Chapter

Bentonite Clay Modified Concrete

Metta Achyutha Kumar Reddy and Veerendrakumar C. Khed

Abstract

Replacing cement with pozzolanic materials to some extent in construction is found to be one of the sustainable approaches in the construction industry. Pozzolanic materials of industrial origin like fly ash and Ground Granulated Blast furnace Slag will have to be replaced with natural pozzolanic materials once the world moves towards renewable energy sources. Bentonite is one such pozzolanic clay material that is rich in SiO_2 content. A little research was made to assess the performance of bentonite modified concrete. Based on those, an improvement in the fresh, hardened, durability properties was reported. This chapter presents the current scenario on the development of bentonite modified concrete. It also reviews the literature about the physical & chemical properties of bentonite, bentonite blended cement mortar, bentonite modified cement concrete, and reinforced concrete. The history and development of Bentonite modified concrete were also briefly presented in this chapter.

Keywords: bentonite clay, bentocrete, workability, strength, durability

1. Introduction

A developing country like India must cater to the construction activity of buildings, bridges, transport facilities, industrial units, and many more on a vast scale. The spiraling costs of such building materials as cement and reinforcing steel hurt the development activity [1].

Cement and construction industries were generating 7–8% of CO_2 emissions globally by manufacturing cement and production of concrete [2]. The utilization of industrial wastes as pozzolanic materials in concrete to enhance workability, strength, and durability emissions became a trend since the early 1980s [3]. The generation of industrial wastes would not have happened if the industries had been shut down [4]. The Discovery of alternatives to the pozzolanic materials generated from industrial wastes was needed. Bentonite is clay, contains a rich amount of SiO_2 [5]. It could be used natural pozzolanic material instead of industrial wastes if the generation was shut down permanently [6]. There have been a few experiments in the past to see if bentonite could be used in concrete. The investigations began in Pakistan and were later expanded by several countries [7, 8]. The use of bentonite in concrete was shown to have favourable benefits in terms of strength and durability [9, 10].

This chapter presents a review of available and related published literature on the properties of bentonite. It also reviews the literature about the physical & chemical properties of bentonite, bentonite blended cement mortar, bentonite modified

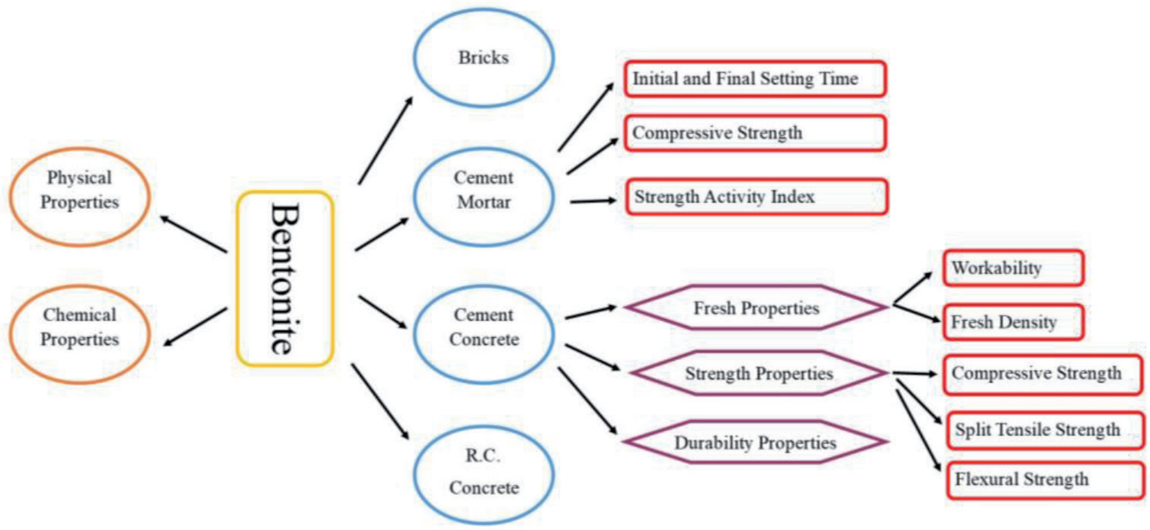

Figure 1.
Overview of the chapter.

cement concrete, and reinforced concrete. The history and development of Bentonite modified concrete were also briefly reviewed in this chapter, **Figure 1** shows the overview.

2. Bentonite

Bentonite is an earth mineral that shows expanding conduct and follows Pozzolanic properties [11, 12]. Huge amounts of bentonite assets are accessible everywhere. It has huge applications in penetrating liquids, foundries, glues, fading earth, earthenware production, etc. [13]. Mirza Initiated the exploration work by involving bentonite as a substitute material to solidify in concrete in 2009 [14]. A lot of examinations were done by scientists from various areas all through the globe. They announced a few realities connected with bentonite use because of the test results [15]. Most of the authors utilized Pakistani bentonite accessible from various areas of Pakistan. Mirza et al. [14] incorporated Karak bentonite in concrete, investigated the properties of concrete. Ahmad et al. [16], employed Jahangira bentonite in concrete and evaluated the properties of cement mortar. Afzal et al. [17] utilized Khyber bentonite in concrete assayed the autogenous shrinkage strain. Lima-Guerra et al. [18] developed concrete using bentonite from the Amazon region of Brazil. Production of artificially expanded clay aggregates is also possible by making use of bentonite [19].

