ECOnstruction: Analysis of Market-Available Green Cement in Building Sustainable Structures and Reducing Carbon Pollution

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Abstract—Environmental problems have long been a global concern, and the Philippines is particularly vulnerable to natural disasters due to its location along tectonic plates. The country experiences an estimated 20 typhoons annually, five destructive. The Philippines is also one of the countries most affected by global warming, according to the World Risk Index 2022. While the Philippines may not contribute significantly to global greenhouse gas emissions, the rapid annual increase in emissions has an impact locally. The construction industry is one of the major contributors to these emissions. As the country's population grows, the infrastructure and cement production demand also rise, causing environmental damage. This study focuses on assessing the viability of green cement as a sustainable alternative to conventional cement. The researchers compared the performance of market-available green cement to that of conventional cement. They evaluated whether the green cement meets the standard requirements of the American Society for Testing and Materials (ASTM). Although both types of cement meet the ASTM standards, the experiments showed that green cement performed significantly differently than conventional cement. The study identified several factors that may have contributed to this difference. The researchers used a mixed-methods action research design to gather quantitative and qualitative data and interpret the results. Despite its lower performance compared to conventional cement, the study suggests that green cement still has the potential to be a viable alternative due to its environmental benefits and compliance with ASTM standards. The study provides valuable information on the feasibility of transitioning to green cement, and further research is necessary to evaluate its long-term performance. Overall, this investigation could be a foundation for a green revolution in the construction industry.

Indexed Terms— Alternative, Green Cement, Sustainable, Viability.

I. INTRODUCTION

In the past few years, the Philippines has seen a noticeable interest in environmental development programs such as environmental sustainability. It is being prioritized because global warming, which impacts the entire planet and is slowly engulfing the world, has emerged as one of humanity's foremost issues. According to the United Nations Agenda for Sustainable Development, Global Warming due to carbon dioxide emission was inflated roughly by 50% since 1990. It is rapidly increasing and endangering the lives of millions of people, plants, and animals by generating more frequent and severe weather events like floods, fires, and droughts. This shows that individuals must take action to lessen its impacts and prepare for its repercussions. There are no clear signs of decreasing global warming effects or concrete plans for making these effects less impactful to the environment.

One of the significant contributors to Global Warming is the progressive Carbon Dioxide (CO_2) emission, an odorless gas that is a by-product of burning fossil fuels and cement manufacturing. The right amount of carbon dioxide keeps the earth habitable. It enhances the natural greenhouse effect and guards against a drop in global surface temperature that could cause freezing. It may appear necessary, but high levels of carbon emissions can raise the temperature, leading to additional adverse outcomes. According to Selin (2022), burning fossil fuels, mainly coal, oil, and gas used in power plants, automobiles, and heavy industry, is the main source of carbon dioxide. Only a few of the resources used in production include steel, cement, and solid waste combustion. When natural gas, petroleum, and coal are consumed, carbon dioxide is created, which makes up roughly 85% of all emissions. These fuels are mostly used in producing electricity, transportation, industry, and residential and commercial structures.

Based on the research conducted by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration, or PAG-ASA, numerous indicators suggest that global warming cannot be merely attributed to natural occurrences alone. Although it may sound cliché, recent research has shown that human actions like the combustion of fossil fuels, land usage, and the other processes stated above are the most likely to be blamed for climate change. This warming has been present for many years and will continue over decades. Although some autonomous adaptation is occurring now, a more proactive adaptation planning strategy is still needed to guarantee sustainable growth.

Cement manufacturing, vital to concrete production, makes up 8 to 10% of the world's total carbon emissions. Since concrete is the essential building material, it was stated that it is the second most consumed substance after water. Due to its exceptional durability, concrete is frequently used to build bridges, pipes, floor slabs, pillars, pavements, and other structures. It is also evident that this enormous advantage significantly harms our ecosystem. The necessity for the building and other industries to undergo a "green revolution," or for them to embrace and promote environmentally friendly materials, is urgent given the country's current climate and the phenomenon of global warming. With this insight, the concrete industry has fortunately discovered some environmentally responsible and sustainable concrete substitutes that we refer to as "green concrete."

On the other hand, as the population grows, the construction sector continues to expand. Due to modernization and population increase, there is an enormous need for structures, roads, buildings, and homes. Dy Faustino (2020) asserts that as our construction sector expands, so will the amount of waste and hazardous gas it generates. Based on the study conducted by Lawson Henry (2019), the demand for buildings that directly service that population's requirements will be the most visible direct effect of population expansion or decline. This includes housing, amenities for health and education, and infrastructure for utilities and transportation. Instituting new initiatives from the construction industry will be necessary to accommodate the surge and relieve the pressure it brings. Aside from the private constitutions, the public infrastructure requires huge expansion to minimize the potential congestion.
In the Philippines, after years of construction fall down, it works around the clock to make up the lost time and recovers rapidly. The nation is anticipated to increase by 21.8% this year in the construction sector, followed by an average annual growth rate of 7.5% from 2023 to 2026. The most well-known and driving force behind this development is the most recent program, called "Build Build Build" (BBB). Across a comprehensive water resources management program, disaster risk reduction, adaptation to climate change, infrastructures prioritizing vulnerable sections, the utilization of bike lanes and facilities, and pedestrian network.

The efficiency and sustainability of the buildings are one of the problems the construction industry has to deal with. The underlying consequences of production on the environment come after the enormous BBB flagship projects. The construction business, according to the United Nations (UN), "had the most promise for providing major and cost-effective GHG (greenhouse gas) emission reductions." The group may be able to lessen 84 gigatons of CO_2 by 2050, added by the UN. It would benefit the environment and save millions of dollars, years of work, and countless hours if the firms in charge of various sites and projects began to purchase more environmentally friendly building materials.

The combination of these two industries, environmental development and construction, each in a crisis, will damage our standard of life and put the future generation in danger. The researchers, as aspiring civil engineers, aimed to further the usage of sustainable constructions without sacrificing the materials' quality, strength, or safety. This prompted the researchers to examine and evaluate the green cement market, the most crucial building material. Millions of tons of naturally existing resources are mined to make cement, which will leave a substantial mark on the environment. This study on green cement is the first big step in implementing green design principles that lower both carbon footprints and overall costs.

1.2 REVIEW OF RELATED STUDIES

This segment proffers the related literature and studies after the thorough exploration done by the researchers. The supplemental information in this section discusses various concepts, ideas, generalizations, and conclusions, as well as several studies relevant to historical and present development. The researchers used this as the foundation for turning the project into useful outputs and tangible results. Moreover, the information in this section helps familiarize details that are opposite and similar to the present study.

1.2.1 Cement Manufacturing as a Source of Carbon Dioxide Emissions

One ton of Portland cement is estimated to release approximately 6% of the total global carbon emissions caused by humans, significantly contributing to the current environmental issues. Creating and applying eco-friendly cement can provide an excellent solution to these pressing problems. (Technavio, 2016)

According to some, concrete is accountable for up to 5% of global carbon emissions, which also helps produce greenhouse gases. Concrete's immense popularity can be attributed to various well-known advantages, such as its minimal price, widespread availability, and diverse applications. This widespread use of concrete, however, has a significant environmental impact. Green construction provides a new perspective in our country today. The environmental advantages of being capable of construction with green concrete are enormous. Green Concrete, as the term suggests, is good for the environment and helps to protect the environment by reusing various industrial waste products. Green concrete is frequently less expensive to manufacture because it utilizes waste material as a partial alternative to cement, minimizing energy usage per unit of cement.

Moreover, green concrete also outperforms traditional concrete in strength and durability. It is logical to assume that technology could be developed to lower the emissions of CO2 from manufacturing concrete. Globally, due to the usage of machinery, transport, and the manufacture of construction materials, construction and building activities account for 33% of GHG emissions and 40% of worldwide energy consumption in developing and industrialized countries. The majority of CO2 emissions result from fossil fuel consumption for power generation and the industrialization of mortar and other building materials.

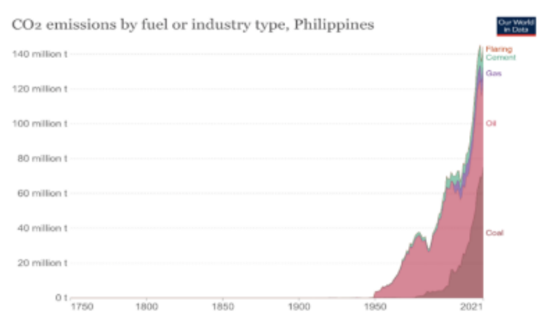

Figure 1.2.1.1 Carbon Emissions by Fuel or Industry Type of Philippines

This graph depicts the sources of annual CO2 emissions, including coal, oil, cement production, and gas flaring. This segmentation is hugely affected by a nation's energy supply and shifts as a nation shifts toward or away from a particular energy source. The figure above depicts the Philippines' annual CO2 emissions according to the Global Carbon Project 2022.

1.2.2 Carbon Footprint Due to Construction Industry

The United Nations Environment Program (UNEP) stated in an article entitled "Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector," co-authored with the International Energy Agency (IA), that "dramatic action by governments, cities, and business will be required if the global buildings and construction sector is to cut its carbon footprint in line with international agreements." This incorporates raising the standard for energy-efficient, green buildings and enhancing construction practices. Environmentalists claim it has enormous potential for lowering emissions; however, this action must be more rapid. Carbon pricing in the Philippines can assist construction firms in selecting lower-emission choices, managing carbon dangers, and reducing emissions. The possible effects of ―greening construction in this manner are staggering: between 2018 and 2023, the industry is expected to expand by more than 50% nationwide. The UNEP-hosted Global Alliance for Buildings and Construction intends to boost energy usage in the buildings and construction industry by 30% to accomplish the Paris Agreement's objectives. The report indicates that new buildings will increase rapidly over the next few years, primarily in African and Asian cities. According to the new analysis, there is a large disparity between the cost of spending on resource solutions and the total amount paid and the money being poured into building development and refurbishment at an exponentially expanding rate. ―If we do not make buildings more efficient, their rising energy use will impact us all, whether through access to affordable energy services, poor air quality, or higher energy bills, commented Birol, 2019.

The document also suggests that building standards shift toward more durable structures in the context of global heating. The effects of climate change are felt strongly by society, businesses, and people. It is becoming clearer that we need to move toward a low-carbon economy. A major contributor to this transition is the building and construction industry.

Emissions of GHG from this industry make up about 40% of the total global emissions (WBCSD 2018). The primary contributors to these emissions are the materials used and the warming, freezing, and lighting of infrastructure and buildings. (Müller ET. Al., 2020)

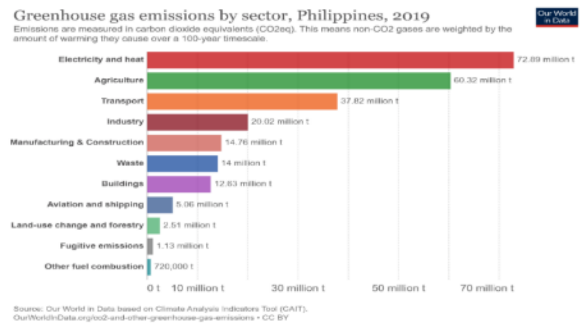

Figure 1.2.2.1 Greenhouse Gas Emissions by Sector

Manufacturing and Construction in the Philippines hold 14.76 million or 15% of the total GHG emissions, the 5th largest contributor, following industry, transport, agriculture, electricity, and heat.

New York, 29 June 2022 (Globe Newswire) — According to studies conducted by the Environmental Protection Agency (EPA) of the United States, the cement market is the third most hazardous industry., releasing more than 500,000 tons of hydrogen sulfide, nitrous oxide, and carbon monoxide, average annual and accounting for approximately 2.4% of all energy and industrial CO2 emissions. Since 2008, the EPA has adopted a coordinated, integrated compliance and enforcement strategy to address problems in accordance with the Clean Air Act's New Source Review (NSR) at the nation's cement manufacturing facilities. In addition, approximately 4.3 gig tons of cement was produced globally in 2020, a slight increase from the approximately 4.2 gig tons produced in 2019. This slight increase was attributable to China's expanding infrastructure, the world's greatest cement manufacturer, accounting for around 55% of global production, followed by India at 8%. Climate change, resource depletion, and rising energy prices are the most significant global issues. Therefore, it has become essential to integrate sustainability into every aspect of business operations.

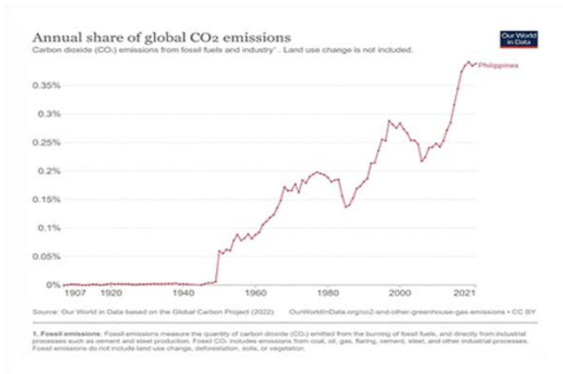

Figure 1.2.2.2 Annual Share of Global CO2 Emissions

The Philippines' annual share of global carbon emissions is depicted in the image above. It blatantly shows an annual growth that needs to be addressed, given top priority, and taken immediate action. Our World Data provided this information based on the Global Carbon Project 2022.

