MECHANICAL PROPERTIES OF CONCRETE BY PARTIAL REPLACEMENT OF BENTONITE UNDER ELEVATED TEMPERATURE

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By

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THESIS ACCEPTANCE CERTIFICATE

This is to certify that the

thesis titled

MECHANICAL PROPERTIES OF CONCRETE BY PARTIAL REPLACEMENT OF BENTONITE UNDER ELEVATED TEMPERATURE

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has been accepted towards the partial fulfillment

of the requirements for the degree of

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DECLARATION

I certify that this research work titled "**Mechanical Properties of Concrete by Partial Replacement of Bentonite Under Elevated Temperature**" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged/referred.

Signature of Student

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This thesis is dedicated to my dearest father and my beloved family.

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ABSTRACT

In large-scale constructions, the strength and durability of the materials used are highly considered features. It has been noticed that the strength and thermal resistance of construction mixtures can be improved by replacing some percentage of any of the construction material in a mix like sand. One such replacement is Bentonite whose usage as a partial replacement of sand is under study. Although concrete plays a significant role in degrading the impact caused by fire, the tensile module and compression strength of concrete degrade when it is exposed to high temperatures. So, a noticeable impact is produced on the concrete along with affecting the bearing capacity of concrete. Bentonite will be used as a filler material (replacement of sand) in concrete mix and its behavior will be observed for strength and fire resistivity at different temperatures. Analysis of the optimum value of bentonite which can replace sand in the context of strength and thermal resistance of concrete is made with the optimum value of bentonite in mortar plaster by replacing sand. This study will also reveal the effect of fire on concrete specimens coated with mortar plaster in which bentonite is replacing sand in three different ratios. The anticipated results will define the comparison with the control samples that are tested at room temperature along with the empirical associations used as the input to evaluate and design the concrete structures.

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CHAPTER 1

INTRODUCTION

1.1 Context of the Study

1.1.1 Overview

In the past, a noticeable impact of the earthquake has been observed in the regions of Khyber Pakhtunkhwa province of Pakistan. The earthquake caused major destructions of which some resulted in fire eruptions in major city areas. The effect of fire and elevated temperatures on cement and concrete has been studied with the conclusion that concrete and cement can be partially replaced with sand or other materials for added resilience to fire eruptions. One such material is "Bentonite", which is found in Khyber Pakhtunkhwa province of Pakistan. This material can prove to be potentially resistant to fire and high temperatures.

With almost half of Pakistan's population already living in poverty, rising prices for necessities are hitting the poor hardest. Cement is just one more commodity whose price has rocketed upwards in the last decade, increasing by more than 150%. To help the building sector and the impoverished of Pakistan, research into low-cost pozzolans (both natural and industrial) is essential. There is a long history of using natural pozzolans in construction. Some societies began using volcanic ash and baked clay as early as 2000 B.C. Proof of the long lifespan of pozzolan concrete may be seen in the many ancient buildings from the Roman, Greek, Indian, as well as Egyptian civilizations that are still standing today. Dams and other public works projects in the beginning of the 20th century in North America were some of the first to employ natural pozzolans to mitigate the thermal expansion of mass concrete and serve as cementing agents. Natural pozzolans are increasingly being used in cement and concrete systems because to the numerous desirable qualities they provide, including low heat of hydration, good ultimate strength, low permeability, good sulphate tolerance, and low alkali-silica activity. Furthermore, it is widely accepted that pozzolanic and concretes materials may secure the long-term viability of the cement concrete industries via their use.

The longevity, life cycle performance, and prices of the concrete buildings are also very important factors in this regard, in addition to the energy performance and environmental elements of the cement industry. As a natural pozzolan, bentonite is often classified as either sodium (High-swelling), calcium (Low-swelling), or intermediate (Moderate-swelling) type, due to the presence of both sodium and calcium ions in its crystalline structure. Bentonite kinds with a limited swelling capacity tend to seem cracked, while those with a high swelling capacity tend to have a frothy texture due to their alternate swelling and drying. Consequently, the characteristics of cement mortars will change based on the kind of bentonite utilized. Bentonite may be found in a wide variety of NWFP regions in Pakistan. In our investigation, we focused on one bentonite that may be found in the Karak region and covers an area of around 18 km2. It has been measured at depths of up to 39 meters, however its typical thickness is closer to 6 meters. Bentonite resources in the Karak area are estimated to be worth roughly 36 million metric tons(Memon et al., 2012).

Several early studies were conducted to assess the quality of Pakistan's industrial wastes such furnace slag, coal ash, ash from rice husks and so on. Data regarding natural pozzolans, however, is scant at best(Mirza et al., 2009). This includes materials like volcanic material, bentonite, meta-kaolin, and other clays. The earthquake-ravaged Khyber Pakhtunkhwa region of Pakistan is now undergoing a great deal of building, with much more expected considering the country's newly announced plans to build hydropower projects. Rebuilding efforts in Afghanistan have also begun. The need for building supplies would likely increase dramatically under such conditions. Cement is the single most important material used in building, and its price has a dramatic impact on every aspect of a construction project. As a result, efficiency in the context of the current environment will continue to play a significant role in all engineering endeavors. Cement production releases a lot of carbon dioxide and other greenhouse gases. Cement manufacturing now accounts for over 7% of global carbon dioxide (CO_2) generation, and according to industry forecasts, this ratio is likely to be stable over the next decade. Cement manufacture also has a high carbon footprint and energy requirement; making one tons of cement uses around 1.6 MWh of energy and releases roughly a tons of carbon dioxide(Rehman et al., 2019). There is a pressing need to investigate the availability of cheap natural pozzolans in Pakistan as a solution to the issues.

1.1.2 Significance

Different construction projects are also initiated in Afghanistan, which highlight the noticeable demand for construction materials to be included to complete these projects. Some projects are also done in collaboration, and it seems like one study carried out is going to prove its effect on various others.

1.2 Problem Statement

Bentonite as partial replacement of sand in construction mixtures is found to be more resistant to elevated temperatures. The partial replacement of sand with Bentonite in fixed percentages is carried out over a period. This research also proves that Bentonite has more plasticity and acts as a cost-effective replacement of sand in construction projects.

1.3 Aim and Objectives

Following are the objectives that will be covered within this study:

- To study the mechanical behavior of concrete by using Bentonite as a filler material under elevated temperature.
- To study the effect of partially replaced Bentonite mortar as plaster under fire.

1.4 Scope

This study will provide information regarding the feasibility of the construction material. Bentonite is easily available in Pakistan so the experiments can be performed with the use of a cost-effective approach. This study will help in calculating life of structure/building keeping in context of fire. This study will also verify that with the use of Bentonite, durability of concrete can be increased.

Previous research carried out by (Memon, 2012) aimed at evaluating Jehangira bentonite as partial replacement of construction materials at the proportion of bentonite at 3%, 6%, 9%, 12%, 15%, 18% and 21%, while keeping constant the other materials of the mixture. It is evident that sand can also be replaced by bentonite which is the contribution of this research work. The replacement of sand by bentonite makes the construction project cost-effective for Pakistan since bentonite is readily available. Economy is the primary driver in all engineering activities and effort is made to make construction projects economical. The availability and ease of choosing construction materials comes with reduced prices and more durability in addition to better economy.

1.5 Significance of the Study

Cement and concrete are of great value to the construction and civil engineering communities. The tensile strength of a set concrete is dependent on the type of the cement in the mortar, the type of aggregate, the cement/ aggregate bond, the water/cement ratio used in the concrete mix and the degree of compaction of the wet concrete. (Khatib, 1999) The standard definitions of aggregates by ASTM (American Society of Testing and Materials) are described by C-125 and D-8 states that “concrete is a mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials”. Hence, the properties of these constituents have a significant effect on the properties of the concrete.

The foremost idea of this research is to measure the mechanical properties of Bentonite in construction mixtures with the focus upon the high heat resistance of Bentonite and its resultant effect on the properties of construction mixtures.

1.6 Thesis Organization

The investigation that was carried out to meet the goals is offered in the form of five chapters here. This research work is organized as follows:

- In the first chapter, this study discussed the relevance of bentonite and how it reacts to heat, as well as the aims of the research, the significance of the research, the scope of the study, the research technique, and a summary of the thesis.
- The prior research that has been provided on bentonite concrete has been presented in Chapter 2, along with a short summary of the research that has been conducted in the past that is relevant to the use of bentonite in concrete. The impact that fire has on bentonite concrete is also included in the review of relevant literature.

- The methodologies and methods for the tests are covered in Chapter 3. This chapter presents the facts of this research investigation, including the temperatures that were intended to be reached, the heating rate that was intended to be achieved, the specimen size, and the equipment used.
- Evaluation, analysis, and discussion of the findings of tests on thermal properties and material properties are included in chapter 4. In addition to that, the results of an examination of compressive strength have been provided.
- The findings of this study are analyzed in Chapter 5, which also includes some thoughts on how future research may build on these findings.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Previous research carried out by (Memon, 2012) aimed at evaluating Jehangira Bentonite as partial replacement of construction materials at the proportion of Bentonite at 3%, 6%, 9%, 12%, 15%, 18% and 21%, while keeping constant the other materials of the mixture. It is evident that sand can also be replaced by Bentonite which is the contribution of this research work. The replacement of sand by Bentonite makes the construction project cost-effective for Pakistan since Bentonite is readily available.

The conservation of the environment has become a burden for a great number of developing nations. The cement industry is responsible for almost 7% of the world's CO2 emissions, which causes significant harm to the environment. Bentonite is the second biggest accessible raw material, and the cost of producing bentonite in Pakistan is much lower when compared to the cost of producing ordinary Portland cement (OPC). Bentonite is a substance that is safe for the environment and did not in any way harm the natural world.

Bentonite is one of the most effective expanding clays and is often used as a lubricant in the process of placing piles in footings and bore wells. Because it has pozzolanic qualities, bentonite clay may be used as a material for the purpose of binding. In this experimental inquiry, calcium bentonite was employed since it is the montmorillonite that is based on bentonite. Other bentonite-based montmorillonites include potassium bentonite and sodium bentonite.

Bentonite clay is a smectite-derived clay mineral with a high montmorillonite concentration, and it is also a nano-clay. Both sodium and calcium ions are present in great numbers, and its surface area is enormous. Bentonite clay is extremely flexible and effective as a binding agent, and it typically has diameters smaller than 0.002 mm. Because of the potential for intercalation when water interacts with the montmorillonite concentration, bentonite clays may expand when brought into contact with water. Bentonite clay is a commercially available clay mineral binder that may be used as a partial replacement for cement in the manufacture of concrete. Bentonite clay can bind the siliceous sand grains together, and the water in concrete helps to enhance the binding between the clay and sand, creating a plastic paste that binds the aggregates together. Bentonite clay and sand react to create magnesium (MgO) as well as potassium (K2O), two oxides crucial to the process of developing concrete's strength and setting it. Since fine bentonite particles give more nucleation sites, the hydration process is boosted, and the setting time is sped up; on the other hand, when Portland cement is substituted with RB, the cement constituents C3A and C3S are decreased, slowing down the paste setting as a result.

Research proposed by (Javed, 2020) aims to provide solutions to the stated problems by incorporating locally available powdered lime-Bentonite composite in compressed and unfired bricks, whereas properties of fired bricks were examined for comparison purpose. Clay was replaced by 0%, 5%, 10%, 15% and 20% of Bentonite content. (Javed, 2020). There is a requirement to explore the materials which could behave like low-cost natural bonding agents for construction available within the country. It has been analyzed that the use of natural agents results in significant advantages e.g., low heat hydration along with high strength. Natural materials e.g., Bentonite can be identified from different regions of Khyber Pakhtunkhwa. However, one sort of Bentonite can be obtained from Jehangira that could be used accordingly in different construction processes as a replacement of sand, and significant benefits will be obtained as a result.

Considerable benefits can also be obtained within the construction system and the manufacturing process can be done in the desired manner (Ramanathan V, 2009).

There are several other studies which analyze the feasibility of using industrial waste such as rice husk ash, fly ash and much more in construction mixtures (Akram T, 2009).

The use of Bentonite will provide positive results for the construction industry for example better resistance to heat. Furthermore, there are few applications determined in the context of Pakistan in which Bentonite can be used having better thermal resistance in the construction projects. This study will analyze the optimum value of Bentonite which can replace sand in the context of compressive strength and thermal resistance. Significant progress has been made over the last two to three decades in the construction sector with regards to experiments in the use of different cementitious materials, often known as pozzolans, for the mixing of various cement - based materials products. Compressive strength and other properties, such as the ability to set and solidify in water, have improved, therefore. The most typical examples of these include coal fly-ash, blast furnace slag, rice husk ash, silica fume, and metakaolin.

Alternate cement production techniques are being studied due to cost and ecological considerations. Formulating cements with a smaller fraction of calcinated material reduces carbon dioxide emissions per unit of product, which contributes to the overall objective of lowering emissions of carbon dioxide and other greenhouse gases. To achieve the same or greater compressive and/or flexural strength, it is also possible to use a smaller proportion of cement and/or gypsum than is customary when using conventional cement or gypsum. This as one that lasts a long time, can be used for many different things, and helps the planet. Additionally, there is a need for refined cement and gypsum items that enable the use of cheaper aggregates.