2.1 Physical properties

Bentonite is for the most part accessible in different shadings and structures. A Few creators announced with regards to the shading. In their exploratory work, Mirza et al. [14] used greenish dim and searing green bentonite while light yellow-shaded bentonite was of bentonite used Ahmad et al. [16]. **Table 1** shows the outline of the actual properties of bentonite detailed by certain authors. Practically all creators revealed various qualities. The explanation for this trait is to change in the area of the source.

S. No.	Property	[10]	[14]	[16]	[20]
1	Specific gravity	2.82	2.63	2.44	2.79
2	Average particle size	4.75 µm	17% retained on # 325 mesh	13.5% retained on # 325 mesh	4.32 µm
3	Blains fineness (cm2/ gm)	4800	—	2689	4800

Table 1.
Physical properties of bentonite.

	Property	[10]	[9]	[11]	[12]	[14]	[15]
1	Silicon dioxide	54.55	49.44	65	49.63	52.1	51.11
2	Aluminum Oxide	20.19	19.7	15	21.11	13.4	16.83
3	Ferric Oxide	8.60	6.2	3	3.23	7.5	7.65
4	Magnesium Oxide	4.20	1.61	6.5	12.56	2.64	7.57
5	Calcium Oxide	7.28	7.45	2.66	3.59	12.0	6.60
6	Sodium Oxide	1.27	0.87	0.12	0.44	-	0.29
7	Potassium Oxide	3.92	0.63	0.27	2.09	2.64	1.34
8	Phosphorus pentoxide	1.107	-	-	0.11	-	0.29
9	Titanium Oxide	0.91	-	-	0.49	-	1.29
10	Loss on Ignition	5.42	13.74	6	-	8.61	6.75

Table 2.
Chemical properties of bentonite.

2.2 Chemical properties

The chemical composition shows a huge effect on the mechanical properties of concrete. **Table 2**. displays the chemical properties of bentonite. The studies reveal a larger amount of SiO_2 presence, $Al2O_3$ as a second focal component in bentonite. It prompts the occurrence of a pozzolanic reaction during the hydration process. Most of the researchers revealed that those are inside limits. 13.74 LoI esteem was accounted for by Mirza et al. [14], which is the only value not within the allowable limits.

3. Bentonite modified cement mortar

The bentonite's behavior in concrete mortars like consistency, introductory and last setting times, strength activity, and compressive strength was accounted for in a few investigations.

3.1 Normal consistency

Bentonite shows 75% as consistency value while Ordinary Portland Cement (OPC) accomplishes at 30–35%, 21 percentage bentonite-OPC combination achieves 35% consistency was accounted for by Memon et al. [10]. Nonetheless, it has been seen that the consistency is straightforwardly relative to how much bentonite is added [21].

3.2 Initial and final setting time

Generally, Initial & final setting time tests will be performed as per standard procedure IS 4031. Upon testing, bentonite displays 68 and 190 minutes where shown OPC 43 and 125 minutes after expansion with water [15]. Beginning and last setting times expanding by expansion bentonite to solidify. The expansion of bentonite to the concrete mortar upgrades the yield pressure of new concrete mortar [22].

3.3 Strength activity index

Mirza et al. [14] directed a few tests on strength activity index according to standard method ASTM C618 for bentonite blends at various temperatures, shown in **Figure 2**. A more prominent strength activity index was seen in 150°C warmed bentonite contrasted and various temperatures. Ahmad et al. [16] revealed 87.3 and 85.23% SI for bentonite at 7 years old and 28 days. 3% bentonite-concrete blends show better strength activity index at 7days, remaining stirs up to 21% displays best similarly among all mixes. A slight decrement in the strength action was seen by bentonite joining in concrete mortars [23].

3.4 Compressive strength

Mirza et al. [14] performed tests as per ASTM C109, which announced that 150°C warmed 20% bentonite-concrete blends accomplish great compressive strength at 7 years old and 28-days remaining blends shown lower than control concrete mortar, displayed in **Figure 3** [9]. Ahmad et al. [16] led probes bentonite blends at room temperature and 500°C; all blends have shown lower compressive strength than the control blend. The concrete mortar containing 20% bentonite shows more compressive strength than control concrete mortar [24]. 30% bentonite-concrete blends show

