonites when the dominant clay species is illite. In addition to montmorillonite and illite, kaolinite is another common clay species that is sometimes dominant. Kaolinite-dominated clays are commonly referred to as tonsteins and are typically associated with coal. Calcined clay seems to have the most significant overall potential as an alternative pozzolanic material for concrete due to its availability in large quanta at a relatively low price. Though the mineralogy of clays varies a lot, which may influence reactivity, its interaction with CSH gel formed during ordinary Portland cement has been beneficial to the final form of the hardened concrete. The benefit of its being used partially to replace a portion of ordinary Portland land cement has been found in strength improvement and durability enhancement.
The following are the objectives of the study.

i. To check the effect of Bentonite on the workability of concrete
ii. To check the impact of Bentonite on the compressive strength of concrete
iii. To investigate the change of microstructure of concrete when blended with Bentonite
iv. To check the resistance of Bentonite blended concrete against sulfate attack

2. Materials and Method

To attain the objectives already mentioned, the following methodology was followed.

2.1. Mix proportion

The first mix design will be done to find out the proportion of ingredients for the control mix to give a compressive strength of 3000psi at 28 days. A blended mix will be prepared using 0%, 5%, 10%, 15%, 20%, etc., of Bentonite in concrete as a replacement for Cement by weight. For the control sample having a strength of 3000psi and for different mixes containing different percent of Bentonite, the proportion prepared is tabulated in the table.

Table 1: Quantity of materials for three (3) cylinders

Mix	Cement (kg)	Sand (kg)	Coarse aggregate (kg)	W/C ratio	Bentonite (kg)
CM	1.74	4.615	6.416	0.68	0.00
BM5	1.653	4.615	6.416	0.68	0.087
BM10	1.566	4.615	6.416	0.68	0.174
BM15	1.479	4.615	6.416	0.68	0.261
BM20	1.392	4.615	6.416	0.68	0.348

2.2. Laboratory Work

The following lab tests were conducted in this research. This experimental work produced high-performance concrete (high compressive strength) by replacing Cement with Bentonite in a different mix. The correct use of this material is essential in insignificant proportion to achieve the required strength.

- Sieve analysis of aggregates.
- Specific gravity of aggregates.
- Density of aggregates.
- Workability of each batch by slump test.
- Sulfate attack of concrete.
- Compressive strength of the concrete specimen at 28 days.
- X-ray diffraction of concrete specimen at 28 days.
- X-ray fluorescence of concrete specimen at 28 days.

2.3. Mixing Procedure

The concrete was mixed at an average temperature, and care was taken during the mixing process. As shown, the concrete batches were made by a concrete mixer machine. For our work, Mixing was carried out in the Mixer available in the concrete lab of CECOS University.

2.4. Casting and Compaction

After the mixing process was completed, the concrete was poured into moulds of standard sizes and shapes, and compaction was done using a standard compacting rod. The moulds used in this research work are cylinders of standard size (4-inch diameter and 8-inch height), and they were made to determine compressive strength.

2.5. Curing

After casting concrete, the specimen was placed for curing in a container containing water free from impurities for 28 days.
Materials used in this investigation are as follows.

2.6. Cement

ASTM C150 type I ordinary Portland cement was used in the concrete. The Cement was fine and grey. The chemical composition of Cement is shown in Table 3.1

Table 2: Chemical composition of Cement

Serial No.	Oxides	Percent content (%)
1	CaO	60–67
2	SiO_2	17–25
3	Al_2O_3	3.0–8.0
4	Fe_2O_3	0.5–6.0
5	MgO	0.1–4.0
6	Alkalies (K_2O, Na_2O)	0.4–1.3
7	SO_3	1.3–3.0

2.7. Bentonite

The Bentonite used for this experimental work was obtained from Nizampur. It was in clay form and then converted into powder form. The colour of Bentonite is yellowish-grey.

Figure: Sodium bentonite and Calcium bentonite

2.8. Fine aggregate

Fine aggregate (sand) was collected from Peshawar for this experimental work. The following tests were performed to determine the fineness modulus, specific gravity, and bulk density of the fine aggregate.

2.9. Coarse aggregate

Coarse aggregate (gravel) was also collected from Peshawar for these tests. This coarse aggregate was used for sieve analysis, specific gravity, and bulk density tests.

3. Results and Discussion

3.1. Sieve analysis of fine aggregate

The sieve analysis test was performed in the laboratory, and the fineness of the fine aggregate was calculated. The cumulative percent passing of fine aggregate is within the ASTM limits.

Sample weight = 500 gram

Table 3: Sieve analysis of fine aggregates

Sieve #	Sieve Size (mm)	Retained Weight (gm)	Cumulative (gm)	Percent retained in each sieve. (%)	Cumulative % retained (%)	Cumulative % passing (%)	ASTM limits
4	4.75	2	2	0.4	0.4	99.60	90-100
8	2.36	9	11	1.8	2.2	97.80	80-100
16	1.18	39	50	7.8	10	90.00	50-90
30	0.60	100	150	20	30	70.00	40-80

50	0.30	146	296	29.2	59.2	40.80	20-50
100	0.15	152	448	30.4	89.6	10.40	0-20
Pan	pan	52	500	10.4	100	00.00	00
		Total= 500			Total= 291.4	Total = 408.6	

Fineness Modulus of Fine Aggregate = ∑ cumulative % retained / 100
Fineness Modulus of Fine Aggregate = 291.4/100
Fineness Modulus of Fine Aggregate = 2.914 (Coarse Sand)

3.2. Limits of Fineness Modulus

The table shows the ranges for the fine modulus of the fine aggregate. The results obtained from sieve analysis show that the fine aggregate used was coarse sand.

Table 4: ASTM range for Fineness Modulus

Serial No.	Type of sand	Fineness Modulus range
1	Fine sand	2.2 – 2.6
2	Medium sand	2.6 – 2.9
3	Coarse sand	2.9 – 3.2

According to the above table, the fineness value of fine aggregate was in the range of coarse sand. Hence, coarse sand was used for this experimental program. The result of the sieve analysis of fine aggregate is graphically shown in the figure.

