Review of application of plain and calcined bentonite as a cement blending material in concrete and mortar

Mayur Madhukar Maske[1*], Dr. Nandkumar Krishnarao Patil[2], Dr. Amey Deepak Katdare
[1]Ph. D. Scholar, School of Civil Engineering, SGU, Atigre and Assistant Professor, RIT, Rajaramnagar, India
[2]Ph. D. Guide and Registrar, SGU, Atigre, India
[3]HoD, Department of Civil Engineering, SGU, Atigre, India
[1]mayurmaske@gmail.com

ABSTRACT

The construction industry been growing at a rate of 5 to 6% in last 05 years. Cement is the major and second most expensive materials amongst all construction materials. Also production of cement very high amounts of CO2 emissions. Hence replacing cement without negatively affecting strength and durability properties cloud be an effective approach to solve the above issues. Out of the many materials used for cement blending bentonite possesses a potential to partially replace cement in production of concrete and mortar effectively.

Bentonite is a clay mineral which finds its use in variety of industrial applications. Here an attempt has been made to summarize the experimental results by many of the researchers to partially replace cement with plain and calcined bentonite. In the literature the concrete and mortars samples were experimentally tested for strength, workability and various durability properties

Keywords
Concrete; bentonite; Durability; SAI; Calcined bentonite; cement blending.

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Introduction

Concrete is the most utilized manmade material in the world, overall it is only second to water in terms of worldwide consumption. For each m3 of concrete 380 to 450 kg of cement is need to be used as per the recommendations specified by IS:456-2000, apart from this a cement is used in mortar manufacturing and further applications. Thus the cement requirement and production is also very huge. India is the second largest cement producer in the world and accounts for over 8% of the global installed capacity, as of 2019, in FY 2020 India has produced 334.48 MT of cement and it is estimated that the production will touch 550MT in the next fiscal term [32]
As cement manufacturing needs temperatures as high as 1500˚C, energy consumption is very high for the clinker formation process, for each tonne of cement 4 GJ of energy is spent [23]. Also large amount of CO2 is liberated during the manufacturing process due to burning of fuel and lime at higher temperatures [1, 4, 5] as given by following equation,

$$5\ CaCO_3 + 2SiO_2 \xrightarrow{1500^0C} (3Cao.SiO_2)\ (2Cao.SiO_2) + 5CO_2\uparrow \qquad (1)$$

From the stoichiometry of above reaction, it is clear that for producing one molecule of C3S and C2S five molecules of CO2 are produced. studies have shown that for each tonne of cement manufactured nearly a tonne CO2 is produced studies have pointed out that, 5 to 8% of the global anthropogenic CO2 emissions are attributed to cement manufacturing. Thus the cement manufacturing industry amounted for nearly 330 MT of carbon dioxide in 2019.
According to Mehta et. al. [23], one of the most effective methodologies to cut down the CO2 emissions accompanying with cement manufacture is to increase the use of blended cements in production of concrete and mortar. In the manufacture of blended cements, using plain or activated clay as a blending material can prove to be an apt solution. As activation requires a lower amount of energy to activate the clay as compared to the required energy for producing cement. Clays like kaolinite, bentonite, dolomite, goethite, cristobalite and palykorskite etc. have been studied by various researchers for the usage as a cement blending material and a lot of research is still going on in this domain. This paper deals with review of use of bentonite clay to use as cement blending material.

Literature Review

A. Morphology of Bentonite clay

The formation of bentonite has its origin in volcanic and hydrothermal activities [2]. It has wide industrial applications in chemical and ceramic productions thanks to its cohesive, bonding and rheological characteristics it is used in the desiccators or dehydrator beds for several gases. Knight (1897)
coined the term bentonite. It is a colloidal clay and natural pozzolana, majorly containing montmorillonite along with supplementary minerals like gypsum, pyrites, cristobalite, mica, calcite, crystalline quartz, feldspars, volcanic glass and organic matter. Paluszkiewicz et. al. (2008) [12] published that, montmorillonite [(Al, Mg)2(OH)2(Si, Al)4O10(Ca)x N.H2O] is a 2:1 layer alumino-oxygen-silicate ideally comprising of one octahedral sheet of alumina sandwiched between two silica-oxygen tetrahedral sheets. As per Van Olphen, (1977) the montmorillonite particles are flat platelets and structurally exist in two styles namely,

1. Card-house structure, and
2. Card-pack structure

The degree of formation of the two structures is governed by the chemical characteristics and the pH of bentonite solution [2].