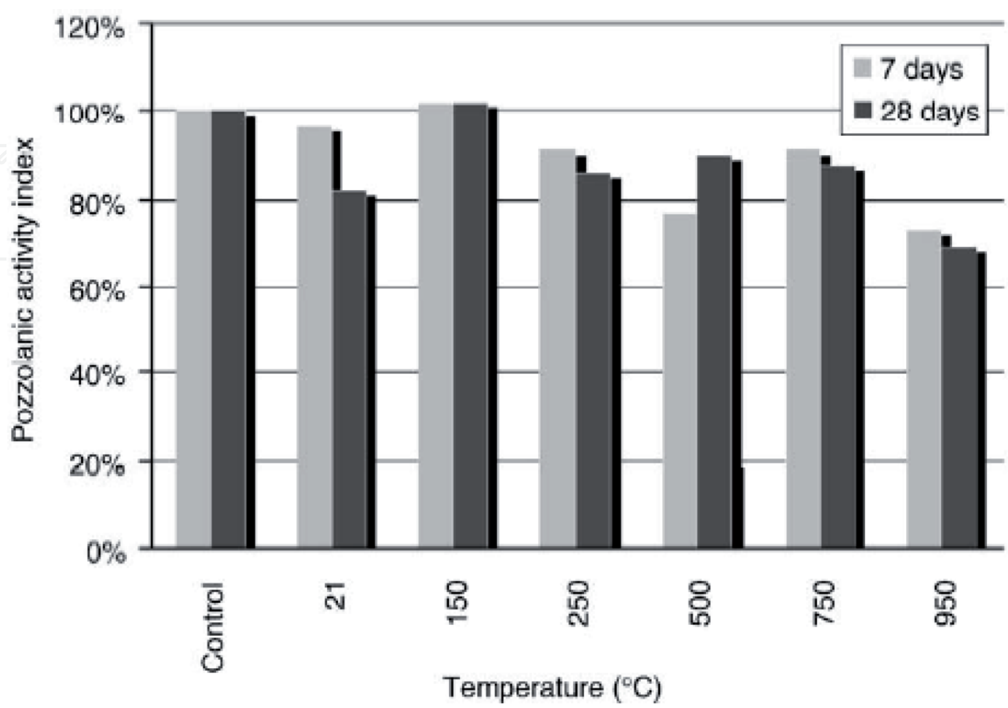

Figure 2.
Strength activity Indices of different bentonite mixes [14].

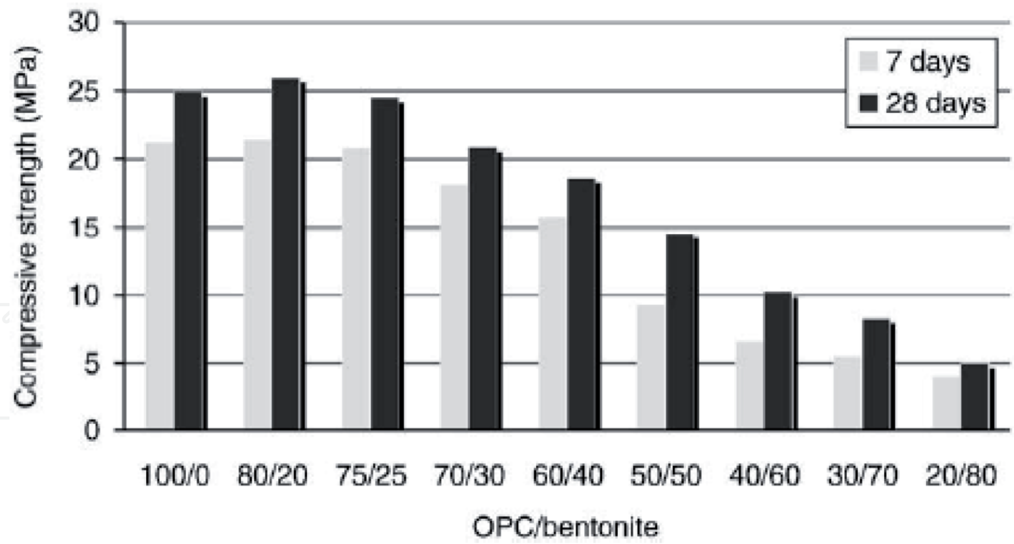

Figure 3.
Compressive strength of different bentonite mixes [14].

higher protection from $MgSO_4$ and Na_2SO_4 [11]. Reddy et al. [25] revealed that 20% bentonite-concrete blend showed ideal compressive strength following 3, 7, and 28 days relieving among all mixes [25]. Bentonite adjusted concrete mortar shows lower compressive strength than control concrete mortar in adjustment sewage slime [26]. Better compressive strength was shown by bentonite adjusted concrete mortar in the redesign of adobe structures over metakaolin [27].

4. Bentonite clay bricks

An attempt was made to manufacture eco-friendly bricks using a combination of bentonite, clay, and lime. Bentonite content was considered as a variable, the properties of the brick were essayed. 31.91% of the carbon footprint was reduced by 20% of