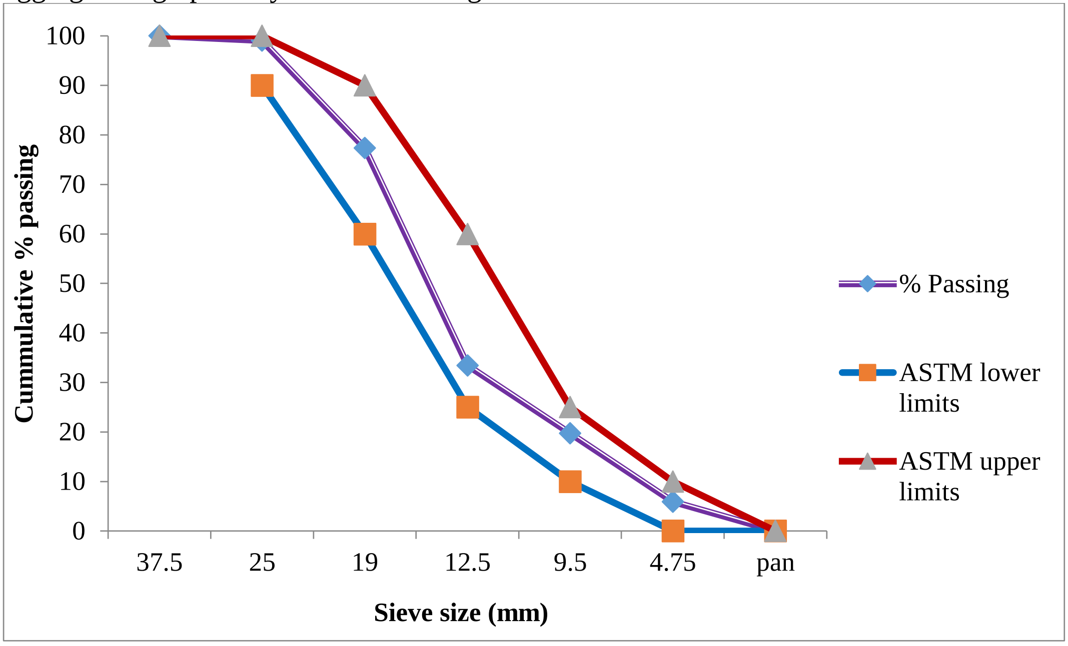


Figure 1: Gradation curve of fine aggregates

3.3. Sieve analysis of Coarse aggregate (ASTM C 136)

The sieve analysis test was performed in the laboratory, and the size of the coarse aggregate was calculated. The cumulative percent passing of coarse aggregate is within the ASTM limits.
The gradation of coarse aggregate was calculated in the given table.
Sample Weight = 3000 gm

Table 5: Sieve analysis of coarse aggregates

Sieve size (in)	Sieve Opening (mm)	Retained Weight (gm)	Percent retained in each sieve (%)	Cumulative % retained (%)	Cumulative % passing	ASTM limits
3/2	37.5	0	0	0	100	100
1	25	28	0.93	0.93	99.07	90-100
¾	19	652	21.74	22.67	77.33	60-90
½	12.5	1318	43.94	66.61	33.39	25-60
3/8	9.5	410	13.67	80.28	19.72	10-25
#4	4.75	416	13.85	94.13	5.87	0-10
Pan		176	5.87	100	0	0
		Total = 3000	100	Total = 364.62	Total= 335.38	

Fineness Modulus of coarse Aggregate = ∑ cumulative % retained / 100
Fineness Modulus of coarse Aggregate = 364.62/100
Fineness Modulus of coarse Aggregate = 3.64 (1” down)
The result for gradation of coarse aggregate is graphically shown in the figure.

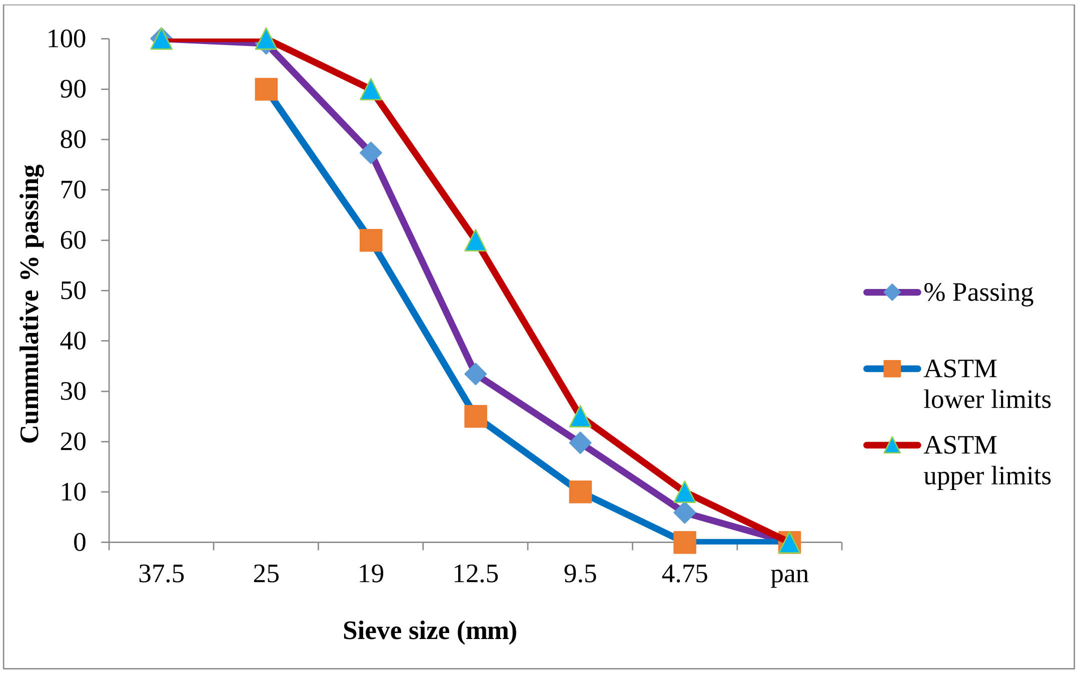


Figure 2: Gradation curve of coarse aggregates

3.4. Slump test

A slump test was performed for the controlled concrete mixes with different percentages of Bentonite, which was used as a replacement for Cement by weight in concrete. The slump values of different mixes are shown in Table 4.4

Table 6: Slump value for different mix

Serial No.	Sample ID	Slump value (in)
1	CM	2.3
2	BM5	2.0
3	BM10	1.8
4	BM15	1.5
5	BM20	1.3

The table shows that the slump of Bentonite mixes decreases because Bentonite absorbs more water. The slump values of different Bentonite mixes are shown in the figure.