2.2 History of Bentonite replacement of concrete

Bentonite, a natural pozzolan found in numerous locations in Pakistan's Khyber Pakhtunkhwa region, was given its name by Knight in 1898. Topographic sheet 43C/1 of the Survey of Pakistan shows a Jehangira bentonite at 33°5905600 latitude & 72°1204700 longitude. Ash from rice husks bagasse ash, fly ash, and other industrial wastes in Pakistan have been the subject of many pilot projects to determine their viability for reuse. The purpose of this study is to investigate the viability of using Jehangira bentonite as a cement substitute. Putting it to use in the current setting will provide the most optimal outcome, with several advantages. As a result, the building sector will have access to a low-priced solution, greenhouse gas emissions will be reduced, and the system's longevity will improve**.**

Bentonite is an aluminum phyllosilicate clay consisting mostly of montmorillonite and is a key component for drilling applications (Vryzas Z, 2016). The stability of Bentonite is of particular interest for containment barriers in nuclear waste disposal facilities. However, very little is known about the stability of montmorillonite (the major component of Bentonite) under high-pressure (HP) conditions. (Frederico Gil Alabarse, 2011).

A Pakistani Bentonite, at normal temperature (21 °C) and heated (150 °C, 250 °C, 500 °C, 750 °C and 950 °C) conditions, was used in mortar cubes, concrete cylinders, and concrete beams as a partial substitute for Ordinary Portland cement (OPC) and the effects on heat resistance were observed. (J. Mirza, 2009). This also reduced the energy consumption, preserved natural resources, and solved environmental problems related to cement production as well as augmented the durability and life cycle of the concrete structures. These characteristics have a significant effect on the usage of concrete in the fresh state of concrete, as well as on the hardened concrete properties like strength, durability, thermal properties, density, and volume stability (Thomas, 2016).

According to published estimates, out of the roughly 16,000,000 tons of bentonite clay produced annually, 120,000 metric tons come from South Africa. Many experts have also said that South Africa has an abundance of bentonite clay that can be mined for at least another 60 years. Bentonite clay has showed promise as a partial substitute for cement in concrete production in recent years, mitigating the harmful impacts of carbon released into the environment due to the overuse of cement (which contributes to ozone depletion and global warming). Concrete, a composite construction material made from cement, sand, stone (or granite), and water in the proper proportions, is used extensively throughout the world for the construction of a building, bridges, dams, sidewalks, and other civil engineering facilities.

During the last two decades, there have been revolutionary advancements in the use of innovative materials for the manufacturing of concrete, as well as adjustments and improvements in the behavior of existing materials. Bentonite, when mixed with regular Portland cement, is a good example of a supplemental cementitious ingredient that has been examined in detail. Pressures to minimize cement usage via the use of supplemental materials have arisen in response to growing environmental concerns about the negative effects of raw material extraction and CO2 emissions during cement manufacturing. Portland cement (PC) as well as pozzolan mixes are widely utilized in concrete manufacturing due to the environmental benefits and cost-effectiveness.

The production of concrete is a very energy-intensive operation. The strength of concrete is significantly affected by the aggregates used in its creation, namely their physical, chemical, mechanical, and microstructural qualities. The mechanical qualities of concrete are determined by its microstructural development; specifically, more densely packed the concrete micrograph is determines how much stronger the concrete is. Concrete's strength and durability decrease as its microstructure gets more disorganized. This means that it is possible to assess the acceptability of materials for use in concrete production by analyzing their qualities.

2.3 Plasticity of Bentonite as a filler material

Bentonites and bentonite containing sealing materials have been used for many years for sealing purposes in foundation, dike construction, hydraulic engineering, and landfill construction, especially for encapsulation of old waste deposits (Koch, 2002). Bentonites are offering numerous possibilities to protect the environment against negative effects of dumping grounds. However, the use of Bentonite to increase the thermal resistance of materials is comparatively a new idea and is now under research(Ahmad et al., 2022).

For cut-off walls Bentonite controls the rheological behavior of the slurry and is responsible for the low permeability of the hardened Bentonite-cement-wall (Koch, 2002). The composition and properties of mineral sealing mixtures can be illustrated by examples of usage as well as the application in the building process. The results of recent developments for improving the material properties of Bentonite contained sealing mixtures, i.e., ready mixtures of Bentonite/cement, are presented followed by a conclusive insight towards further possible developments(Ahmad et al., 2021).

In the past, materials have been tested for plasticity and have achieved a better-quality index. But the use of Bentonite as a filler material is comparatively a new study and work is being done upon checking the feasibility of using it in constructions projects in Pakistan and worldwide(Farhan Mushtaq et al., 2022). The thermal resistivity of Bentonite has not been studied as a partial replacement of sand, cement, or concrete in construction mixtures.

Trials of various cementitious materials, often known as pozzolans, for the compounding of different cement-based products have advanced the building industry significantly during the last two or three decades. Not only has this led to an increase in the hardened concrete value obtained, but it has also led to improvements in other attributes, such as the ability to set and harden in water. The most typical examples of these include coal fly-ash, blast furnace slag rice husk ash, silica fume, and metakaolin.

Alternatives to the traditional cement manufacturing process are being investigated in light of rising production costs and environmental concerns; these alternatives include gypsum, gypsum fines, Cementitious materials, cement, lime dust, crushed stone, and calcined clay. Cement formulations utilising less calcinated material may reduce carbon dioxide emissions per unit of product, which is one strategy for meeting the aim of lowering carbon dioxide emissions as well as greenhouse gases. Another strategy is to use a lesser amount of cement and/or gypsum than is typical with regular cement and/or gypsum but still achieve the desired compressive strength and/or flexural strength. This option is sustainable since it lasts long and may be used in a wide variety of contexts. There is also a need for better cement as well as gypsum products that may save costs by allowing cheaper aggregates to be used.

2.4 Different roles of Bentonite in Concrete

Numerous studies conducted by a variety of researchers have shown that bentonite may be successfully used in the production of concrete in different roles. In many studies, concrete was supplemented with bentonite, which is a kind of clay that is more often used. In addition to researching the influence that clay constituents like these have on the mechanical properties of concrete, the authors looked at the chemical resistance of concrete to being exposed to sulphates, carbonation, and chloride(Karthikeyan et al., 2015; Lingnau et al., 1996; Peng, Wang, Xiao, et al., 2017; Reddy et al., 2017). Many researchers also have discovered that the barrier to carbonation in the material containing bentonite-bearing was perhaps lower than the barrier to carbonation in the plain Portland cement concrete that served as a reference(Akinwunmi et al., 2019; Cho et al., 1999; Savage et al., 2002; Wei et al., 2019; Wei & Gencturk, 2019).

When added to concrete, bentonite has the potential to considerably increase the material's durability and reduce the likelihood that it would break because of shrinking after it has been allowed to cure. The presence of certain minerals in pozzolanic materials has a significant impact on the performance characteristics of concrete, including its strength and its capacity to withstand wear and tear. There is some evidence that adding bentonite clay to a material may help to boost its compressive strength. The early-age compression strength of the concrete that had been supplemented with bentonite did not show a significant increase. When the concrete specimen is aged for a longer period, however, the amount of the defect grows to a point that is much higher than that of the control concrete specimen. In addition to that, the proportion of water to binder was raised to 55%, the OPC content was raised to 340 kg/m3, and the maximum bentonite replacement ratio was set at 21%(Mirza et al., 2009). In addition to compressive strength, research was conducted on other parameters of durability.

Trials of various cementitious materials, often known as pozzolans, for the compounding of different cement-based products have advanced the building industry significantly during the last two or three decades. Not only has this led to an increase in the hardened concrete value obtained, but it has also led to improvements in other attributes, such as the ability to set and harden in water. The most typical examples of these include coal fly-ash, blast furnace slag rice husk ash, silica fume, and metakaolin. Alternatives to the traditional cement manufacturing process are being investigated in light of rising production costs and environmental concerns; these alternatives include gypsum, gypsum fines, Cementitious materials, cement, lime dust, crushed stone, and calcined clay. Cement formulations utilising less calcinated material may reduce carbon dioxide emissions per unit of product, which is one strategy for meeting the aim of lowering carbon dioxide emissions as well as greenhouse gases. Another strategy is to use a lesser amount of cement and/or gypsum than is typical with regular cement and/or gypsum but still achieve the desired compressive strength and/or flexural strength. This option is sustainable since it lasts long and may be used in a wide variety of contexts. There is also a need for better cement as well as gypsum products that may save costs by allowing cheaper aggregates to be used.

According to the results of several research that were conducted incorporating bentonite in concrete, the specimens that were treated with bentonite resulted in better of their resistance to acid corrosion(Abbaslou et al., 2016; Adeboje et al., 2020; Albinsson et al., 1996; Trümer et al., 2019). This was the case for the samples that had been tested. According to the findings of a research, the use of bentonite clay in concrete results in a reduction in the material's overall mechanical performance. Researchers have investigated the hydration process in a Portland cement mix that also contains sodium bentonite and metakaolin to identify the effect that pozzolanic components have on the finished product. Strength development, portlandite consumption, and the calcium-silicate hydrate (C-S-H) stage are only few of the criteria that were taken into consideration while determining whether a combination of sodium bentonite as well as metakaolin improved the hydration of cement. In addition, the presence of bentonite has been shown to hasten the breakdown of metakaolin into its component parts. Bentonite-based concrete requires more curing time to get the desired level of strength. In comparison to untreated bentonite, the pozzolanic activity of the bentonite that had been modified with silane was much higher(Ashraf et al., 2022). Instead of cement, many research projects are looking at the possibility of using bentonite clay in concrete.

However, information on the use of bentonite clay in concrete is dispersed, and as a result, it is difficult for anybody to accurately assess the significance of the use of bentonite clay in concrete. Because of this, the primary emphasis of this study is on the physicochemical make-up of bentonite as well as its fresh qualities, as well as the durability and mechanical performance of concrete made using bentonite clay rather than cement(Kazemian et al., 2016). Clay composed of bentonite typically has particle sizes that are smaller than 0.002 millimeters in size; it is very plastic and may be used as a binding agent. Bentonite clays do not have a favorable response or interaction with ionic compounds, and they have the potential to swell when they meet water owing to the likelihood of intercalation, which occurs when water interacts with the montmorillonite component of the clay. Bentonite clay is a kind of clay mineral that acts as a binder(Masood et al., 2020). It is available in amounts sufficient for industrial usage and may partly substitute cement when it comes to the creation of concrete. Bentonite clay can bind the grains of sand (which is siliceous) together, and the water that is present in concrete helps to stimulate the bonding between the bentonite clay and the sand. This results in the formation of a plastic paste that bonds or binds aggregates together to form a concrete mix that can be worked. Because of the interaction between bentonite clay and sand, important oxides of magnesium (MgO) as well as potassium (K2O) may be produced(Amlashi et al., 2019). These oxides are beneficial for the development of concrete's strength as well as its setting.

Bentonite is also used in nuclear waste storage facilities. Multiple options for nuclear waste storage facilities' building materials are being considered(Terzić et al., 2018). To stop the convective flow of water, mechanical barriers, such as concrete as well as bentonite clay, are necessary. These obstructions, because to their mechanical restrictions and chemical bonding with the material, will also slow the transit (diffusion regulated) of dissolved radionuclides. Interaction of the sodium bentonite with calcium from the concrete might cause the bentonite to transform into the calcium form, which is a serious concern(Xie et al., 2019). Radioactively spiked cement in touch with compacted bentonite was used to examine the first leaching of concrete. Five different kinds of concrete were tested to determine the diffusion rates of Cs, Am, and Pu into the pore water they were in contact with. When compared to data from the literature, the measured diffusivity for Cs is quite consistent. Despite the prolonged contact durations, no discernible motion between Am and Pu (0.2 mm) was detected. Na, Ca, and Cs diffusion rates were also measured from concrete into bentonite(Afzal et al., 2014).

2.5 Effect of temperature on the properties of bentonite

The impact of temperature on bentonite characteristics has been the subject of many controlled experiments(Peng, Wang, Shen, et al., 2017). The experimental settings, bentonite composition, compression, and water content make it difficult to draw conclusions about the temperature dependency of the swelling pressure of bentonite. When exposed to higher temperatures, swelling pressure may either reduce or grow. Multiple investigations have shown that, relative to ambient temperature, the swelling pressure decreases when the temperature is raised(Abdel Rahman et al., 2013; Laidani et al., 2020; Man et al., 2019). Temperature's impact on the diffused double layer, water molecule transfer from micropores to porous structure, loss of hydrating water, and cement formation are all thought to contribute to a decrease in swelling pressure.

However, the temperature's impact on pore water pressure, moisture pressure, and osmotic pressure, the increase in heat energy and diffusion of ions, and the enhance in the double layer repulsive force have all been used to explain the observed rise in pore pressure at elevated temperatures. Researchers have also looked at how compacted bentonites expand as the temperature drops below freezing(Chen et al., 2019; Daniels et al., 2017; El-kurdi et al., 2017; Savage et al., 2007). As the temperature is reduced, the swelling pressure drops, and below a certain threshold, it disappears entirely. The swelling pressure returns to normal when the clay is heated down to room temperature, hence the transformation is reversible. The significant disparity between the partial entropies of ice and water is thought to be the cause of the drop in swelling pressure below 0 °C. Bentonite's freezing point is said to fluctuate with its dry density. Several theoretical investigations on bentonite clay's effect on temperature have been documented. Due to increased thermal mobility of the interlayer species, interlayer distance increases as temperature rises. As the temperature rises, so do the total displacement of water and other interlayer species.