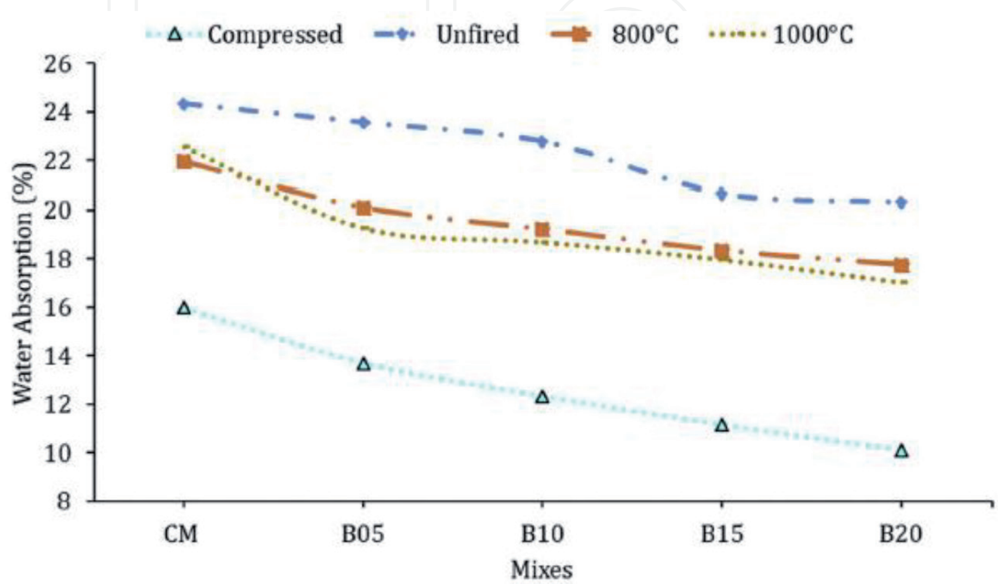

Figure 4.
Water absorption of clay, unfired and fired bricks [28].

bentonite replacement with clay. The durability of the bricks enhances by the incorporation of bentonite in bricks manufacturing. Water absorption was also reduced by improving the percentage of bentonite substitution, displayed in **Figure 4** [28].

5. Bentonite modified cement concrete

5.1 Fresh properties

1–2% on cement quantity addition of sodium bentonite to cement concrete will improve the workability and segregation of concrete can be avoided [7]. Later, plenty of examinations were made to measure workability precisely. The elastic modulus was reduced by more than 15 percent of bentonite for the plastic concrete [29].

5.1.1 Workability

A radical lessening in workability was seen at higher rates (least of 20%) of bentonite replacement in concrete. Bentonite usage was done in bring down rates (0–21 at 3% stretch) by Memon et al. [10]; he prescribed utilizing superplasticizer expected to upgrade workability, slump values were displayed in **Figure 5**. The addition of a superplasticizer can attain the desired workability. Production of bentonite modified concrete is also possible by using recycled crushed aggregates [30]. The concrete made with crumb rubber and bentonite also exhibits decrement in workability [31].

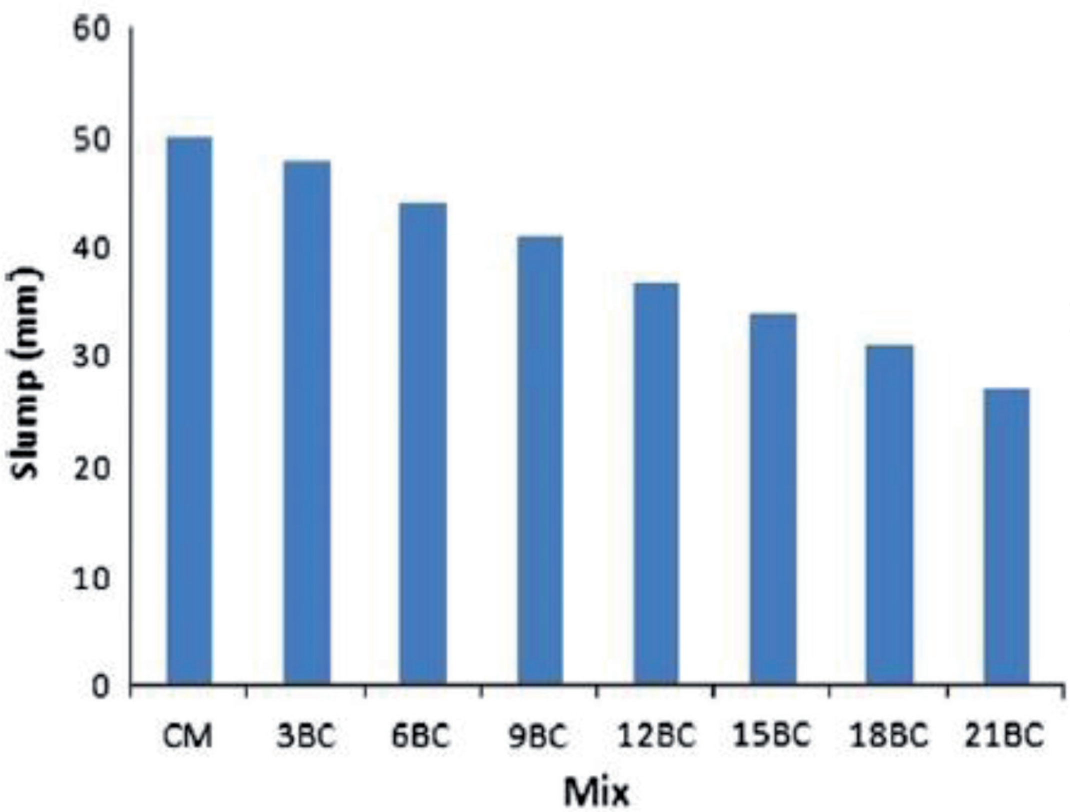

Figure 5.
Slump values of all mixes [10].