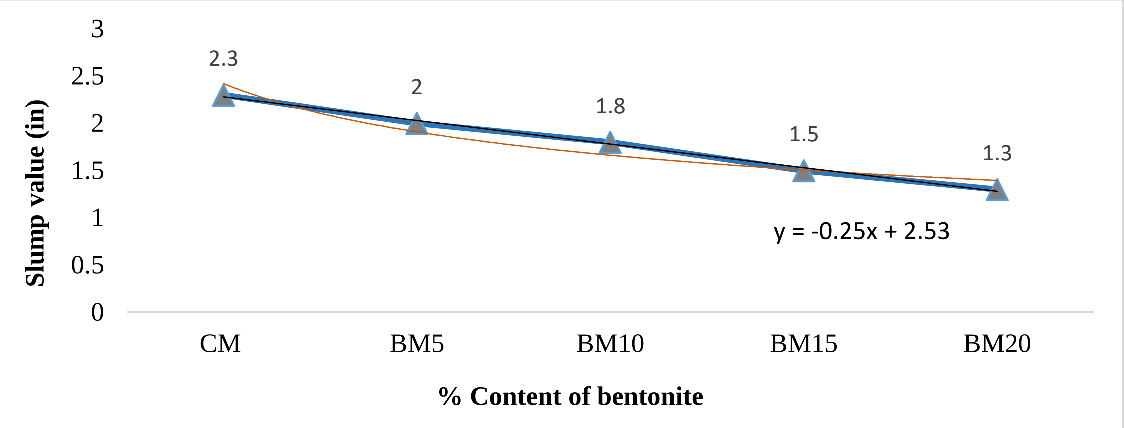


Figure 3: Slump values of different mixes

3.5. Compressive strength test

As we know, concrete is weaker in tension than compression, so it is normally used in compression members. Due to this phenomenon, it is now well known that concrete is a compressive material, and its compressive strength is a parameter used to judge the quality of concrete. For this purpose, samples of concrete were tested at different ages, i.e. 7, 14 & 28 days, to know the exact behaviour of the concrete gaining strength for other mixes. Five mixes were prepared and marked as CM, BM5, BM10, BM15 & BM20 (Normal Strength Concrete Mix) having different proportions of ingredients. The compressive strength of a concrete cylinder was tested for controlled mix and also for partial replacement of Cement with Bentonite at the ages of 7, 14 and 28 days, respectively, in a universal testing machine (UTM) and found the results given in Table 4.5, 4.6 and 4.7 respectively.

3.5.1. Compressive strength test (7 days)

The compressive strength result of a concrete cylinder at seven days is given in the table.

Table 7: Compressive strength at seven days

Sample ID	Specimens No	Compressive strength at Seven days (psi)	Average compressive strength (psi)	Change in strength %	
				% Increase	% Decrease
CM	1	2312	2308	-	-
	2	2288			
	3	2322			
BM5	1	2162	2211	-	4.02
	2	2215			
	3	2256			
BM10	1	2165	2183	-	5.41
	2	2196			
	3	2188			
BM15	1	2132	2157.33	-	6.52
	2	2176			
	3	2172			
BM20	1	2112	2143.33	-	7.68
	2	2134			
	3	2185			

The comparative values in chart form are shown in the figure, which shows concrete containing a controlled mix and different proportions of Bentonite at seven days' strength.

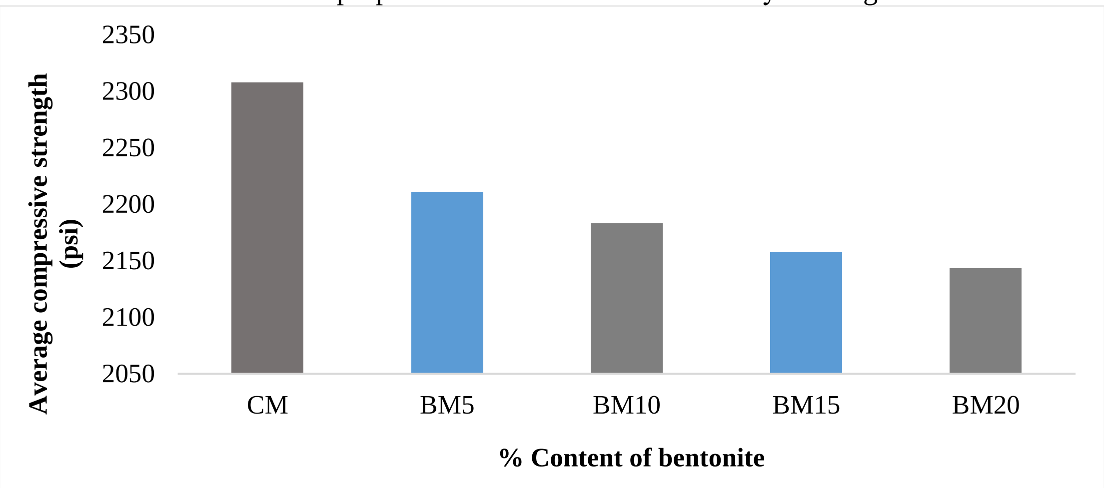


Figure 4: Average Compressive strength at seven days

3.5.2. Compressive strength test (14 days)

The compressive strength result of a concrete cylinder at 14 days is given in the table.

Table 8: Compressive strength at 14 days

Sample ID	Specimens No	Compressive strength at 14 days (psi)	Average compressive strength (psi)	Change in strength %	
				% Increase	% Decrease
CM	1	2789	2715	-	-
	2	2645			
	3	2711			

BM5	1	2624	2617.33	-	3.59
	2	2632			
	3	2596			
BM10	1	2612	2597	-	4.34
	2	2576			
	3	2605			
BM15	1	2552	2554	-	5.93
	2	2599			
	3	2512			
BM20	1	2538	2517	-	7.29
	2	2495			
	3	2516			

The comparative values in chart form are shown in the figure, which shows concrete containing a controlled mix and different proportions of Bentonite at the age of 14 days' strength.