B. Physico- Chemical properties of Bentonite

Mesboua et al. (2018) [2] studied the particle size distribution of bentonite samples (Algerian bentonite) using laser granulometry technique developed in 1970s which is an accurate and effective method for measuring particle sizes between 0.05 to 900 µm. Their experiments have shown that particle size range for bentonite 0.2µm to 200µm, leading to the inference that bentonite contains a sufficient amount of fine particles enabling it to be used in cement replacement. Similar results have been presented by Laidani et. al., (2020) regarding the particle size of bentonite.
The chemical composition of bentonite was compared with to that of OPC by researchers [1, 2]. The mineral composition is identified using X-ray diffraction analysis. The EN 197-1 (2011) standard specifies that the amount of reactive SiO2 content shall not be less than 25% by weight, the chemical composition of bentonite confirms that bentonite satisfies this prerequisite.

Table 1. Chemical Properties of bentonite

Composition	OPC	Bentonite
CaO	60 - 65	01 - 02
SiO_2	20 - 25	60 - 65
Al_2O_3	04 - 05	10 - 20
Fe_2O_3	05 - 06	02 - 05
MgO	01 - 02	02 - 05
K_2O	0.4 - 0.5	01 - 02
Na_2O	0.1 - 0.2	01 - 03
SO_3	0.2 - 0.25	0.2 - 1.0
TiO_2	0.2 - 0.25	0.2 - 0.5
Blaine Fineness	03 - 03.5	02 - 02.5
Specific gravity	03 - 03.5	04 - 04.5

C. Studies on Plain bentonite blended cements

Usage of plain bentonite to partially replace cement in the manufacturing of concrete is investigated by many researchers like Taylor-Lange et al. (2015) [11], they observed that with the increased blending of cement with bentonite, the fresh concrete properties like workability, water absorption and density were declined, though, an increase in the strength properties was seen in the later age of concrete. Similar results are reported elsewhere [3, 11] described the favorable effect of calcined bentonite as substitute for cement in the blending with calcined kaolinite.

Workability

Mesboua et. al. (2018) [2] have investigated the effect of partial blending of cement by Algerian bentonite on mechanical and flow characteristics of cement-grout system. According to Mesboua et al., (2018) [2] the rheological characteristics of bentonite renders it to exhibit a thixotropic behavior.

Strength Properties

The studies on compressive strength of the cement grout blended with bentonite resulted in marginally inferior values compared to plain cement mortars. The results by Gustin et.al. (2007) [18], Mesboua et al. (2018) [2] and other researchers presented that at the age of 28 days' average decrease in compressive strength of mortar mixes having bentonite is 1.75- 2% compared to control grout.
ASTM Standard C618 recommends that a pozzolan is considered as active if its strength activity index (SAI) at 28- days is more than 75%. Tests conducted by Mesboua et al. (2018) [2] have shown that SAI was more than 93% even for 18% cement replacement by bentonite in the mortar, which confirms to the C618 ASTM Standard.

Durability- Water absorption

When cement is blended with bentonite in an aqueous medium it is likely to increase the viscosity of the mixture. The apparent viscosity of cementitious mortars decreases as the applied shear rate upsurges. The absorption of water in the mortars containing bentonite tend decrease up to 30% clay and then steadily amplified at higher bentonite blending [2, 3]. The increase in the amount of bentonite in cement-based grouts led to the rise of flow time, plate cohesion meter, and rheological properties while decreasing the workability. Mesboua et al., (2018) [2], reported that, density of fresh grouts reduced with increase in cement replacement by bentonite, reference value of density with plain cement was 1.63gm/cm3 which was maximum.
According to ASTM C 940 (ASTM, 2016), if the final bleeding of a grout is not more than 5% after 2 hrs., it is considered as stable. Bentonite absorbs water, thus controls bleeding and prevents segregation. However, bleeding is controlled by the lessening in the gel and viscosity and promote the settlement of solids in cement. Bentonite reduces bleeding of grouts considerably up to 16% cement replacement with bentonite, further cement replacement leads to complete prevention of bleeding [2, 17, 18]. It happens because, bentonite exhibits a negative zeta potential in a pH range from
2 to 12 [1]. On the other hand, zeta potential of OPC is positive. The resulting zeta potential of aqueous mixture of cement and bentonite is negative which is dominated by the bentonite clay. Hence, these repulsive forces overcome the van der Waals forces which leads to decline of bleeding. The stability of grout is improved by fineness of the bentonite grains and its colloidal properties.
Studies by Mehta et. al. (2011) [23], Mesboua et. al. (2018)
[2] conclude that, blending cement with bentonite results in enhanced particle packing. It also lowers volume of voids and water absorption of the cement paste, as microparticles of bentonite fills up the micropores also leads to formation of secondary C–S–H at a lower water binder ratio.