5.1.2 Fresh concrete density

The fresh concrete density was decreased upon increasing the bentonite content in concrete. The density values are displayed in **Figure 6**. It is attributed to the lower specific gravity of bentonite, examined by standard procedure ASTM C642 [10].

5.2 Hardened properties

A lot of studies detailed the impact of bentonite on the mechanical properties of hardened concrete. Compressive strength was measured at various periods of concrete. Resistance of cement was tried and detailed under different climatic conditions. Most studies revealed that lower qualities were seen by the addition of bentonite at early ages (3,7 and 28 days), the better exhibition displayed at later ages (56 and 90 days) of restoring similarly with control concrete.

5.2.1 Compressive strength

Mirza et al. [14] conducted investigations by altering bentonite (0–50%) at room temperature and warmed at 150°C for 3 hours. Ahmad et al. [16] explore bentonite warmed at 500°C. They announced that 20% of bentonite (warmed at 150°C for 3 hours) subbed substantial blends display better compressive strength at 28 days restoring among all. The compressive strength of cement is straightforwardly corresponding to the temperature at which bentonite was warmed for 3 hours. Khushnood et al. [20] announced warmed bentonite mixed substantial blends showed higher compressive strength than crude bentonite. Memon et al. [10] analyzed up to 21% bentonite replacement, revealed that lower compressive strength shows at 3 years old, 7day, better compressive strength displayed at 28, 56 days in the wake

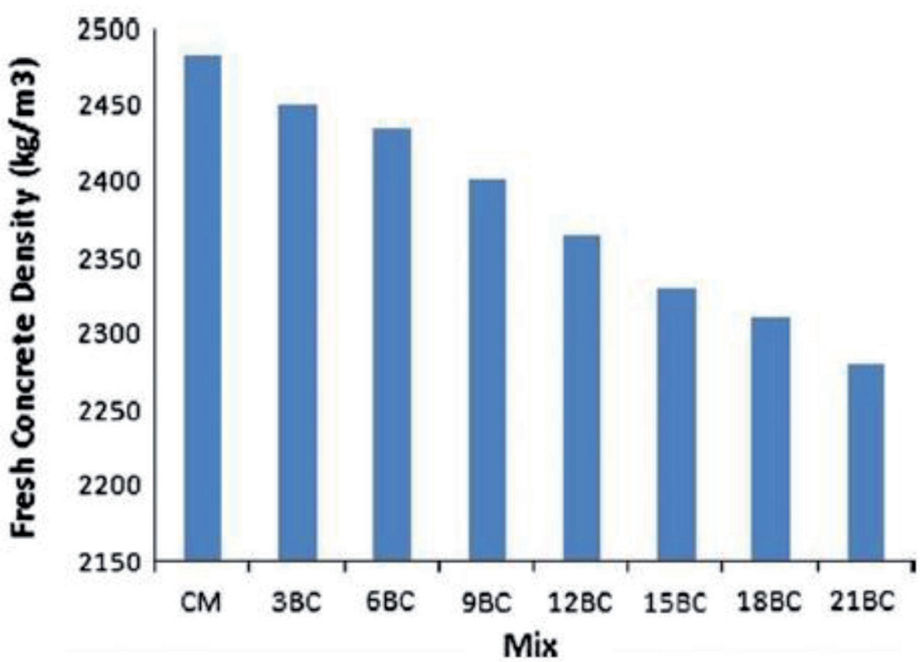

Figure 6.
The fresh concrete density of all mixes [10].

of relieving, shown in **Figure 7**. Akbar et al. [32] researched at 20% bentonite replacement, poor compressive strength results were accounted for while contrasting and control blend.

Reddy et al. [25] utilized 10–30% bentonite replacement at 5% stretches. Tests were led, detailed that lower compressive strength was noticed for mixed blends among all. It was seen that 30% of bentonite substitution brings about higher compressive strength than control mix [3, 33]. Divyana [34] and Kadar and Dhanalakshmi [35] detailed that 20% bentonite replacement showed more noteworthy compressive strength than control blend [34, 36]. Chamundeeswari [37] and Selvaraj and Priyanka [38] announced that bentonite expansion diminishes in compressive strength of cement. Chandrakanth et al. proposed that 5% bentonite expansion accomplishes the greatest compressive solidarity to the substantial [39]. Aravindhraj and Sapna proposed that a 15-half bentonite-quarry dust combination shows the most extreme compressive strength at 28 days [40].

Shabab et al. [5] examined bentonite-fly ash mixes, stated that the concrete contains an equivalent combination (50–50%) of bentonite and fly ash displays improved outcomes at the age of 90 days, displayed in **Figure 8** [5, 41]. Bentonite modified concrete has shown better compressive strength in lateral days even though the performance was poor in the early days [32, 42]. Bentonite replacement can be done up to 10% in the making of concrete combined with waste rubber tires [43]. The addition of bentonite in the concrete showed a better result than wheat straw ash (WSA) as a supplementary cementitious material, shown in **Figure 9** [44]. An optimal bentonite substitution percentage was found as 2.7 while using the combination of kaolin and slag [45]. In foamed concrete, it was observed that more than 10% bentonite replacement would result from the decrement in compressive strength, and fluidity can be improved by more than 20% bentonite substitution [46].