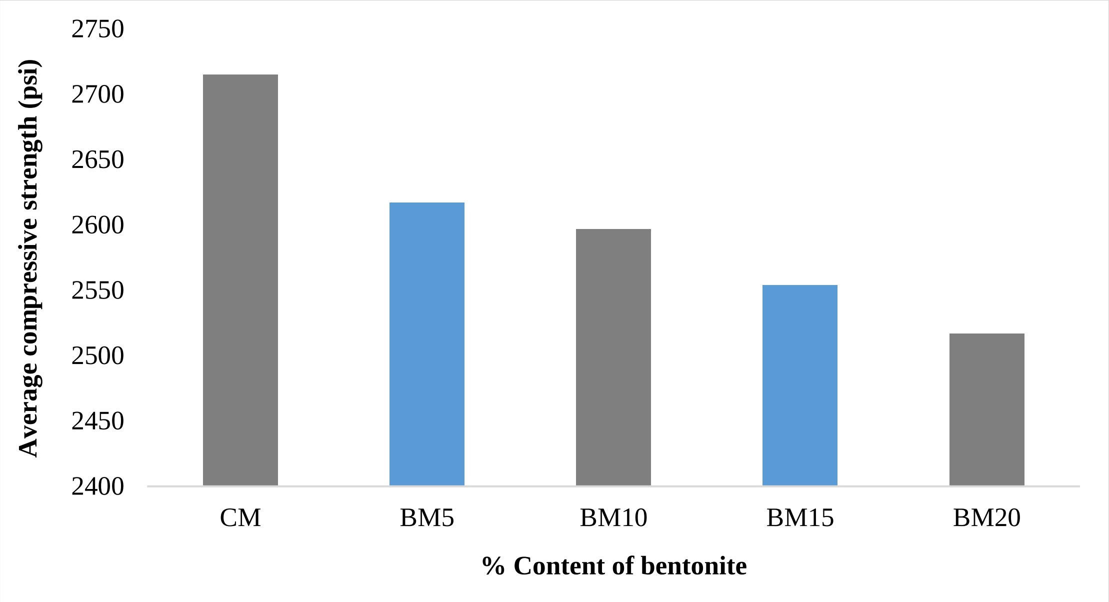


Figure 5: **Average Compressive strength at 14 days**

3.5.3. Compressive strength test result of 28 days

The compressive strength result of a concrete cylinder at 28 days is given in Table 4.7.

Table 9: Compressive strength at 28 days

Sample ID	Specimens No	Compressive strength at 28 days (psi)	Average compressive strength (psi)	Change in strength %	
				% Increase	% Decrease
CM	1	3445	3455.33	-	-
	2	3465			
	3	3456			
BM5	1	3396	3349	-	3.07
	2	3275			
	3	3376			

BM10	1	3305	3316	-	4.03
	2	3308			
	3	3335			
BM15	1	3264	3272.33	-	5.29
	2	3272			
	3	3281			
BM20	1	3235	3229.67	-	6.53
	2	3212			
	3	3242			

The figure shows the comparative values in chart form. It shows concrete containing a controlled mix and different prBentonite proportions at 8at eight days' strength.

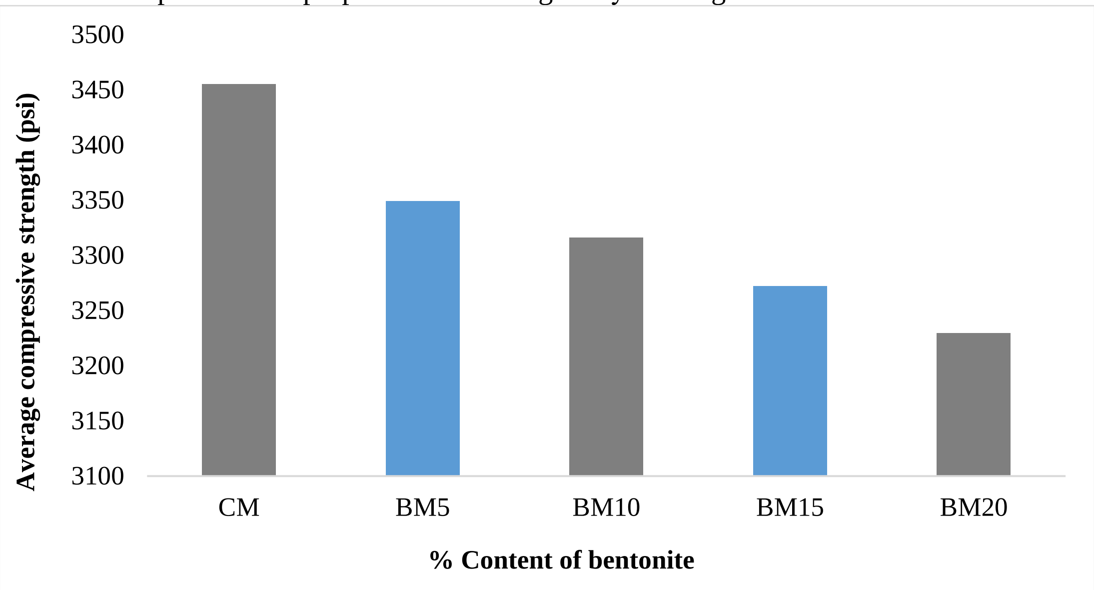


Figure 6: Average Compressive strength at 28 days

3.6. Sulphate attack test on concrete

The ASTM C 1012 test was conducted for acid attack. The concrete cylinder was immersed in the solution to determine the sulphate resistance. The weight loss for the controlled mix was maximum in the sodium sulphate solutions. The poor performance of the controlled mix against the acid attack is because it contains a significant amount of lime, which, upon hydration, releases a considerable portion of free calcium hydroxide that reacts with the acid, and a soft and mushy mass is left behind. In the case of a mix containing Bentonite, the calcium hydroxide reacts with the silica in the bentonite mix to form silica gel; this results in a negligible amount of calcium hydroxide, thus making the Bentonite mix more resistant to acid attack. The trend of weight loss in sodium sulphate solutions was more. The sodium sulphate solution caused more deterioration. It is because, in the case of sodium sulphate, a product called calcium sulfoaluminate (Ettringite) is formed, which expands and hence causes disruption of the set cement paste. The effect of sulphate attack on the properties of concrete was identified in terms of weight loss and strength loss, shown in multiple tables.

Table 10: Loss in Weight after immersion in Sodium Sulphate Solution

Sample ID	Percentage Mass Reduction		
	28th days	56th days	90th days

CM	2.18	1.98	1.84
BM5	1.95	1.72	1.61
BM10	1.62	1.47	1.32
BM15	1.41	1.26	1.08
BM20	1.03	0.98	0.85

The figure graphically shows the reduction in mass of the concrete cylinder of different mixes containing different percentages of Bentonite.

