Adaptability and Performance of Slag Cement As Partial Replacement to Ordinary Portland Cement in Concrete

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Abstract

Portland cement is extensively used in the construction industry, making it one of the biggest construction expenditures in the Philippines and worldwide. It plays a vital role in concrete technology and is also the one used more often as compared to the other types of cement. In this study, the feasibility of partially replacing Portland cement with Slag cement, an industrial byproduct of iron manufacturing was investigated. This provides alternative and sustainable solutions to concrete design that could aid in the construction cost reduction. In this research, the effect of replacing Portland cement with 0 percent, 30 percent, 40 percent and 50 percent slag cement in concrete mix design were investigated for compressive and flexural strengths. For the determination of strengths, a Universal Testing Machine (UTM) was used to apply compressive and flexural loads to concrete cylindrical and beam samples, respectively. Water demand, slump and slump retention at constant water-cement ratio for the said proportions were also tested. The results show that concrete using slag cement has lower water demand as it achieves higher slump and better slump retention versus concrete using pure Portland cement. Moreover, with the increasing amount of slag cement replacement to Portland cement, the compressive and flexural strength of concrete increases. An optimum replacement of 50 percent slag cement to Portland cement in concrete is therefore recommended for both compressive strength and flexural strength designs.

Keywords: concrete mix design, Portland cement replacement, slag cement

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I. Introduction

With the wide use of Portland cement in many infrastructure developments in the Philippines and abroad, various alternatives are being considered and desired in order to reduce construction costs. Moreover, the trend for sustainable engineering advancement has been more favored and pursued.

Currently, the most common Pozzolan cement is Fly-Ash. Here again, intergrading is the common manufacturing process and the Pozzolan may account for 15 to 40 percent of the weight of the cement (Federal Highway Administration, 1995). Some advantages of using Pozzolan are improved workability, economy and sulfate resistance. Other advantages are reduced alkali-aggregate reaction, heat generation, volume change and bleeding. Examples of pozzolans are fly ash, ground granulated blast-furnace slag, and microsilica or silica fume. Slag cement, with its pozzolanic properties, has been identified to be a possible partial replacement to ordinary Portland cement. Being a byproduct from the iron manufacturing process, slag cement can be put to good use in concrete technology.

In the Philippines, there are some companies in the iron and steel industry that uses slag as a raw material for cement, iron and steel for road construction. These companies made an effort to effectively minimize potential environmental waste.

In 2020, ores, slag, and ash ranked fifth in the Philippines top ten exports with 2.7 percent as reported. Ores, slag, and ash were the fastest grower among the top 10 export categories, up by 40.6 percent from 2019 to 2020 propelled by higher international sales of nickel and iron ores and concentrates. The only other top export product to increase copper via a 23.4 percent gain. Additionally, the Philippines also imports slag from countries like India. In 2014–2015, the Philippines imported 18,000 tons of slag from India.

Cement companies such as Holcim Philippines produce blended cement volumes with ground granulated blast furnace slag (GGBFS). Raw materials for blended cement namely the GGBFS is imported and stored at their plant in Barangay Pulong Balibaguhan, Mabini, Batangas.

A. Statement of the Problem

There is a need for alternative solutions in concrete technology since Portland cement is a huge construction expenditure and is widely used.

Also, slag cement is a waste byproduct and can be put to good use in concrete due to its pozzolanic properties. By partially replacing Portland cement with slag cement in concrete, an alternative and sustainable solution can therefore be provided.

B. Objectives of the Study

1. Find out the effect of slag cement as replacement to Portland cement in concrete in terms of: (a) Compressive Strength; (b) Water Demand; (c) Slump; and (d) Slump Retention.

2. Check and evaluate the optimum slag cement replacement on the compressive strength and flexural designs.

3. Make a comparison of concrete design parameters of the slag cement combination to ordinary Portland cement.

C. Significance of the Study

It is great to present this to all the engineers, architects, contractors, consumers, and educators to inform and give them an alternative in the future to help them cut costs in construction and, at the same time, be part of the varied sustainable initiatives of using slag cement.

This study also lays down a great opportunity in the construction business and economy of the Philippines. Supporting and opening more steel producing businesses where wastes can be made to slag cement or establishing connections from slag cement - producing countries like South Korea and Japan will have a significant boost in the economy.

D. Scope and Limitations of the Study

1. The study focuses on the effect of slag cement replacement up to 50 percent to Portland cement at different concrete mix designs for compression and flexure.

2. The study uses a constant water to cement ratio approach just to primarily check if replacing part of cement in the design with slag cement using a defined water-cement ratio set by using pure ordinary Portland cement has an effect on the workability and strength of concrete.

3. The study is limited to the use of naptha based admixture. The researcher just would like to establish a certain pattern on the effect of different slag cement replacement to cement in different concrete designs.

4. The detailed economic and cost efficiency of the slag cement as a partial replacement is not included in this study. This study will only focus on the sample's compressive strength and other design parameters

5. The procedures in this study are based on the American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (ASSHTO) and British Method.

II. Review of Related Literature

A. Portland Cement in the Philippines

In concrete, the most commonly used is Portland cement. It is a hydraulic cement which sets and hardens through a chemical reaction with water and can do so underwater. Cement serves as "glue" that binds the concrete ingredients together and is instrumental for the strength of the composite. (Lee & Estrada, 2020).

David Saylor started the United States' concrete production in the early 1870s, in Coplay, Pennsylvania (Federal Highway Administration, 1995).

Portland cement is made up primarily of four mineral components: tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite. Each of which has its own hydration characteristics. By changing the relative proportions of these components, cement manufacturers can control the properties of the product (Lee & Estrada, 2020).

The primary product of cement hydration is a complex and poorly crystalline calcium-silicate hydroxide gel (CSH). A secondary product of hydration (in the production of cement) is calcium hydroxide, a highly crystalline material. The American Society for Testing and Materials (ASTM) defines five types of cement, specifying for each the mineral composition and chemical and physical characteristics such as fineness. The most common cement is Type I. Type III cement is used if more rapid strength development is required. The other types are characterized by either lower heat of hydration or better sulfate resistance than that of Type I cement such as calcium hydroxide, a highly crystalline material.

According to the research article entitled, "Analysis of Chemical Composition of Portland Cement in Ghana: A Key to Understand the Behavior of Cement" written by Bediako and Amankwah in 2015, Portland cement is the most commonly utilized cement in almost every part of the world. The understanding of the embodiment of Portland cement could lead to a more sustainable concrete and mortar design. It chemically reacts with water to attain setting and hardening properties when used in the construction of buildings, roads, bridges, and other structures. Portland cement was patented by Aspdin in 1824 and was named after the cliffs on the isle of Portland in England. Table 1 presents the summary of chemical data for a selection of Portland Cement.

Table 1. Summary of Chemical data for a selection of Portland cement

Component	Minimum	Average	Maximum
SiO_2	18.40	21.02	24.50
Fe_2O_3	0.16	2.85	5.78
Al_2O_3	3.10	5.04	7.56
CaO	58.10	64.18	68.00
MgO	0.02	1.67	7.10
SO_3	0.00	2.58	5.35
Na_2O	0.00	0.24	0.78
K_2O	0.04	0.70	1.66
Equivalent alkalis	0.03	0.68	1.24
Free lime	0.03	1.24	3.68

Source: Analysis of Chemical Composition of Portland Cement in Ghana

These chemical compositions can be used to further improve the characteristics of concrete in terms of slump, compressive strength, setting time, etc. by addition of certain material (composites) that would react to the given elements in Table 1 and/or by altering the said elements in terms of their ratios to the mixture.

A research paper by Miranda et al. in 2014 entitled, "Increasing the Compressive Strength of Portland Cement Concrete Using Flat Glass Powder" analyzes the compressive strength of Portland cement concrete in response to the incorporation of five percent, 10 percent and 20 percent of flat glass powder in place of sand, at water/cement (w/c) ratios of 0.50, 0.55, and 0.58.

The purpose of this study was to analyze the influence of partially substituting natural fine aggregate for flat glass powder on the compressive strength of Portland cement concrete. This is the first study focusing on the application of this type of waste glass as fine aggregate in Portland cement concrete.

Cylindrical test specimens (10 cm x 20 cm) were molded and cured as recommended by the Brazilian technical standard NBR 57389. The test specimens were first cured for 24 hours in the molds at an ambient temperature of 28.5°C. They were then released from the molds and immersed in water at 26.5°C to cure for seven, 14 and 28 days (Miranda, Bezerra, Politi, & Paiva, 2014).