The building and construction sector significantly contributes to greenhouse gas emissions and urgent action is needed to achieve international agreements' objectives to reduce carbon emissions. The UN Environment Program and International Energy Agency recommend shifting towards energy-efficient and green buildings and better construction practices to achieve this goal. Carbon pricing can also promote the use of lower-emission options to reduce emissions. The cement industry is another major contributor to emissions, and the US Environmental Protection Agency is enforcing compliance with the Clean Air Act's New Source Review to reduce emissions from cement manufacturing facilities. Sustainability should be integrated into all business operations to address global issues. The annual growth of carbon emissions in the Philippines, as shown by the Global Carbon Project, underscores the need for immediate and concerted action to reduce emissions and mitigate the impacts of climate change.

1.2.3 Production of Concrete

In 3000 BC, more than 5000 years ago, the Egyptians used traditional concrete forms to assemble pyramids. They made bricks from mud and straw and mortars from gypsum and lime. In the eighteenth century, engineers rediscovered concrete and experimented with its constituents. In the 1820s, Portland cement was developed. A variety of admixtures were developed to alter the properties of concrete during the 20th century. Currently, the properties of concrete continue to evolve. There are numerous emerging methods for enhancing concrete, such as discovering a carbon-negative manufacturing process for eco-friendly green cement.

This has been a crucial component in building construction for centuries, offering durability and dependability to the structures we rely on daily. Throughout its history, advancements in materials and techniques have improved its characteristics, including the development of Portland cement and admixtures. As the environmental consequences of traditional cement production become more evident, experts are seeking alternative ways to produce eco-friendly and sustainable concrete. Ongoing innovations will enable concrete to maintain its vital role in construction while minimizing its ecological footprint.

1.2.4 Demand for Infrastructures

In 2019, the building market continued to rise until 2020, when COVID-19 occurred. The construction industry suffered due to the COVID-19 pandemic and the lockdowns ordered by the Philippine government to stop the spread of the virus. In the second quarter of 2020, construction activity decreased by 34%, and more than 50% of the employment losses in industrial activities were attributable to the construction industry. However, building firms are still struggling from the pandemic's health and economic effects. As a result of a variety of causes, a substantial number of businesses are still running at reduced capacity.

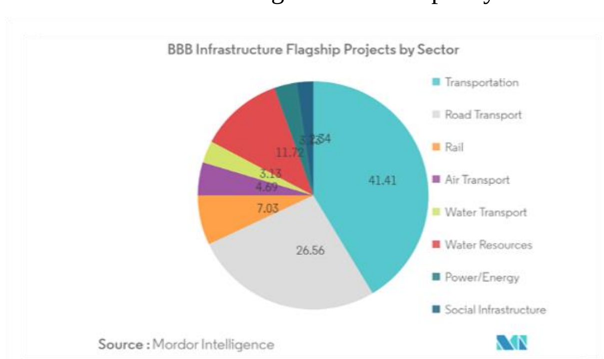

Figure 1.2.4.1 Graph showing the distribution of BBB projects per industry

After almost two turbulent years of building project delay, the Philippine construction industry is recovering quickly to get back on track, and it was expected in 2021 because the Build Build Build Program has been boasted as the prime vision of the current Philippine administration. The "BBB" initiative comprises Around 20,000 infrastructure projects, including government buildings, schools, hospitals, and lighthouses, which are included in the "BBB" program. With a budget of over PHP 8 trillion, it is the cornerstone and one of the administration's highest front-burner programs (2017-2022). This is the Philippines' greatest infrastructure budget.

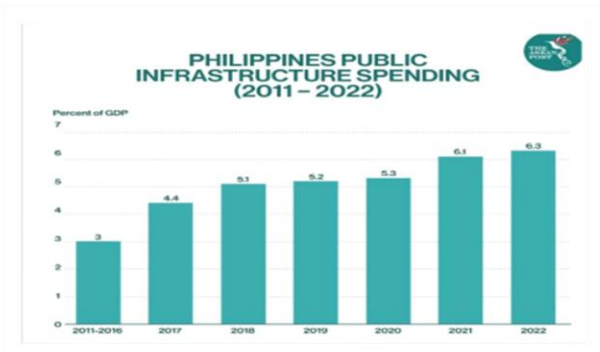

Figure 1.2.4.2 Total Spending for Infrastructures

In the first quarter of 2022, were 37,270 constructions based on authorized building licenses. This annual growth rate of ch is less than the previous quarter's annual growth rate of 9.2%. Annually, construction climbed by 4.7% in the first quarter of 2021 (Philippine Statistics Authority, 2022).

Table 1.2.4.1 Summary of Approved Building Permits in the Philippines

TABLE A. Summary of Construction Statistics from Approved Building Permits, Philippines

First Quarter 2021, Fourth Quarter 2021[r] and First Quarter 2022[p]

Type of Construction	First Quarter 2021		Fourth Quarter 2021[r]		First Quarter 2022[p]	
	Level	Annual Growth Rate (percent)	Level	Annual Growth Rate (percent)	Level	Annual Growth Rate (percent)
Total						
Number	36,621	4.7	39,513[r]	9.2	37,270	1.8
Floor Area (sq.m.)	7,251,716	-17.7	8,225,536[r]	26.1	7,720,289	6.5
Value (PhP '000)	87,548,880	-9.5	100,810,811[r]	38.4	86,781,856	-0.9
Residential						
Number	25,535	10.0	28,898[r]	11.6	26,546	4.0
Floor Area (sq.m.)	4,220,115	8.8	4,609,124[r]	31.1	4,132,221	-2.1
Value (PhP '000)	50,180,608	21.0	50,213,001[r]	35.8	45,012,950	-10.3
Non-residential						
Number	5,798	-9.4	6,106[r]	16.6	6,145	6.0
Floor Area (sq.m.)	2,888,318	-39.5	3,524,942[r]	19.4	3,512,401	21.6
Value (PhP '000)	32,496,068	-33.7	44,292,448[r]	51.4	35,404,618	9.0
Addition						
Number	883	-30.9	1,066[r]	94.5	1,131	28.1
Floor Area (sq.m.)	143,283	-9.8	91,470[r]	62.8	75,667	-47.2
Value (PhP '000)	1,438,123	-20.1	869,435[r]	88.4	731,025	-49.2
Alteration and Repair						
Number	4,405	7.5	3,443[r]	-23.7	3,448	-21.7
Value (PhP '000)	3,434,080	-23.0	5,435,927[r]	-12.0	5,633,263	64.0

71.2% of the total number of constructions during the quarter were residential building constructions, which accounted for 26,546 of the total number of constructions reported. This type of construction expanded at a rate of 4%, less than the annual increase of 10% during the same quarter the previous year. The majority (85.9%) of all residential constructions were single-family dwellings.

Non-residential projects accounted for 16.5% of the total number of constructions for the quarter, or 6,145. This number represents an increase of 6.0% in comparison to the same time of the previous year. Approximately 70.4% of non-residential projects were commercial structures.

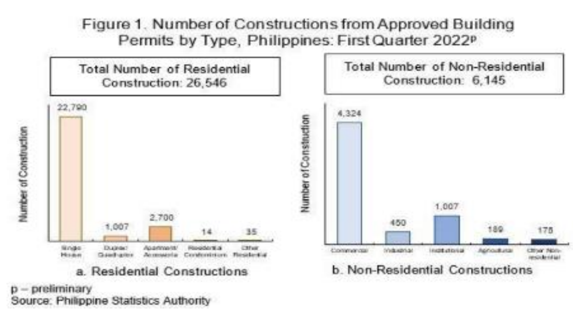

Figure 1.2.4.3 Number of Constructions from Approved Building Permits

Additionally, any new construction that increases the elevation or area of an established structure or building and alterations and repairs to existing structures contribute 3.0% and 9.3%, respectively, to the overall number of constructions. This quarter, addition-type construction increased at a pace of 28.1% compared to their respective yearly rates in the same period last year, while alteration and repair decreased at -21.7% each.

The growth of the Philippine population has driven an urgent need for infrastructure, prompting swift project delivery. The government's Build Build Build Program, which has a budget of over PHP 8 trillion, is a significant effort to improve the nation's infrastructure. Despite the COVID-19 pandemic's adverse impact on the construction industry, it is rebounding and approaching pre-pandemic levels. The first quarter of 2022 saw a 1.8% annual increase in approved building licenses, with the majority being residential constructions. Non-residential projects, such as commercial structures, also grew. Alterations and repairs decreased while additions increased faster. The construction industry is critical to the country's ongoing growth and development, and the government's infrastructure initiatives will be essential to meet rising demands.

1.2.5 Construction and Demolition Waste

On the other hand, readily available natural sand sources are being depleted at an alarming rate as a direct result of the explosive growth of the construction industry. Using waste in new goods or as an additive saves natural resources, improves product quality, and reduces costs. Recycled concrete is manufactured from crushed, graded construction, and demolition waste. Buildings, highways, and bridges are common sources. With the fast proliferation of buildings and growing environmental consciousness, waste control and management have become a key challenge for sustainable development. Construction and demolition (C & D) debris comprise damaged concrete, bricks, masonry, limestone, pottery, and other materials. Structures include residential and non-residential buildings, roadways, and bridges. Concrete, asphalt, E-waste, wood, metals, gypsum wallboard, and roofing are examples of C & D detritus. Brick, concrete, wood, and tile are prominent CDW components. Brick and cement blocks are the most frequent building materials, especially in 19th-century structures. Sorting, crushing, and screening concrete and masonry waste produces recovered aggregate.

Recycled concrete is used to make road and construction concrete. E-waste, commonly known as WEEE, refers to old, outmoded, or abandoned electrical appliances. It contains abandoned computers, devices, and refrigerators. Processing electronic waste in developing nations offers health and pollution risks due to lead, cadmium, beryllium, and brominates flame retardants. Recycling and disposing of e-waste are dangerous even in industrialized countries. Concrete is a paste-and-gravel combination. Fly ash, rice husk, PCB board, and glass fiber admixture are utilized to attain the desired qualities. The paste determines the concrete's quality. Precision in proportioning, mixing, and compacting components produces durable concrete. This electronic equipment creates large amounts of wasted printed circuit boards (PCBs). 3% of electronic waste is PCBs. PCBs hold integrated circuits, electrical devices, and connectors. PCBs contain 30% metals and 70% non-metals (Guo et al., 2008; Goosy & Kellner, 2002). Organic, metals, and ceramics make up PCBs.

Given the explosive growth of the construction industry and the alarming depletion of readily available natural sand sources, construction, and demolition waste (C & D) management has emerged as a crucial aspect of sustainable development. Utilizing waste materials in new products or as additives can conserve valuable natural resources and enhance product quality while reducing costs. Recycled concrete, produced from crushed C & D waste such as damaged concrete, bricks, and masonry, offers a practical solution for constructing buildings, highways, and bridges. However, the effective control and disposal of electronic waste (e-waste) present a significant challenge due to its hazardous components. Proper sorting, processing, and disposal methods must address these concerns and promote sustainable waste management. By embracing innovative approaches, we can pave the way for a more sustainable future while ensuring the efficient utilization of resources.

1.2.6 Local Green Cement Studies

Cement is the second most used substance around the world, following water. People frequently associate factories and cars with carbon dioxide emissions into the atmosphere, but cement is a huge emitter of CO2 that's often overlooked. It releases significant gas during its production, making the construction industry accountable for total carbon emissions.

One of the local studies is the country's natural pozzolans for sustainable solutions. Pozzolans are identified as cementitious materials that can be added to the ordinary mixture of cement ingredients making the blended cement type. This study covers the importance and benefits of using natural resources as part of the development program of the fast-growing construction industry.

As the most prevalent cementing material, Portland cement releases the highest carbon dioxide among all other types of cement. One bag of Portland Cement Type I was discovered to be equal to the impact of 13 trees when comparing their respective quantities. These toxins pollute the environment, thus exposing humans to different health issues. One of the potential solutions that can be rewritten to the situation is the replacement of conventional cement with green or eco-friendly cement. This green concrete process may lower construction costs and lessen environmental damage, improving the sustainability of the global cement business. Concrete sustainability may result in better water sanitation, enhanced natural and human capital, more affordable housing, and decreased particulate and carbon dioxide pollution.

According to the study conducted by Harris et al., natural pozzolans are substitutes for Portland cement that do not need to be imported into less developed nations. The accessibility of local natural pozzolans lowers the cost of cement. Volcanic and rice husk ash are natural pozzolans that can replace Portland cement in certain ratios. Six criteria were used to assess the viability of substituting these natural pozzolans covered in the study. These criteria were the availability, strength, practicability, implementation, environmental impact, and economics. Compressive strength tests revealed that volcanic ash, rice husk ash, and diatomaceous earth could all be safely replaced for Portland cement up to 25%.