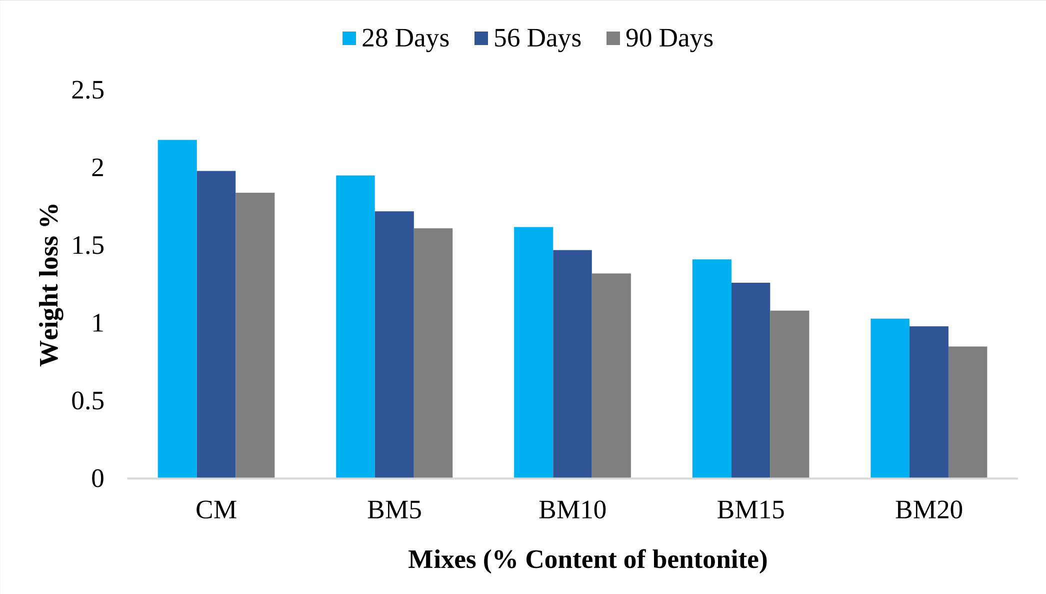


Figure 7: Effect of acid attack on weight loss of different bentonite mixes

3.6.1. Compressive strength after sulphate attack test

The compressive strength of the concrete was determined. The strength of the concrete of different mixes decreased when it was immersed in a sulphate solution. The strength reduction after 28 days is shown in Table 4.9.

3.6.2. Compressive Strength reduction after 28 days (After curing)

Table 11: 28 days' compressive strength test results (sulphate attack)

Sample ID	Specimens No	Compressive strength at 28 days (psi)	Average compressive strength (psi)	Reduction in strength after 28 days
CM	1	2988	2969	14.07
	2	2956		
	3	2965		
BM5	1	3012	3020	9.28
	2	3006		
	3	3042		
BM10	1	3112	3090	6.81
	2	3086		

	3	3074		
BM15	1	3114	3118	4.71
	2	3123		
	3	3119		
BM20	1	3186	3175	1.69
	2	3175		
	3	3164		

The figure graphically shows the average compressive strength reduction value of different mixes of Bentonite after 28 days.

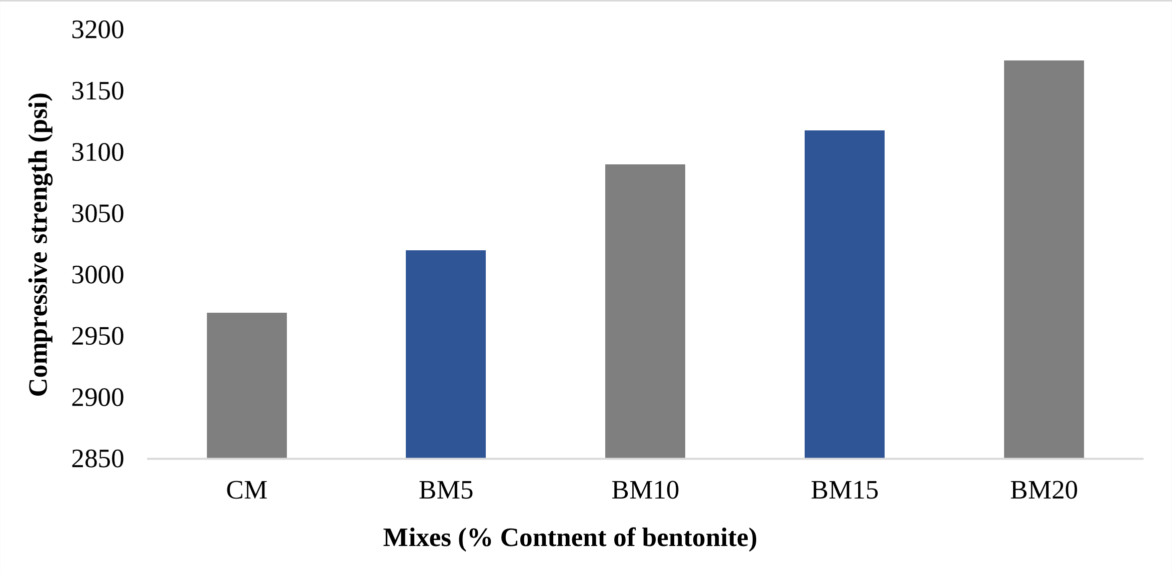


Figure 8: Comparative value of compressive strength at 28 days (Sulphate attack)

3.6.3. Compressive Strength reduction after 56 days (After curing)

The result for strength reduction after 56 days is shown in this table.

Table 12: 56 days' compressive strength test results (sulphate attack)

Sample ID	Specimens No	Compressive strength at 56 days (psi)	Average compressive strength (psi)	Reduction in strength after 56 days
CM	1	3020	3017	12.68
	2	3011		
	3	3021		
BM5	1	3026	3062	8.56
	2	3076		
	3	3084		
BM10	1	3112	3121	5.88
	2	3128		
	3	3123		
BM15	1	3164	3155	3.58
	2	3154		
	3	3149		
BM20	1	3196	3180	1.53

	2	3175		
	3	3169		

The figure graphically shows the average compressive strength reduction value of different mixes of Bentonite at 56 days.

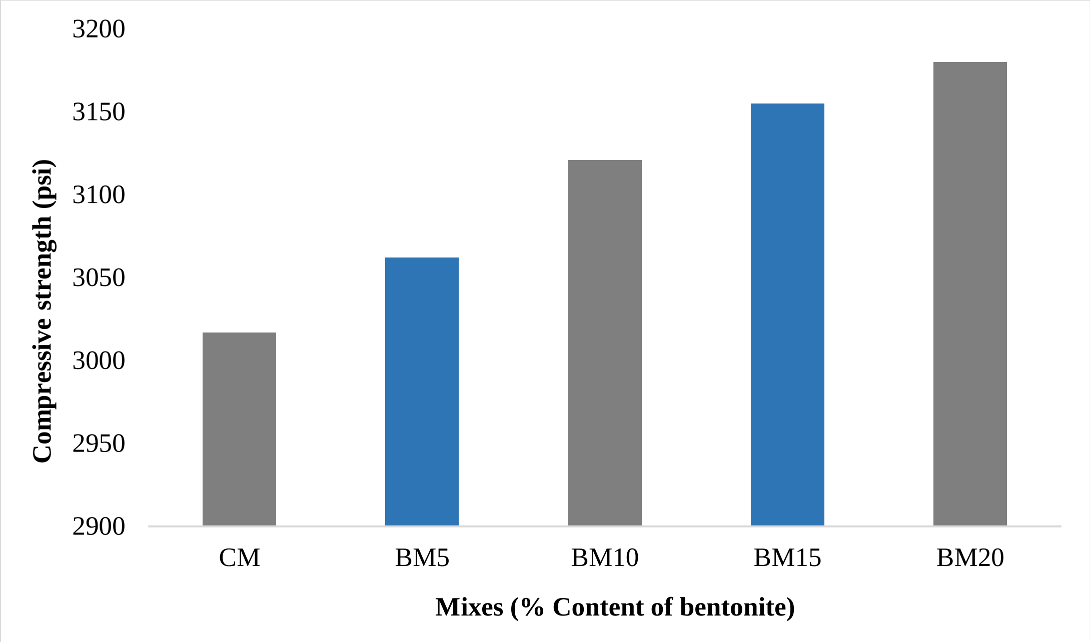


Figure 9: Comparative value of compressive strength at 56 days (Sulphate attack)