D. Studies on Calcined bentonite blended cements

The removal of hydroxyl ions from the clay which is known as calcination process. In calcination clay is heated to a temperature of 700 to 900˚C, numerous chemical reactions result in to mineralogical crystallographic alterations by removal of hydroxyl ions [1, 8, 11]. Various scholars like Chakchouk et al. (2006) [8]; have studied the potential pozzolanic reactivity of different calcined clays such as smectite, kaolinite, muscovite, montmorillonite illite and low purity mica clay and found that calcination improves degree of reactivity of clays.

Workability

Laidani et. al. (2020) [1], investigated cement blending by two types of bentonite available near Algeria, which was calcined at 800˚C to use in the manufacture of SCC using mini slump cone and V funnel test. They determined that bentonite blending reduced the flowability of SCC at the same W/B ratio and super plasticizer dose. Laidani et. al. (2020) [1] suggested that the increase in super plasticizer dose was owing to lower density of the mortar similar observations were made by other researchers [13]. Also the range of particle size for calcined bentonite is from 1 μm to 100μm [1] which may lead to increase in the water demand and reduction in the workability.

Strength Properties

Laidani et. al. (2020) [1], Ahmad et al. (2011) [17] investigated the effect of the blending of bentonite with cement paste with various percentages and established that the blending improves the consistency, setting time, bulk density and compressive strength of mortars. They linked the strength increase with the reduction in the porosity of systems.

Strength activity index of plain bentonite and bentonite calcined at 500˚Cand 900˚C was studied by Ahmad et al. (2011) [17]; their results pointed out that strength activity index of bentonite calcined confirms to ASTM Standard C618 specifications. They also determined that if the bentonite heated at temperatures of 900˚C were not confirming to ASTM Standard C618 specifications. with increasing amount of bentonite blending water absorption decreased for mortar containing up to 30% bentonite, the same increased beyond 30% blending. Hence they concluded, to produce a concrete with necessary compressive strength blending cement with 30% of bentonite is acceptable.

Mirza et al. (2009) [20] studied the potential of blending calcined bentonite with cement at 150, 250, 500, 750 and 950˚C temperatures in mortars and concrete and established that 20% of unheated bentonite and 25% of bentonite heated to 150˚C can be used as low-cost cement additives in mortars and concrete.

Laidani et. al. (2020) [1], determined that the optimum duration desirable to acquire pozzolanic activity was 180 minutes for calcium bentonite and 2400 minutes for sodium bentonite found near Algeria. Calcination temperature of 800˚C was required for both types of bentonites. From the results obtained from compressive strength test they concluded that optimum % replacement of OPC by calcium bentonite was 15% and 10% by sodium bentonite which produced an increase of 28.37% and 35.81% respectively for a characteristic compressive strength of 25MPa. SCC cubes subjected to temperature of 100, 600, 800 and 1000˚C. The compressive strength tests here showed that the compressive strength increases up to 600˚C and then declines on exposure to 800 and 1000˚C temperature, along with formation of micro cracks. However, the SCM produced with calcined bentonite showed higher residual compressive strength compared to control mixes, even mass loss was observed to be lower in case of blended mortars.

Durability- Water Absorption

Laidani et. al. (2020) [1], studied water absorption by concrete made using sodium and calcium bentonite calcined at 8000C by means of capillary (NF P10- 502) and immersion methods (ASTM C642-97). Following equation was used by Laidani et. al. (2020) [1] to calculate the water absorption by concrete through capillary action,

$C=(\triangle M)/(A\sqrt{t})$ (2)

Where,

$\triangle M$: mass of water absorbed in grams

A: section of the base of the test piece in mm2 t: absorption time in minutes.

Their experimental investigation showed that concrete made using cement blended even with 25% of bentonite exhibited lesser absorption than pure OPC. The capillary ingress was lowest for 10% of each calcined bentonite, i.e. 0.36 g/mm2 for sodium bentonite and 0.38 g/mm2 for calcium bentonite. It implies that being finer than the cement calcined bentonite grains seal the pores of the concrete system. If we relate the water absorption to porosity, it is clear that cement-bentonite system has less porosity therefore it can prove to be more durable in case of chemical attacks.

Durability- Exposure to fire

Laidani et. al. (2020) [1], studied for the effect of exposure to fire on bentonite blended mortar specimen at 600, 800 and 1000˚C for 2 hours. When mortar specimen ware heated to 600˚C for 2 hours an increase in the compressive strength was observed specifically for 15% and 20% bentonite blending it was more than 40% of its original strength. The compressive strength of mortars increases due to a pozzolanic action of amorphous aluminosilicates present in calcined bentonite with portlandite produced during cement hydration, which produces more CSH at a low Ca/Si ratio with high. While Zadražil et.al. (2004) [21], attributed the increase in strength to densification of pore structure leading to reduction in the thermal stresses generated nearby the gel pores. After exposure to 800 and 1000˚C for 2 hours a gradual loss of compressive strength was reported by Laidani et. al. (2020) [1] and other researchers.