According to many researchers, water strata are rather consistent in terms of temperature(Ahad et al., 2018; Jadda & Bag, 2020; Morozov et al., 2022). At elevated temperatures, the one-layer hydrate form of montmorillonite clay is the most stable. Even though there are simulation studies on the effect of temperature on the swelling behavior of bentonite clay, the impact of temperature on the swelling pressure has been neglected in molecular dynamics, and there are different conclusions to be drawn from the experimental results. There are several structural and environmental elements that hinder determining how swelling pressure varies with temperature. When trying to figure out how swelling pressure varies with temperature, though, it's helpful to have some knowledge of the swelling phenomenon that occurs in the interlayer space. At room temperature, the swelling pressure of smectites has been studied using molecular dynamics simulations. Swelling pressures calculated using a computer model of smectite sheets submerged in a water box have been demonstrated to correlate well with experimental results. Swell pressure simulations at temperatures other than room temperature may be easily added to the approach.

Because of its unique qualities when combined with groundwater, bentonite clay is an excellent choice for nuclear waste containment in geological repositories. High swelling capacity, limited permeability, strong radionuclide retention, and considerable self-sealing ability are only few of these features. It has been shown via research into the swelling processes of bentonites that the main component of bentonites, montmorillonite, is in fact responsible for the absorption of water and swelling behavior of bentonite-based materials. When subsurface water saturates compacted bentonite, the material expands and creates pressure. It is the compressed bentonite that prevents the nuclear waste canister from shifting in the ground. Extensive research has been conducted on the characteristics of swelling, the methods used to quantify swelling pressure, and the variables that contribute to the onset of swelling. The radioactive wastes decay process generates heat, which may warm the water and bentonite in the canisters near vicinity. Concerns about the bentonite buffer's effectiveness have been raised because of the effect that increased temperature may have on the material's swelling pressure and hydraulic conductivity qualities. Electric triple layer theory and water migration from micropores to macropores explain why bentonite swelling pressure decreases with increasing temperature.

According to the electric triple layer theory, the swelling pressure reduces with rising temperature because an increase in temperature causes the electrostatic force at the Stern plane to rise, hence decreasing the Gouy layer charge, the Stern charge, and the Debye length(Ghanizadeh et al., 2019). It was also taken into consideration that water would migrate from micropores/intra-aggregate to macropores/inter-aggregate when the temperature increased, which would cause the swelling pressure to decrease. According to the literature, the swelling pressure is reduced due to a drop in micropore water density with increasing temperature(Raúl Fernández et al., 2016; Shabab et al., 2016). However, the shift in system pressure and pore fluid characteristics has been used to explain the observed rise in swelling pressure with rising temperature. Researchers have shown that when temperatures rise, the pressure exerted by water molecules in the hydrated state decreases while the pressure exerted by osmotic and pore water increases. Furthermore, the depth of the diffuse layer grows and the dielectric constant and interface tension of the pore fluid both drop with increasing temperature(Zaki et al., 2022).

It is important to highlight that direct comparisons are difficult in experimental investigations due to the different experimental circumstances and chemical clay compositions. And the pressure impacts that have been documented are, at best, negligible. The simulations agree better with the tests, which found that the swelling pressure increased with temperature. Since dynamics simulations are not particularly good at evaluating the minor charge changes involved in the layer theories, it is not possible to conduct a full investigation of the phenomenological models.

As a result of its inherent robustness, low hydraulic properties, high sorption capacity, and self-sealing properties, bentonite has been suggested as a potential buffer material. Depending on the dry density, the conductivity of compact bentonite may increase or decrease. Since tightly compacted bentonite has a sufficiently high hydraulic conductivity, diffusion coefficient will be the primary method by which radioactivity migrates through the buffer and into the surrounding environment if the waste receptacle is breached. However, following repository closure, the buffer temperature is predicted to grow due to decay heat of high-level waste, which would compromise the buffer's integrity. If temperatures were to rise, the hydraulic conductivity of the buffer would improve, speeding up the flow of water, which in turn might speed up the discharge of radioactive materials from the repository. As a result, from the perspective of long-term functioning of the ceramic barrier for high-level waste storage, it is important to have a thorough understanding of the impacts of heat on the conductivity in the buffer.

It has taken a long time for bentonites to be characterized and employed for sealing applications in civil engineering. Clay minerals serve an active role and are not only passive bystanders in all their uses. Fibrous clays (Sepiolite) with a typical structure and intermediary of kaolinite and montmorillonite features are intriguing clay resources, for the research of various mix designs. The phyllosilicate clay mineral sepiolite, which is both needle-like and fibrous, may be found in the sediments and soils of arid and semiarid locations all over the world. Structure plays a role in the peculiar qualities of sepiolite minerals, which include high porosity, a large specific surface, and potent adsorptive and rheological capabilities. Due to its unique set of qualities, sepiolite may be used in a wide variety of contexts, including as a viscosity builder in saltwater or higher amount drilling muds and as an adsorbent for a wide variety of compounds.

2.6 Summary

From above literature review, the use of bentonite as a partial replacement of sand or cement is not extensively investigated. To evaluate bentonite's potential as a cement replacement material, it will be necessary to first determine the mechanical characteristics of the material when it is used to replace a particular amount of cement at an elevated temperature. According to the findings of several studies, bentonite has a high degree of flexibility and a propensity to form pallets when it is combined with water and soil. This leads to an inhomogeneous wetting of bentonite, which, in turn, causes the reduction ability of concrete to be slowed down. The most important aspect of this research is an analysis of the potential for fire and the modifications that high temperatures bring about in mixtures that include bentonite. When exposed to high temperatures, concrete experiences a reduction in both its tensile module and compression strength. Even though concrete plays a significant part in reducing the impact that is caused by fire, this reduction in strength occurs when concrete is exposed to high temperatures. Therefore, a visible impact is created on the concrete, in addition to influencing the ability of the concrete to bear weight.

Given the facts depicted in literature review, the purpose of this research is to examine the effects of using bentonite as a filler ingredient (in lieu of sand) in concrete mix on the mix's strength and fire resistance at varying temperatures. Compressive strength, tensile strength, as well as stress-strain response are only some of the concrete qualities that will be examined in this research. This research will examine the best sand replacement ratio for bentonite in mortar plaster and the best sand replacement ratio for bentonite in concrete for its strength and thermal resistance. With the second half, we'll see how fire affects concrete samples covered in mortar plaster in which bentonite replaces sand at three distinct ratios (30 percent, 40 percent, and 50 percent) and how they react to various high temperatures. The study's outcomes will be compared to those of the samples examined as controls at room temperature. Finally, this study induces the empirical connections that serve as the input for the assessment and design of the physical buildings.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter defines the testing procedures employed in this research work. The system model works by defining the material properties of Bentonite as a filler material in concrete mixtures. High heat resistance, plasticity, and compression of Bentonite – incorporated mixtures are the variables of this research. Overall, the procedure of calculating results is mentioned with illustrations of the apparatus in use.

Following subsections cover the study of instruments involved in determining procedures of use, fixing threshold parameters in respect of capacities of instruments and their calibration. This testing was carried out using state-of-the-art equipment at the Structural Engineering Laboratory at Military College of Engineering, Risalpur which has all the necessary instruments required for thermal resistivity and compression tests for strength of concrete. While calibrating the equipment, the primary objective of this activity was to develop understanding of instrumentation process and ensuring proper working of the instruments/tools.

The process included four distinct stages or steps. After obtaining the materials from any nearby quarries that were still operational during the initial phase of the project, we moved on to testing those materials. Bentonite, also known as Gachi in the local language, will be obtained from "Jehangira" once it has been graded in the laboratory. Following the analysis of the materials, the second step consisted of the design of the combination. To reconfirming the executed mix design and strength parameters, trial samples were cast for both 14 and 28 days.

The final process consisted of casting the specimens that were collected. It took a total of 96 samples to get everything ready, and then 24 of them were used to make the control specimens. This stage was broken up into two parts for the remaining 72 specimens that needed to be examined.

Sand was used to replace 20 percent, 30 percent, and 40 percent of the bentonite that was used as filler in the compression test samples. After 14 and 28 days, these specimens were subjected to a battery of tests, the findings of which were compared to those obtained from the controls, and an optimal percentage of integrated bentonite was determined to have been achieved. In the same manner, control concrete samples used in phase B were covered with partly replaced bentonite mortar plaster. In this instance, bentonite was used in lieu of sand at percentages of 30, 40, and 50 percent to test the thermal resistance of the concrete after it had been allowed to cure for 28 days. Evaluation of the results was carried out at the fourth step of the process.

3.2 Testing Methodology

The methodology was divided into following four phases:

- In first phase the materials were procured from the local available quarry sites and then tests were performed on the materials. Bentonite was procured from "Jehangira" and later it was graded in laboratory. Some tests were carried out on materials before casting.
- In second phase mix design was carried out after the characterisation of materials. Trial samples were casted for 14 and 28 days to reconfirm the performed mix design and strength criteria.
- In third phase casting of specimens was carried out. A total of 96 samples were prepared out of which 24 samples were casted for control specimens. For remaining 72 specimens this stage was subdivided into 2 phases.

Phase A: Bentonite filler concrete Compression and thermal resistivity test contain three sets. Each set comprising of 16 specimens.

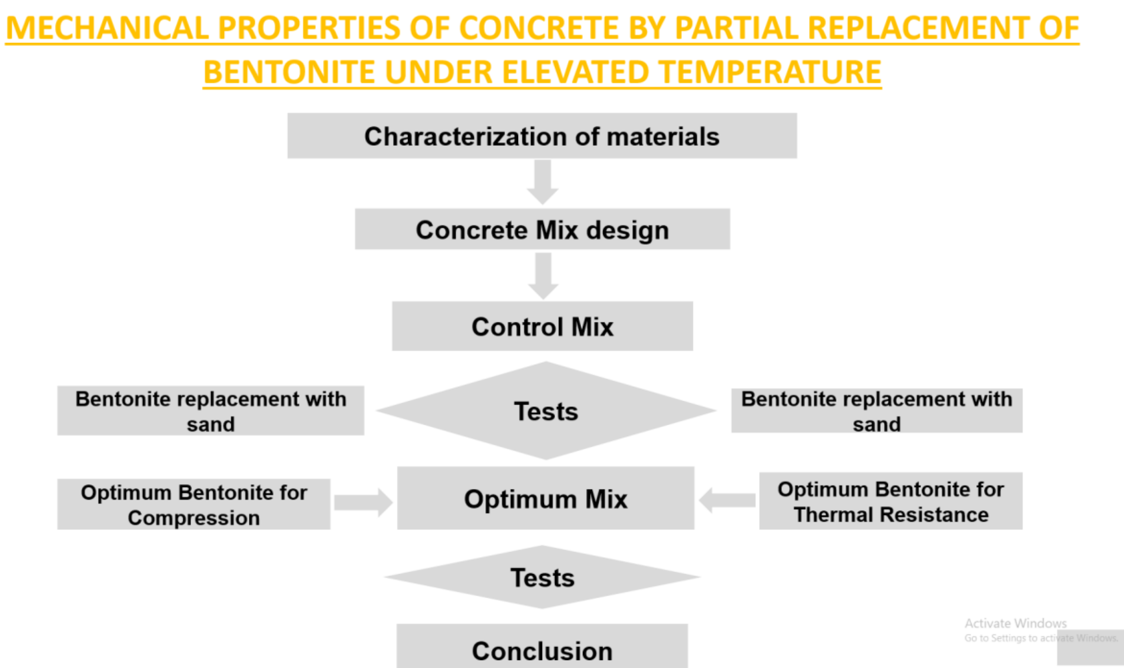
Phase B: Consists of 3 sets each comprising of 8 specimens.

- In fourth phase, results evaluation was carried out.

3.3 Procedural hierarchy

Table 1 describes the hierarchical steps and procedures for Bentonite replacement of sand in concrete mixtures as part of the thesis methodology:

Table 1: Methodology adopted for this thesis



The Bentonite incurred from Jehangira was subjected to various phases of testing. The following subsections provide a series of steps which formulate the testing procedure of Bentonite – included concrete mixtures.

3.3.1 Casting of samples

To start with, the Bentonite material was selected from Jehangira and brought to the laboratory. The design mix was taken in the cement–sand–aggregate ratio of 1:1.5:2.5. Bentonite mixtures were prepared, and molded, and concrete samples were made into casts in decided ratios for Batch–A and Batch–B testing. For Batch – A, the sand was replaced by Bentonite in the casts while for Batch – B testing, the casts were of control samples and coated with Bentonite to check the thermal resistance of Bentonite replaced mixture. (Illustrations are given in Appendix B).

3.3.2 Curing of samples

The samples were left for 14 and 28 days so that the concrete material with Bentonite as filler material would settle in the cast and dry up. After that the casts were subjected to compression and temperature testing.

3.3.3 Control samples

Control samples refer to initial concrete mixtures without the addition of Bentonite in them. These were 24 in number and were afterwards coated with Bentonite (plastering) and heated in a furnace to check effect of heat upon them.

3.3.4 Plastering of samples

The plaster is a mixture of lime or cement concrete and sand along with a required quantity of water. Plastering is a process of covering rough walls and uneven surfaces with plaster while constructing structures. In this research, plastering of Bentonite containing mixture in fixed ratios was done over control samples with the purpose of checking their heat resistance.

3.4 Testing equipment

The laboratory equipment needs to be defined before an analysis of the underling techniques. Following equipment was used for the analysis of the materials under study:

3.4.1 Compression Testing

With the expansion of the construction business, quality assurance is necessary. In the construction industry, a lot of projects fall short due to inaccurate testing and findings. Compressive testing is one of the fundamental and crucial tests, and it should be carried out properly since it serves as the foundation for all other concrete-related tests in civil engineering. Since it offers us a quick sense of the grade and quality of concrete, compression tests are nearly always necessary.