In this study, the compressive strength of Portland cement concrete was found to increase in response to the use of waste flat glass powder, which has not been used as a fine aggregate. The concrete containing flat glass powder was found to be suitable for structural applications when prepared with a w/c ratio of 0.55 and waste glass content of 20 percent, and with a w/c ratio of 0.50, regardless of the percentage of glass used. The w/c ratio of 0.50 showed the best potential when substituting sand for waste glass (Miranda et al., 2014).

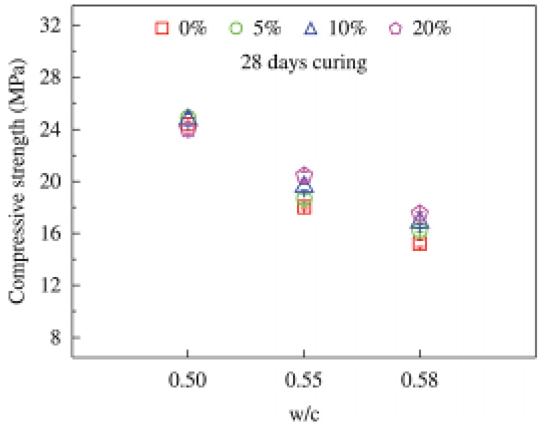

Figure 1. Compressive strength as a function of the w/c ratio after 28 days of curing.
Source: Increasing the Compressive Strength of Portland Cement Concrete Using Flat Glass Powder.

The findings presented indicate the promising potential of using flat glass powder as a fine aggregate in Portland cement concrete to produce an environmentally-friendly and structurally-applicable concrete.

An "Experimental Study on Strength Gaining Characteristics of Concrete using Portland Composite Cement" by Uddin, Jameel, Sobuz, Islam and Hasan in 2013 dealt with the investigation of strength gaining characteristics of concrete made with Portland Composite Cement (PCC) and Ordinary Portland Cement (OPC). This experimental study represents a general scenario of the strength gain characteristics of concrete made with PCC and OPC both at earlier and later ages. All properties of concrete ingredients were kept constant and cement type was varied with different composition. The work was performed using locally available materials such as stone chips, sand (coarse sand) and cement (Portland composite and ordinary Portland).

Strength developments of five concrete types have been investigated in terms of cement content and curing duration. Experimental observations on 495 specimens revealed that the early age strength of PCC concrete is lower than that of OPC concrete. Based on the test results, lack of proper pozzolanic reaction in the presence of fly ash in PCC concrete strength was lower at early age. The pozzolanic activity of fly ash also contributed to the strength gain at later stages of continuous curing. This study also concluded that drying ambient conditions reduced the strength potential of PCC concrete as the secondary (pozzolanic) reaction fails to contribute to the development of strength (Uddin et al., 2012).

Another experimental study focusing on "Compatibility of vegetable fibers with Portland cement and its relationship with the physical properties" by Marques et al. in 2016 studied the use of vegetable matrices as a sustainable technological alternative. The significant volume of agroforestry residues generated by agro-industrial and human activities is probably being inadequately deposited in the environment without sustainable reuse. From the technological and environmental perspectives, the use of residues from agro-industry in civil construction has gained relevance, because it promotes technical quality, decreasing the costs of energy and natural materials for the production of constructive elements, and also avoids damages to the environment.

The study evaluated the compatibility of vegetable fibers with cement using three methods of calculation and determined certain physical properties of the fibers and the curve of the temporal evolution of temperature for each composite. The following figures show the hydration curve of the different composite materials.

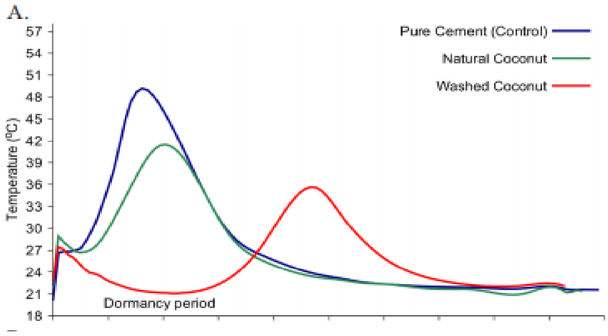

Figure 2. Hydration curves of natural and washed coconut fibers.

Source: Compatibility of vegetable fibers with Portland cement and its relationship with the physical properties.

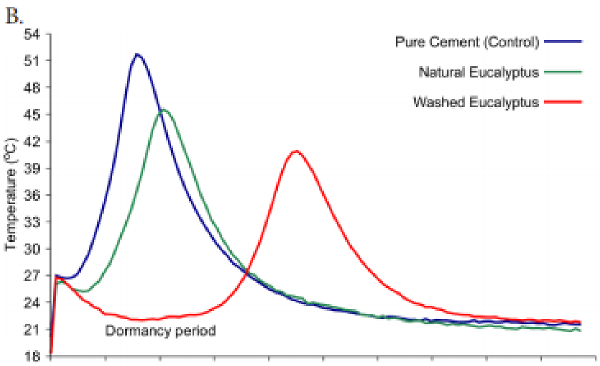

Figure 3. Hydration curves of natural and washed eucalyptus fibers.

Source: Compatibility of vegetable fibers with Portland cement and its relationship with the physical properties.

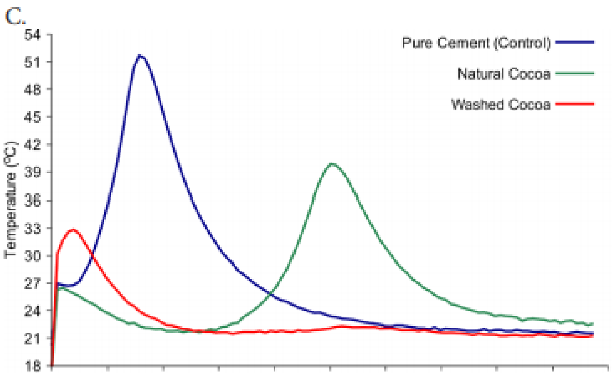

Figure 4. Hydration curves of natural and washed cocoa fibers.

Source: Compatibility of vegetable fibers with Portland cement and its relationship with the physical properties.

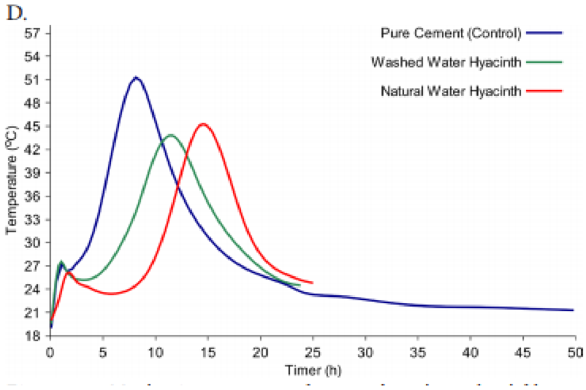

Figure 5. Hydration curves of natural and washed water hyacinth fibers.

Source: Compatibility of vegetable fibers with Portland cement and its relationship with the physical properties.

From the experiment, it can be concluded that there is a significant potential use for residues of washed fibers of eucalyptus, water hyacinth, coconut and cocoa. The pretreatment of washing of water hyacinth fiber did not alter the compatibility performance of the composites. The compatibility of the composites is favored by the decrease in the degree of swelling, packing density and specific mass. The physical properties of the studied vegetable fibers can be used as indicators in the selection of fibers and their pretreatment, aiming to use them in cementitious masses (Marques et al., 2016).

More importantly, the adherence regions found in the microscopic images that strengthen the fiber-cement link were directly associated with the depressions on the topographic profile of the surface of the fibers. The apparent irregularity found in the microscopic images of cement distribution in the composite may be related to the degree and the type of crystallinity in the cellulosic structure of the fibers (Marques et al., 2016).

This Philippine National Standard Specification for Portland cement PNS 07:2005 was prepared by the Bureau of Product Standards' Technical Committee on Cement and Lime (BPS/TC 3) and was approved for adoption as Philippine National Standard. Table 2 shows the types of Portland cement in accordance with its use.

Table 2. Classification of Portland cement in accordance with the following types.

Type	Use
Type I	For use when the special properties specified for any other type are not required
Type II	For general use, more especially when moderate sulfate resistance or moderate heat of hydration is desired
Type III	For use when high early strength is desired
Type IV	For use when a low heat of hydration is desired
Type V	For use when high sulfate resistance is desired

Source: Philippine National Standard Specification for Portland cement PNS 07:2005.