The resulting percentage was second-motioned by Anderson et. al. (2004) mentioned that both natural pozzolans were used for them to be easily applied in community-based infrastructure systems. Test results also revealed that these natural pozzolans, namely volcanic ash, husk is much more productive than other pozzolans, such as diatomaceous earth. One of the biggest consumers of natural resources is the construction industry. An element of green building that can influence the building sector is the usage of natural pozzolans.

In light of the detrimental environmental impact of cement production and the urgent need for sustainable solutions in the construction industry, local studies on green cement have emerged as a promising avenue for addressing these challenges. However, with the construction sector being accountable for substantial carbon emissions, it becomes crucial to explore alternatives that can reduce environmental harm while supporting economic growth. Among these studies, the focus on natural pozzolans as a sustainable solution in the Philippines has gained attention. By incorporating locally available pozzolans into cement production, the industry can mitigate the release of harmful gases and promote a more environmentally conscious approach to construction.

1.2.7 Market Available Green Cement

The global market for green cement generated approximately USD 25 billion in revenue in 2021 and is projected to expand at a CAGR of 12% from 2022 to 2030. Increasing environmental concerns and implementing stringent regulations regarding emissions from the construction sector is anticipated to drive market growth. Green cement is used in construction projects to reduce greenhouse gas emissions. According to the Global Alliance for Buildings and Construction's '2020 Global Status Report for Buildings and Construction,' in 2019, the construction industry was accountable for 38% of total global energy-related CO2 emissions, with the construction of structures accounting for 10% of green product innovations in the construction sector emphasize waste reduction or material recycling, energy conservation, and control of pollution (Alsharif & Tong, 2019). Whereas specifically for cement production, it should focus on: a). energy efficient technologies, b). product and feedstock modification, c). using alternative fuels and carbon dioxide, and d). Carbon dioxide reduction systems (Mokhtar, 2020).

Focusing on using fuel and raw material alternatives, solid recovered fuel (Khan et al., 2021), recycled concrete aggregates (Makul et al., 2021), alkali-activated binders, and supplementary cementitious materials (Sivakrishna, 2019) are viable alternatives. Further, captured carbon dioxide from cement plants can produce nano calcium carbonate ($CaCO_3$), which can be integrated into cement manufacturing (Poudyal & Adhikari, 2021). However, the concern about using alternatives is how it will impact the quality of the cement produced. In a study by Hashim et al. (2022), ground granulated blast furnace slags and pulverized fuel ash produce green cement. Though the final output is environmentally and economically beneficial, it has less compressive force than conventional cement.

In addition, a manufacturer in the Philippines, a leading building solutions provider, launched Sustainable Cement, its most eco-friendly product, which has a smaller carbon footprint than other multi-purpose cement. A line of environmentally friendly cement known as ECOPlanet was created by this group, a leader in worldwide building solutions. This cement is suited for structural applications and provides excellent construction performance while lowering the carbon footprint of buildings. A 40-kilogram bag, both paper, and plastic, will be available for this product.

This cement has a CO_2 reduction of over 70%. It is used by investing in projects which reduce emissions or physically remove CO_2 in the atmosphere, such as planting trees or protecting against deforestation through an independently audited and verified project. This cement also claims that there is one ton less in the atmosphere for every ton of CO_2 emitted by this.

To summarize, the global market for green cement has witnessed remarkable growth, generating approximately USD 25 billion in revenue in 2021, and is projected to expand at a CAGR of 12% from 2022 to 2030. As environmental concerns continue to rise and regulations become more stringent, the demand for sustainable construction materials, such as green cement, is expected to soar. By reducing greenhouse gas emissions and offering innovative solutions, the adoption of green cement can pave the way for a more sustainable and eco-friendly construction industry.

1.2.8 Importance of the Basic Physical Property Test of Concrete

Physical properties testing evaluates the characteristics of various materials used in the construction industry, including chemicals, bulk materials, polymers, plastics, coatings, and raw materials. It also involves examining the properties of the local terrain, such as soil composition, and assessing the potential impact of construction activities on nearby structures.

This type of testing involves a range of techniques to assess different aspects of a material, such as its hardness, strength, impact resistance, abrasion resistance, elasticity, plasticity, brittleness, fatigue, and creep (which refers to the material's deformation under constant loads over extended periods). Understanding these properties is crucial when selecting and utilizing materials in construction projects.

According to (Kosmatka et al., 2002), the setting time of cement refers to the time it takes to harden after it is mixed. The cement needs to have an appropriate setting time that allows enough time for handling and placing the concrete mixture before it begins to solidify. Depending on the specific requirements of a project, either rapid-setting or slow-setting cement may be used, each serving different purposes.

The soundness test, meanwhile, as stated by (Neville & Brookes, 2010), is conducted to assess the ability of the cement to maintain its volume without undergoing disruptive expansion or cracking after it has set and hardened. This test helps identify the presence of any uncombined lime or magnesia in the cement, which can cause such issues. The Le Chatelier test is the commonly employed method for soundness testing, which involves measuring the expansion of cement when exposed to water immersion and high temperatures.

On the other hand, according to (Kosmatka et al., 2002), the fineness test determines the particle size distribution of cement, which is an important factor in indicating its reactivity and the speed at which it hydrates. This test is carried out to measure the specific surface area of cement particles. The Blaine air permeability test is the widely utilized method for determining the fineness of cement, which measures the time taken for air to pass through a compacted bed of cement.

The compressive strength of cement is a crucial characteristic that determines its capacity to withstand applied loads and ensure structural stability in concrete structures. The acceptable criteria for desirable compressive strength can vary depending on the specific application and the governing standards applicable in different regions.

The ASTM C150, the American Society for Testing and Materials (ASTM) C150 standard, outlines the minimum compressive strength requirements for various types of Portland cement at different ages. For instance, type I cement, commonly used in general construction, typically needs a minimum compressive strength of 3,500 psi (24 MPa) at 7 days and 5,000 psi (34 MPa) at 28 days. These values serve as benchmarks to ensure the cement's quality and performance.

1.2.9 Carbon Oxide Release Carbon Dioxide

Quicklime, as stated by (Housecroft & Sharpe, 2012), also known as calcium oxide (CaO), can release carbon dioxide (CO_2) through a chemical process called carbonation or calcination. This reaction occurs when calcium oxide comes into contact with atmospheric carbon dioxide in the presence of moisture or water vapor. The carbonation reaction can be summarized as follows:

$$CaO + CO_2 + H_2O \rightarrow CaCO_3 + H_2O$$

During this reaction, calcium oxide reacts with carbon dioxide to form calcium carbonate ($CaCO_3$), a solid product. As a result of this reaction, carbon dioxide is released as calcium oxide interacts with the carbon dioxide present in the surrounding environment.

1.3 BACKGROUND OF THE STUDY

The Philippines is facing a growing number of disasters linked to climate change. Sadly, most human activities have negative effects on the environment, worsening the situation of global warming. Some human practices contributing to climate change include deforestation, fossil fuel combustion, improper waste management, electricity usage, and transportation activities such as driving cars. It is crucial to reduce these harmful practices to mitigate the effects of climate change in the Philippines and worldwide. However, one factor is still why global warming and climate change occur - the construction industry.

Indeed, the construction industry plays a significant role in exacerbating climate change, particularly in the Philippines. The industry is responsible for a substantial amount of carbon emissions due to several factors, such as the production of building materials like cement, steel, and other construction-related products. The extraction and transportation of these materials also contribute to greenhouse gas emissions. The construction industry must adopt sustainable practices that reduce its carbon footprint. By implementing sustainable practices, the construction industry can play a crucial role in mitigating the impact of climate change and promoting a more sustainable future.

Green cement is considered a promising solution to reduce carbon emissions in the construction industry in the Philippines. Cement production is known to be a significant source of carbon dioxide emissions globally, and this is where green cement can make a difference. It is produced using alternative materials or processes that emit lower carbon emissions than traditional cement production.

Green cement undergoes rigorous evaluation to ensure its strength and chemical and physical properties meet the necessary standards. Researchers and scientists are developing new types of green cement that can match the strength and durability of traditional cement. This innovation in the construction industry can significantly reduce carbon emissions and contribute to mitigating the impact of climate change.

By adopting green cement, the construction industry in the Philippines can significantly reduce its carbon footprint. In addition to green cement, other sustainable practices must also be implemented to reduce carbon emissions and promote a more environmentally-friendly approach to construction. It is a critical step towards achieving a sustainable future for the country and the world.

In this study, the researchers sought to analyze the properties and investigate the potential of market-available green cement in the Philippines. Not only it contributes to the development of this innovation, but it also aspires to impact shifting to more sustainable construction positively.

1.4 OBJECTIVES OF THE STUDY

1.4.1 General Objective

The researchers sought to compare and contrast the physical properties of green cement to those of conventional cement, specifically fineness, setting time, soundness, and compressive strength; also, to determine the carbon emission differences between the two types of cement for developing green design strategies making structures eco-friendly and more sustainable.

1.4.2 Specific Objectives

Specifically, this study aims the following:

1. To compare and contrast the physical properties of green cement to conventional cement, such as fineness, soundness, compressive strength, and setting time.
2. To quantify the costs and financial difference between sustainable cement to conventional cement.
3. To estimate the overall carbon footprint released by green cement compared to other general-purpose cement in terms of carbon dioxide emission.
4. To investigate the potential of using eco-friendly cement as a sustainable alternative to conventional cement in the construction industry.
5. To identify the factors that affect the performance and properties of eco-friendly cement, such as the type and proportion of raw materials used, curing conditions, and additives.

1.5 STATEMENT OF THE PROBLEM

The researchers aimed to outline the issue or gap in knowledge that this research study desires to address, specifically to answer one of the components of this analysis;

1. Is there a significant difference between conventional cement and green cement in terms of their:

a. 7-day Compressive Strength (in psi),
b. 14- day Compressive Strength (in psi), and
c. 28-day Compressive Strength (in psi)?

Hypothesis

1. Null Hypothesis (h0): There is no significant difference between the conventional cement and the green cement in terms of their 7-day Compressive Strength (in psi), 14- day Compressive Strength (in psi), and 28-day Compressive Strength (in psi).
2. Alternative Hypothesis (ha): There is a significant difference between the conventional cement and the green cement in terms of their 7-day Compressive Strength (in psi), 14- day Compressive Strength (in psi), and 28-day Compressive Strength (in psi).

1.6 SIGNIFICANCE OF THE STUDY

Green cement currently on the market was developed to have an advantage over conventional cement in terms of the environment and economy. Due to the lack of market awareness of these benefits, there needed to be more demand for this important and cutting-edge product.

The study would like to contribute a deeper understanding of the qualities of green cement as a replacement for conventional cement. Researchers wanted to elaborate a thorough analysis of the products.

Vital results were expected to be highly significant, specifically for the following:

Academe Industry

Civil engineering students would have an outlook on the potential of green cement in the marketplace.

The Construction Industry

The study would be an advantage in the marketing of green cement. Construction industries would be more acquainted with the value it holds. The study will be a component of the Research and Development Program, which is crucial in selecting the appropriate materials for an infrastructure project.

The Economy

As the trajectory of the demand for green cement goes up, more companies would be interested in producing massively that would be beneficial to the economy.

The Environment

As the demand for green cement revolutionizes in the marketplace, conventional cement contributes more carbon emissions resulting in environmental pollution and will be replaced with more sustainable concrete.

The Community

This study aims to address the gap in knowledge about sustainable constructions. To impart information and awareness about the subject matter, particularly the country's current position and how individuals may contribute to the country's lowering of CO2 emissions.

The Future Researchers

This study can serve as a tool or reference point for future researchers who intend to compare the qualities of green cement to conventional cement. Future research and innovations regarding cement may benefit greatly from the framework provided by this study.

1.7 SCOPE AND LIMITATIONS

The study analyzed market-available green cement to build sustainable structures and reduce carbon pollution. It sought to compare and contrast green cement to conventional cement based on its four basic physical properties: fineness, soundness, setting time, and compressive strength. Under compressive strength, two tests were utilized under compressive strength: mortar cube and concrete cylinder. For the concrete cylinder, three (3) trials or samples each for the seventh (7th), fourteenth (14th), and twenty-eighth (28th) day of curing was tested. However, for mortar cubes, only one (1) sample each for the third (3rd) and fourteenth (14th) day of curing underwent testing. This study did not cover other physical properties like consistency, hydration heat, ignition loss, bulk density, and specific gravity. Costing of cement was analyzed as the study sought to compare the expense of using these two types of cement. The pricing comparison between Portland Type 1 cement and Green cement is bounded to the local pricing only, specifically to the price per bag in the province of Pampanga. Carbon footprint comparison limited to the Calcium Oxide (CaO) content of these two types of cement was administered and determined.