Compression testing is used to establish compressive force or crush resistance of a material. The ability of the material to recover to its original shape is measured after a specified compressive force is applied. A Compression Testing Machine (CTM) is shown in Figure 1. A CTM is a kind of universal testing machine (UTM) designed specifically to assess the durability and deformation characteristics of a material under compressive (pressing) force. The components of a conventional compression tester include a load cell, one or more crossheads, compression test equipment, electronics, and a driving system. CTM are used for testing of endurance of glass, metals, plastics, composites, ceramics, and others.

For using CTM for the concrete mixtures, the CTM was calibrated against benchmark samples and then tests for replacement of Bentonite in calculated percentages were carried out.

Figure 1: Compression testing

3.4.2 Heat resistance

The performance of the material is the main factor in determining the intensity of heat-resistant concrete, and the consumption of gelling material, water-cement ratio, grading of aggregate, particle diameter, adulterant consumption, and admixture etc., have a significant impact on heat-resisting high-temperature behavior. The constantly increasing rates of both fire and dangerous factors in modern industrial production make it more urgent to find cost-effective solutions to the challenge of making buildings fireproof and heat resistant. Because of its low cost and high durability, concrete remains the material of choice for building projects.

An apparatus used to provide high heat to mixtures in this thesis is called muffle furnace. Muffle furnace design consists of a triple – wall structure with insulation. A microprocessor controls the temperature, and the settings can be changed accurately with a clear display. The inner walls are equipped with zirconia fiber board which makes the walls durable.

The aggregate has a significant impact on how concrete reacts to fire. The compressive strength of concrete made with lightweight aggregate and carbonate aggregate (limestone) is mostly unaffected by temperatures up to 650 degrees Celsius. Fires may produce a wide variety of problems for concrete, from superficial flaws to severe cracking and spalling on the surface.

The choice of aggregate is the most crucial consideration. Damage might occur because to the differing thermal expansion and contraction rates of the cementitious material and the aggregate. When it comes to bond failure and fire damage, quartzite aggregate is the worst offender. At low temperatures, limestone aggregate shows greater resilience to flames.

Heat resistant concrete is often required at higher temperatures (above roughly 400 °C). For application in temperatures exceeding 550 °C, calcium aluminate cement is the material of choice. The unique new cement altering substance concrete, however, was only lately identified. An amazing improvement in heat resistance may be achieved when using this material in the making of concrete or mortar. Mortars made from cement have withstood temperatures as high as 2000 degrees Celsius without suffering significant harm.

Nonetheless, at 650 degrees Celsius, only about 55% of the compressive strength of concrete made with siliceous aggregates like granite, quartzite, and other materials composed largely of silica is retained. The heat resistance of Bentonite – incorporated mixtures was found by placing them one by one in a muffle furnace. Figure 2 shows a muffle furnace where samples were placed under temperature maintained till 200, 400, 600 and 800 degrees.

Because of this, the ability of research materials and building materials to withstand high temperatures is of utmost significance. Concrete with high heat resistance is a special kind of concrete that can maintain its appropriate physical and mechanical properties as well as its volume stability when subjected to temperatures ranging from 250 to 900 degrees Celsius over extended periods of time.

Figure 2: Muffle furnace

3.4.3 Thermocouple mounting

Finally, a thermocouple temperature sensing was made for each casting. Thermocouple consists of metal junctions which when heated or cooled, a voltage is created that can be correlated back to the temperature. In the following tests, thermocouple was used to measure the temperature inside the benchmark casts as well as Bentonite – replaced casts.

Figure 3: Thermocouple installed in Bentonite coated samples

Figure 3 shows a thermocouple incorporated Bentonite – replaced cast. A 6-inch drill was made into the cast and thermocouple installed which is connected to a computer to record temperature readings.

3.5 Testing

3.5.1 Thermal Resistance

Thermal resistance refers to the degree to which a material can withstand heat. If the material does not melt and change its morphological structure, the material is said to be heat resistant or thermally resistant. Muffle furnace was used to determine the heat resistance of Bentonite – incorporated mixtures. The temperature was kept as high as 200, 400, 600 and 800 degrees and the results on the material properties in terms of thermal resistance were recorded.

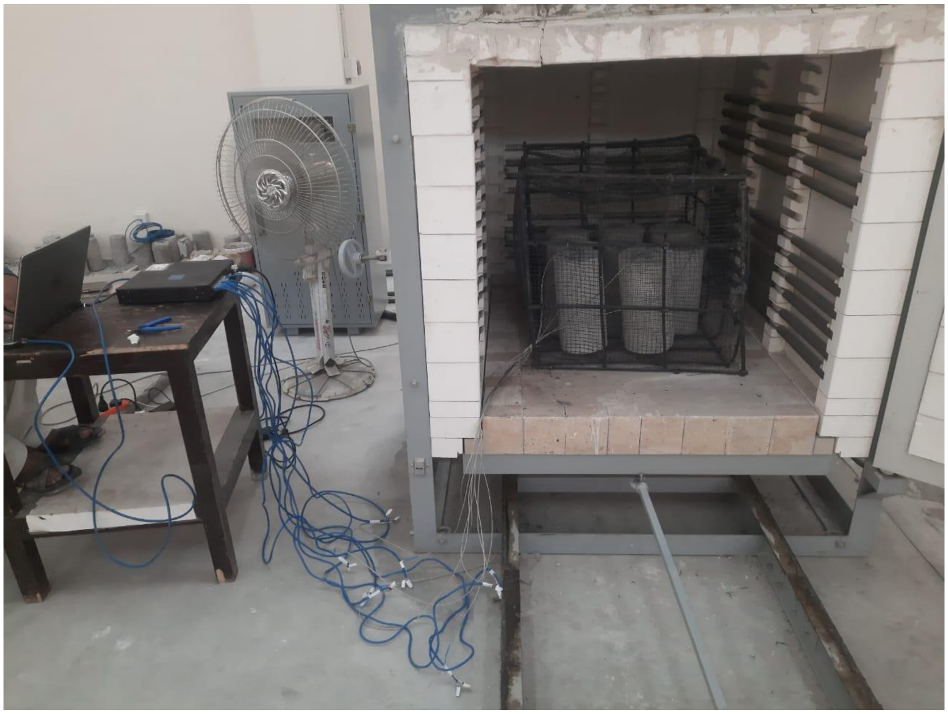


Figure 4: Thermocouples in Lab

Bentonite samples were then prepared for heat testing. Afterwards, control samples were made (which did not contain Bentonite) and they were plastered (coated) with Bentonite. These samples were then placed in muffle furnace and the temperature was gradually increased from 200 to 800 degrees Celsius.

3.5.2 Compression Tests

For compression testing, a CTM (Compression Testing Machine) was used as shown in Figure 2. When structures are subjected to compression tests, their ability to return from the impact is recorded, which was one of the main concerns of this research. The compression of Bentonite incorporated concrete mixtures was observed in this study.

Figure 5: Compression test

After curing of samples for 14 days, the compression test was performed. The test incurred about 3000 psi strength of mixture which is about 70 percent of the requirement. After curing up to 28 days, the strength availed was around 4000 psi.

With a cement–sand–aggregate ratio of 1:1.5:2.5, the achieved sustenance was agreeable towards the demand. The 14 days cured samples once subject to compression in CTM with the compression readings of 70 percent recorded. The 28 days cured samples were then inserted in CTM to check the effect of pressure. These Bentonite replaced samples cured for 28 days showed the best compression results.

3.6 Number of samples

Table 2 contains a list of samples used for each testing and their proportions according to the materials involved.

Table 2: List of samples and their proportions

<table>
<tr><th rowspan="2">MIX</th><th colspan="3">CONCRETE</th><th rowspan="2">BENTONITE</th><th colspan="4">THERMAL RESISTANCE TEST</th><th colspan="2">COMPRESSIVE STRENGTH</th><th rowspan="2">WATER ABSORPTION</th></tr>
<tr><th>CEMENT</th><th>F.A</th><th>C.A</th><th>T200</th><th>T400</th><th>T600</th><th>T800</th><th>14DAY</th><th>28DAY</th></tr>
<tr><td>CNTR</td><td>100</td><td>100</td><td>100</td><td>00</td><td>2</td><td>2</td><td>2</td><td>2</td><td>3</td><td>3</td><td>2</td></tr>
<tr><td>B20</td><td>100</td><td>80</td><td>100</td><td>20</td><td>2</td><td>2</td><td>2</td><td>2</td><td>3</td><td>3</td><td>2</td></tr>
<tr><td>B30</td><td>100</td><td>70</td><td>100</td><td>30</td><td>2</td><td>2</td><td>2</td><td>2</td><td>3</td><td>3</td><td>2</td></tr>
<tr><td>B40</td><td>100</td><td>60</td><td>100</td><td>40</td><td>2</td><td>2</td><td>2</td><td>2</td><td>3</td><td>3</td><td>2</td></tr>
<tr><th rowspan="2">MIX</th><th colspan="3">MORTAR PLASTER</th><th rowspan="2">BENTONITE</th><th colspan="4">THERMAL RESISTANCE TEST</th><th colspan="2">COMP: STRENGTH</th><th rowspan="2">WATER ABSORPTION</th></tr>
<tr><th>CEMENT</th><th colspan="2">F.A</th><th>T200</th><th>T400</th><th>T600</th><th>T800</th><th colspan="2">28DAY</th></tr>
<tr><td>CNTR</td><td>100</td><td colspan="2">100</td><td>00</td><td>2</td><td>2</td><td>2</td><td>2</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>C30</td><td>100</td><td colspan="2">70</td><td>30</td><td>2</td><td>2</td><td>2</td><td>2</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>C40</td><td>100</td><td colspan="2">60</td><td>40</td><td>2</td><td>2</td><td>2</td><td>2</td><td colspan="2">0</td><td>0</td></tr>
<tr><td>C50</td><td>100</td><td colspan="2">50</td><td>50</td><td>2</td><td>2</td><td>2</td><td>2</td><td colspan="2">0</td><td>0</td></tr>
<tr><td colspan="5" rowspan="2">NO. OF TOTAL SAMPLES</td><td>16</td><td>16</td><td>16</td><td>16</td><td>12</td><td>12</td><td>8</td></tr>
<tr><td colspan="7">96</td></tr>
</table>

Before plastering, Bentonite was molded with concrete to make casts and subjected to compression test for the range of 20%, 30% and 40% Bentonite. The percentages for cement, coarse aggregate (C.A) and fine aggregate (F.A) are given in Table 1 for each sample. After that, control samples were plastered with Bentonite coating for the range of 30%, 40% and 50% and subjected to thermal resistance test. Therefore, in Batch – A, the Bentonite containing samples were tested for thermal resistance and pressure while in Batch – B, control samples were coated with Bentonite mixture and thermal resistance test was conducted.

For Batch A, compression strength was monitored after curing (settling) of samples for 14 days and 28 days, whereas, for Batch B, compressive strength was measured after curing of samples for 28 days. Overall, out of a total of 96 samples, 24 Bentonite plastered samples were set for compression test, 64 for thermal resistance test and 8 for water absorption. Thermal resistance test was made for both Batch A and Batch B for the temperatures of 200, 400, 600 and 800 degrees and results have been recorded accordingly.

3.7 Conclusions

This chapter explained the underlying schemes and techniques involved in determining the effect of adding Bentonite to concrete mixtures. The tests involved include compression tests, thermal resistance test and the results for the same were generated using thermocouples. The duration for each step was recorded along with the number of samples for each test. The process was divided into two batches, Batch – A with the addition of Bentonite in mixture and Batch – B with the coating of Bentonite over samples to check how they withstand high temperature.

CHAPTER 4

ANALYSIS, RESULTS AND RECOMMENDATIONS

4.1 Overview

This chapter includes the results and discussion for each step introduced into the gathering of elements, the experimentation, and the testing phases. The experimentation and testing were performed on samples of concrete with the incorporation of Bentonite. All tests were carried out in the structure's lab in Military College of Engineering, Risalpur.

4.2 Thermal resistance test

To serve as a standard for the bentonite samples, control samples were collected. Two batches were made for the thermal resistance test:

Batch – A contained samples which included Bentonite in fixed ratios. The ratios are given in Table 2 for reference in which B20, B30 and B40 represent 20%, 30% and 40 percent replacement with Bentonite.

Batch – B contained control samples with Bentonite proportional coating where C30, C40 and C50 represent 30%, 40% and 50% replacement of Bentonite in coating aggregate. The T200, T400, T600 and T800 represent temperature in degrees Celsius.