Each type of cement shall conform to the chemical requirements specified in Table 3 when tested in accordance with PNS ASTM C 114:2005. In addition, optional chemical requirements are shown in Table 4.

Table 3. Chemical requirements.

Cement type	I	II	III	IV	V
Silicon oxide (SiO_2) %, min.	-	20.0	-	-	-
Aluminum oxide (Al_2O) %, max.	-	6.0	-	-	-
Ferric oxide (Fe_2O_3), %, max.	-	6.0	-	6.5	-
Magnesium oxide (MgO), %, max.	6.0	6.0	6.0	6.0	6.0
Sulfur trioxide (SO_3), %, max.					
a. When (C_3A) is 8% or less	3.0	3.0	3.5	2.3	2.3
b. When (C_3A) is more than 8%	3.5	-	4.5	-	-
Loss in ignition, %, max.	3.0	3.0	3.0	2.5	3.0
Insoluble residue, %, max.	0.75	0.75	0.75	0.75	0.75
Tricalcium silicate (C_3S), %, max.	-	-	-	35	-
Dicalcium silicate (C_2S), %, min.	-	-	-	40	-
Tricalcium aluminate (C_3A), %, max.	-	8	15	7	5
Tetracalcium aluminoferrite plus twice the tricalcium aluminate $C_4AF + 2(C_3A)$ or solid solution ($C_4AF + C_2A$), as applicable, %, max.	-	-	-	-	25

Source: Philippine National Standard Specification for Portland cement PNS 07:2005)

Table 4. Optional Chemical requirements.

Cement type	I	II	III	IV	V	Remarks
Tricalcium aluminate (C_3A), %, max.	-	-	8	-	-	For moderate sulfate resistance
Tricalcium aluminate (C_3A), %, max.	-	-	5	-	-	For high sulfate resistance
Sum of tricalcium silicate and tricalcium aluminate, %, max.	-	58	-	-	-	For moderate heat of hydration
Alkalis ($Na_2O + 0.658K_2O$), %, max.	0.6	0.6	0.6	0.6	0.6	Low-alkalicement

Source: Philippine National Standard Specification for Portland cement PNS 07:2005.

Each type of Portland cement shall conform to the physical requirements specified in Table 5.

Table 5. Physical requirements.

Cement type	I	II	III	IV	V	Test method
Air content of mortar, volume %, max.	12	12	12	12	12	PNS ASTM C 185: 2005
Fineness, specific surface, m²/kg (alternative methods):						
Turbidimeter test, min.	160	160	-	160	160	PNS ASTM C 115: 2005
Air permeability test, min.	280	280	-	280	280	PNS ASTM C 204: 2005
Autoclave expansion, %, max	0.80	0.80	0.80	0.80	0.80	PNS ASTM C 151: 2005
Time of setting						
Gillmore test:						
a. Initial set, minutes, min	60	60	60	60	60	PNS ASTM C 266: 2005
b. Final set, hours, max.	10	10	10	10	10	
Vicat test:						
a. Initial set, minutes, min.	45	45	45	45	45	PNS ASTM C 191: 2005
b. Final set, hours, max.	8	8	8	8	8	
Strength, minimum values shown for the ages indicated below						
Compressive strength						
3 days	12.4	10.3	24.1	-	8.3	PNS ASTM C 109/ C 109M: 2005
7 days	19.3	17.2	-	6.9	15.2	
28 days	27.6	27.6	-	17.2	20.7	

Source: Philippine National Standard Specification for Portland cement PNS 07:2005

B. Pozzolan Cement

Pozzolan is a siliceous or siliceous and aluminous material, which, alone, possesses little or no cementitious value but will react with water and calcium hydroxide to form compounds possessing cementitious properties. The most common Pozzolan is Fly-Ash.

A research by Al-Chaar, Alkadi, & Asteris in 2013 investigated the feasibility of "Natural Pozzolan as a Partial Substitute for Cement in Concrete." In this paper, the use of natural pozzolan as a partial cement substitute in concrete materials was investigated. By means of a test series, four mixes using three types of natural pozzolan, as well as a Class F fly ash, were evaluated. The effectiveness of each pozzolan in controlling alkali-silica reactions has been studied (Al-Chaar et al., 2013).

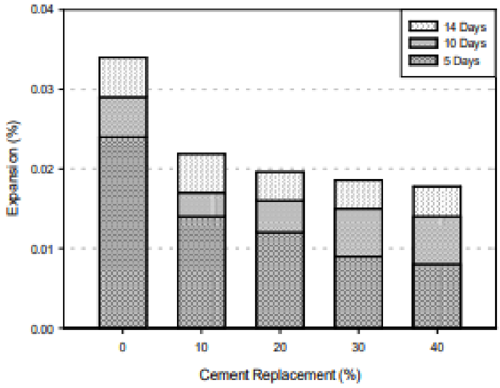

Figure 6. Effect of cement replacement with fly ash on ASR expansion

Source: Natural Pozzolan as a Partial Substitute for Cement in Concrete

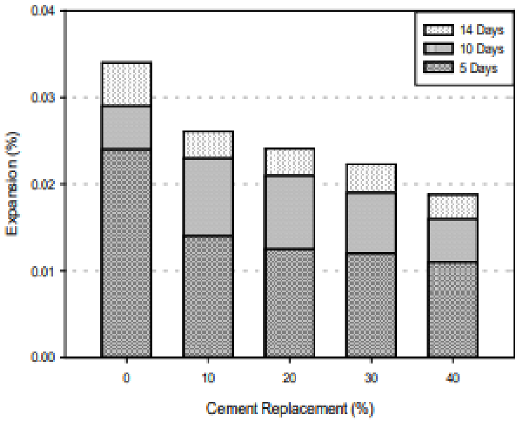

Figure 7. Effect of cement replacement with Pozzolan J on ASR expansion

Source: Natural Pozzolan as a Partial Substitute for Cement in Concrete

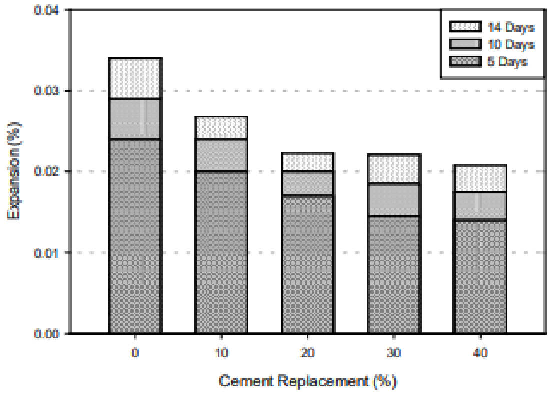

Figure 8. Effect of cement replacement with Pozzolan SI on ASR expansion

Source: Natural Pozzolan as a Partial Substitute for Cement in Concrete

Based on the results of the study, it can be concluded that Pozzolan S1 can provide a satisfactory substitute for fly ash and other natural pozzolans as tested against ASTM C618-00 [29]. It was clearly found to be effective in controlling ASR. It also produces about 15 percent less heat of hydration than Class F fly ash, whereas Class F fly ash produces about 30 percent less heat of hydration than Portland cement only. The chemical and physical properties of Pozzolan S1 are comparable to fly ash, and the one can be substituted for the other (Al-Chaar et al., 2013).

C. Slag Cement

Ground granulated blast furnace slag (GGBFS) or slag cement is a by-product from the blast furnaces used to make iron. Blast-furnaces are fed with controlled mixture of iron-ore, coke and limestone, and operated at a temperature of about 1,500°C. When iron-ore, coke and limestone melt in the blast furnace, two products are produced—molten iron and molten slag. The molten slag is lighter and floats on the top of the molten iron. Figure 9 illustrates the process of the production of Granulated Iron Blast Furnace Slag (GBFS) and Ground Granulated Blast Furnace Slag (GGBFS). The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone. The process of granulating the slag involves cooling of molten slag through high-pressure water jets. This rapidly quenches the slag and forms granular particles generally not bigger than 5mm. The rapid cooling prevents the formation of larger crystals, and the resulting granular material comprises around 95 percent non-crystalline calcium-aluminosilicates. The granulated slag is further processed by drying and then grinding in a rotating ball mill to a very fine powder, which is GGBFS (Siddique & Khan, 2011).