The analysis was limited to the two types of cement to have a better way of comparison. The researchers used CEMEX Rizal Portland Vertua Cement Ultra for green cement, while KAITO Cement is for Type 1 Portland cement. Testing through testing centers was the primary basis of information in this analysis.

1.8 Conceptual Framework

The primary concept of the research is to compare and contrast the physical properties of green cement to conventional cement. The figure shows the procedures that the researchers underwent. It starts with the selection of cements that was compared and evaluated by the different tests used. Results were to be interpreted using graphical representation tables. Researcher conclusions and recommendations were made in the end.

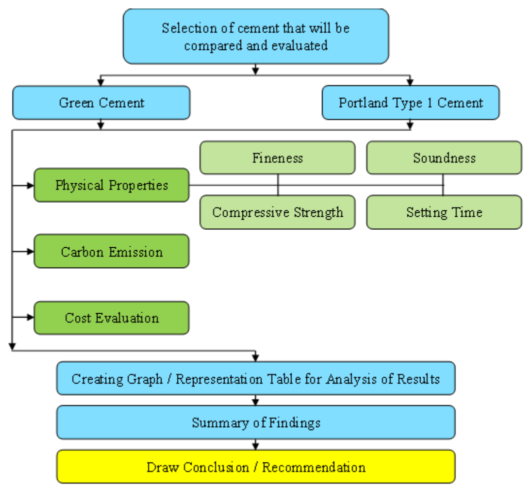

Figure 1.8.1 Conceptual Framework

1.9 DEFINITION OF TERMS

The researchers supplied operational and conceptual definitions of the following terminology to help readers better comprehend the contents of this paper:

Carbon Dioxide - is the primary cement component, and clinker is an intermediate product in cement production. Additionally, CO2 is released when fossil fuels are used to make cement.

Cement - is a dry, powdery material produced by calcining lime and clay. It is used to build concrete, mortar, or both. It functions as a binder.

Climate Change - describes long-term alterations in weather and temperature. Human activity has been the main contributor to climate change, particularly because of the release of gases during the combustion of fossil fuels, which trap heat.

Concrete - is a building material made of cement, sand, and other fine and coarse aggregates combined with water.

Conventional - is based on or in line with what is typically practiced or thought. Construction Industry - describes the manufacturing and trade business sector involved in building, maintaining, and repairing infrastructures.

Demolition Waste - is leftover material after destroying roads, bridges, buildings, or other infrastructure.

Fineness - is a metric for cement particle size and is used to express the specific surface area of cement.
Fly Ash - is the finely divided by-product of pulverized coal combustion carried from the combustion chamber by exhaust gases.

Greenhouse Gas (GHG) - is a gas that causes the greenhouse effect by taking in and giving off heat infrared radiation.

Global Warming - occurs as a result of light and solar energy reflecting off the earth's surface and being absorbed by the atmosphere's concentration of carbon dioxide (CO_2) and other air pollutants.

Green Cement – cement substances emit fewer greenhouse gases, require less manufacturing energy, and contain reused or environmentally friendly components. Cement qualifies as green if it can decrease the environment's natural waste problems while still performing its primary functions and retaining its critical properties.

Infrastructures - the set of facilities a country, city, or other place employ to sustain its people, businesses, and economy.

Setting time - is required to thicken cement paste to a particular consistency.

Sustainable - involving, relating to, or being a method of using a resource that does not cause permanent harm or depletion.

Strength - is the ability of a material to withstand failure brought on by loads operating on it.

Pollution - is the release of toxic substances into the environment.

Pozzolans - are identified as cementitious materials that can be added to the ordinary mixture of cement ingredients that can be found in nature.

II. METHODOLOGY

This chapter outlines various data-gathering and analysis methods utilized for this investigation. The methodology covers the study's setting, research design, various data types, data collection methods, and data management.

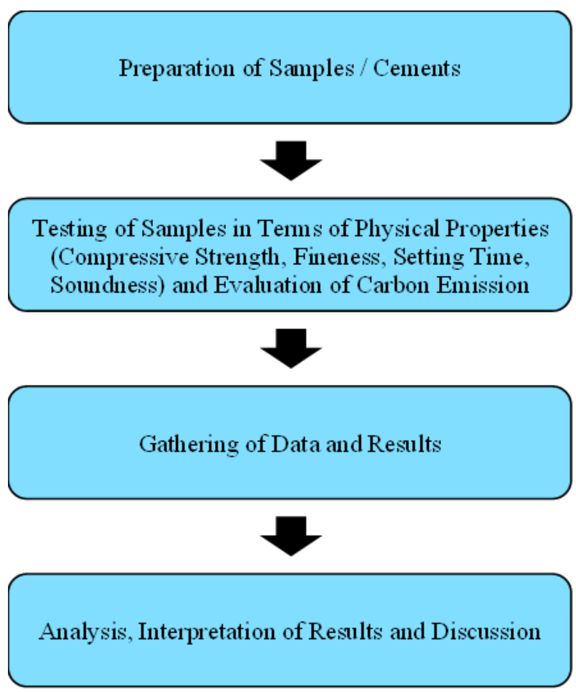

Figure 2.1 Methodology Flowchart

2.1 RESEARCH DESIGN

(a) The descriptive-comparative methodology was used in this study. Creswell (1994) defines descriptive research as the collection of facts about the environment's current state. The aim is to describe the facts and crucial information without altering it. Descriptive research tries to shed light on the current situation by validating related hypotheses. This method also allows for flexibility and acknowledges the need for additional research when pressing issues or queries arise during the study.

Richardson (2018), on the other hand, characterizes comparative research as a type of study that compares two variables to conclude. Finding and examining the subject's similarities and differences is the goal of this type of research. Comparative studies can create a basis for collaboration and compromise by cultivating better understanding across different cultures and societies. This research used both quantitative and qualitative research methodologies.

(b) Quasi-Experimental Design – this design is also utilized to accomplish this study. This research methodology is used by obtaining samples of both types of cement and subjecting them to tests to measure their physical properties, such as compressive strength, soundness, setting time, and fineness. Ensuring that the tests are performed under the same conditions and standard procedures is important. According to Morgan (2015), a Quasi-experimental design is used to compare, in this case, the physical properties of the two cements and determine if there is any significant difference between them.

2.2 RESEARCH INSTRUMENT

The researchers used specific research equipment to compare the qualities of green cement and conventional cement. The tool was intended to assess fineness, setting time, soundness, and compressive strength, among other physical properties. For this study, researchers employed ASTM standards as the testing method to ensure that cement qualities are tested using established and widely acknowledged testing procedures. Using ASTM standards, the researchers can ensure that the results acquired are accurate and comparable to other investigations.\

2.3 PHASE 1

2.3.1 Preparation of Samples/Cements

The preparation of equipment and samples was the first phase of the study, where the researchers prepare all the necessary materials and samples to be used. This part was important to help the researchers compare the properties of ordinary Portland cement and Green cement. It gives a detailed report of the experimental system and procedures used in data obtainment and data gathering and processing throughout the experiment.

2.3.1.1 Preparation of Green Cement

Figure 2.3.1.1 Green Cement

To prepare the green cement, the researchers acquired a few bags of sustainable cement, which was marketed as eco-friendly green cement and was developed to be a more sustainable alternative to ordinary Portland Cement (OPC). Green Cement costs P227.00 per 40kg bag. According to the manufacturer in the Philippines, its lower carbon footprint is primarily due to the addition of blast-furnace slag to the cement mixture, reducing the clinker content. Also, the manufacturer claims that Sustainable Cement provides similar to superior performance to OPC and that replacing OPC with Sustainable Cement for construction works resulted in at least a 70% reduction in CO2 emissions.

2.3.1.2 Preparation of Portland Type 1 Cement (Conventional)

Figure 2.3.1.2 Premium Portland Cement (Type 1) for Conventional Cement

To prepare Conventional Cement, the researchers purchased a few 40kg bags of Premium Portland Cement (Type 1). Premium Portland cement is a Type 1 cement, also called ordinary Portland cement (OPC) or simply Portland cement. Conventional Portland Cement (Type 1) costs P225.00 per 40kg bag. A versatile cement suitable for all types of construction work, Premium Portland cement is designed for all kinds of construction projects, from structural to finishing work. OPC is currently the most widely used type of cement in the world. It is composed of up to 95% clinker, and most of the CO2 emissions in cement manufacturing come from clinker production.

The researchers intended to conduct multiple tests and assess the outcomes based on various criteria to compare Conventional Cement with Sustainable Green Cement.

2.4 PHASE 2 – TESTING OF SAMPLES

In this phase, the researchers tested both samples to identify their physical properties, such as Fineness, Soundness, Setting Time, and Compressive Strength. Sampling is necessary to provide an overview and make inferences about the population the sample represents. Since the results were based on laboratory testing, coning or quartering technique method was obtained in this study. According to the article by the Concrete Society, coning or quartering is an alternative method of sampling if bulk samples are to be tested by reducing their size without the results being biased. This technique was suitable for samples with large quantities like cement. This method was also unrestricted if process repetition was necessary.

2.4.1 Fineness Test

Concrete gains strength as a result of water and cement particle interaction. Cement particles and reactions constantly begin at the surface of the water. Therefore, the rate of hydration increases as the surface area available for reaction increases. The fineness of cement is a very important property. The finer the cement, the quicker it sets. The active element in the cement is Impalpable powder. About 40%-50% of standard Portland cement is active, and the rest is, to some extent, inert.

Cement with a higher fineness index will have a more significant surface area, allowing for faster and more complete hydration. Therefore, accurate measurement of the fineness of cement is crucial for ensuring concrete's consistent and predictable performance in construction applications. Specific materials and equipment are required, including a sieve, balance, and apparatus to measure the air permeability of the cement sample to perform this test. This section describes in detail the materials and equipment used for the fineness test of cement and the procedures followed to obtain accurate results.

The chemical composition, physical qualities, and other specifications for Portland cement are outlined in the ASTM C150 standard specification. The fineness of cement is one of its crucial physical characteristics. A representative cement sample can be run through to determine the cement's fineness using a series of sieves with progressively smaller mesh sizes. To evaluate the fineness of cement, the ASTM C150 standard mandates using a #200 sieve mesh. The percentage of the sample weight made up of cement-retained on the #200 sieve was calculated by weighing it. Depending on the requirements of the particular project or application, different Portland cement fineness requirements may apply.

The following are the steps for performing the cement fineness test on #200 mesh using ASTM C 150:

a. Collect a representative sample of the cement to be tested.
b. Weigh 50 grams of the sample to the nearest 0.1 g, and record the weight.
c. Place the 50-gram sample in a No. 50 sieve and shake it for a minimum of 5 minutes. This is to remove any lumps or agglomerates from the sample.
d. Collect the material that passes through the No. 50 sieve in a clean container.
e. Weigh the material that passed through the No. 50 sieve to the nearest 0.1 g, and record the weight.
f. Repeat steps 3-5 using a No. 200 sieve.
g. Calculate the percentage of material passing through the No. 200 sieve using the following formula: % Fineness = (Weight of material passing through No. 200 sieve / Weight of sample) x 100
h. Record the percentage fineness and compare it with the specifications in ASTM C150 to determine if the cement meets the required fineness.

Table 2.4.1.1 Materials/Tools/Equipment for Fineness Test

Materials / Tools / Equipment	Uses / Purpose	Image
1. Cement	The cement sample should be thoroughly mixed before testing. This will serve as the representative of the lot of cement being tested.	
2. #200 Mesh Sieve	The #200 mesh sieve is a wire mesh with openings of 75 microns or 0.075 mm. It should be free of any deformities or damages. The sieve condition will highly affect the accuracy of the test.	
3. Brush	The sieve should be cleaned before and after putting the cement sample. Use a brush to gently remove any cement particles that may be stuck on the surface.	
4. Weighing Balance	The weighing balance should be calibrated and accurate to at least 0.1g or better. This will be used in weighing the cement sample and the amount of cement that passes through the #200 mesh sieve.	
5. Container	Finally, a container is needed to collect the cement that passes through the sieve during the test. This container should be clean and dry.	

2.4.2 Setting Time Test

Mixing cement with water forms a cement paste. Due to its plasticity, this paste can be molded. During this time, cement reacts with water, loses flexibility, and hardens. The initial setting time is when cement starts hardening and loses its plasticity; the final setting time is when cement becomes rigid. Transport, pouring, and compacting concrete require initial setting time. An initial setting time is needed to postpone hydration and hardness. The final setting helps safely remove shuttering or formwork.

The laboratory used Cement Time Setting ASTMC191 for this test. This test technique determines compliance with a specification limit for Vicat setting time. Assess the relevant cement specification to see if this test method is employed for specification compliance. The time of setting measured by this approach may produce different results than the time of setting of hydraulic cement paste measured by other methods or the time of setting of mortar or concrete measured by other methods.