3.6.4. Compressive Strength reduction after 90 days (After curing)

Table 13: 90 days' compressive strength test results (sulphate attack)

Sample ID	Specimens No	Compressive strength at 90 days (psi)	Average compressive strength (psi)	Reduction in strength after 90 days
CM	1	3051	3038	12.07
	2	3039		
	3	3025		
BM5	1	3086	3104	7.31
	2	3110		
	3	3116		
BM10	1	3136	3144	5.18
	2	3154		
	3	3142		
BM15	1	3196	3192	2.45
	2	3188		
	3	3192		
BM20	1	3208	3212	0.54
	2	3213		
	3	3217		

The figure graphically shows the average compressive strength reduction value of different mixes of Bentonite at 90 days.

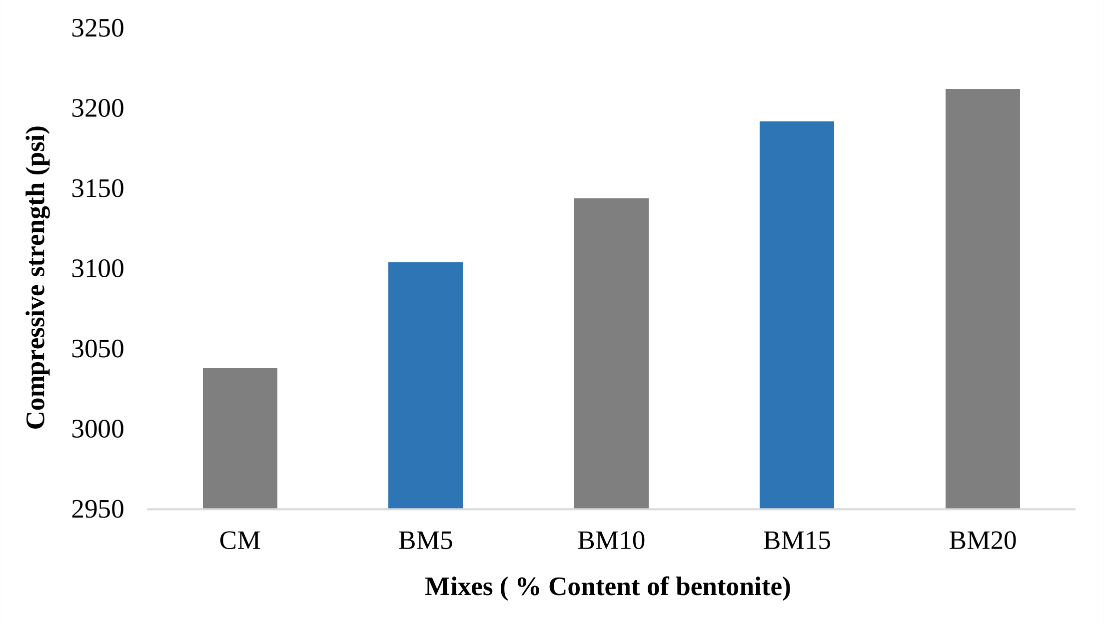


Figure 10: Comparative value of compressive strength at 90 days (Sulphate attack)

3.7. X-Ray Fluorescence test

The X-ray fluorescence test was done on different samples of concrete mix, and the following major elements were found present in different mixes of concrete.

Table 14: XRF test of bentonite sample at 28 days

Serial No.	Major elements (Weight %)	Bentonite	BM 5	BM 10	BM 15	BM 20
1	Na_2O	3.10	2.31	3.18	2.41	1.82
2	Al_2O_3	24.06	15.04	12.56	11.45	14.2
3	MgO	3.97	1.98	1.12	1.02	0.87
4	CaO	5.40	1.21	4.04	12.17	16.02
5	SiO2	56.30	73.54	70.53	66.15	63.2
6	K_2O	2.62	0.99	2.57	1.98	1.63
7	MnO	0.06	0.32	0.89	0.78	0.41
8	P_2O_5	0.15	0.16	1.64	1.13	0.81
9	Fe_2O_3	3.99	3.04	2.04	1.94	1.8
10	TiO_2	0.34	1.41	1.43	0.97	0.24

The above-tabulated value of the element of different mixes of Bentonite is graphically shown in the figure.