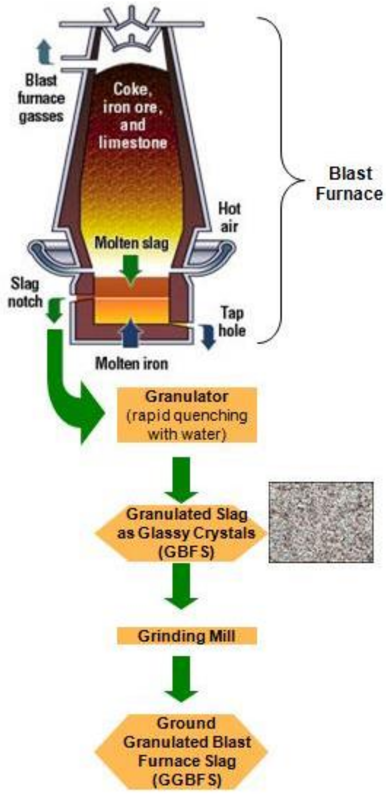

Figure 9. Production of Granulated Iron Blastfurnace Slag (GBFS) and Ground Granulated Blast Furnace Slag (GGBFS).
Source: Ground Granulated Blast Furnace Slag.

In general, GGBFS has the following composition: CaO (30 to 50 percent), SiO_2 (28 to 38 percent, Al_2O_3 (eight to 24 percent), and MgO (one to 18 percent). Increasing CaO ratio also increases the basicity of the slag, which manifests into an increase in compressive strength (Ifran et al., 2018).

Slag Cement, or ground granulated blast-furnace slag (GGBFS) is a recovered byproduct of the iron manufacturing process and can be used to replace a portion of Portland Cement in concrete mix design. Commonly, it is found in ready-mixed concrete, precast concrete, masonry, soil cement and high temperature resistant building products (Slag Cement Association, 2020).

The use of slag cement has demonstrated long-term performance enhancements like higher compressive and flexural strengths, allowing designers to reduce the environmental footprint of concrete while ensuring improved performance and workability (Slag Cement Association, 2020).

In a technical report by Ueki entitled "History and Utilization of Portland Blast Furnace Slag Cement," he analyzed existing structures dating back to 1970 to evaluate the long-term reliability and stability of slag cement. Cements used in the research were manufactured during 1963–1964, each of which had their own slag ratios. These were normal Portland cement, PBFSC Type A (20 percent slag ratio), PBFSC Type B (50 percent slag ratio), low-heat PBFSC (50 percent slag ratio), and PBFSC Type C (65 percent slag ratio).

Several tests were conducted which evaluated the compressive strength of the concrete, with or without admixtures, and its pore size distribution. It was determined that there was a directly proportional relationship between the increase in the ratio of slag cement, the concrete's long-term compressive strength and in the increase in pore size distribution proportion which all point to reliable stability (Ueki, 2015).

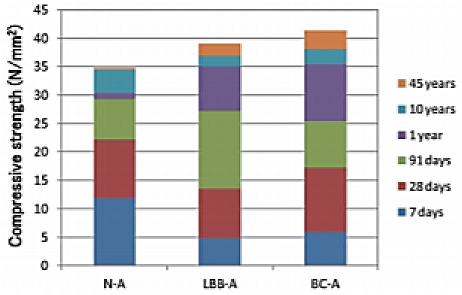

Figure 10. Compressive strength of AE concrete.
Source: History of Utilization of Portland Blast Furnace Slag Cement.

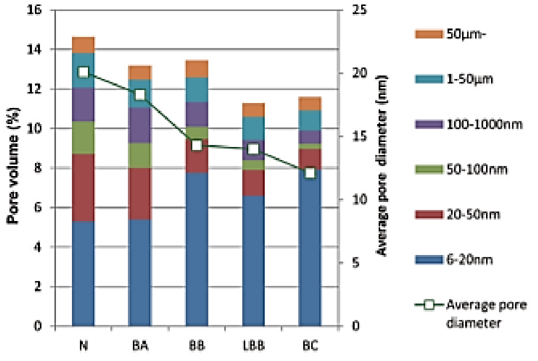

Figure 11. Pore size distribution.
Source: History of Utilization of Portland Blast Furnace Slag Cement.

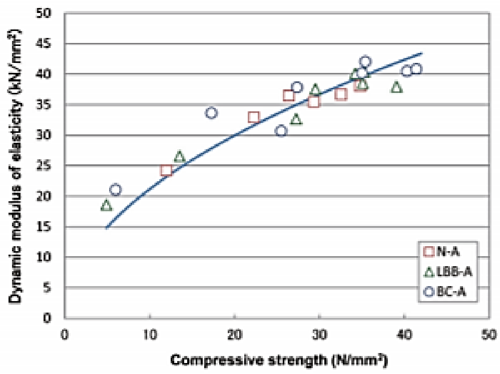

Figure 12. Relationship between dynamic modulus of elasticity and compressive strength.
Source: History of Utilization of Portland Blast Furnace Slag Cement.

Figure 12 shows the relation between compressive strength and dynamic elasticity modulus of AE concrete up to 45 years. With the increase in compressive strength, the dynamic elasticity modulus increased at the same time. It is considered that the dynamic elasticity modulus is not influenced by the presence or absence of slag and can obtain a stable concrete structure over a long period of time (Ueki, 2015).

An expanded study submitted to the University of Wisconsin—Madison Department of Civil and Environmental Engineering by LaBarca, Foley, & Cramer in 2007 entitled "Effects of Ground Granulated Blast Furnace Slag in Portland Cement Concrete" focuses on the use of slag cement as a replacement material for ordinary Portland cement (OPC).

This study aimed to determine variations in performance for grade 120 slag cement concrete using a range of materials common to Wisconsin highway pavement.

The performance of grade 120 slag cement concrete was generally comparable to OPC concrete in most cases. It was found, however, that variations in slag cement replacement level, coarse aggregate type, OPC brand, and mixing and curing conditions play a large role in the performance of hardened concrete (LaBarca et al., 2007).

It was found that the use of grade 120 slag cement did not have a significant effect on the tensile-compressive strength ratios compared to OPC concrete. Additionally, the effects of slag cement replacement on the actual split-tensile strength values were similar to the effects on compressive strength (LaBarca et al., 2007).

A study by Samad et al. in 2017 entitled "Strength development characteristics of concrete produced with blended cement using ground granulated blast furnace slag (GGBS) under various curing conditions" studied on the effect of partial replacement of cement with GGBS or slag cement on the strength development of concrete and cured under summer and winter curing environments. They selected three levels of cement substitution: 30 percent, 40 percent, and 50 percent.

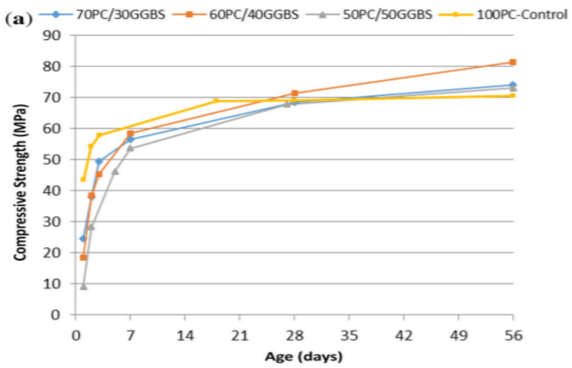

Figure 13. Compressive strength development of GGBS concrete under different curing condition 1.

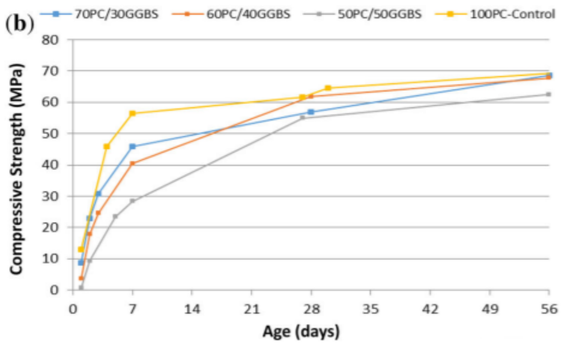

Figure 14. Compressive strength development of GGBS concrete under different curing conditions 2.

The strength development in blended concrete at the early ages decreased with the increase of GGBS content as compared to PC. There was a marked difference in strength gain between the compressive strength on the 3rd and 7th days; however, this difference was negligible at 28 days. This shows that initially the strength gain of GGBS concrete was slow but it enhanced rapidly between seven and 14 days. The specified strength of GGBS concrete at 28 days was more than 100 percent Portland cement mix, which supports its use for structural concrete and other major works (Samad et al., 2017).

It is concluded that the concrete containing 30 percent, 40 percent and 50 percent GGBS gains more strength than the PC concrete after the age of 28 days as seen in Figures 13 and 14 (Samad et al., 2017).