4.2.1 Results

Figure 6 shows graphical results of thermal resistance tests for core temperature of concrete samples:

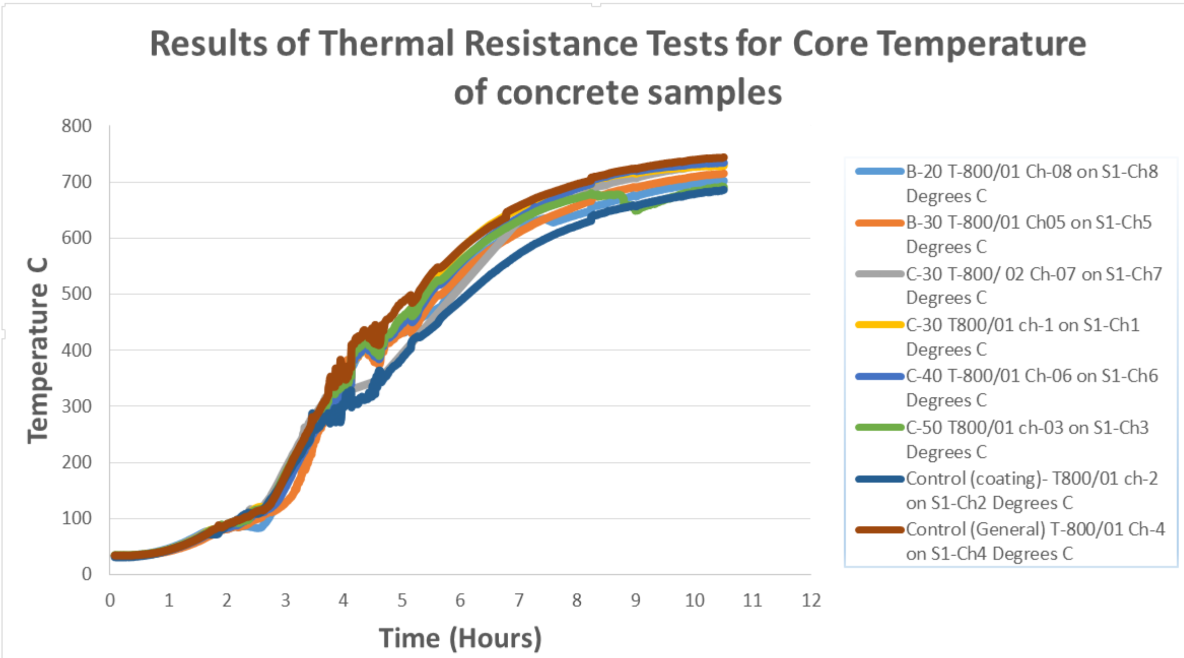


Figure 6: Results for Thermal Resistance Test

4.2.2 Analysis

The control mix (bottom most line) has shown the minimum resistance to temperature by attaining a high degree reaching 800 degrees Celsius. The control mix with coating (dark blue line) has attained the best temperature resistance which is an obvious case. The 20% replacement of Bentonite into the mixture (B20) showed optimum temperature resistance. For replacement in aggregate for coated samples, 30% replacement (C30), the temperature rested at about 700 degrees in 10 hours. This is the optimum mix for Bentonite coated samples. Deep contrast was shown in control samples before and after coating.

From the results B20 and C30 as replacement of cement and aggregate respectively, has capacity to be more heat resistant as compared to other samples, when it comes to using bentonite as a cement replacement. This is because of the reason that, at temperatures of the magnitude used in this study, many different types of materials experience a loss of strength, as well as stiffness and spalling. However, concrete is a substance that offers protection. Clay, limestone, gypsum, and aggregate are some of the ingredient components that are needed to build concrete. These constituent components combine to create a material that is resistant to heat and flames. Because the mixture itself renders concrete non-combustible while simultaneously rendering it chemically inert, there is no need for extra fire protection. So, bentonite complemented the properties of concrete to resist heat and replacing cement or aggregate at the same time. This potential of bentonite can be promising for concrete industry as it not only provides advancement in concrete technology but also help in shaping the sustainability of modern concrete technology.

Therefore, it can be inferred that that because of the slow rate at which heat moves, bentonite concrete can sustain very high temperatures without breaking, cracking, spewing hazardous fumes, smoking, or producing molten particles. Bentonite Concrete containing bentonite content up to 20 percent retained its structural capability even when exposed to fire, and the material did not burn up in the process. This reduces the likelihood of there being a fire when bentonite will be used as replacement of both cement (up to 20%) and aggregate (up to 30%), while also needing the least amount of care to keep itself from becoming damaged.

4.2.3 Optimum mix

It is evident from the Figure 6 that the B20 mixtures – the mixtures for which 20% Bentonite was replaced instead of sand – showed the best resistance to high temperature. This is because the absorption of heat by the mixture decreased as the temperature increased – in case of 20% replacement of Bentonite. Referring to the graph, the optimum value of Bentonite replacement comes out to be 20%. At 20% proportion of Bentonite in the concrete mix, the thermal resistance is seen to be optimum. Therefore, 20% Bentonite is the selection criterion of Bentonite for thermal resistance.

4.3 Compression test

Bentonite – incorporated (B) samples and Bentonite – coated (C) samples were subjected to compression tests respectively in a UTM (Universal Testing Machine) which is like CTM by definition and function. The results are shown in the Section 4.3.1.

4.3.1 Results

Figures 7 – 9 show the trends for Bentonite replacement into the concrete samples i.e. the control, B20, B30 and B40 samples. Empirical values are given in Appendix A.

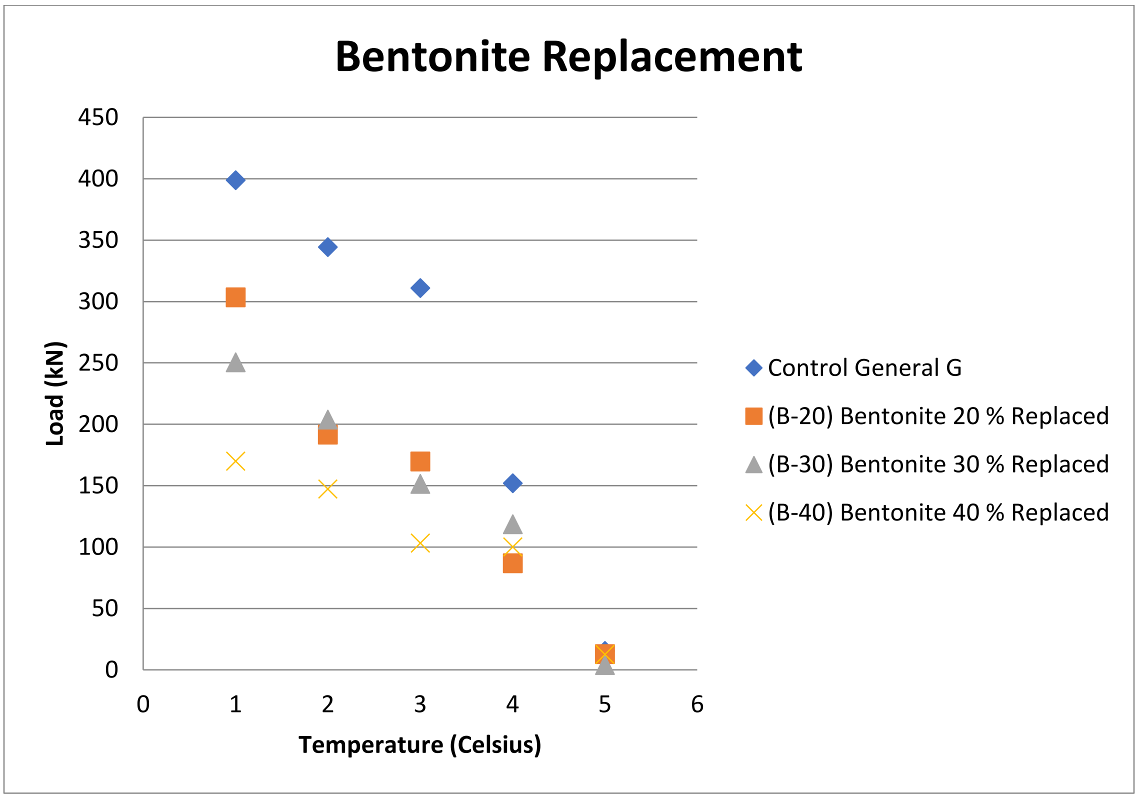


Figure 7: Scatter plot of Results of Bentonite replacement

With 30% replacement of Bentonite, the samples showed greater strength (around 200kN) at 200 degrees Celsius. When concrete mix in in which bentonite was used as replacement up to 40%, showed greater stability of 170kN at 300 degrees temperature.

The Control General Mix showed the best thermal resistance because of lesser water absorption. Bentonite incorporated samples absorb more water and therefore their strength decreases. As shown from Figure 9, the control general mix has comparatively maximum strength against each value of elevated temperature. B30 (30% replacement of Bentonite) has incurred the best strength especially at temperatures of 200 and 600 degrees Celsius. Therefore, it is the optimum mix in terms of compressive strength for Bentonite replacement. Figures 10 – 12 depict the results for Bentonite coating of samples.

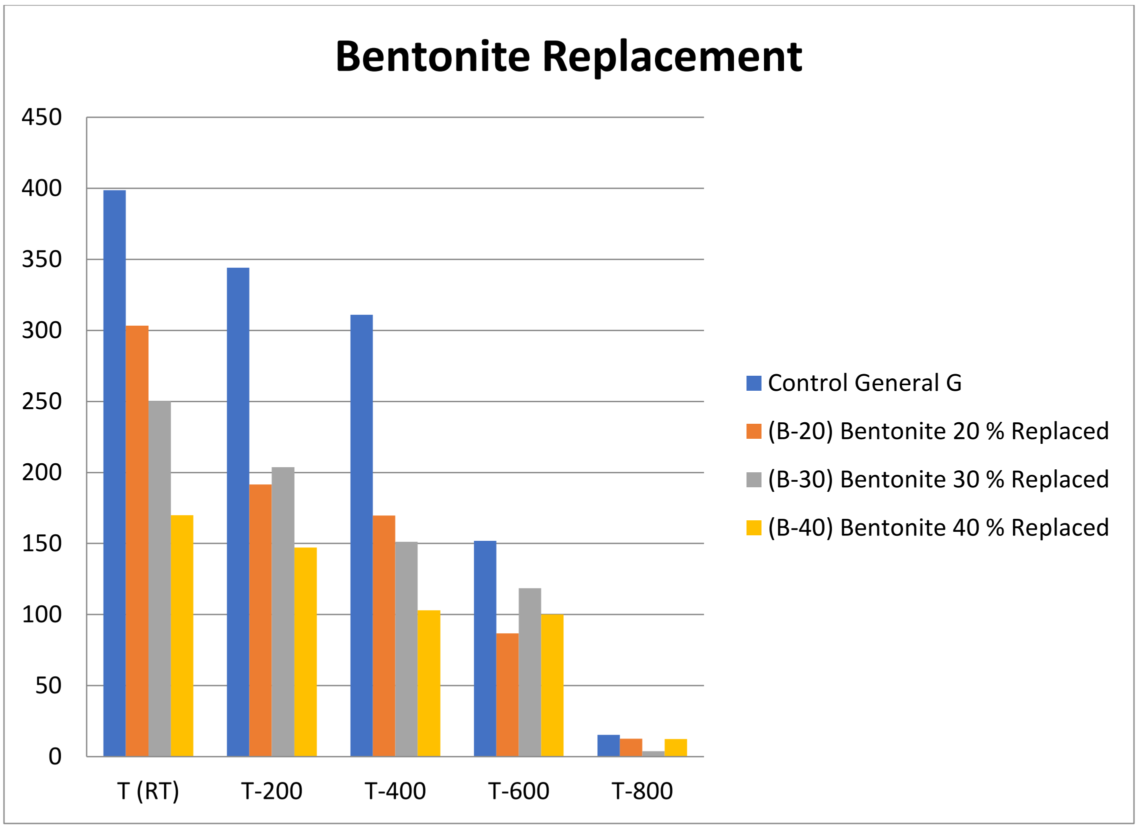


Figure 8: Results of Bentonite replacement (bar graph)