The experimentation by Laidani et. al. (2020) [1] showed that loss of mass, for 20% calcined sodium bentonite was 4.55% which was less than mortar specimen made with pure

OPC (5.20%) on heating at 600, 800 and 1000˚C. Thus mortar specimen containing 20% bentonite blended with OPC have produced better results in mass loss and compressive strength tests than pure OPC mortars when subjected to temperature in excess of 600˚C up to 1000˚C.

Discussion

From the literature study, it is evident that bentonite has various applications in different products of various industries. In case of use in concrete and mortars as a cements blending material a lot of research is going on. Bentonite can be used in concrete and mortar in different forms viz. plane bentonite, calcined bentonite and surface activated bentonite. Bentonite exhibits pozzolanic action of amorphous aluminosilicates present in calcined bentonite with portlandite produced during cement hydration, which produces more CSH at a low Ca/Si ratio. Bentonite contains reactive silica in the rage of 50% to 65%, this enables it, to exhibit pozzolanic activity, on blending with cement. Due to the pozzolanicity, bentonite can prove to be an economical and sustainable replacement material for cement in concrete and mortar casting. If bentonite is calcined at 8000C for 4 hours a cement replacement of 30% is possible, compared to 18% and 20% cement replacement by plane and surface activated bentonite, without negatively affecting the strength properties of mortars and concrete. Hence calcination of bentonite to replace cement can prove to be the best of the available option.
The experimental investigations have shown that the workability of concrete and mortars reduces with increase in bentonite blending in all the mentioned forms of bentonite. The higher fineness of bentonite leads to increased water demand hence the workability of the concrete and mortars, while some of the researchers have suggested that, the increase in super plasticizer dose was owing to the lower specific gravity of bentonite. The calcined bentonite was even used in manufacturing self-compacting concrete with use of superplasticizer and have produced positive results. The specific gravity of bentonite is less than cement, hence the blending of bentonite leads to reduction in the density of concrete.
The bentonite blending facilitates pore refinement of the cementitious systems leading to improved microstructure in concrete and mortars even compared with pure ordinary portland cements. Hence the pore sizes reduce which is evident by the results of different tests like capillary and forced absorption tests conducted by the researchers. As the water absorption and porosity are correlated, it is clear that cement- bentonite system has shown lower porosity therefore it can lead to improved durability of concrete mixes in chemically harsh environments.
Blending cement with bentonite leads to complete inhibition of bleeding in grouts and concrete. Bentonite absorbs water, thus prevents bleeding and controls segregation. Bleeding is affected as, bentonite displays a negative zeta potential in a pH range from 2 to 12, on the contrary, zeta potential of OPC is positive. The resulting zeta potential of aqueous mixture of cement and bentonite is negative which is dominated by the bentonite clay. Hence, these repulsive forces overcome the van der walls forces which leads to decline of bleeding. The grout stability is enhanced by higher fineness of the bentonite particles and its colloidal characteristics.
Tests were conducted by researchers to investigate performance of concrete subjected to elevated temperatures. Calcined bentonite blended concrete performs better than pure cement concrete, when subjected to temperatures of 100˚C, 600˚C, 800˚C and 1000˚C in case of compressive strength performance. The compressive strength increases up to 600˚C and then declines on exposure to 800˚C and 1000˚C temperature, accompanied by formation of micro cracks.

Conclusion

From the literature review it can be concluded that the optimum temperature and time for calcination of bentonite is 800˚C and 2400 minutes respectively for cement replacement in concrete and mortars.
The bentonite clay possesses a good potential to be used as a cement replacement material in concrete and mortars. In case of calcined bentonite, a replacement of 30% of cement has produced desirable results from the point of view of compressive strength and SAI. However, more studies needed to carried out on durability and economical aspects of use of plain or calcined bentonite as a blending material in cement.
The bentonite blending with cement adversely affects the workability of the concrete and mortars, however this problem can be solved by the appropriate usage of workability modifying admixtures. Though it reduces workability, the cement blending with bentonite has the potential to improve the viscosity of the concrete and mortars.
The blended cement samples have exhibited improved particle packing and durability when it was measured in terms of water absorption tests on mortar and concrete specimen. Also when the concrete is subjected to elevated temperatures the bentonite blended concrete samples performed better than the pure cement concrete. Hence it can be inferred that bentonite blending helps improving durability of cementitious systems.

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