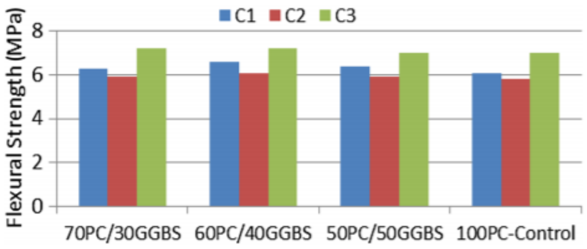

Figure 15. Flexural strength of GGBS concrete at the age of 28 days.
Source: Strength development characteristics of concrete produced with blended cement using ground granulated blast furnace slag (GGBS) under various curing conditions.

The flexural strength of the mixture also followed an increase as per the increase in compressive strength. It can be observed in Figure 15. The flexural strengths of the concrete mixes are designed equal at 28 days (Samad et al., 2017).

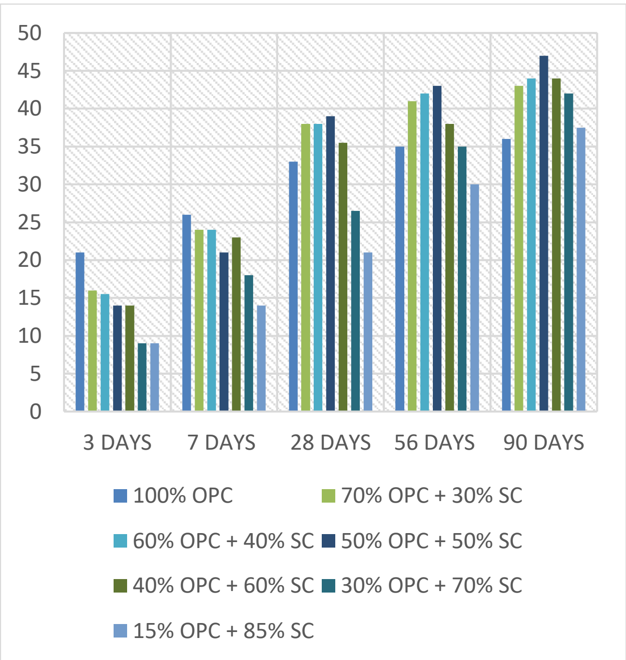

Figure 16. Effect of slag cement to the strength of OPC.

According to the Slag Cement Association in 2006, there is a principal advantage of using Slag cement for improved sustainability. They have developed suggested replacement levels according to its usage in accordance with the Leadership in Energy and Environmental Design (LEED) guidelines and standards. Table 6 shows the suggested Slag cement replacement percentage according to its application.

Generally, substitution at these high percentages can reduce cementitious requirements as Slag cement concrete may require less cementitious material to achieve ultimate strength. Thus, it reduces embodied energy and greenhouse gas emissions in concrete (i.e., the resource inputs and emissions outputs resulting from the manufacturing of concrete and its constituent materials (Slag Cement Association, 2006).

Table 6. Environmental Benefits Comparison of Slag cement and Fly Ash in 3000psi concrete.

Environmental Benefit (Substitution rate for Portland Cement)	Slag Cement (35%)	Slag Cement (50%)	Fly Ash (20%)
Carbon Dioxide Emissions Savings*	30%	43%	17%
Energy Savings	21%	30%	14%
Reduction in Extracted Materials	5%	7%	3%

Source: Slag Cement Association Manual: Slag Cement and the Environment.

Note: Percentages listed for savings in Carbon dioxide, energy and material are based on 100 percent Portland cement systems compared with systems containing Slag cement or Fly Ash substitution.

Table 7. Suggested Slag Cement Replacement Levels.

LEED-NC 2.1 Guide: Using Slag Cement in Sustainable Construction	
Concrete Application	Slag Cement*
Concrete Paving	25-50%
Exterior flatwork not exposed to deicer salts	25-50%
Exterior flatwork exposed to deicer salts with w/cm ≤	25-50%
Interior flatwork	25-50%
Basement floors	25-50%
Footings	30-65%
Walls and columns	25-50%
Tilt-up panels	25-50%
Prestressed concrete	20-50%
Precast concrete	20-50%
Concrete blocks	20-50%
Concrete Pavers	20-50%
High strength concrete	25-50%
Alkali-silica reaction mitigation	25-70%

Sulfate resistance	
• Type II Equivalence	25-50%
• Type V Equivalence	50-65%
Low permeability	25-65%
Mass concrete (heat mitigation)	50-80%

Source: Slag Cement Association Manual: Slag Cement and LEED.

Slag cement has been used in concrete projects in the United States for over a century. Earlier usage of slag cement in Europe demonstrated that long-term performance was enhanced in many ways. Based on these early experiences, modern designers have found that these improved durability characteristics help further reduce life-cycle costs and lower maintenance costs (Slag Cement Association, 2013).

Using slag cement to replace a portion of Portland cement in a concrete mixture is a useful method to make concrete better and more consistent. Among the measurable improvements are:

- Better concrete workability
- Easier finishability
- Higher compressive and flexural strengths
- Lower permeability
- Improved resistance to aggressive chemicals
- More consistent plastic and hardened properties
- Lighter color

III. Methodology

The main objective of the research is to check on the maximum proportion of the Slag cement as partial replacement to OPC in concrete.

The researcher adapted an experimental design as the study would focus on testing different mix proportions of slag cement versus the OPC in concrete. Upon gathering related literature of this study, the researcher devised an approach to determine the materials needed and its specification.

1. Gathering of different test results data relative to the study of slag cement.
2. Field instrumentations, experiments and laboratory testing of different mix proportions used in the design of concrete.
3. Testing of different mix proportions used in the design of concrete following the procedures in accordance with the American Society for Testing Materials (ASTM), and other guidelines of the Department of Public Works and Highways (DPWH).
4. Analysis and synthesis of both the physical and chemical properties gathered and other tested technical data.
5. Simulation and comparison of concrete engineering design parameters via Slag cement combination to ordinary Portland cement.

The results of both the physical and chemical tests that will be derived from the laboratory and instrumentation testing procedures as outlined and other available technical data will be subjected to statistical evaluation, synthesis and analysis. Moreover, concrete engineering design parameters via slag cement combination to ordinary Portland cement will be simulated and analytically compared.

Table 8. Different mix proportions used in the design of concrete.

Materials	PURE Type 1 Cement	70% Type 1 OPC 30% SC	60% Type 1 OPC 40% SC	50% Type 1 OPC 50% SC
Pure Type 1 OPC	300	210	180	150
Slag Cement		90	120	150
G-1 Agg.	595	595	595	595
3/4" Agg.	396	396	396	396
Vibro Sand	843	838	836	835
Water	180	180	180	180
Naptha Admix	3.0	3.0	3.0	3.0

Note: Concrete mix designs may vary depending on the quality of aggregates and admixtures in the area.

Table 9. At constant water-cement ratio, slump of concrete mixture with SC is higher vs. that of pure Type 1 OPC.

Slump	Pure Type I OPC	70% OPC + 30% SC	60% OPC + 40% SC	50% OPC + 50% SC
Slump initial (mm)	135	195	195	190
Slump 60 mins (mm)	65	95	110	110
Density (kg/cm^3)	2322	2337	2324	2337

Note: Concrete using SC has lower water demand as it achieved higher slump and better slump retention vs. pure OPC.

IV. Results and Analysis

Slump Retention Analysis
300 kg Binder Factor
Compressive Strength Design

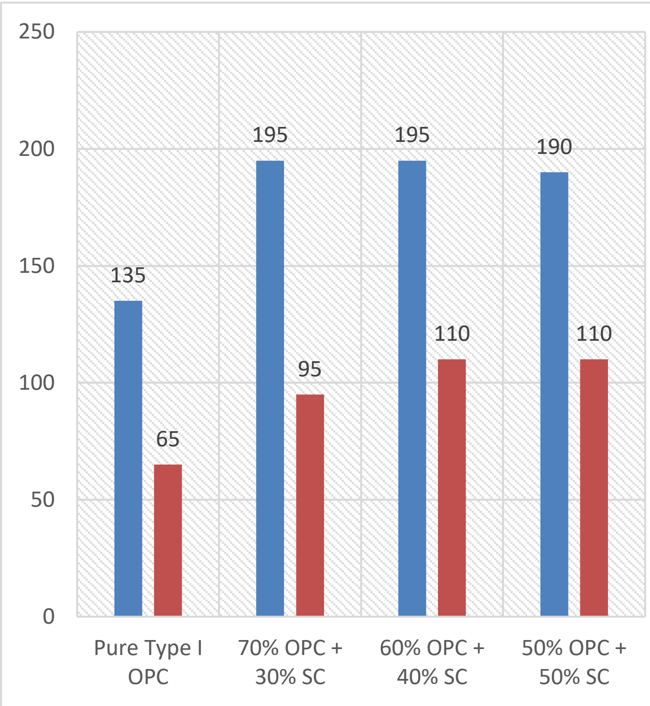

Figure 17. Slump retention analysis for 300 kg binder factor

Table 10. Actual photos of slump of different concrete designs

Table 11. A difference of 1000 psi or equivalent of 1 bag (40 kg) savings per cubic meter (m^3) is realized if you replace your cement requirement by 40–50 percent SC.