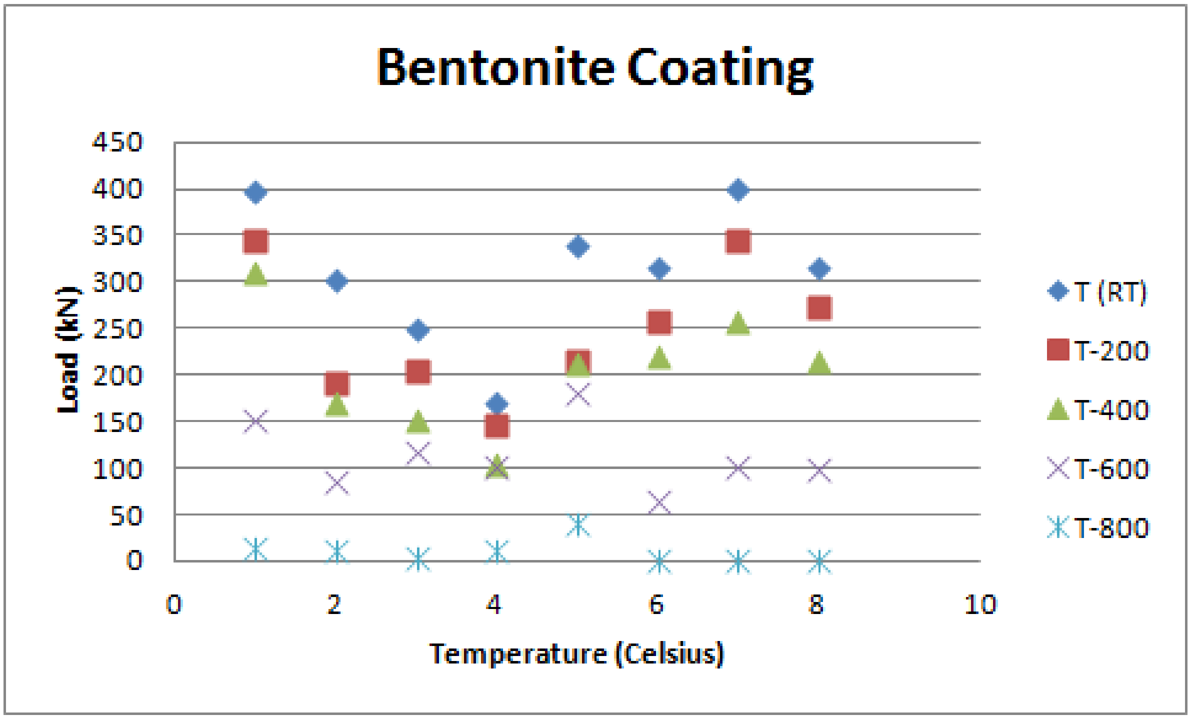


Figure 9: Scatter plot of Results of Bentonite coating

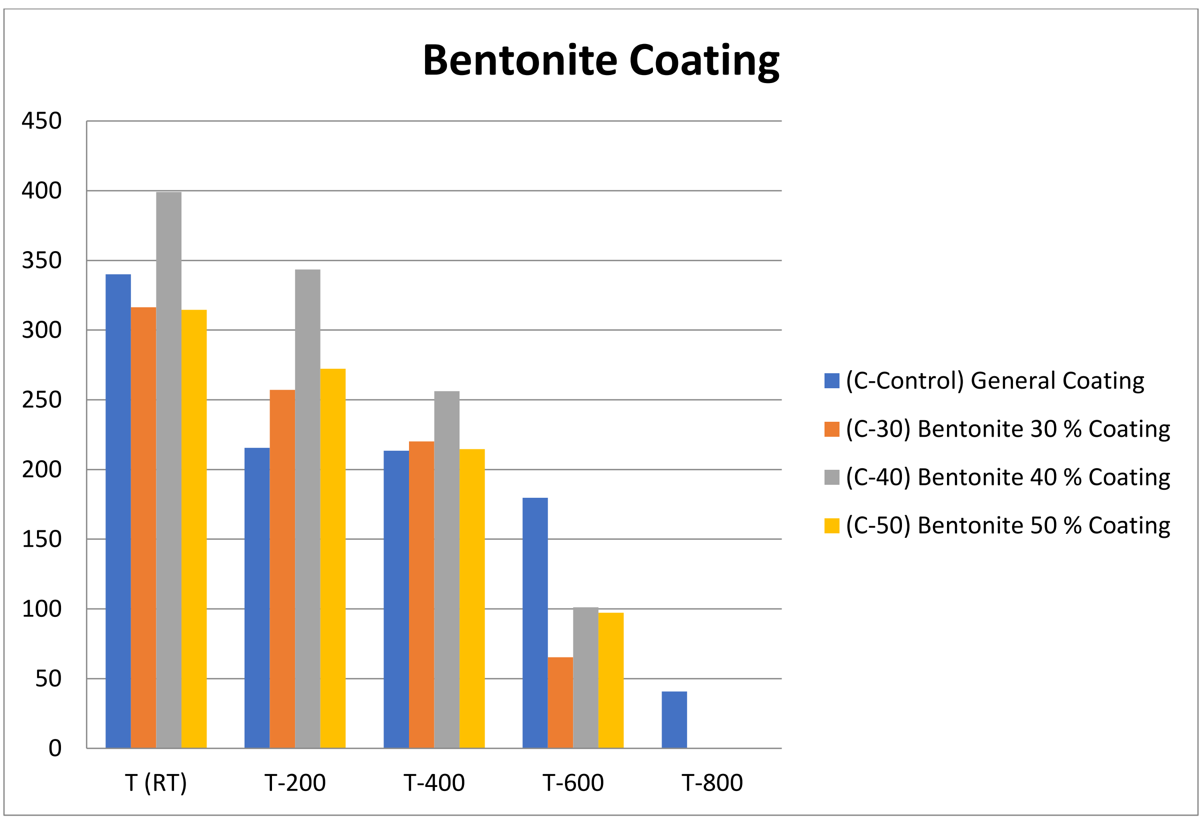


Figure 9: Trends of Bentonite coating

Coating of Bentonite has resulted in greater strength of mixture as compared to replacement of Bentonite. This is because of the water absorption criteria for Bentonite mixing since Bentonite absorbs more water. But the coating of samples with Bentonite yielded better compressive strength.

It can be seen from the Figure 12 that 40% coating of Bentonite sample was the most robust and resilient to temperature range of 200 – 300 degrees Celsius. At all temperature ranges, the C40 (40% coated Bentonite) has shown the best compressive strength and is therefore considered as the optimum coating mix. Technicians and engineers must be aware of the factors that might reduce the compression strength of concrete in a building or cause a concrete cube to break under loads below the minimum required strength. Compressive strength of concrete is affected by several factors, not the least of which are the cement's quality and grade as well as the water-to-cement ratio of the concrete mix.

4.3.2 Analysis

Figure 13 shows a comparative analysis of Bentonite replaced VS Bentonite coated samples. It can be observed from the comparative analysis in Figure 13 that:

- 40% Bentonite Coating showed the best strength under high temperature.
- 20% replacement of Bentonite experienced the best strength at 200 degrees Celsius while 30% replacement of Bentonite showed better strength.
- 40% replacement of Bentonite showed the least resistance under elevated

temperature but with better resistance from 300 to 400 degrees Celsius.

- B-30 (Bentonite 30% replaced) has shown the best resilience to high temperature.
- Bentonite 30% replaced has shown the best strength of 200kN at 200 degrees temperature.

- Bentonite 40 percent coated has shown the best resistance of 345kN at 200 degrees.

Therefore, C40 is the optimum mix for compressive strength where C40 refers to 1:3 of cement – aggregate in which 40% is Bentonite and 60% is the fine aggregate. The strength shown was 345kN at 200 degrees Celsius. For Bentonite replacement, B20 (20% replacement of Bentonite) has shown the best strength of 303.39 kN at 200 degrees Celsius. The Control Mix showed the least resistance to temperature, while the coated mixes showed better resilience towards temperature. It can be observed from this research that the compressive strength was maximum for C40 mixtures i.e., those having 40% replacement with Bentonite in aggregate. The strength achieved was 345kN.

4.3.3 Optimum mix

C40 is the optimum mix for compressive strength where C40 refers to 1:3 of cement – aggregate in which 40% is Bentonite and 60% is the fine aggregate. This is the best achieved strength of 345kN at the temperature of 200 degrees Celsius. Similarly, for Bentonite replaced samples, B30 showed sustenance of 200kN at 200 degrees Celsius. So, 30% replaced with Bentonite is the optimum mix for Bentonite replacement.

Bentonite replacement may not be used for high strength due to the mechanical property. Also, the water absorption for Bentonite mixtures is more than control mixtures. The samples without Bentonite coating heated up first. Coating showed best compressive resistance for C40, and replacement for B30.

4.4 Compressive strength comparison of control and bentonite replaced concrete samples at elevated temperature

Prior research found that the mechanical properties of the concrete reduced with increasing bentonite concentration, indicating that bentonite may enhance the porous structure of concrete mixtures, leading to increased durability. These findings reveal that the bentonite-containing samples outperformed the control mix even when kept at ambient temperature. This distinction may be due in large part to the filler effect provided by bentonite and the slower pozzolanic reaction compared to the hydration of cement.

An increase in residual compressive strength was also seen in concrete treated with bentonite. As measured by post-heating residual compressive strength, concrete with 20% bentonite performed better than control mixes. This is since bentonite-containing mixes have a higher heat capacity and lower thermal conductivity than control mixes, respectively, which improves the microstructure and slows the spread of microcracks. Compressive strength at room temp is affected by several factors, including the water-cement ratio, aggregate type and size, aggregate-paste interface zone, curing environment, and admixtures.

Additives, the concrete's strength at room temperature, and the pace of heating are the primary factors determining the material's compressive strength when heated. Water loss causes hydrothermal changes in concrete at temperatures up to 200 C. When heated to temperatures about 600 °C, the calcium silicate hydrate (CSH) gel decomposes, reducing both the material's strength and stiffness. The degradation of calcium carbonate (CaCO3) between 600 and 800 degrees Celsius significantly reduces its strength.

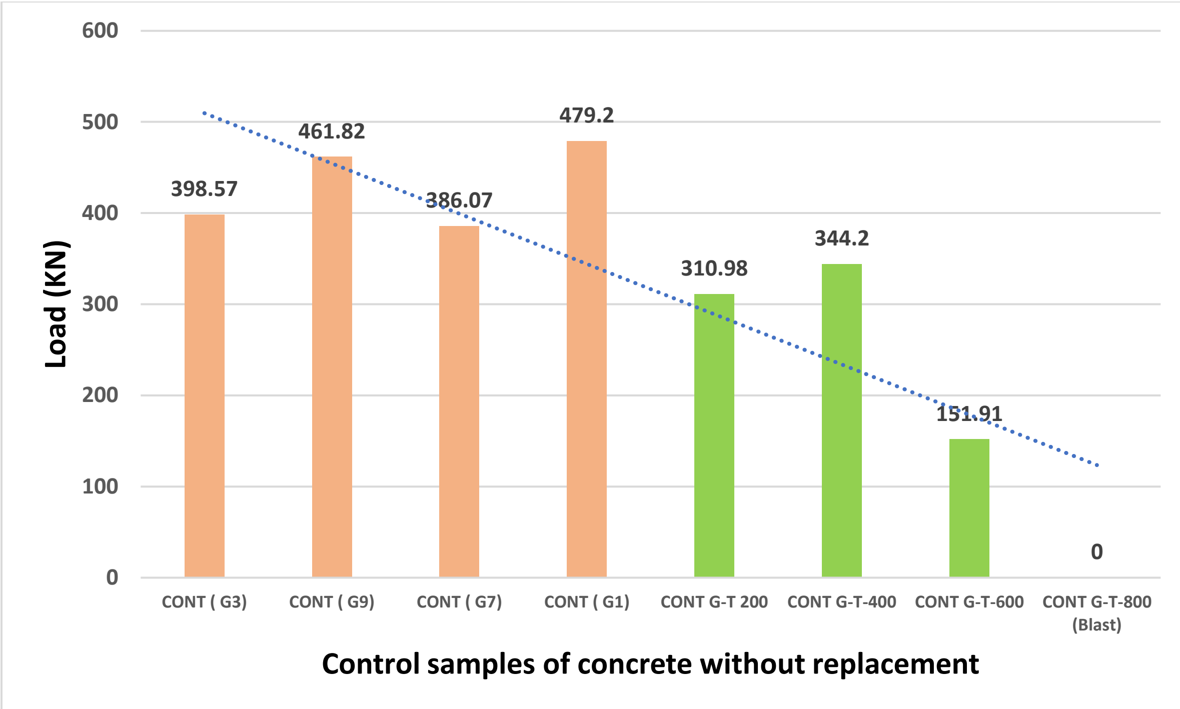


Figure 10: Concrete Strength (KN) of Control Samples Under Different Temperatures

Figure 11 depicts the graph that has been plotted between the load in KN against the concrete strength without replacement. The sample named CONT (G1) showed the maximum strength, and it can be confirmed from figure 11. While the sample named CONT G-T-600 showed the least strength, and this can also be confirmed from figure 11. As the concrete strength depends upon a lot of factors that can be crucial for a concrete mixture to withstand the subjected load.

The compressive strength of concrete samples using 20% substituted bentonite as a filler ingredient is shown in Figure 12, which shows the results for a range of temperatures. It can be observed that the sample named B 20 Gen shows the optimum compressive strength. This increased in compressive strength can be attributed to mechanical properties of bentonite, as this aspect is very crucial for the overall strength of concrete mix. However, this increased in strength was seen to a certain extent, because as the temperature was increased the compressive strength was decreased, which again, is an obvious fact. It is crucial to think about the stress-strain behavior of the control specimens that are subjected to elevated temperatures so that one can foresee the behavior of bentonite in concrete under these conditions. Exposed to high temperatures, concrete undergoes several chemical and physical changes, including loss of moisture, drying of the cement paste, and breakdown of the aggregate.