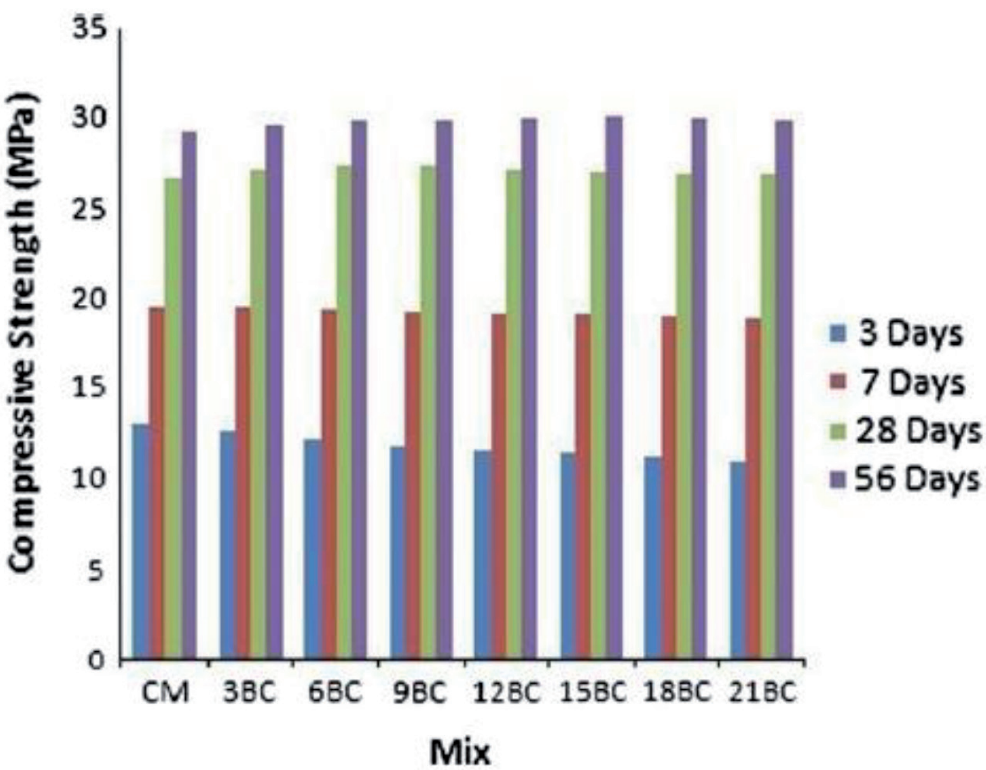

Figure 7.
Compressive strength of bentonite mixes [10].

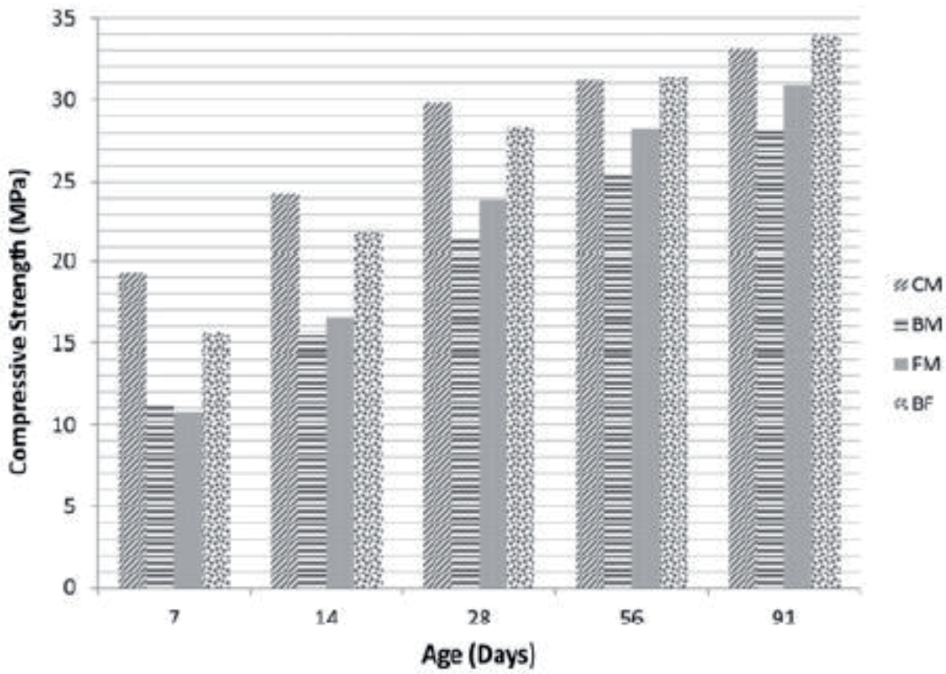

Figure 8.
Compressive strength of bentonite-fly ash mixes [5].