Days (psi)	Island Cement	Island Cement with 30% SC	Island Cement with 40% SC	Island Cement with 50% SC
3 days (psi)	3363	2564	2387	2263
7 days (psi)	3877	3558	3150	2999
14 days (psi)	4064	4809	4907	4853
28 days (psi)	4987	5341	5838	5812

OPC Type I vs. OPC Type with different SC replacement
300 kg Binder Factor
Compressive Strength Design

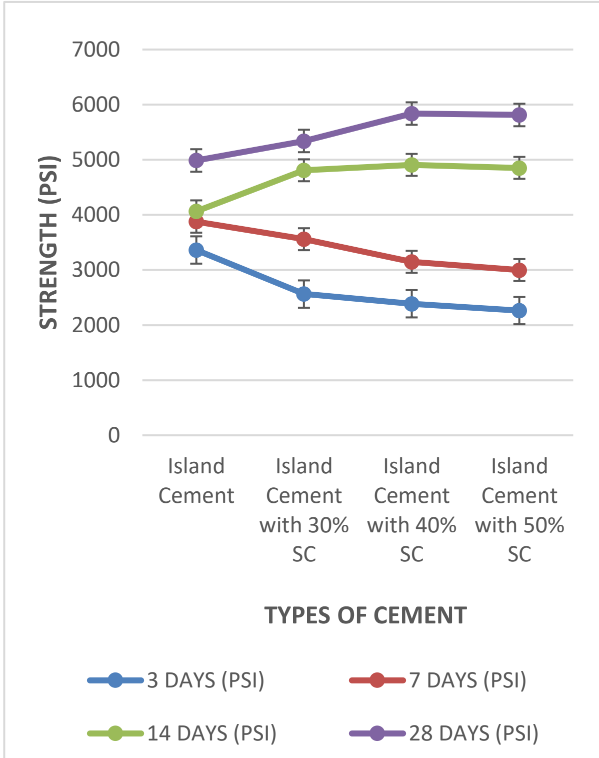

Figure 18. Compressive strength chart for 300 kg binder factor.

Table 12. Different mix proportions used in the design of concrete.

Materials	Pure Type I OPC	70% Type I OPC 30% SC	60% Type I OPC 40% SC	50% Type I OPC 50% SC
Pure Type 1 OPC	400	280	240	200
Slag Cement		120	160	200
G-1 Agg.	595	595	595	595
3/4" Agg.	396	396	396	396
Vibro Sand	733	726	724	722
Water	190	190	190	190
Naptha Admix	4.7	4.7	4.7	4.7

Note: Concrete mix designs may vary depending on the quality of aggregate and admixtures in the area.

Table 13. Higher slump, higher slump retention at constant water-cement ratio is observed in mixture with SC vs. Pure Type I OPC.

Slump/ Density	Pure Type I OPC	70% OPC + 30% SC	60% OPC + 40% SC	50% OPC + 50% SC
Slump initial (mm)	200	210	230	240
Slump 60 mins (mm)	140	150	180	195
Density (kg/cm³)	2379	2385	2377	2371

Slump Retention Analysis
400 kg Binder Factor
Compressive Strength Design

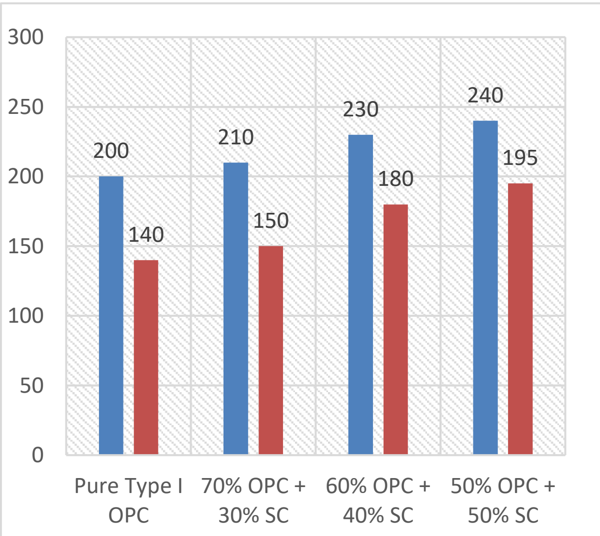

Figure 19. Slump retention analysis for 400 kg binder factor.

Table 14. Actual photos of slump.

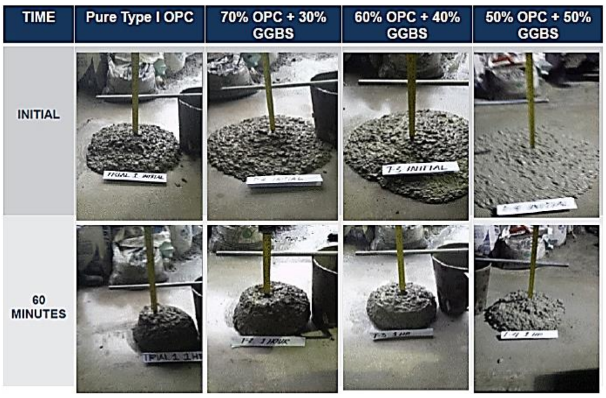

Table 15. Higher compressive strength of mixture with SC – savings of around 1 bag per cubic meter (m³) at a replacement of 40–50 percent.

Days (Strength)	Pure Type 1 OPC	70% OPC + 30% SC	60% OPC + 40% SC	50% OPC + 50% SC
3 days (psi)	5022	4765	4481	3673
7 days (psi)	5492	5812	5767	5794
14 days (psi)	6167	7515	7666	7045
28 days (psi)	7036	8039	8323	8367

OPC Type I vs. OPC Type with different SC replacement
400 kg Binder Factor
Compressive Strength Design

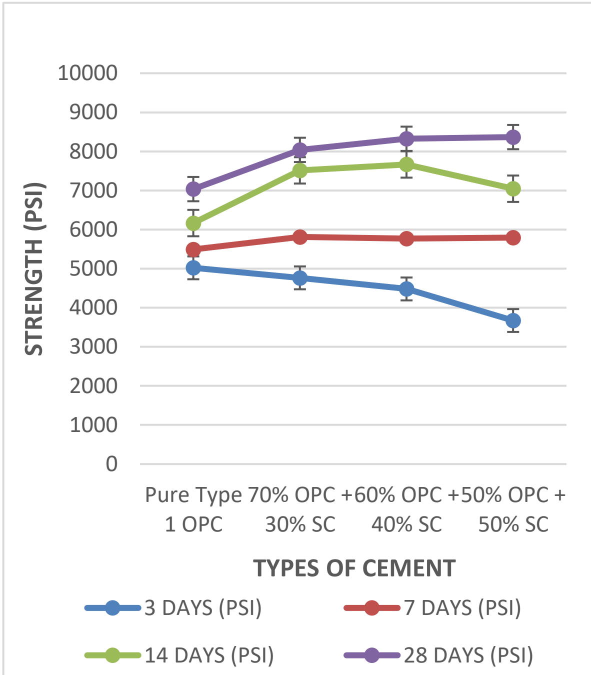

Figure 20. Compressive strength chart for 400 kg binder factor.

Table 16. Concrete mix designs.

Materials	Pure Type I OPC	70% Type I OPC 30% SC	60% Type I OPC 40% SC	50% Type I OPC 50% SC
Pure Type 1 OPC	480	336	288	240
Slag Cement		144	192	240
G-1 Agg.	595	595	595	595
3/4" Agg.	396	396	396	396
Vibro Sand	666	641	638	652
Water	190	190	190	190
Naptha Admix	6.6	6.6	6.6	6.6

Note: Concrete mix designs may vary depending on the quality of aggregates and admixtures in the area.