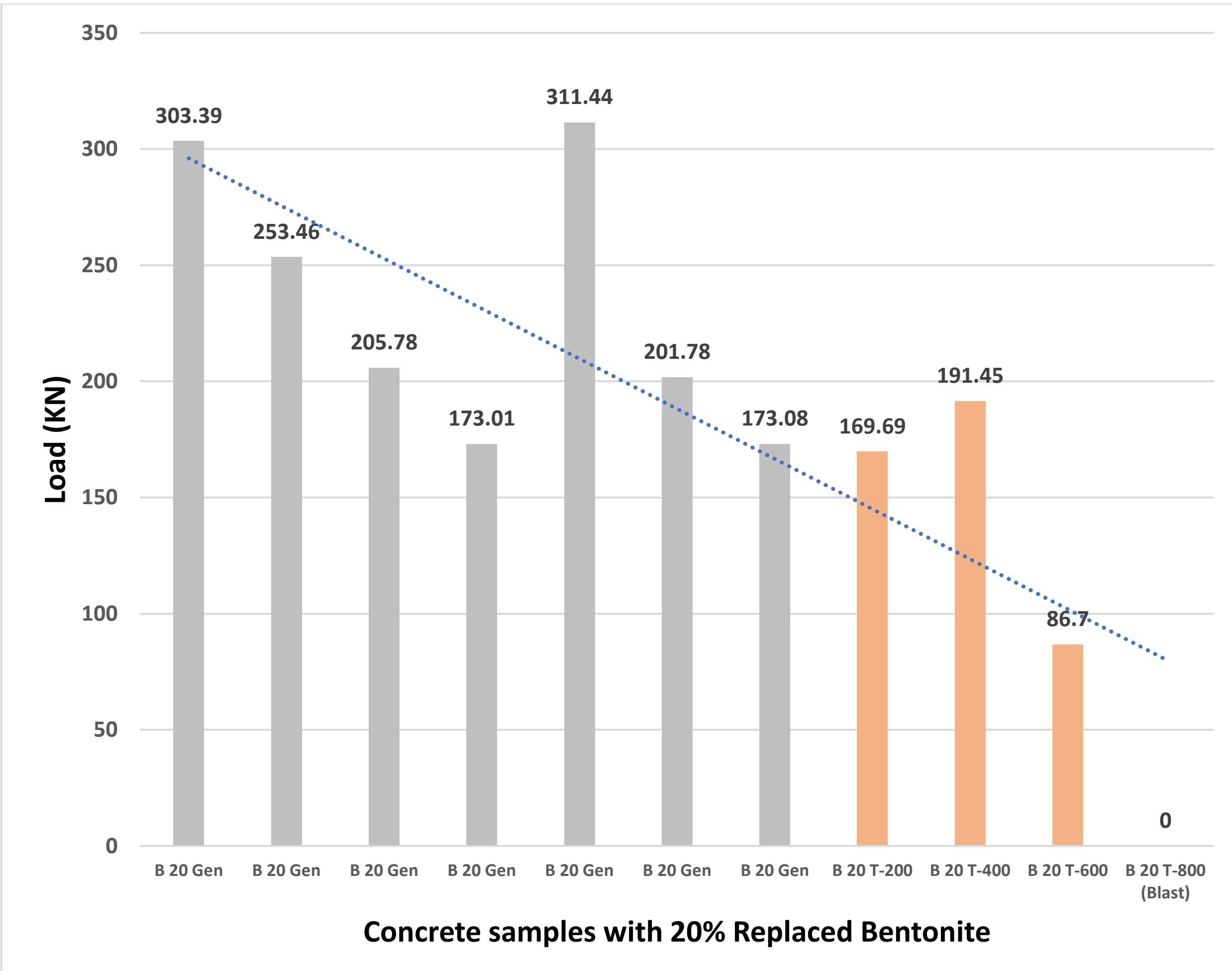


Figure 11: Compression Strength/Behavior of Concrete Samples with 20% replaced Bentonite (as a filler material) against mentioned Temperatures

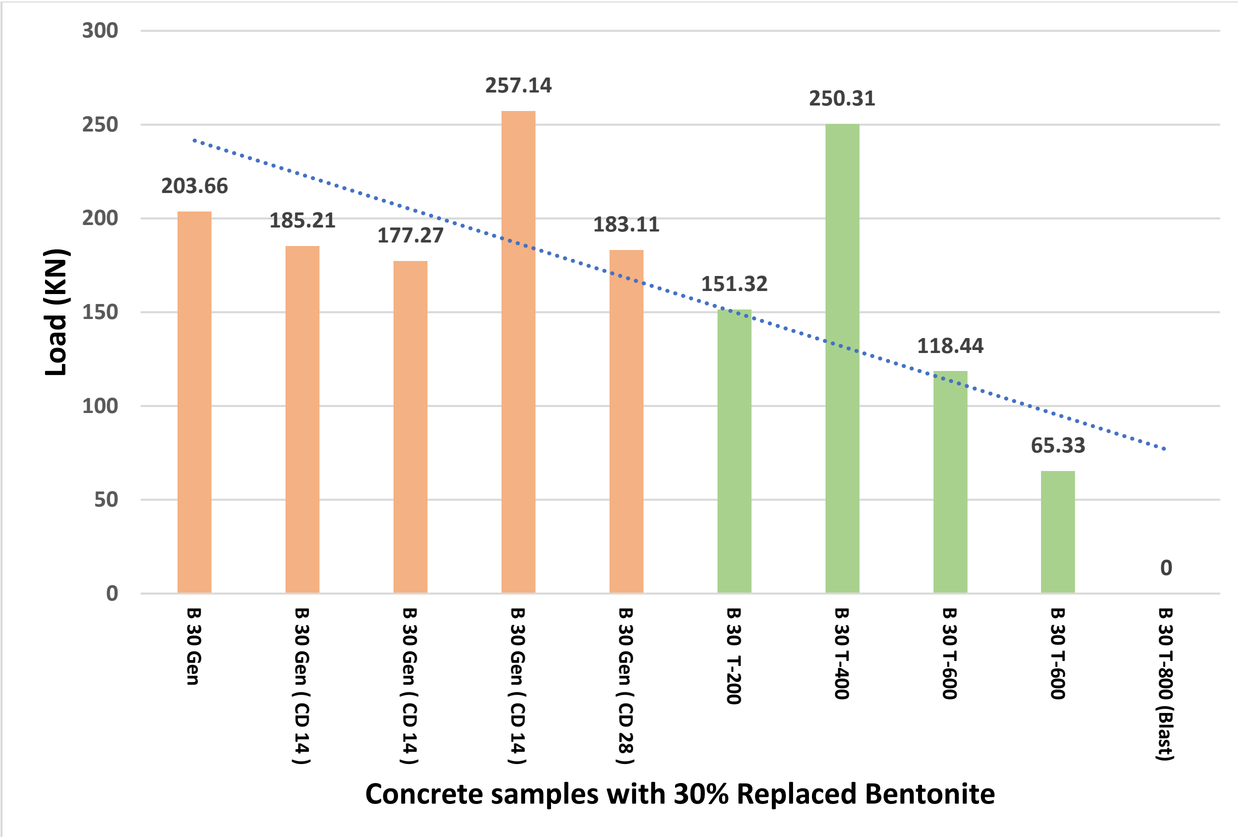


Figure 12: Compression Strength/Behavior of Concrete Samples with 30% replaced Bentonite (as a filler material) against mentioned Temperatures

The compression strength and behavior of concrete samples containing 30% replaced bentonite as a filler material is depicted in Figure 13 and is shown at a variety of temperatures. When the bentonite was used as a filler to replace the filler material up to 30 percent, the overall compressive strength of all the mixtures were lower than the compressive strength of concrete mixtures in which bentonite was used to replace the filler material up to 20 precent. As the temperature has an indirect relationship with the concrete strength so this fact can be logically accepted. When the bentonite was used to replace the filler material up to 30 precent, the sample named B30 Gen (CD 14) showed the maximum compressive strength. While the lowest compressive strength at elevated temperatures was recorded as 65 KN.

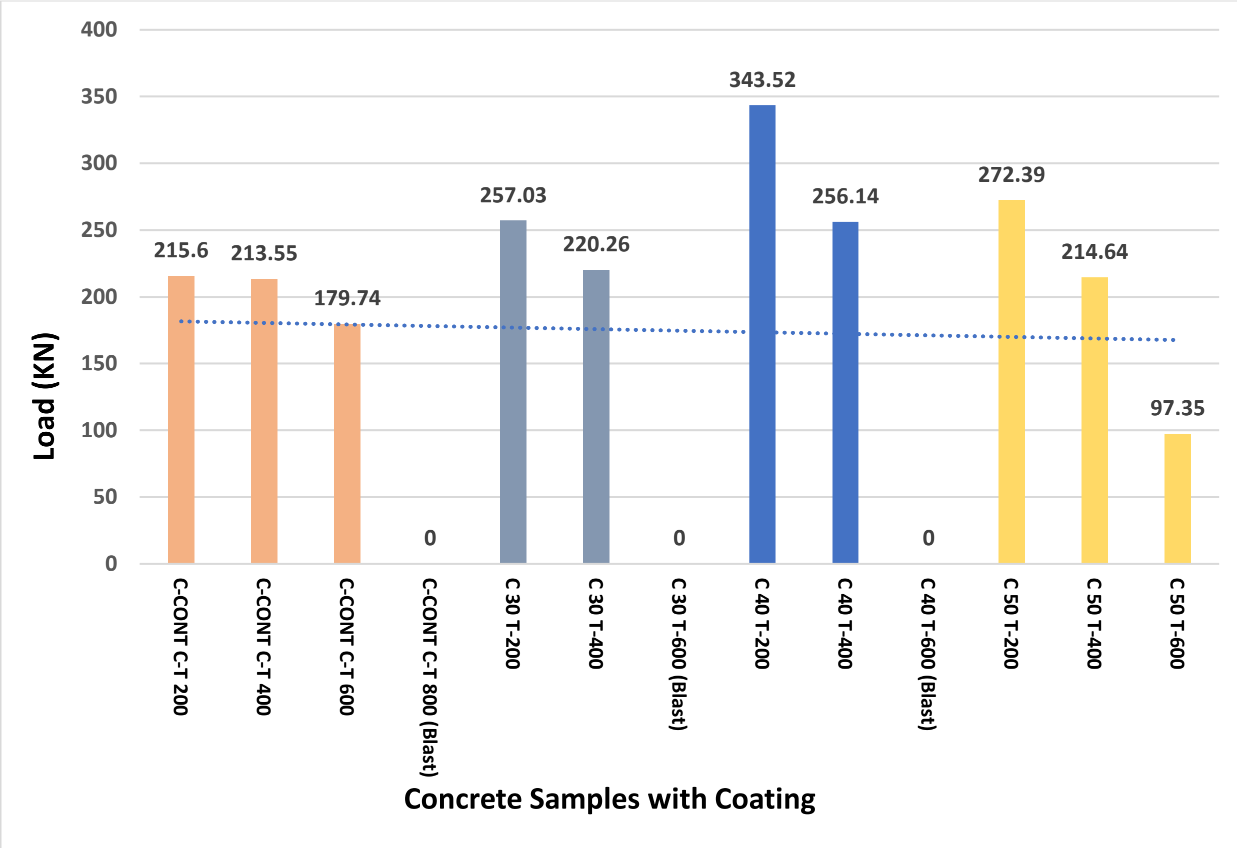


Figure 13: Compression Strength/Behavior of Bentonite Coated Samples against mentioned Temperature

Figure 14 shows the compression strength and the behavior of coated concrete samples at different temperatures. The overall compressive strength of all the concrete samples were higher than the compressive strength of concrete mixtures in which bentonite was employed to replace the filler material up to 30 precent. Seeing as how temperature does, in fact, have an indirect link with the strength of concrete, this is a truth that may be accepted on sound reasoning. When compared to other samples, C40 T-200 had the highest compressive strength.

Figure 15 depicts, throughout a range of temperatures, the compression strength and behavior of concrete samples using 40% substituted bentonite as a filler ingredient. The compressive strength of all the combinations was lower when bentonite was employed as a filler to replace the filler material up to 40 percent, compared to when bentonite was used to replace the filler material up to 20 percent in concrete mixtures. This is a reasonable conclusion to reach, given the indirect nature of the link between temperature and concrete strength. When the bentonite was employed to replace the filler material up to 30 precent, the sample designated B40 Gen (CD 14) demonstrated the greatest compressive strength. In contrast, at high temperatures, compressive strength dropped to 101.29 KN.

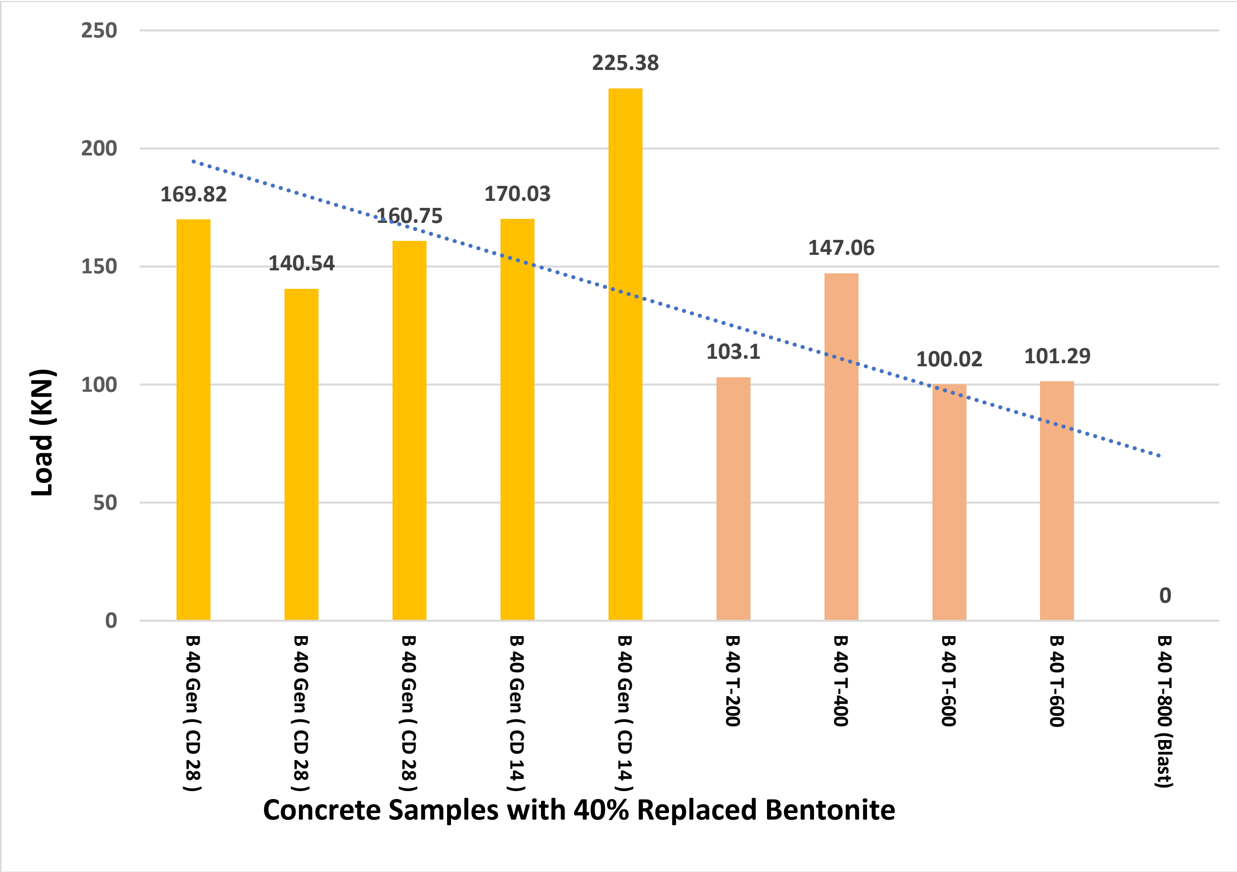


Figure 14: Compression Strength/Behavior of Concrete Samples with 40% Replaced Bentonite (as a filler material) against mentioned Temperatures

From the above figure, the trend can be observed that as the temperature increases the strength decreases. This fundamental aspect can be seen in the previous graphs also, because temperature tends to deteriorate the compressive strength of concrete mixes. Temperature has a major impact on the compressive behaviour of concrete because concrete builds strength via a hydration process between cement and water curing. A stronger and hotter reaction yields a shorter time to completion.