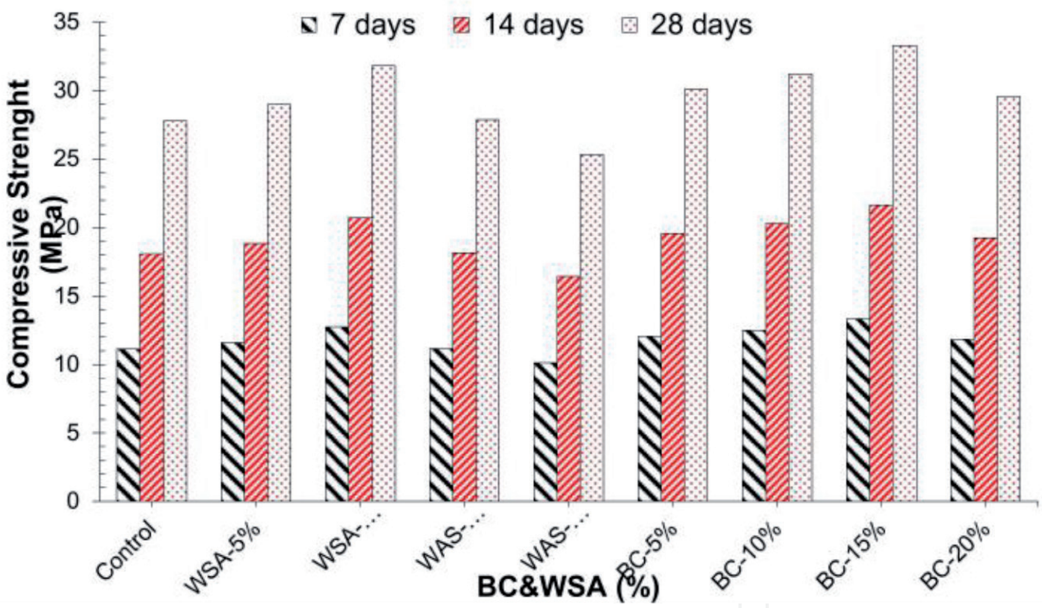

Figure 9.
Compressive strength results of WSA & bentonite clay concrete [44].

5.2.2 Split tensile strength

Karthikeyan et al. [47] detailed that 30% replacement of bentonite brings about the most extreme split tensile strength to concrete, showed in **Figure 10**. Reddy et al. [25] led tests according to standard technique IS5816, revealed that lower split tensile strength was seen in bentonite mixed blends. Divyana [34] revealed that better-parted rigidity was accomplished by 20% bentonite substitution. Mohammed et al. [36] tried on bentonite-steel slag blend with different extents, detailed that 20–60% bentonite-steel slag mixtures [35]. Chandrakanth et al. [39] revealed that 5% bentonite expansion further develops results split tensile strength of cement.

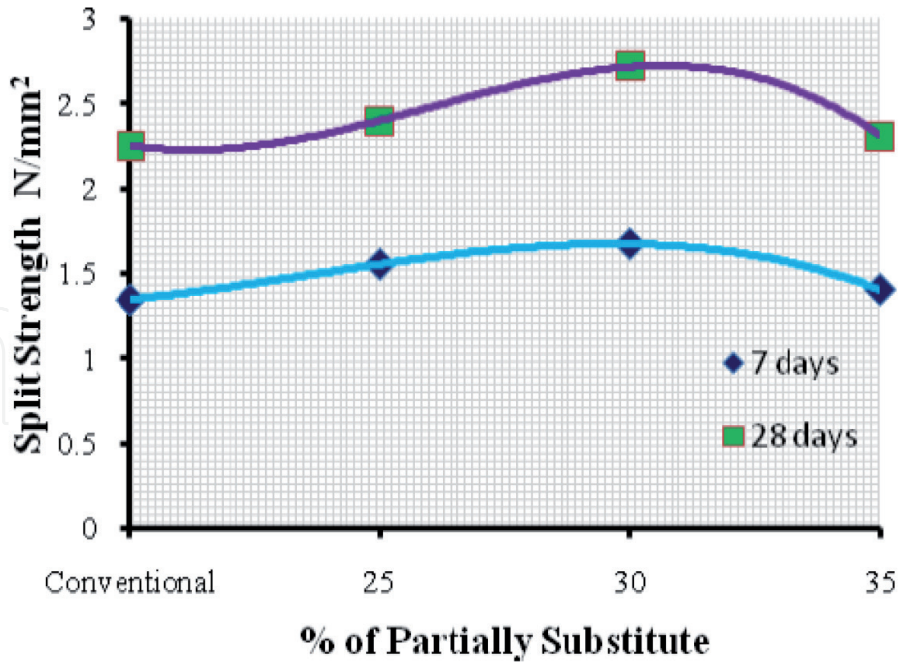

Figure 10.
Split tensile strength of bentonite mixes [47].