Procedure:

a. Preparation of specimen - form a paste by combining 650g of cement with the as indicated in ASTM C187, use the proportion of mixing water required for normal consistency, or, at the tester's discretion, use the test specimen used to determine normal consistency or the residual paste from creating autoclave bars.
b. Set up and position the Vicat apparatus on a level surface, making any required adjustments.
c. Subsequently, proceed to transfer the cement paste into the Vicat mold while ensuring the removal of any excess material by employing a trowel.
d. Now carefully position the Vicat mold onto the Vicat apparatus and gently initiate the release of the plunger by making gentle contact with the surface of the cement paste.
e. Release the plunger and allow it to penetrate the cement paste while carefully observing and recording the measurement displayed on the gauge scale at the Vicat mold's bottom.
f. Repeat the procedure by gradually incorporating varying amounts of water into the cement paste until the measurement aligns within the 5mm to 7mm range.

Table 2.4.2.1 Materials/Tools/Equipment for Setting Time

Materials / Tools / Equipment	Uses / Purpose	Image
1. Trowels	Also known as brick trowels or mason's trowels, have pointed noses and are used for "buttering" mortar onto bricks or concrete blocks. The blade's design provides for pinpoint control over mortar distribution.	
2. Mortar Pan	A steel or hard plastic pan used to contain or transport sand, cement, mortar, and concrete. Fill a mortar pan with an amount of material that you feel comfortable handling.	
3. Stop Watch	A timepiece with a hand or a digital display that can be started and stopped at any time for precise timing.	
4. Vicat Apparatus	A machine for evaluating the typical consistency and duration of setting of cements that consists of a 300-gram rod mounted in a frame with a graduated scale to measure the depth to which the needle penetrates the cement.	
5. Water		
6. Weighing Balance		

2.4.3 Compressive Strength Test

The basic cement strength can be estimated from the cement's compressive strength. It provides the assurance needed for use. You can determine the amount of cement needed and the expected strength from this test. The fundamental information required for mix design is the cement's compressive strength. Fundamentally, compressive strength is how cement is identified. Grades of cement, such as Grade 53, Grade 43, and Grade 33, are used to identify them. This grade represents the cement's compressive strength, so a cement cube with a grade of 53 has a compressive strength of 53 N/mm2 (MPa), or 530 kg/cm2, after 28 days of curing.

2.4.3.1 Concrete Cylinder Compressive Strength - (ASTM C39)

For over 80 years, ASTM C39 has been the established norm in the industry for evaluating the compressive strength of cylindrical concrete samples, including those made from molding cylinders and drilling cores. This standard outlines the procedures for determining the compressive strength of such specimens.

In order to determine the compressive strength of concrete, molded cylinders or cores are subjected to a compressive axial load until they fail. This is done by dividing the maximum load achieved during the test by the cross-sectional area of the specimen. The results of this test are important for ensuring the quality of concrete.

To conduct this test, a testing machine with the ability to apply the prescribed load rates and equipped with two steel bearing blocks is necessary. One of these blocks is spherical and bears on the top of the specimen, while the other is solid and serves as the base for the specimen. It is essential to read the entire specification in the relevant ASTM publication before conducting the ASTM C39 test.

In preparing concrete cylinder samples, the researchers followed the recommended volume ratio 1:2.5:5 or a Class B mixture of cement, sand, and gravel. This ensures the quality and strength of the final product. It is important to measure the water used in the mixture carefully to achieve the desired consistency and durability of the sample. A minimum of 13 liters of water should be used to ensure the quality and strength of the concrete cylinder samples.
According to the article presented by Constro Facilitator (2022), utilizing Class B concrete proportioning in the testing of physical properties offers numerous benefits. Firstly, it enables the flexibility to test a variety of properties. By adjusting the proportions of Class B concrete, a wide range of physical attributes, including strength, workability, and durability, can be achieved. This adaptability empowers researchers and engineers to assess specific characteristics based on the unique requirements of each project. Secondly, it contributes to cost-effective testing. Compared to higher strength classes, Class B concrete proportioning requires fewer cement and materials, resulting in cost savings in procurement and testing expenses. This cost efficiency makes it a more economical option while still providing valuable insights into the physical properties of the concrete. Thirdly, it facilitates representative testing. Class B concrete proportioning ensures that the test results accurately reflect real-world behavior and performance by closely emulating the properties of concrete used in actual construction. This enhances the reliability and precision of the obtained data. Lastly, it aids in optimizing performance. The ability to adjust mix proportions within the Class B range enables evaluating and comparing different combinations. This optimization process assists in fine-tuning the concrete's physical properties to meet specific project requirements, such as achieving a balance between strength and workability or enhancing durability. Overall, Class B concrete proportioning in testing physical properties provides versatility, cost efficiency, representative results, and optimization potential. This, in turn, contributes to more informed decision-making in construction and engineering projects while ensuring the desired performance of the concrete. Adhering to these guidelines is essential to any concrete-based construction project's success, as it helps ensure the structure's integrity and longevity.

Procedures:

a. Verify first if the Compressive Strength Machine was calibrated.
b. Prepare the entire Sample specimen. Use 3 sample specimens for each Testing to get the average strength of concrete.

c. Test each sample of concrete as soon as possible after it has been removed from its previous state of conditioning.
d. Calculate and list the results.
e. Identify what type of failure was made from each sample.
f. Conduct this test on the 7th, 14th, and 28th day of the curing process of each sample.

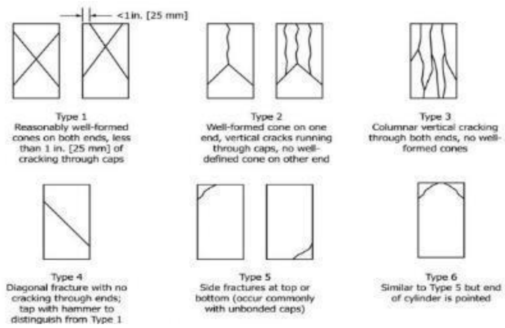

Figure 2.4.3.1.1 Schematic of Typical Fracture Patterns

A set of values was utilized as the reference of the sampling proportioning and a basis if the samples passed or failed the minimum requirements set by the ASTM to determine the required compressive strength of each cylindrical concrete sample.

Class of Concrete	Cement: Sand: Gravel	Probable Strength after 28 days
Class AA	1: 1 ½ : 3	4, 000 – 3, 500 psi
Class A	1: 2: 4	3, 000 – 2, 500 psi
Class B	1: 2 ½: 5	2, 000 – 1, 500 psi
Class C	1: 3: 6	1, 000 – 500 psi
Class D	1: 3 ½: 7	Less than 500 psi

Figure 2.4.3.1.2 Probable Strength after 28 Days of Different Concrete Class

2.4.3.2 Compressive Strength of Hydraulic Cement Mortars Test – (ASTM C109)

ASTM C109 is a compression test used to assess the compressive strength of hydraulic cement and mortars and is commonly referenced in specifications and other test methods. It is important to exercise caution when using the test results to predict the strength of concretes.

According to ASTM C109, it is recommended to create specimens that measure 50mm x 50mm x 50mm by using a mold and following the manufacturer's instructions for curing. The samples should be cured at room temperature and maintained at a minimum of 50% humidity for 20 to 72 hours.

In preparing mortar cubes, the researchers applied a mixture of cement and sand in a volume ratio 1:2. For thinner structures. It is advisable to use a richer mix. To ensure the quality and strength of the mortar, the water-cement ratio used does not exceed 0.5/1.0. Therefore, it is important to carefully measure the amount of water used in the mixture to achieve the desired consistency and durability of the mortar. Following these guidelines can help ensure the success of any mortar-based construction project.

Procedures:
a. Verify first if the Compressive Strength Machine was calibrated.
b. Prepare the entire Sample specimen. Use 3 sample specimens for each Testing to get the average Strength of concrete.
c. Test each sample of concrete as soon as possible after it has been removed from its previous state of conditioning.
d. Calculate and list the results.
e. Conduct this test on the 3rd and 14th day of the curing process of each sample.

Table 2.4.3.1 Materials/Tools/Equipment for Compressive Strength Test

Materials / Tools / Equipment	Uses / Purpose	Image
1. Sand	Sand is frequently used in construction, giving other materials including asphalt, concrete, mortar, render, cement, and screed bulk, strength, and stability.	
2. Gravel	A loose collection of tiny, different-sized rock particles is known as gravel. It can be used in a variety of ways in the building sector.	
3. Concrete Cylindrical Molder	A molder for creating geometrically uniform concrete test cylinders made of expandable polystyrene that can withstand temperature changes while the test cylinder is being formed in the mold while still accurately reflecting the structural characteristics of the concrete mix used to create it.	
4. Shovel	Shovel is a tool used to dig as well as to move loose, granular materials (like dirt, gravel, grain, or snow) from one spot to another.	
5. Tape Measure	Tape measures are the most accurate and efficient way to measure invoices and many other purposes.	

1. Concrete Cylinder Samples	Samples of concrete cylinders are prepared for your laboratory technician to crush in a hydraulic press and determine the compressive strength of the concrete to be poured for a particular structural part.	
2. Cube Concrete Molder	Cube molds made of plastic or reinforced concrete are used to form specimens for testing the compressive strength of concrete.	
3. Cube Concrete Samples	A concrete test cube is a small sample of concrete that represents the concrete used in a construction project. If a concrete cube is subjected to a compression test, it is possible to determine the maximum compressive load that the cube can withstand before breaking.	
4. Compressive Strength Machine	A compressive strength machine is used to determine the maximum load a material can bear before it fails, providing essential information for assessing the quality and structural integrity of materials in construction and engineering applications.	
5. Water		
6. Cement		

2.4.4 Soundness Test

Testing the soundness of cement is crucial to ensuring that there has not been any notable subsequent expansion. It is pivotal that the cement experiences no substantial volume change during the setting. After setting, it has been discovered that some cement experience significant expansion, which disturbs the mass after it has hardened and set. When such cement is utilized, it drastically affects how long construction lasts. The soundness test determines if the cement is sound or unsound. Unsound cement is most likely developing cracks in the buildings over time. Thus, using this kind of cement must be avoided. Desai (2018) enumerated some factors that result in unsound cement, such as but not limited to excess lime, excess magnesia, inadequate burning, and excess calcium sulfate.

ASTM C151 - Standard Test Method for Autoclave Expansion of Hydraulic Cement

ASTM C151 is a widely recognized test method that measures the potential volume change of hydraulic cement when exposed to an autoclave. The test involves subjecting a cement paste sample to high-pressure and temperature conditions in an autoclave for a specific period. This method helps determine the potential for expansion or contraction of hydraulic cement products, which can cause defects in finished structures. The test requires specialized equipment, specific proportions of cement, water, and additives and is performed under controlled conditions to ensure reliable results. ASTM C151 provides a standardized test method for evaluating hydraulic cement products, ensuring that they meet the required standards for use in construction projects.

The procedure for conducting ASTM C151, also known as the Standard Test Method for Autoclave Expansion of Hydraulic Cement, can be summarized in the following steps:

a. First, mix hydraulic cement with water in a mixing bowl using mixing equipment like a spatula, ensuring the proportions are as per the specification.
b. Place the mixed paste in a cube-shaped mold, and compact it while smoothing the surface with a trowel.

c. To ensure proper hydration of the cement, store the mold in a moist cabinet for at least 24 hours at a temperature of 73 ± 3 °F (23 ± 1.7 °C).
d. Afterward, remove the mold and let the specimen dry in air for 24 hours at 73 ± 3 °F (23 ± 1.7 °C).
e. Using a micrometer or any other measuring device with an accuracy of 0.001 in (0.025 mm), determine the specimen's initial length, width, and thickness.
f. Next, subject the specimen to a pressure of 300 psi (2.07 MPa) for 3 hours at a temperature of 121 ± 2 °C by placing it in an autoclave apparatus.
g. Take the specimen out of the autoclave apparatus and let it cool in the air for 30 minutes at a temperature of 73 ± 3 °F (23 ± 1.7 °C).
h. Once the specimen has cooled, measure its final length, width, and thickness using the same measuring device as in Step 5.
i. Calculate the change in volume by comparing the initial and final dimensions of the specimen.
j. Finally, calculate the percentage of expansion or contraction using the formula (Change in Volume / Initial Volume) x 100.

By following these steps, construction professionals can obtain valuable information on the potential volume change of hydraulic cement under high-pressure and temperature conditions, ensuring that materials meet the necessary standards for use in construction projects.

Table 2.4.4.1 Materials/Tools/Equipment for Soundness Test

Materials / Tools / Equipment	Uses / Purpose	Image
1. Autoclave Apparatus	A piece of equipment designed to expose materials to high-pressure and high-temperature conditions.	
2. Measuring Cylinder	A laboratory device used to precisely measure the volume of liquids.	
3. Mixing Equipment (e.g., spatula, mixing bowl)	Tools used to thoroughly mix hydraulic cement and water.	
4. Digital Micrometer	A measuring device with high precision used to measure the initial and final dimensions of the specimen.	
5. Moist Cabinet	A cabinet used to store the mold at a constant humidity level to ensure proper hydration of the cement.	
1. Prism Mold (25 x 25 x 285 mm)	a mold in the shape of a rectangular prism used to form the cement specimen.	
2. Water		
3. Cement		
4. Weighing Balance		
5. Trowel		

2.4.5 Carbon Footprint Evaluation

The cement industry is a major source of carbon dioxide, a potent greenhouse gas. Measuring our carbon footprint is absolutely essential for identifying the sources of CO2 emissions and putting in place the necessary measures to reduce them. The two types of cement were compared on their Calcium Oxide (CaO) or Lime content, the primary contributor of carbon emissions in cement.