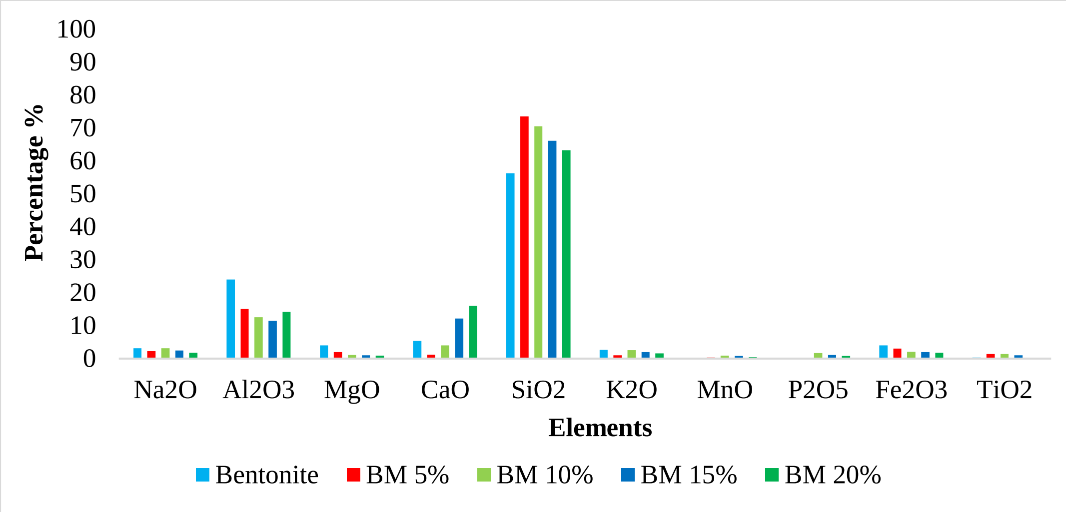
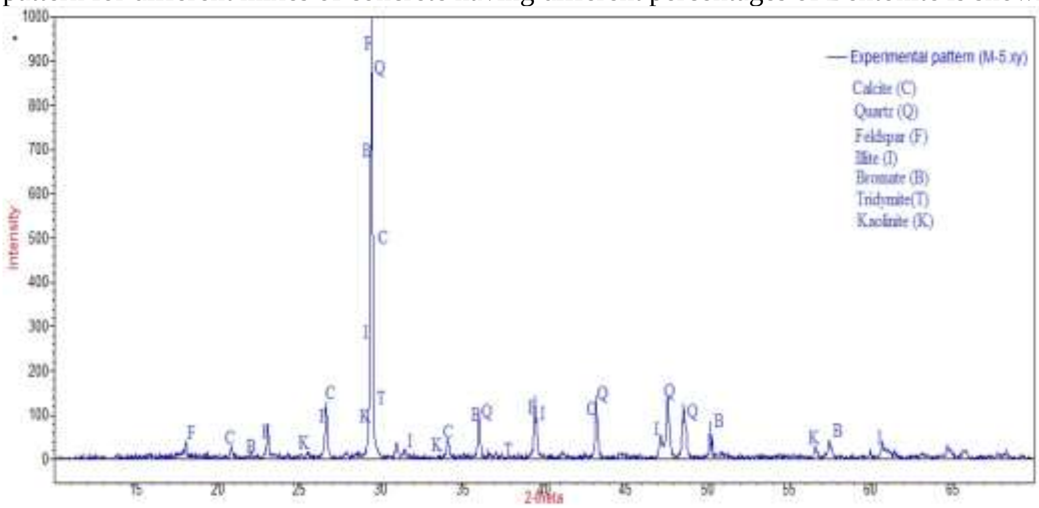


Figure 11: X-ray fluorescence test of different mixes

3.8. X-Ray Diffraction test

The sample of Bentonite was collected from Nizampur, and different mixes of concrete were prepared. Sample for XRD were crushed into powder form. The X-ray diffraction test was done on concrete samples of different mixes having different percentages of Bentonite to determine the mineral composition of the concrete. The characterization of XRD showed us the presence of quartz (Q), calcite (C), feldspar (F), illite (I), kaolinite (K), tridymite (T) and Bromate (B). Scanning electron microscopy (SEM) was done to obtain Bentonite's particle shape and size. The analysis of the scanning electron micrographs showed that the bentonite particles are flaky and elongated. The average length of the particle ranged from 3 to 5 µm, which agrees with that determined by the Laser technique. The XRD pattern for different mixes of concrete having different percentages of Bentonite is shown in the figure.