To recapitulate, Bentonite has a filler effect and reduces the porosity of concrete, reducing the amount of water absorbed by capillary action, which eventually increase the compressive strength. In addition, bentonite's superior thermal capacity means it performs better than the control sample at elevated temperatures, with less fracture propagation occurring consequently.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The main purpose of this research was to configure the optimum mix for construction purposes in terms of strength and temperature resistance. Two mixes were developed after a series of tests. The first mix was of partial replacement of Bentonite into the concrete mix while the second mix proposed after conducting tests was of coating of Bentonite over the control mixes. Stability and pressure were measured in kN against the temperature in degrees. It was observed that some mixtures can withstand more pressure than others when the temperature is increased. Although a limit to the temperature was kept in experiments, the temperature can exceed those limits in fire outbreaks. In those circumstances it is therefore mandatory to deploy construction mixture having properties of resilience and temperature resistance. Bentonite – a material taken from Jehangira in KPK, Pakistan – was therefore tested as a productive solution to the load resistance under fire and has proved to be optimum. Following conclusions can be made after conducting this comprehensive investigation:

- Bentonite was employed as a filler ingredient in concrete mix (replacing sand), and its behavior in terms of strength and fire resistance at various temperatures was examined. In the context of the strength and thermal resistance of concrete, an analysis was conducted of the ideal value of bentonite that can replace sand in mortar plaster. This analysis was made using the optimum value of bentonite in mortar plaster that can replace sand.
- This research also demonstrated the impact that fire has on concrete specimens that have been covered with mortar plaster in which bentonite has replaced sand in one of three distinct

proportions. The findings specified the comparison with the control samples that were evaluated at room temperature, as well as the empirical associations that were utilized as the input to assess and build the concrete structures.

- Based on the findings, Bentonite may be utilized as a partial replacement of cement in structural concrete (by weight), leading to concrete that is both strong and long-lasting. Because Bentonite produces weak early-stage compressive strength but strong late-stage results, it may be employed in concretes when late-stage strength is needed.
- The coated mixes had superior temperature resilience than the Control Mix, which demonstrated the least resilience. According to this study, C40 mixes, or those with an aggregate that contains 40% bentonite, had the highest compressive strength. The best mixture for compressive strength is C40, which is a cement-aggregate ratio of 1:3, with 40% Bentonite and 60% fine aggregate.
- It was discovered that a coating of 40% bentonite on the sample was the most strong and resistive to a temperature range of between 200 and 300 degrees Celsius. The C40 formulation, which consists of 40% coated bentonite, has shown the highest level of compressive strength across the board, and it is for this reason that it is regarded to be the optimum coating mix.
- In addition to this, it was discovered that covering the Bentonite with more Bentonite led to a combination with a stronger strength as compared to the mixture in which Bentonite was replaced. This is because the water absorption standards for bentonite mixing need a higher level of bentonite, which has a greater capacity to absorb water. However, the application of bentonite to the samples resulted in an increase in compressive strength.
- The best temperature resistance was reached by the control mix with coating (dark blue line), which is a clear example. The blend (B20) with 20% more bentonite demonstrated the best

temperature resistance. The temperature rested at around 700 degrees for 10 hours for replacement in aggregate for coated samples, 30% replacement (C30). For samples coated with bentonite, this mixture is ideal. In control samples both before and after coating, there was a strong difference.

5.2 Recommendations

The results have demonstrated that bentonite may not be used for very high strength therefore it is not recommended for high strength applications. During the mixture design, the water: aggregate ratio is more, so the mixture absorbs more water during the hydration process. This is linked to the mechanical property of the mixture as water reduces strength. But it can be seen from the results that with Bentonite replacement and Bentonite coating respectively, the samples became more resistant towards high temperature and high compression.

The use of bentonite clay as an alternative to cement in concrete production has been proven in the literature to result in materials with superior mechanical qualities. Research in this area has also shown that bentonite may be used not only as a substitute for sand but also to replace aggregate in the production of concrete, which results in a compromise in the material's mechanical and microstructural qualities. To create modified bentonite clay- concrete with mechanical and microstructural properties comparable to those of conventional concrete, this work examined the design properties of materials for its production and evaluated the effects of concurrently replacing cement and sand with low percentages of bentonite clay.

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Appendices

Appendix A

Empirical results for Bentonite replacement and coating

Samples	T (RT)	T-200	T-400	T-600	T-800
Control General G	398.57	344.2	310.98	151.91	15.22
(B-20) Bentonite 20 % Replaced	303.39	191.45	169.69	86.7	12.62
(B-30) Bentonite 30 % Replaced	250.31	203.66	151.32	118.44	3.91
(B-40) Bentonite 40 % Replaced	169.82	147.06	103.1	100.02	12.45
(C-Control) General Coating	339.994	215.6	213.55	179.74	40.77
(C-30) Bentonite 30 % Coating	316.33	257.03	220.26	65.33	Blast
(C-40) Bentonite 40 % Coating	399.045	343.52	256.14	101.29	Blast
(C-50) Bentonite 50 % Coating	314.592	272.39	214.64	97.35	Blast

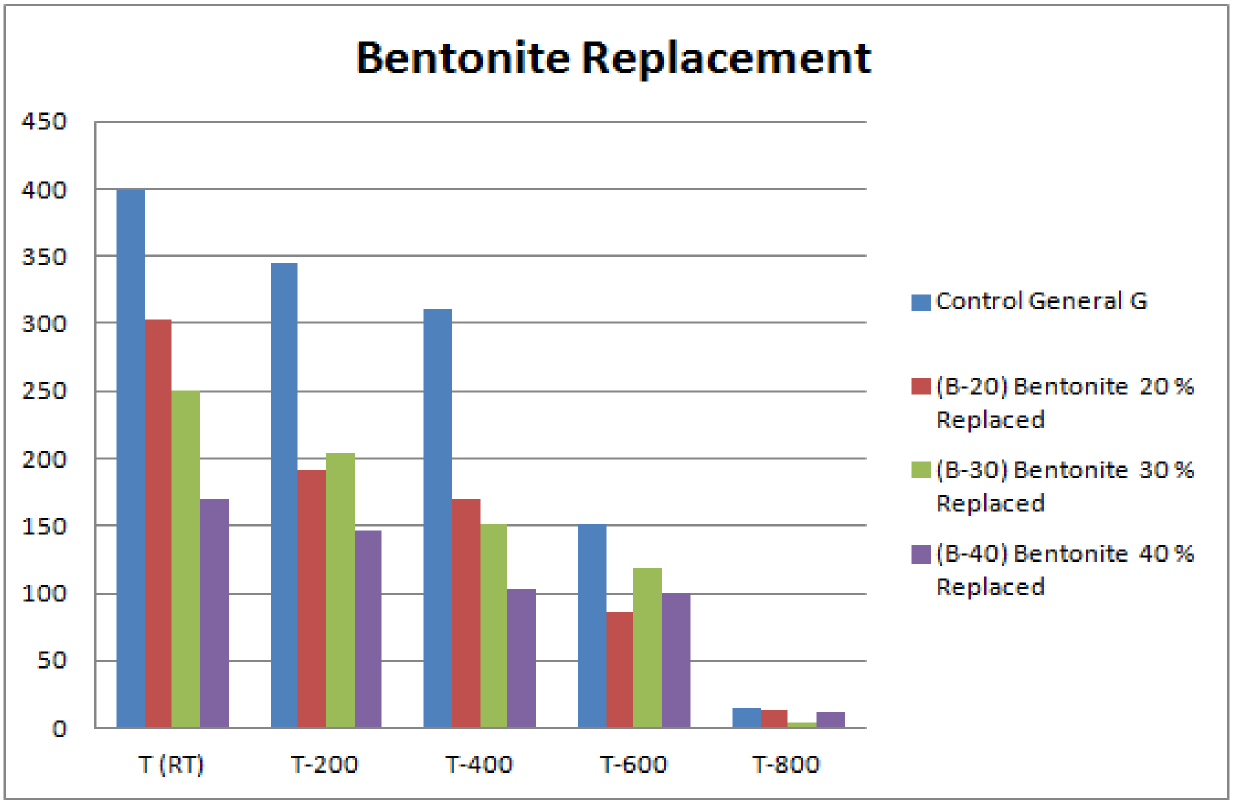

Figure 15: Strength of concrete after Bentonite replacement

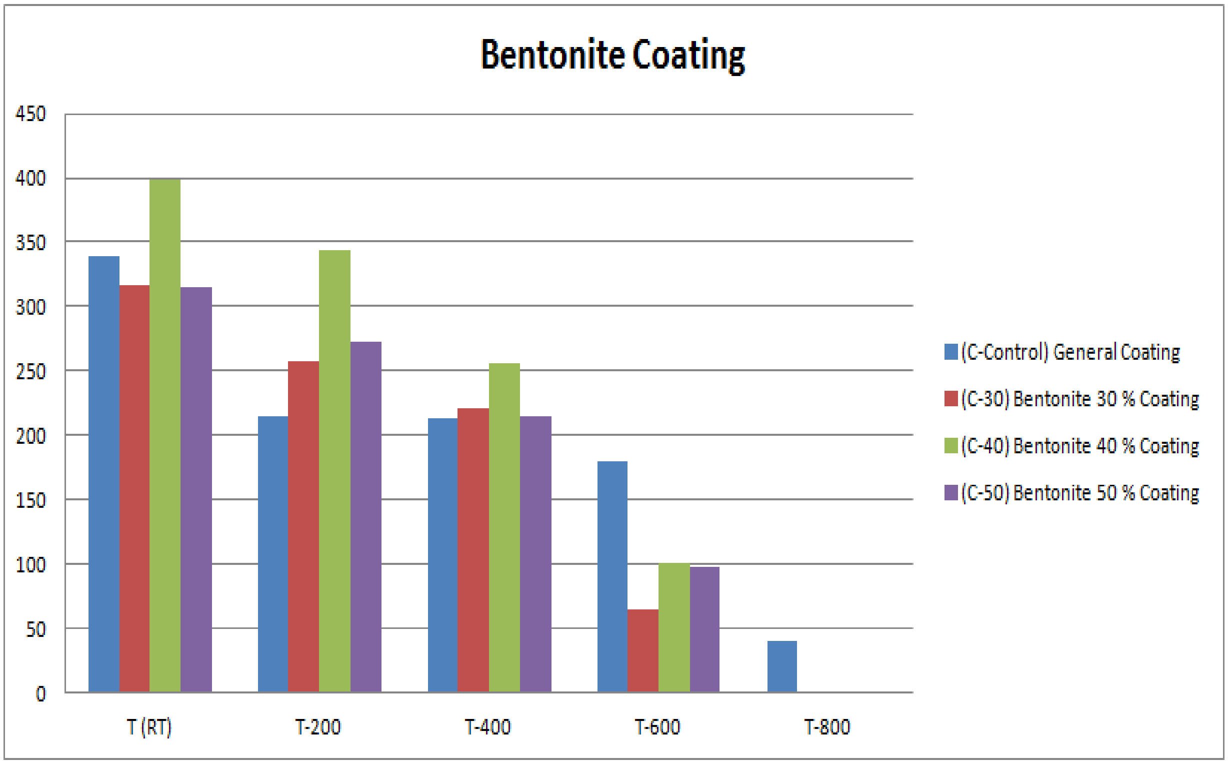

Figure 16: Strength of concrete after Bentonite coating

Appendix B:

Illustrations of experimental work

Figure 17: Sample of Aggregate

Figure 18: Typical Physical appearance of bentonite (Stone Form)

Figure 19: Powdered Bentonite

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Figure 20: Mixing process

Figure 21: Casting

Figure 22: Curing of samples

Figure 24: Cured samples

Figure 23: Plastering of samples

Figure 25: Thermal resistance test

Figure 26: Compression test