Lower Lime Formula:

$$100\% - \frac{\%\ of\ Lime\ Content\ of\ Green\ Cement}{\%\ of\ Lime\ Content\ of\ Portland\ Type\ 1\ Cement} * 100 = \%\ Lower\ Lime$$

2.5 PHASE 3 – GATHERING OF DATA AND RESULTS

In this part of the study, the researchers collected all the essential data and information from the testing laboratory. Data were obtained from the different testing procedures to compare the properties of Ordinary Portland Cement against Green Cement. The following tests were the Fineness Test, Setting Time, Soundness Test, Compressive Strength, and Carbon Footprint Evaluation. The results were evaluated for further analysis.

2.6 PHASE 4 – ANALYSIS, INTERPRETATIONS OF RESULTS AND DISCUSSION

Data Analysis covers evaluating or assessing results and data gathered from the testing phase. It is the most critical part of any research study. To conduct an accurate inquiry, researchers must analyze data without bias and synthesize the facts in accordance with the actual findings. The researchers were able to weed out mistakes and keep accurate data in this study phase. The researchers interpreted data using logical and analytical reasoning without altering the results to identify patterns and the relationship between the two comparing variables. The researchers organized and separated the findings for each test to be reviewed by the laboratory and the research adviser.

In terms of fineness test, according to the ASTM C150/C150M standard specification for Portland cement, the maximum percentage retained on the 75-µm (No. 200) sieve for Type I Portland Cement shall be 7 % when tested according to ASTM C4301.

While the ASTM C595/C595M standard specification for Blended Hydraulic Cement states that the maximum percentage retained on the 75-µm (No. 200) sieve for blended hydraulic cement shall be 15 % when tested according to ASTM C4302.

For the soundness test, the ASTM C150/C150M standard specification for Portland cement sets a limit of 0.8 % for the autoclave expansion of Type I Portland Cement, which ASTM C151/C151M measures.

Similarly, the ASTM C595/C595M standard specification for Blended Hydraulic Cement sets a limit of 0.8 % for the autoclave expansion of blended hydraulic cement, which ASTM C151/C151M also measures.

Meanwhile, for the setting time test, according to the ASTM C150/C150M standard specification for Portland cement, the initial setting time of Type I Portland Cement should not be less than 45 minutes, and the final setting time should not be more than 10 hours.

Likewise, ASTM C595/C595M standard specification for Blended Hydraulic Cement states that the initial setting time of blended hydraulic cement should be at least 45 minutes, and the final setting time should be at most 10 hours.

For the compressive strength of concrete cylinder statistical analysis, the researchers adopted the group statistical category in which the mean, standard deviation, and standard error mean was determined. According to Hald (1998) in his article ―A History of Mathematical Statistics‖, Standard Deviation is the measure of the amount of variation or dispersion of a set of data values. It defines how much the data deviates from the standard value. In this case, the researchers aimed to compare the compressive strength of Green cement to Portland cement (conventional), wherein the standard deviation dictates whether the cement has higher consistency or none.

In solving the standard deviation, this formula is beingX1 followed:

$$\sigma = \sqrt{\frac{\Sigma(X_1 - \mu)^2}{n}}$$

Where;
σ - Standard Deviation
X_1 – data point
µ – mean of the data set
n - Total number of data points

Meanwhile, Standard Error Mean is calculated by the formula:

$$SEM = \frac{\sigma}{\sqrt{n}}$$

For the compressive strength of mortar cube, the following standards were utilized to evaluate if both green cement and conventional cement passed the set requirements.

The Philippine National Standard (PNS 07:2005) specifies the minimum compressive strength of cement in terms of mortar cubes at different ages as follows:

For 3 days: The minimum compressive strength requirement for Ordinary Portland Cement (OPC) and Portland Pozzolan Cement (PPC) is 3.5 MPa (507 psi) at 3 days.

For 7 days: OPC and PPC's minimum compressive strength requirement is 5.0 MPa (725 psi) at 7 days.
In terms of the standards set by the American Society for Testing and Materials (ASTM C595), the minimum compressive strength required for a mortar cube is as follows:

For 3 days: The minimum compressive strength requirement for Ordinary Portland Cement Type I and Portland Pozzolan Cement is 12.0 MPa (1740 psi) at 3 days.

For 7 days: OPC and PPC's minimum compressive strength requirement is 19.0 MPa (2755 psi) at 7 days.

2.7 PHASE 5 – SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

This last methodology phase covers the systematic and comprehensible presentation of the findings. In this section, the readers can expect a summary of the experimental outcome of the study. Since the study is comparative research between sustainable cement and ordinary Portland cement, this methodology section answers the objectives and incorporates conclusions according to the results obtained. Final inferences and stating the weaknesses of this study provided in the last section of this research, and recommendations were drawn for further investigation if required.

III. RESULTS AND DISCUSSIONS

3.1 RESULTS

This chapter contains the data collected from the research material testing and in-depth analysis and interpretation of the findings. The results section presents the raw data in tables, graphs, and charts, while the discussion section provides a detailed explanation of the findings and their implications. This chapter is crucial as it allows for conclusions and recommendations based on the research findings. It provides an opportunity to evaluate the research objectives, answer the research questions, and assess the significance of the results in relation to the existing body of knowledge.

In this part of the chapter, the results contain (five) different tests primarily to show the material testing results of the physical properties of both sustainable and conventional cement.

3.1.1 Fineness Test

The fineness of the cement was determined. With the same apparatus and test, here are the results obtained:

Table 3.1.1.1 Fineness Test of Cement Results

TYPE OF CEMENT	INITIAL WEIGHT	FINAL WEIGHT	PERCENTAGE
Portland Type 1	0.500	0.485	97%
Green Cement	0.502	0.441	87.8%

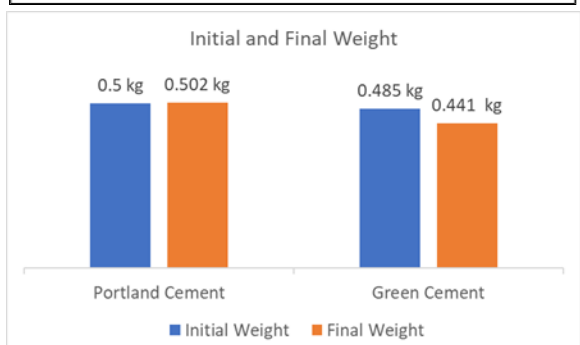

Figure 3.1.1.1 Fineness Test of Cement Results

Cement fineness is a measure of the size of cement particles and is defined in terms of cement-specific surface area. Precise fineness measurement is essential for ensuring that concrete performs consistently and predictably. The ASTM 150 standard specifies using a #200 sieve mesh to measure cement's fineness. The amount of cement-retained on the #200 sieve will be estimated by weighing the sample.

The figure shows the initial weight of Portland Type 1, which is 0.500kg, while its final weight is 0.485kg which has a difference of 0.015kg, and its percentage is 97%. The Green Cement's initial weight is 0.502kg while its final weight is 0.441kg which has a difference of 0.061kg, and its percentage is 87.8%. These finding states that Portland Type 1 is finer than Green Cement, implying that Type 1 reacts with water more quickly and develops strength at a higher rate at a higher hydration temperature. Cement fineness is an important factor that impacts the characteristics and quality of concrete. Finer cement particles increase the concrete's strength, durability, workability, and shrinkage resistance.

Figure 3.1.1.2 Fineness Test of Cement Documentation

3.1.2 Setting Time Test

Setting time is the time the cement takes to harden and develop strength after mixing it with water. It is an important parameter in determining the workability and strength of the final product. In this test, the result of conventional cement and green cement are as follows:

Table 3.1.2.1 Setting Time of Cement Results

TYPE OF CEMENT	INITIAL SET (minutes)	FINAL SET (minutes)	MINIMUM	MAXIMUM
Portland Type 1	115	199	45	375
Green Cement	123	215	45	375

Table 3.1.2.2 Normal Consistency of Cement Results

TYPE OF CEMENT	NORMAL CONSISTENCY (%)	MAXIMUM (%)
Portland Type 1	0.32	0.35
Green Cement	0.35	0.35

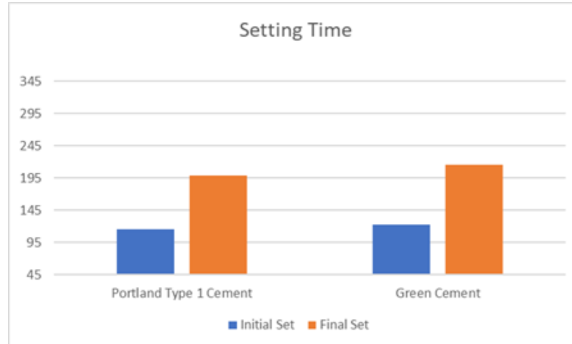

Figure 3.1.2.1 Setting Time of Cement Results

Initial Setting:

$$100\% - \frac{115}{123} * 100 = 6.504\%$$

Final Setting:

$$100\% - \frac{199}{215} * 100 = 7.442\%$$

The minimum time for the initial setting of cement is 45 minutes, while the maximum time for the final setting is 375 minutes. Portland type 1 cement sets are faster for both initial and final settings than green cement. Portland type 1 cement sets initially at 115th minute, 6.504% quicker than green cement with an initial setting time of 123 minutes. On the other hand, the final setting time of Portland Type I cement is 199 minutes, 7.442% faster than the 215 minutes of green cement. Although there is a difference in setting time, both types of cement meet the initial and final setting standards.

In cases where the test results are compared to the requirements provided in the ASTM specifications for Type I Portland Cement and Blended Hydraulic Cements, both types of cement suit the initial and final setting time standards.

According to the ASTM C150/C150M standard for Type I Portland Cement, the minimum initial setting time is 45 minutes, and the maximum final setting time is 375 minutes. Portland Type I cement meets these standards with an initial setting time of 115 minutes and a final setting time of 199 minutes, both within the specified range. On the other hand, green cement has an initial setting time of 123 minutes and a final setting time of 123 minutes, which is also within the required range.

Similarly, the ASTM C595/C595M standard for Blended Hydraulic Cements specifies a 45-minute minimum initial setting time and a 10-hour maximum final setting time. Based on the test findings, both types of cement meet this condition, showing that the cement does not expand significantly after setting.

In addition, the normal consistency of cement, 35% as its maximum, affect the setting time. The higher percentage, the longer it is set. Green cement reaches the maximum percentage of 35, while type 1 cement has a normal consistency of 32%. Hence, green cement sets slower compared to Portland-type I cement.

Figure 3.1.2.2 Setting Time Test of Cement Documentation

3.1.3 Soundness Test

Cement soundness is a critical parameter for quality control. The soundness of cement determines if the material meets the necessary standards and specifications for the intended application. Unsound cement can compromise the safety of a structure. This test is important to prevent structural failure. Thus, it is important to determine the soundness of the two types of cement being compared in this research, and the results are as follows:

Table 3.1.3.1 Soundness Test of Cement Results

TYPE OF CEMENT	AUTOCLAVE EXPANSION	MAXIMUM
Portland Type I	0.52%	0.80%
Green Cement	0.60%	0.80%

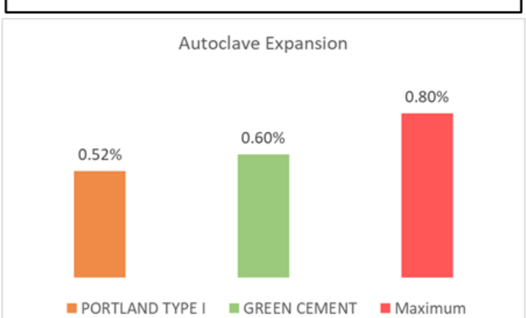

Figure 3.1.3.1 Soundness Test of Cement Results

Autoclave expansion is an important factor to consider in the soundness test of cement. It helps to ensure that the cement will not cause issues such as cracking or deformation when used in construction. ASTM C151-Standard Test Method for Autoclave Expansion of Hydraulic Cement is a widely recognized test method that measures the potential volume change of hydraulic cement when exposed to an autoclave with a maximum allowable limit of 0.80% expansion.

The figure shows that Green Cement had a higher autoclave expansion percentage of 0.60%, while Ordinary Cement had a 0.52% expansion. The difference between their expansion percentages is 0.08%, which may indicate that Green Cement has a higher potential of experiencing an excessively expansive reaction to concrete structures than Ordinary Cement.