Table 17. Higher slump, higher slump retention at constant water-cement ratio is observed in mixture with SC vs. Pure OPC.

Slump/ Density	Pure Type I OPC	70% OPC + 30% SC	60% OPC + 40% SC	50% OPC + 50% SC
Slump initial (mm)	240	250	260	270
Slump 60 mins (mm)	220	230	235	240
Density (kg/cm³)	2379	2382	2416	2422

Slump Retention Analysis
480-kg Binder Factor
Compressive Strength Design

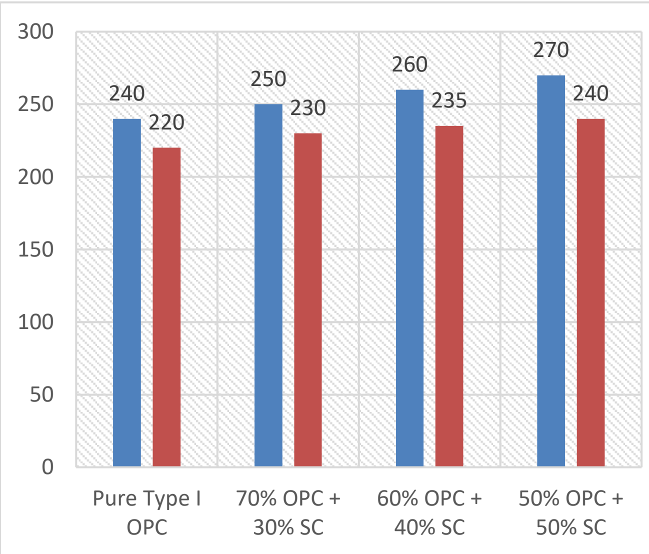

Figure 21. Slump retention analysis for 480 kg binder factor.

Table 18. Higher compressive strength of mixture with SC -- savings of around 1 bag per cubic meter (m³) at a replacement of 40–50 percent.

Days (Strength)	Pure Type 1 OPC	70% OPC + 30% SC	60% OPC + 40% SC	50% OPC + 50% SC
3 days (psi)	5599	6273	6495	6468
7 days (psi)	5876	6548	6832	7249
14 days (psi)	7586	7852	8749	8793
28 days (psi)	8474	8562	9370	9512

SC Type 1 vs. OPC Type 1 with Different PSP Replacement
480-kg Binder Factor
Compressive Strength Design

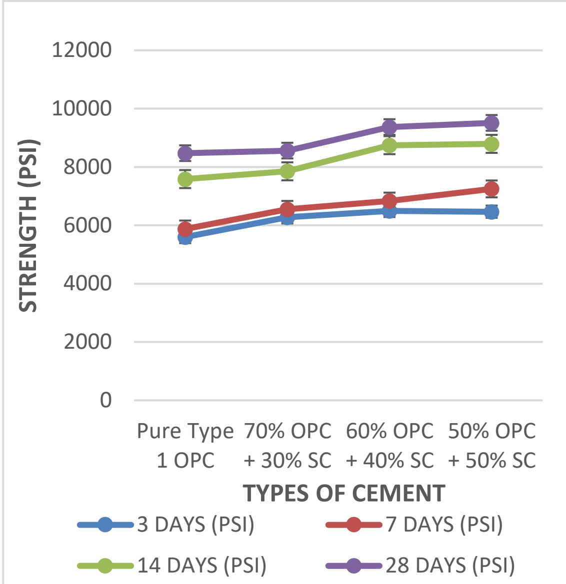

Figure 22. Compressive strength chart for 480 kg binder factor

Table 19. Flexural designs using SC at different replacement

MATERIALS	PURE TYPE 1 OPC	70% TYPE 1 OPC 30% SC	60% TYPE 1 OPC 40% SC	50% TYPE 1 OPC 50% SC
Pure Type 1 OPC	364	255	218	182
Slag Cement		109	146	182
G-1 Agg.	722	722	722	722
3/4" Agg.	152	152	152	152
Vibro Sand	778	772	770	768
Water	175	175	175	175
Naptha Admix	2.9	2.9	2.9	2.9

Note: Concrete mix designs may vary depending on the quality of aggregates & admixtures in the area.

Table 20. Higher slump, higher slump retention at constant water-cement ratio is also observed on mixture with SC vs. pure OPC in flexural designs

Slump	Pure Type 1 OPC	70% OPC + 30% SC	60% OPC + 40% SC	50% OPC + 50% SC
Slump initial (mm)	125	130	140	150
Slump 60 mins (mm)	80	95	105	115

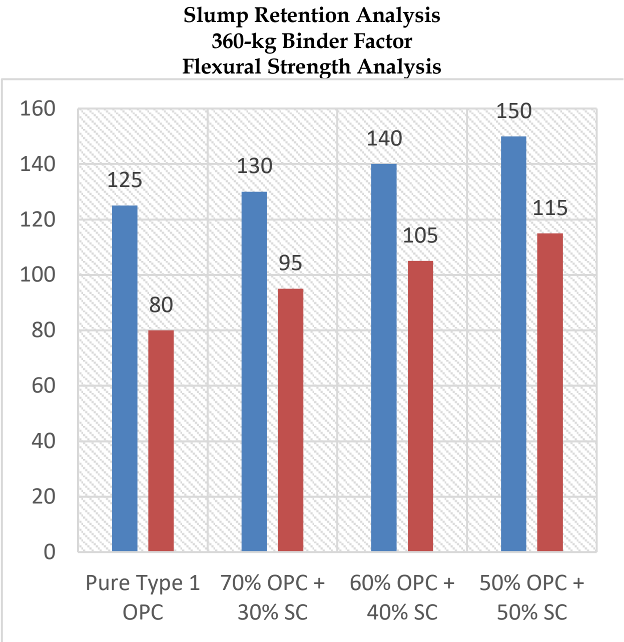

Figure 23. Slump retention analysis for 360 kg binder factor

Table 21. Same early strength observed on mixtures having 30–40 percent SC replacement to the flexural strength of concrete

	Pure Type 1 OPC	70% OPC + 30% SC	60% OPC + 40% SC	50% OPC + 50% SC
3 days (psi)	657	675	657	533
7 days (psi)	763	710	692	710
14 days (psi)	799	834	799	817

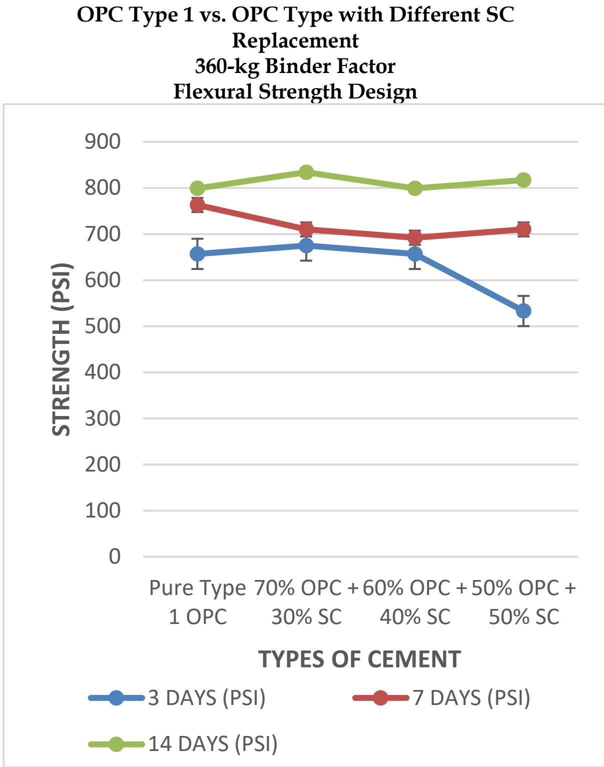

Figure 24. Compressive strength chart for 360 kg binder factor.

Table 8 shows the different mix proportions of Type 1 ordinary Portland cement and slag cement used in this study for the design of concrete for 300 kg. binder factor. Moreover, Tables 9 and 10 and Figure 17 show that the slump of concrete increases with increasing percentage of slag cement for the 300 kg binder factor. In addition, Table 11 and Figure 18 show that for the same binder factor, the compressive strength of concrete also increases as the slag replacement increases. The same trends are also shown for the following binder factors: 400 kg (Tables 12 to 15 and Figures 19 and 20); 480 binder factors (Tables 16 to 18 and Figures 21 and 22); and 360 kg (Tables 19 to 21 and Figures 23 and 24).