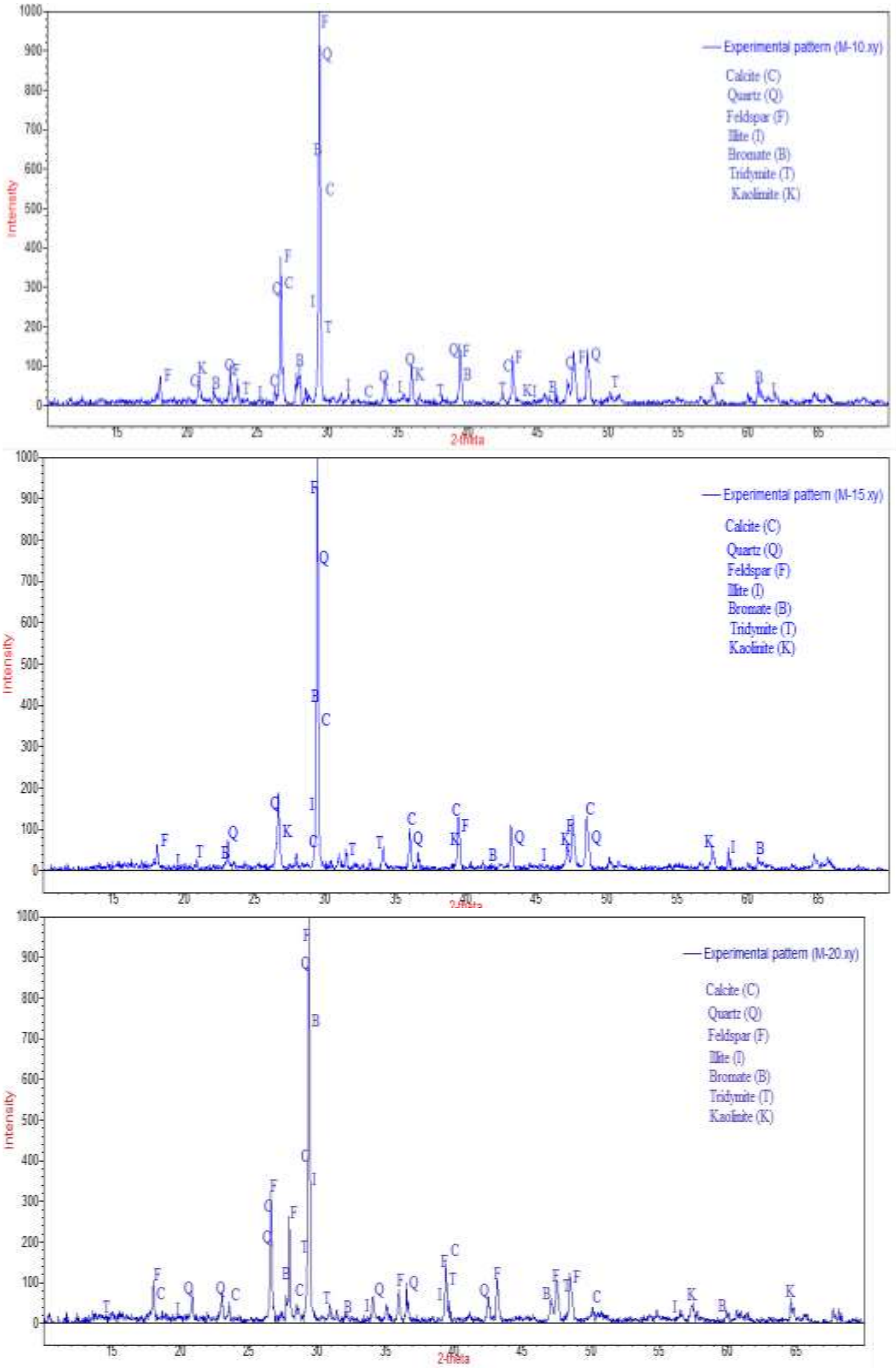


Figure 12: XRD analysis of different mixes at 28 days

3.9. Discussion on an experimental program

First, a mixed design was performed for the concrete cylinder. After this, the concrete cylinders were prepared with different mixes with different percentages of Bentonite. The concrete cylinder was then placed for curing and tested at various ages for compressive strength. The compressive strength result shows us that the early age strength of bentonite concrete was not good, but the later age strength was excellent. After 28 days of compressive strength, the concrete sample was tested for XRF and XRD. The XRF test was done for various elemental analyses, and XRD was used to determine the major and minor minerals present. After this, the sulphate attack test was performed against the sulphate resistance. The concrete cylinder was first kept in water for curing in this test. At 28 days, the cylinder was removed from the water, sodium sulphate solution was prepared, and the cylinder was kept in the acid solution for 28, 56, and 90 days. After that, the weight loss and reduction in the compressive strength of the concrete were determined.

4. Conclusion and Recommendation

4.1. Conclusion

The following conclusions are drawn from this study

- The concrete slump decreases with an increase in the content of Bentonite because Bentonite absorbs relatively more water.
- The compressive strength of the concrete decreases at all ages with an increase in the bentonite content.
- The Cement replaced by Bentonite gives better durability results in sulphate solutions than the control mix.

4.2. Recommendations and suggestions for future work

- It is suggested that further research be carried out to determine the optimum heating temperature for Bentonite, which can be used successfully to improve the properties of concrete.
- Also, studies on the crushing of Bentonite should be carried out to determine its properties in the resulting concrete.
- Other percentages of Bentonite and fly ash should be worked out to attain better results for strength and durability.
- Similar research needs to be done on Chloride ingress in concrete using Bentonite instead of Cement.

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References

1. G R. M. Andrew, “Global CO 2 emissions from cement production,” Earth Syst. Sci. Data, vol. 10, pp. 195–217, 2018
2. R. Siddique, “Utilization of industrial byproducts in concrete,” Procedia Engineering, vol. 95, no. Scescm. Elsevier B.V., pp. 335–347, 2014.
3. K. Nizar, H. Kamarudin, and M. Sobri Idris, “Geopolymer lightweight aggregate View project Electrodes for Li-ion batteries View project,” 2007
4. Guttikunda, S. K., & Jawahar, P. (2014). Atmospheric emissions and pollution from the coal-fired thermal power plants in India. Atmospheric Environment, 92, 449-460.

5. Akbar, J.; Alam, B.; Ashraf, M.; Afzal, S.; Ahmad, A.; Shahzada, K. Evaluating the Effect of Bentonite on Strength and Durability of High Performance Concrete. Int. J. Adv. Struct. Geotech. Eng. 2013, 2, 1–5. [Google Scholar]
6. Shihada, S. Effect of polypropylene fibers on concrete fire resistance. J. Civ. Eng. Manag. 2011, 17, 259–264. [Google Scholar] [CrossRef]
7. Lau, A.; Anson, M. Effect of high temperatures on high-performance steel fibre reinforced concrete. Cem. Concr. Res. 2006, 36, 1698–1707. [Google Scholar] [CrossRef]
8. Baloch, W.L.; Khushnood, R.A.; Memon, S.A.; Ahmed, W.; Ahmad, S. Effect of elevated temperatures on mechanical performance of normal and lightweight concretes reinforced with carbon nanotubes. Fire Technol. 2018, 54, 1331–1367. [Google Scholar] [CrossRef]
9. Xu, Y.; Wong, Y.; Poon, C.S.; Anson, M. Impact of high temperature on PFA concrete. Cem. Concr. Res. 2001, 31, 1065–1073. [Google Scholar] [CrossRef]
10. Andrejkovičová, S.; Alves, C.; Velosa, A.; Rocha, F. Bentonite as a natural additive for lime and lime–metakaolin mortars used for restoration of adobe buildings. Cem. Concr. Compos. 2015, 60, 99–110. [Google Scholar] [CrossRef]
11. Memon, S.A.; Arsalan, R.; Khan, S.; Lo, T.Y. Utilization of Pakistani Bentonite as partial replacement of Cement in concrete. Constr. Build. Mater. 2012, 30, 237–242. [Google Scholar] [CrossRef]
12. Mirza, J.; Riaz, M.; Naseer, A.; Rehman, F.; Khan, A.; Ali, Q. Pakistani bentonite in mortars and concrete as low cost construction material. Appl. Clay Sci. 2009, 45, 220–226. [Google Scholar] [CrossRef]
13. Ozyildirim, C., 1998, "Permeability Specifications for High-Performance Concrete Decks," TRR 1610, Concrete in Construction, Transportation, Research Board, pp. 1-5
14. Amran, M., Huang, S. S., Onaizi, A. M., Makul, N., Abdelgader, H. S., & Ozbakkaloglu, T. (2022). Recent trends in ultra-high performance concrete (UHPC): Current status, challenges, and future prospects. Construction and Building Materials, 352, 129029.
15. Bassuoni, M. T., & Nehdi, M. L. (2009). Durability of self-consolidating concrete to different exposure regimes of sodium sulfate attack. Materials and Structures, 42, 1039-1057.
16. Kijjanon, A., Sumranwanich, T., Saengsoy, W., & Tangtermsirikul, S. (2023). Chloride penetration resistance, electrical resistivity, and compressive strength of concrete with calcined kaolinite clay, fly ash, and limestone powder. Journal of Materials in Civil Engineering, 35(3), 04022462.
17. Khan, A.N. and Riaz, M., 2003. Use of karak bentonite as partial replacement of Cement. Journal of engineering and applied sciences, 22(2).
18. Badshah, E., 2003. Use of Jehangira bentonite as partial replacement of Cement (Doctoral dissertation, MSc. Thesis, UET Peshawar).
19. Mirza, J., Riaz, M., Naseer, A., Rehman, F., Khan, A.N. and Ali, Q., 2009. Pakistani Bentonite in mortars and concrete as low cost construction material. Applied Clay Science, 45(4), pp.220-226.

List of Abbreviation

ASTM	American Society for Testing and Materials
CM	Control Mix
BM	Bentonite Mix
BM5	Bentonite Mix by 5 Percent
BM10	Bentonite Mix by 10 Percent
BM15	Bentonite Mix by 15 Percent
BM20	Bentonite Mix by 20 Percent