Comparing the test results obtained for Green Cement and Ordinary Cement with the specifications mentioned in the ASTM C150/C150M standard for Type 1 Portland Cement, it is observable that both types of cement satisfy the soundness requirements.

The ASTM C150/C150M standard specifies that the maximum autoclave expansion allowed for Type 1 Portland Cement should be 0.80%. The test results for Ordinary Cement and Green Cement show that their autoclave expansion percentages are 0.52% and 0.60%, respectively, within the specified limit.

Similarly, the ASTM C595/C595M standard specifies that the maximum autoclave expansion allowed for blended hydraulic cement should not exceed 0.80% at 16 hours or 1.00% at 24 hours. In comparison, the test results for Green Cement and Ordinary Cement do not exceed these limits.

The excessive expansion of cement can lead to various issues in concrete structures, such as cracking, distortion, and reduced durability. These issues may arise due to several factors, including high alkali content in the cement, exposure to high temperatures and humidity, or expansive aggregates. With a higher autoclave expansion percentage, Green Cement may be more vulnerable to these effects than Ordinary Cement, making it a less desirable option for construction projects where the potential for expansive reactions must be minimized.

3.1.4 Compressive Strength Test

Cement's compressive strength is the most critical and essential property, designed to resist stresses and loads. It measures the maximum load that concrete can withstand before it fails or collapses under compression. In this study, the researchers conducted 3 concrete trials for each curing period, and the results are as follows:

3.1.4.1 Compressive Strength Test in Concrete Cylinder

Table 3.1.4.1.1 Compressive Strength of Cements in psi (Concrete Cylinder)

TYPE OF CEMENT	7 DAYS (psi)			14 DAYS (psi)			28 DAYS (psi)		
	1	2	3	1	2	3	1	2	3
Portland Type 1	1360	1260	1350	2090	1910	1850	2720	2370	2810
Green Cement	930	1310	1110	1630	1000	1440	1920	1460	1990

Table 3.1.4.1.2 Compressive Strength of Cements in MPa (Concrete Cylinder)

TYPE OF CEMENT	7 DAYS (MPa)			14 DAYS (MPa)			28 DAYS (MPa)		
	1	2	3	1	2	3	1	2	3
Portland Type 1	9.35	8.69	9.28	14.41	13.15	12.75	18.74	16.36	19.39
Green Cement	6.42	9.06	7.67	11.21	6.92	9.90	13.22	10.10	13.74

Figure 3.1.4.1.1 Compressive Strength Test of Cement Results

Table 3.1.4.1.3 Statistical Analysis of Compressive Strength Test Results

Group Statistics					
Compressive Strength (psi)	Cement Type	N	Mean	Std. Deviation	Std. Error Mean
7-day	Type 1 Cement	3	1323.33	55.076	31.798
	Green Cement	3	1116.67	190.088	109.747
14-day	Type 1 Cement	3	1950.00	124.900	72.111
	Green Cement	3	1356.67	323.161	186.577
28-day	Type 1 Cement	3	2633.33	232.451	134.205
	Green Cement	3	1790.00	287.924	166.233

The results obtained from the compressive strength test were tabulated and analyzed statistically, showing the Standard Deviation (SD) and Standard Error Mean (SEM), where SD and SEM are used to determine how the values vary and show the precision of the mean sample estimate referring to the table above.

In comparing the compressive strength of conventional cement and green cement, it is generally desirable to have a lower standard deviation for both types of cement because the lower SD indicates less variation in the compressive strength, which in turn indicates greater consistency in the performance of the cement.

Based on the table, the standard deviation of green cement in 7 days, 14 days, and 28 days of curing is much higher than that of conventional cement, with a lower difference in standard deviation. This suggests that green cement could be more consistent regarding its compressive strength properties. This result indicates that green cement has a less predictable performance than green cement, which is one important aspect in applying structural designs where consistency and reliability are critical factors.

In analyzing SEM, the smaller the standard error of the mean, the more precise the estimate of the population means is likely to be. However, aside from the statistical approach utilized in this study, more factors need to be considered, especially the compressive strengths attained by the two types of cement, which is the primary concern of this test. If green cement meets the standard compressive strength and has no significant difference from conventional cement, it may still be a suitable alternative despite its higher variability.

Table 3.1.4.1.4 Independent Samples Test of Concrete

Independent Samples Test									
Compressive Strength (psi)		Levene's Test for Equality of Variances		t-test for Equality of Means					
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
7-day	Equal variances assumed	1.947	.235	1.809	4	.145	206.667	114.261
	Equal variances not assumed			1.809	2.333	.194	206.667	114.261
14-day	Equal variances assumed	2.825	.168	2.966	4	.041	593.333	200.028
	Equal variances not assumed			2.966	2.584	.071	593.333	200.028
28-day	Equal variances assumed	.327	.598	3.947	4	.017	843.333	213.646
	Equal variances not assumed			3.947	3.830	.018	843.333	213.646

SOP1: Is there a significant difference between conventional cement and green cement in terms of their:

• 7-day Compressive Strength (in psi),
• 14-day Compressive Strength (in psi), and
• 28-day Compressive Strength (in psi)?

Based on the Independent Sample Test table, the following conclusions are drawn:

3. There was no significant difference, t(4)=1.809, p=.145, despite the concrete samples made using sustainable green cement (mean=1116.67, standard deviation=190.088) having lower 7-day compressive strengths compared to the concrete samples made using conventional cement (mean=1323.33, standard deviation=55.076).

An insignificant difference between the compressive strength of green cement and conventional cement in 7-day curing results suggests that sustainable cement can be used as an alternative to conventional cement and that green cement's strength meets conventional cement's performance.

2. The concrete samples made using Green Cement (mean=1356.67, standard deviation=323.161) compared to the concrete samples made using conventional cement (mean=1950.00, standard deviation=124.900) demonstrated significantly lower 14-day compressive strengths, t(4)=2.966, p=.041.

3. The concrete samples made using Green Cement (mean=1790.00, standard deviation=287.924) compared to the concrete samples made using conventional cement (mean=2633.33, standard deviation=232.451) demonstrated significantly lower 28-day compressive strengths, t(4)=3.947, p=.017.

In terms of 14 days and 28 days of curing, conventional cement shows impressively high results compared to green cement, resulting in a significant difference. This suggests that in 14 days and the whole curing time of 28 days, conventional cement shows better performance in terms of resistance to heavy loads and stress. Although green cement meets the required strength of the concrete mix, the comparison indicates that conventional cement proves why it is called convenient while serving its purpose with quality.

Table 3.1.4.1.5 Comparison of Compressive Strength to ASTM Requirements

TYPE OF CEMENT	COMPRESSIVE STRENGTH FOR 28 DAYS OF CURING (psi)	PROBABLE STRENGTH AFTER 28 DAYS (ASTM)	REMARKS
Portland Type I	2633.33psi	1500-2000psi	**Passed**
Green Cement	1790psi	1500-2000psi	**Passed**

To summarize, while green cement's compressive strength is lower than conventional cement, both types have successfully surpassed the minimum requirements stipulated by ASTM standards. Despite the disparity in strength, this accomplishment highlights the possibility of green cement as a sustainable alternative for construction by demonstrating its capacity to meet the required standards for safe and reliable application. Although the compressive strength of green cement and conventional cement may differ, the fact that both fulfill ASTM requirements justifies the possibility of green cement as an environmentally beneficial solution without compromising structural integrity.

3.1.4.2 Compressive Strength Test in Mortar Cube

The researchers also applied the mortar cube method to test the compressive strength. This method provides an accurate measure of the compressive strength of cement. Not only does it ensure that the cement meets the required standards and specifications, it will also identify any issues with cement production that must be addressed. In this study, the following results obtained by the two types of cement being compared are as follows:

Table 3.1.4.2.1 Compressive Strength of Cements in psi (Mortar Cube)

TYPE OF CEMENT	3 DAYS (psi)	7 DAYS (psi)
Portland Type 1	3597	4308
Green Cement	2495	3669

Table 3.1.4.2.2 Compressive Strength of Cements in MPa (Mortar Cube)

TYPE OF CEMENT	3 DAYS (MPa)	7 DAYS (MPa)
Portland Type 1	24.8	29.7
Green Cement	17.2	25.3

Figure 3.1.4.2.1 Compressive Strength Test of Cement (Mortar Cube)

The results show that conventional cement demonstrates higher compressive strength than green cement. However, both types of cement passed the required strength given by the Philippine National Standard and ASTM, which suggests that green cement is still suitable for construction applications and can produce strength that can resist loads and stresses.

3.1.5 Comparison of Results for Physical Properties Results

Test results attained at the testing center conducted by the researchers were compared to that of company results, as shown in the table below:

Table 3.1.5.1 Comparison of Physical Properties Results

PHYSICAL TEST	COMPANY RESULTS (CEMEX)	TEST RESULTS (RESEARCHERS)
Fineness (Passing %)	82.8%	87.8%
Initial Setting Time	100 minutes	123 minutes
Final Setting Time	310 minutes	215 minutes
Soundness of Cement	-	0.80
Compressive Strength Mortar Cube (3 days)	15.9 MPa	17.2 MPa
Compressive Strength Mortar Cube (7 days)	20.2 MPa	25.3 MPa

Based on the tabulated values presented above, the researchers' results slightly vary from those given by the company. However, it performs better in all aspects of the tests except for the initial setting time. The values obtained by the researchers show that the company's claims of their green cement were significantly true and considerable.

The variations in the results may be due to the following factors:

Several factors can influence the results when testing the fineness of the same cement sample conducted by different testing centers. Here are some factors that can affect the fineness measurements: (a) Test Method - different testing centers may use different methods to determine the fineness of the cement. The test method can have variations in equipment, procedures, and calculations, leading to different results (b) Sieve Analysis Technique - the technique used during the sieve analysis can also impact the results. Factors such as the duration of sieving, agitation intensity, and the presence of airflow can influence the particles' ability to pass through the sieve apertures (c) Calibration and Maintenance - the calibration and maintenance of the testing equipment, including the sieves, can affect the accuracy and consistency of the measurements. Suppose the equipment needs to be properly calibrated or maintained. In that case, it can introduce errors in the results (d) Sampling - the method and location of sampling the cement sample can impact the fineness measurements. If the samples are representative of the entire batch and are collected properly, the results may differ between testing centers.

Several factors can influence the results when testing the setting time of the same cement conducted by different testing centers. Here are some factors that can affect the setting time measurements: (a) Temperature and Humidity - the setting time of cement is significantly influenced by temperature and humidity conditions. Testing centers operating under different environmental conditions may observe variations in the setting time measurements. Higher temperatures generally accelerate the setting process, while lower temperatures delay it (b) Water-Cement Ratio - the water-cement ratio used during the testing can impact the setting time. Higher water-cement ratios typically result in longer setting times, while lower ratios can accelerate the setting process. Variations in the water-cement ratio between testing centers can lead to different setting time results (c) Sample Preparation - the method and conditions of preparing the cement paste sample can influence the setting time measurements. Factors such as the mixing technique, mixing time, and consistency of the paste can affect the setting characteristics.

Several factors can influence the results when testing the compressive strength of mortar cubes conducted by different testing centers. Some factors can affect the compressive strength measurements: (a) Mix Proportions - the proportions of the constituent materials in the mortar mix, including cement, sand, and water, can significantly impact the compressive strength. Different testing centers may use different mix designs or have variations in the mix proportions, leading to differences in the compressive strength results (b) Curing Conditions: The curing conditions applied to the mortar cubes after casting can affect their strength development. Factors such as temperature, humidity, and duration of curing can vary between testing centers and influence compressive strength measurements. Inconsistent curing conditions can result in variations in the strength development of the cubes (c) Testing Age- the age at which the compressive strength is tested can affect the results. Mortar cubes gain strength over time, and the testing age can vary between testing centers. If the cubes are tested at different ages, it can lead to variations in the compressive strength measurements.

In conclusion, it is important to consider various factors, including test methods, sample preparation, curing conditions, and human error, when comparing the measurements of cement fineness, setting time, or compressive strength conducted by different testing centers. These factors can result in variations in the obtained results. Therefore, adhering to standardized procedures, ensuring quality control, and actively participating in proficiency testing programs are crucial for obtaining reliable and comparable measurements across diverse testing centers.

3.1.6 Carbon Emissions

The primary contributor to carbon emissions among the chemical properties of cement is lime (CaO). The process of calcination, which involves heating limestone (CaCO3) to produce lime, releases carbon dioxide (CO2) as a byproduct. In cement production, the typical procedure involves quarrying and crushing limestone, then heating it in a kiln at high temperatures (approximately 1450°C) to obtain lime. This thermal treatment, calcination, causes calcium carbonate to decompose into calcium oxide (lime) and carbon dioxide.