All technical data exhibited in the aforementioned table and figures can be utilized in calculating and estimating other engineering parameters that are very useful and material in the course of concrete mix design and other related concrete proportioning of elemental components in structural design.

The results show that the workability of concrete improves in the presence of slag cement.

The research was analyzed comparing the other mixture to that of the properties of Type 1 ordinary Portland cement. Results show that certain percentages of slag cement in the mixture has effects to the concrete's slump retention and compressive strength with regards to the binder factor. Hence, the workability of concrete with the presence of slag cement was observed.

For the slump retention analysis, as seen in Figures 17, 19, 21, and 23, concrete using slag cement has lower water demand as it achieved higher slump and better slump retention than that of the Type 1 ordinary Portland cement.

As for strength of concrete, as seen in Figures 18, 20, 22, and 24, it can also be seen that the strength improves as slag cement replacement approaches 50 percent. There is a difference of almost 1,000 psi or an equivalent of 1 bag per cubic meter (m^3) savings is realized at 50 percent slag cement replacement. The same pattern is observed on both compressive and flexural designs.

V. Conclusion and Recommendations

Based on the analysis of results, an optimum replacement of 50 percent is hereby recommended for compressive strength designs. On the other hand, for flexural designs, an optimum replacement of 30 percent slag cement is hereby recommended as the study shows no significant change observed in the flexural strength versus that of pure Type 1 ordinary Portland cement at early days. However, if 14 days is the basis of acceptance, 50 percent slag cement replacement is recommended. In addition, slag cement has a specific gravity slightly lower than Portland cement; therefore, slight changes also in the design should be implemented. Further noted that the cost benefit of a 50 percent slag replacement shows a savings of ½—one bag cement factor per cubic meter of concrete. However, for those designers, architects, engineers, contractors, and possible customers who are familiar in the design using fly ash, the same approach shall be done also to avoid under yield/over yield of the actual concrete mixture.

Further studies are recommended for the same design mix proportions with other available admixtures in the market focusing on the same factor and designs involving 10,000 psi and powder-type self-compacting designs using different slag cement replacement. It is also recommended to study on the understanding of the effect of slag cement versus a different fly-ash replacement vis-à-vis a combination of slag cement and fly-ash in design mix and to consider a detailed economic study of the cost benefit analysis of the said products and design mix.

VI. Acknowledgments

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VII. References

ACI Committe 318. (2005). *Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (ACI 318R-05).* American Concrete Institute.

ACI Committee 211. (1991). 211.1-91: Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (Reapproved 2002). 38. American Concrete Institute. Retrieved 2018, from https://pdfs.semanticscholar.org

Al-Chaar, G. K., Alkadi, M., & Asteris, P. G. (2013). Natural Pozzolan as a partial substitute for cement in concrete. *The Open Construction and Building Technology Journal*, *7*, 33–42. Retrieved June 2018, from https://www.researchgate.net/publication/270101034_Natural_Pozzolan_as_a_Partial_Substitute_for_Cement_in_Concrete

American Association of State Highway and Transportation Official. (2018). *AASHTO M85: Standard Specification for Portland Cement.* AASHTO.

American Society for Testing and Materials. (2018). *ASTM C150: Standard Specification for Portland Cement.* West Conshohocken: ASTM International.

American Society for Testing and Materials. (2018). *ASTM C33/C33M-18: Standard Specification for Concrete Aggregates.* West Conshohocken: ASTM International.

Association of Structural Engineers of the Philippines, Inc. (2015). *National Structural Code of the Philippines* (7th ed., Vol. 1: Buildings, Towers, and other Vertical Structures).ASEP

Brown, R. W. (2001). *Practical Foundation Engineering Handbook, 2nd edition.* Retrieved June 2018, from Access Engineering Library: https://www.accessengineeringlibrary.com/content/book/9780071351393/chapter/chapter5

Department of Public Works and Highways (DPWH). (2004). *DPWH: Standard Specifications for Public Works & Highways (Volume 2: Standard Specifications for Highways, Bridges and Airports).* DPWH.

Department of Public Works and Highways. (2016). *Department Order No. 133 , Series of 2016 : Amendments to DPWH Standard Specifications for Item 311 - Portland Cement Concrete Pavement.* Manila: DPWH.

Federal Highway Administration. (1995, March). NHI Course No. 13119: Portland Cement Concrete Materials. FHWA.

Federal Highway Administration. (1995). NHI Course No. 13119: Portland Cement Concrete Materials. FHWA. Retrieved 2018, from https://www.fhwa.dot.gov

Ifran, M., Chen, Y., Ali, M., Abrar, M., Qadri, A., & Bhutta, O. (2018). Geotechnical properties of effluent-contaminated cohesive soils and their stabilization using industrial by-products. *Fluid Flow in Fractured Porous Media, 6*(10), 203. https://doi.org/10.3390/pr6100203

Júnior, E. J., Bezerra, H.D., Politi, F. S., & Paiva, A. E. (2014, April 13). Increasing the compressive strength of Portland cement concrete using flat glass powder. (17). Sao Luis, Brazil: Materials Research. Retrieved June 2018, from http://www.scielo.br/pdf/mr/v17s1/aop_matres_218013.pdf

Kamran, N. (2015). Proportioning Concrete Mixes. (U. of. Washington, Ed.) Retrieved June 2018, from https://www.scribd.com/document/404219216/mix-pdf

LaBarca, I. K., Foley, R. D., & Cramer, S. M. (2007). *Effects of ground granulated blast furnace slag in Portland Cement Concrete (PCC) - expanded study.* Wisconsin Highway Research Program. https://minds.wisconsin.edu/handle/1793/53318

Luke S. Lee, P. P., & Hector Estrada, P. P. (2020). *Materials for civil engineering: Properties and applications in infrastructure.* McGrawHill Education. Retrieved May 2020, from Access Engineering Library.

Marques, M. L., Luzardo, F. H., Velasco, F. G., González, L. N., Silva, E. J., & Lima, W. G. (2016, April 4). Compatibility of vegetable fibers with Portland cement and its relationship with the physical properties. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *20*(5), 466-472. Retrieved from http://www.agriambi.com.br

McCormac, J. C. (2001). *Design of reinforced concrete* (5th edition ed.). John Wiley & Sons.

McGraw-Hill Companies, Inc. (2003). Concrete. (10th edition). McGraw-Hill Encyclopedia of Science and Technology.

Rebelo, J. (2014). *Evaluation of test methods for determining the water to cement ratio of fresh and hardened concrete* [Masteral thesis, University of Toronto], Library of Toronto. Retrieved June 2018, https://tspace.library.utoronto.ca/bitstream/1807/65599/1/Rebelo_Jonathan_201406_MASc_thesis.pdf

Samad, S., Shah, A., & Limbachiya, M. (2017). Strength development characteristics of concrete produced with blended cement using ground granulated blast furnace slag (GGBS) under various curing conditions. *Sadhana*, 42(7), 1–11. https://doi.org/10.1007/s12046-017-0667-z

SEAONC Construction Quality Assurance Committee. (2013). *Guidelines for reviewing concrete mix designs.* SE University.

Siddique, R., & Khan, M. I. (2011, March). Ground granulated blast furnace slag. *Waste Materials and By-Products in Concrete*, *163*(2), 121–173.

Slag Cement Association. (2006). *Slag cement and LEED*. Retrieved June 2018, from https://www.slagcement.org/aboutslagcement/is-28.aspx

Slag Cement Association. (2013). *Slag cement*. Retrieved June 2018, from https://www.slagcement.org/aboutslagcement/is-01.aspx

Uddin, M. A., Jameel, M., Sobuz, H. R., Islam, M. S., & Hasan, N. M. (2012, August 19). Experimental study on strength gaining characteristics of concrete using Portland composite cement. *KSCE Journal of Civil Engineering, 17*(4), 1–8.

Uddin, M. A., Jameel, M., Sobuz, H. R., Islam, M. S., & Hasan, N. M. (2012, August 19). Experimental Study on Strength Gaining Characteristics of Concrete using Portland Composite Cement. *17*(4).https://doi.org/10.1007/s12205-013-0236-x

Ueki, Y. (2015). *History and utilization of Portland blast furnace slag cement* (Nippon Steel & Sumitomo Metal Technical Report No. 109). Nippon Steel and Sumitomo. https://www.nipponsteel.com/en/tech/report/nssmc/pdf/109-19.pdf

Wang, C.-K., Salmon, C. G., & Pincheira, J. A. (2010). *Reinforced concrete design* (7th edition ed.). John Wiley & Sons Inc.