5.2.3 Flexural strength

Mirza et al. [14] and Khushnood et al. [20] detailed that no change in flexural strength was seen by warmed bentonite over crude bentonite, a decline in flexural strength was accounted for by the expansion of bentonite to concrete. Karthikeyan et al. [47] announced a slight augmentation in flexural strength upon bentonite expansion. 30% replacement displays the greatest flexural strength among all blends. Chandrakanth et al. [39] revealed that 5% of bentonite expansion works on the flexural strength of cement. All a large portion of the creators detailed no impact of bentonite replacement. Memon et al. [10] detailed a diminishing in water assimilation by expanding the level of bentonite mixing.

5.3 Durability

Durability shows a pivotal job when cement is presented to outrageous conditions [48]. A couple of examinations were done on the toughness of bentonite mixed cement-like sulfate attack, corrosive attack, and salt attack. Memon et al. [10] tried bentonite mixed cement (0–21% @3 span) against hydrochloric corrosive and Sulfuric corrosive. They revealed that obstruction is straightforwardly corresponding to bentonite mixing (up to 21%). Mirza et al. [14] concentrated on the impact of bentonite (20–80% @20intervel). Ahmad et al. [16] inspected structure 20–50% @10intervel against 2% $MgSO_4$ and 5%Na_2SO_4. They announced that substantial obstruction is expanded against sulfate by adding bentonite around 20–30%. Sreeniva et al. detailed that 15% bentonite mixed cement showed superb opposition against hydrochloric acid [49]. They also recommend that bentonite use results decline in opposition against NaOH. Swarup et al. revealed that the bentonite-fly debris (50–50%) mixed cement showed helpless obstruction against hydrochloric corrosive and NaOH [50].

6. Bentonite modified reinforced cement concrete

Mirza et al. [14] played out a test on the R.C.C beam having a design load of around 40 kN with a three-point loading, load versus deflection plots shown in **Figure 11**. R.C.C beams were cast by using 20% bentonite, 25&40% (warmed at 150°C for 3 hours) bentonite with OPC. They detailed those lower ultimate strengths were seen in bentonite mixed cement beams.

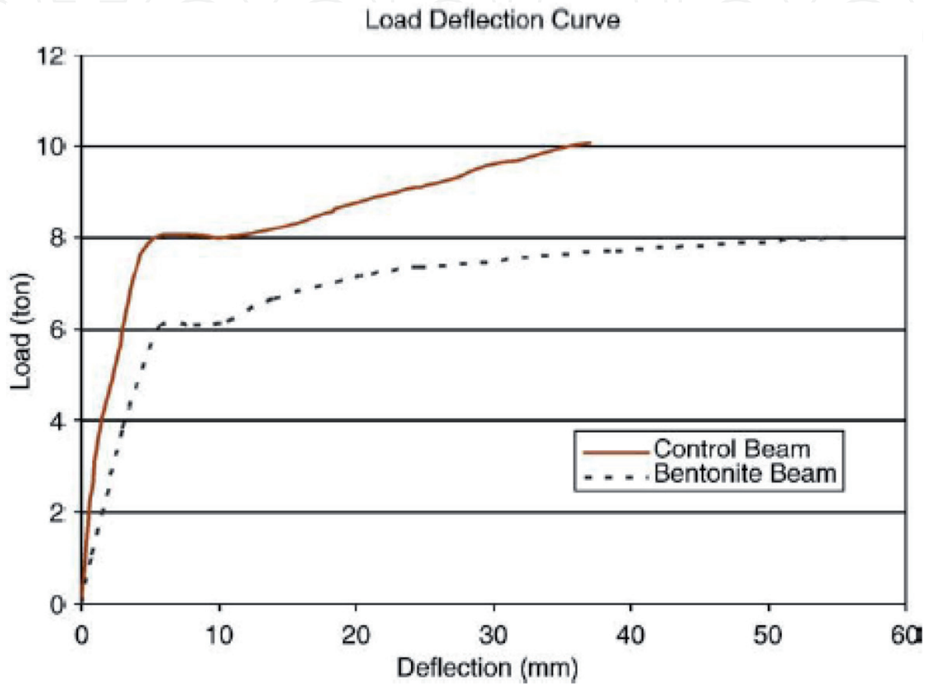

Figure 11.
Load vs deflection curve of concrete and bentonite modified concrete.

7. Conclusions

In this chapter, the current scenario on the development of bentonite modified concrete was presented. It also reviews the literature about the physical & chemical properties of bentonite, bentonite blended cement mortar, bentonite modified cement concrete, and reinforced concrete. The history and development of Bentonite modified concrete were also briefly presented.

8. Further research and recommendations

Based on the discussions, additional areas of research are identified to increase the understanding the' behavior. of bentonite modified concrete These areas of research include:

- Durability aspects of reinforced bentonite modified concrete columns.
- Fire resistance of bentonite modified concrete columns.

- Improvement of workability by adding suitable admixtures
- Development of bentonite-based geopolymer concrete.
- Effect of sustained loads.
- Effect of loading rate.

Conflict of interest

The authors declare no conflict of interest.

Acronyms and abbreviations

BC	Bentonite modified concrete
OPC	Ordinary Portland Cement
SEM	Scanning Electron Microscope
XRD	X-ray diffraction
ASTM	American Society Testing Method
C-S-H	Calcium-Silicate-Hydrate
MPa	Mega Pascal
kN	Kilo Newton
IS	Indian Standard

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