Table 3.1.6.1 Chemical Properties of Portland Type 1 and Green Cement

CHEMICAL COMPOSITION	PORTLAND TYPE 1 CEMENT	GREEN CEMENT
Lime (Calcium Oxide) (CaO)	63.36%	45.80%
Silica (Silicon Dioxide) (SiO_2)	21.23%	28.80%
Alumina (Aluminum Oxide) (Al_2O_3)	5.40%	8.00%
Iron oxide (Ferric Oxide) (Fe_2O_3)	3.26%	4.54%
Magnesia (Magnesium Oxide) (MgO)	2.28%	1.60%
Sulphur trioxide (SO_3)	1.84%	2.58%
Soda and/or Potash (Na_2O+K_2O)	0.42%	1.84%
Loss of Ignition	0.92%	7.7%

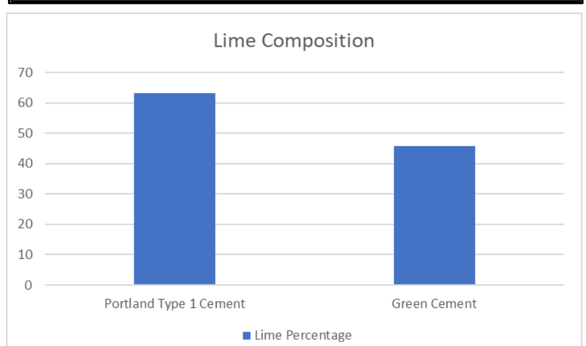

Figure 3.1.6.1 Lime Composition of Portland Type 1 and Green Cement

$$100\% - \frac{45.80}{63.36} * 100 = 27.715\%$$

The figure shows that Portland Type 1 Cement has 63.36% of lime (CaO) in its chemical composition. However, Green Cement only comprises 45.80% of lime (CaO), 27.715% lower than Portland Type 1.

3.1.7 Cost Comparison

Table 3.1.7.1 Cost Comparison of Portland Type 1 and Green Cement

Types of Cement	Price Per 40kg Bag in Peso
Portland Type 1 Cement	225
Green Cement	227

The analysis of the pricing of these two types of cement is limited to the available prices in the locality of Pampanga. Portland Type 1 cement has a price value of 225 pesos per bag, 2 pesos cheaper than green cement, valued at 227 pesos per bag.

The use of eco-friendly cement has a strong worth despite its slightly higher cost than conventional cement. The environmental benefits and long-term advantages outweigh the initial expense. Here is a summary of the justifications:

1. Carbon footprint reduction: Eco-friendly cement significantly lowers carbon emissions by 20-50% compared to traditional manufacturing methods, making it a valuable choice for mitigating CO2 emissions (Jiang et al., 2017).
2. Energy efficiency: Innovative technologies and practices in eco-friendly cement production enhance energy efficiency, reducing energy consumption by up to 20% through alternative fuels (Wang et al., 2019).
3. Waste utilization: Eco-friendly cement incorporates waste materials like fly ash, slag, and rice husk ash, reducing waste disposal and conserving natural resources. Resource savings of up to 60% can be achieved by using fly ash as a partial replacement for cement (Siddique & Klaus, 2009).
4. Market demand and regulations: The construction industry increasingly prioritizes sustainability, with regulations and certifications promoting eco-friendly materials. Choosing eco-friendly cement enhances eligibility for green building certifications, resulting in higher property values, market competitiveness, and public recognition.

Considering these factors, the higher cost of eco-friendly cement is justified by its long-term environmental benefits, reduced carbon footprint, energy efficiency, waste utilization, and compliance with market demands and regulations.

IV. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the study's findings, conclusions, and recommendations. It aims to determine the difference between green cement and conventional cement in fineness, setting time, soundness, and compressive strength using various test findings.

4.1 SUMMARY OF FINDINGS

This study analyzed the market available green cement by comparing it with conventional cement in terms of its physical properties, such as fineness, setting time, soundness, and compressive strength. This study also assesses the carbon emissions of both types of cement, which is a key reason green cement is being introduced to the construction industry to create a more sustainable planet. The data and information acquired in this research will provide the construction sector with an overview of the sustainable approach to developing structures in our country. This study provides an intelligent investigation and strong hopes that our country will see a brighter future more sustainably. The study's findings were discussed as follows:

4.1.1 Objective-based Findings

a. General Objectives

The physical properties of conventional and green cement were determined through laboratory tests. The results showed the difference between the two types of cement and suggested that the cement is applicable for construction purposes and meets the required standards.

b. Specific Objectives

To quantify the cost and financial difference of sustainable cement to a conventional cement. - Based on findings, Portland Type 1 cement is barely cheaper than green cement. In the stats provided, Portland Type 1 cement has a 2-peso difference from green cement. Regardless of the small discrepancy value, the cost disparity will be much more noticeable and appreciated in bulk orders. In addition, considering that green cement passed all the tests of four properties, green cement can be used as an alternative in small projects due to minimal differences in price.

To estimate the overall carbon footprint released by green cement compared to conventional cement in terms of carbon dioxide emission. - The results of the chemical properties test revealed that Conventional Cement contains 63.36% Lime (CaO) in its composition, while Green Cement has only 45.80% Lime (CaO). This finding indicates that Green Cement has a 27.715% lower Lime (CaO) content than Conventional Cement, which is a promising result for the construction industry's eco-friendly use of Green Cement.

To investigate the potential of using eco-friendly cement as a sustainable alternative to conventional cement in the construction industry. - The findings suggest that the performance of green cement tested in the experiment was slightly inferior to that of conventional cement. Nevertheless, the potential of green cement remains significant, as it satisfies all the requirements set by the ASTM Standards.

To identify the factors that affect the performance and properties of eco-friendly cement, such as the type and proportion of raw materials used, curing conditions, and additives. - The difference between green cement and conventional cement in ingredients affects the performance of green cement as this cement contains a higher amount of natural industrial waste compared to a highly concentrated clinker of conventional cement- which is the primary ingredient of cement. These findings highlight the need for further experimentation to optimize green cement, such as exploring different curing conditions, concrete proportioning, and modifications to its composition.

4.1.2 General Findings

Table 4.1.2.1 Summary of Results Compared to ASTM Requirements

TYPE OF CEMENT AND TEST	RESULTS ATTAINED	MINIMUM REQUIREMENT (ASTM)	REMARKS
Portland Fineness	0.97	0.93	PASSED
Green Cement Fineness	0.878	0.85	PASSED
Portland Setting Time			
*Initial	115	45 min.	PASSED
*Final	199	375 max.	PASSED
Green Cement Setting Time			
*Initial	123	45 min.	PASSED
*Final	215	375 max.	PASSED
Portland Soundness	0.52	0.80	PASSED
Green Cement Soundness	0.60	0.80	PASSED
Portland Compressive Strength			
- 7 days	1323.33 psi	-	
- 14 days	1950.00 psi	-	
- 28 days	2633.33 psi	1500-2000psi	PASSED
Green Cement Compressive Strength			
- 7 days	1116.67 psi	-	
- 14 days	1356.67 psi	-	
- 28 days	1790.00 psi	1500-2000psi	PASSED
Portland Mortar Cube			
- 3 days	24.8 MPa	12.0MPa	PASSED
- 7 days	29.7 MPa	19.0MPa	PASSED
Green Cement Mortar Cube			
- 3 days	17.2MPa	12.0MPa	PASSED
- 7 days	25.3MPa	19.0Mpa	PASSED

The findings of this study suggest that, while eco-friendly or green cement may function and behave differently than conventional cement, it has the potential to be a sustainable alternative in the construction industry. While the compressive strength of green cement was lower in certain circumstances than conventional cement, it nonetheless met the specifications established in the ASTM Standards. While there are some differences in the performance and properties of green cement compared to conventional cement, this study suggests that these differences can be minimized or potentially eliminated through further optimization of its composition and processing. Further experimentation with different raw material proportions, additives, and curing conditions may lead to improved performance and properties of green cement.

In conclusion, this study underscores the potential of eco-friendly cement as a sustainable alternative to conventional cement in the construction industry. While further research is needed to optimize this alternative fully, our findings provide a valuable foundation for future investigations into the various factors that impact its performance and properties.

4.2 CONCLUSIONS

Recognizing that the cement industry contributes significantly to greenhouse gas emissions, there is considerable interest in developing green cement as a more sustainable option. The researchers intend to investigate the potential of green cement as an alternative to conventional cement and evaluate its performance in accordance with the American Society for Testing and Materials (ASTM) standards in this study.

A series of experiments were undertaken to evaluate the performance of green cement, and the results demonstrate that both green cement and conventional cement meet the required requirements specified by the American Society for Testing and Materials. However, this study discovered that green cement performs slightly poorly than regular cement.

Aside from the quantitative results achieved in the experiments, several factors could have influenced green cement performance:

1. Raw Materials - The raw materials used to make green cement may need to be better developed than those used to make conventional cement. For example, green cement production frequently entails using industrial waste materials, which might have varying chemical compositions and physical qualities that can affect the end product's performance. In contrast, ordinary cement raw materials have been refined over many years to optimize their qualities for cement manufacturing.
2. Production Process - Traditional cement production may be better established than green cement production. As a result, the cement's physical and chemical qualities may need to be more consistent, impacting its performance.
3. Water Absorption - Green cement demonstrates a higher water absorption, affecting its other physical properties, including setting time and compressive strength. High water absorption can degrade concrete workability and increase setting time. If the concrete mix is excessively dry, it will not be easy to work with and may not fill all the necessary areas. However, if the mix is too wet, it can cause segregation, which is the separation of the mix components due to weight differences. Green cement has a higher chance of increased entrained air in the concrete. This can cause a reduction in the compressive strength of the concrete and affect its durability, explaining why it obtains lower compressive strength compared to conventional cement regardless of similar curing and mixing conditions.
4. Impurities - Given that green cement incorporates natural waste from industrial processes, contaminants in the raw materials used may impact the end product's performance.

Based on the analysis, the researchers reckoned that green cement has the potential to be a viable alternative to conventional cement in terms of meeting ASTM criteria. However, more research and development are required to improve green cement's performance and ensure its widespread use in the construction industry. Finally, using green cement is a significant step toward a more sustainable future for the construction industry, and the researchers encourage the exploration of innovative and ecologically friendly solutions to minimize the industry's environmental impact.

4.3 RECOMMENDATIONS

After completing the study, the study's findings led to the proposal of the following recommendations:

1. The researchers strongly advise that future studies build upon the information and insights gained from their research by exploring ways to optimize and maximize its application. This may involve further investigation into the variables and factors identified in the study and exploring new avenues for research that could lead to more robust and effective solutions.
2. To conduct a comprehensive cost analysis between Green Cement and Conventional (Portland Type 1) Cement, researchers estimate the cement cost for an entire structure. This would involve the total cost of cement required for the project, factoring in the cost of raw materials, transportation, manufacturing, and any associated environmental costs. This approach would provide a more accurate assessment of the cost-effectiveness of Green Cement compared to Conventional Cement.
3. In addition to their previous recommendation, the researchers suggest that different concrete mix

ratios (conventional and sustainable cement) be applied to optimize the study further. By testing various combinations of water, sand, gravel, and cement, researchers can better understand how these components interact and how they can be adjusted to achieve optimal and varying results. This could involve exploring new combinations of materials or adjusting the proportions of existing materials to create a more efficient and sustainable concrete mixture. Furthermore, by incorporating sustainable practices into the mix design, researchers can explore the potential benefits of reducing the environmental impact of concrete production without compromising its quality or strength. The researchers believe that by taking a comprehensive and systematic approach to studying concrete mix design, the industry can continue to innovate and develop more sustainable solutions for the future.

4. The researchers also suggest conducting other physical tests for cement (both conventional and sustainable) to further compare the material's physical properties. By using a variety of physical tests, researchers can gain a more comprehensive understanding of the behavior and characteristics of cement and how it performs under different conditions. This could involve testing the material's compressive strength, tensile strength, durability, and other physical properties and exploring how it responds to environmental factors such as temperature, humidity, and exposure to chemicals. By comparing the results of different physical tests, researchers can identify any inconsistencies or variations in the material's properties and work to address them. Ultimately, this could lead to the developing of more reliable and consistent cement formulations that can meet the demands of various applications and industries.
5. Moreover, researchers suggest conducting more chemical tests on conventional and sustainable cement to compare their properties. These tests would help understand how cement interacts with other substances and how its chemical properties affect its behavior. Researchers can identify potential issues or limitations by analyzing the material's reaction to different chemicals, its resistance to corrosion and degradation, and its performance under various environmental conditions. These tests can also help determine the ideal ratios for concrete mixtures, leading to improved cement quality, consistency, and sustainability. Overall, conducting additional chemical tests would provide a comprehensive understanding of cement composition and behavior, leading to better industry practices.

In conclusion, if researchers and industry experts adopt the suggestions presented in this study, they can further the progress of sustainable and effective cement manufacturing. By implementing a proactive and organized methodology that employs diverse physical and chemical analyses, researchers can obtain a more inclusive comprehension of cement's characteristics and actions and strive to improve its efficiency while reducing its ecological footprint. By accepting these guidelines and implementing them practically, we can build a more sustainable and robust future for the cement industry and other areas.

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