Investigation of Adama Industrial Park's Dried Sludge Powder as a Partial Cement Substitute in Concrete Mixes

Namara Temesgen Wakwaya

A Thesis Submitted to the Department of Chemical Engineering

College of Mechanical, Chemical, and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Chemical (Process Engineering)

Office of Graduate Studies

Adama Science and Technology University

May, 2025
Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled” Investigation of Adama Industrial Park’s Dried Sludge Powder as a Partial Cement Substitute in Concrete Mixes” is my own work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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We, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled "Investigation of Adama Industrial Park's Dried Sludge Powder as a Partial Cement Substitute in Concrete Mixes" prepared under my guidance by Namara Temesgen Wakwaya submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Chemical Process Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

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Co-Advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the advisors of the thesis entitled "Investigation of Adama Industrial Park's Dried Sludge Powder as a Partial Cement Substitute in Concrete Mixes" and developed by Namara Temesgen; hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Ashenafi Hailu ____________ ____________
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We, the undersigned, members of the Board of Examiners of the thesis by Namara Temesgen have read and evaluated the thesis entitled "Investigation of Adama Industrial Park's Dried Sludge Powder as a Partial Cement Substitute in Concrete Mixes" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Chemical Process Engineering.

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LIST OF ACRONYMS AND SYMBOLS

ACI	America Concrete Institution
AIP-WWTP	Adama Industrial Park Wastewater Treatment Plant
ASR	Alkali- Silica Reaction
ASTM	American Society for Testing Materials
ASTU	Adama Science and Technology University
C-25	Concrete with 25MPa at 28 days of Compressive Strength
DSP	Dried Sludge Powder
C-S-H	Calcium silica Hydrate
EDX	Energy Dispersive X-ray Spectroscopy
ft^3	Cubic Foot
GGBFS	Ground Granulated Blast Furnace Slag
gm	Gram
h	Hour
kg/m^3	Kilogram per Meter Cube
KN	Kilo Newton
lb/ ft^3	Pounds Per Cubic Foot
m^3	Meter cube
ml	Milliliter
mm/sec	Millimeter per Second
MPa	Mega Pascal
N/mm^2	Newton per millimeter square
OPC	Ordinary Portland Cement
SCMs	Supplementary Cementitious Materials
SEM	Scanning Electron Microscope
SEM	Scanning Electron Microscope
W/C	Water to Cement Ratio
µm	Micrometer
%	Percent
^0C	Degree Celsius

ABSTRACT

The increasing generation of industrial wastewater sludge, such as that from the Adama Industrial Park, presents a significant environmental and economic challenge, while conventional cement production remains a major contributor to global carbon emissions. this study investigate the potential valorizing Dried Sludge Powder(DSP) from the Adama Industrial Parks' wastewater treatment as a partial replacement for Ordinary Portland Cement(OPC) in concrete mixes, aiming to develop sustainable construction materials.The research systematically characterized the physicochemical properties of DSP, including its chemical compositions, heavy metal content, and fineness. Concrete mixes where prepared with DSP substituting OPC at 0%, 5%,10%,and 15% by weight ,followed by comprehensive testing of fresh(workability) and hardened (compressive, flexural strength, water absorption, and sulfate attack) properties at 7 and 28 days of curing. Microstructural analysis using Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray (EDX) spectroscopy was also conducted. Results indicate that increasing DSP content generally enhanced concrete workability. While both compressive and flexural strength decreased with higher DSP percentages, statistical analysis (two-way ANOVA) confirmed these significant impacts. Notably, 5% DSP replacement yielded acceptable compressive strength (31.56 MPa at 28 days), making it suitable for certain nonstructural applications. Durability properties were negatively affected, with statistically, significant increases in water absorption and susceptibility to sulfate attack (one-way ANOVA) driven by increased porosity and limited pozzolanic activity observed micro structurally. This study concludes that DSP from Adama industrial park can be a viable partial replacement at low percentages (5%) for non-structural concrete, offering a sustainable waste utilization solution. Future prospects include investigating DSP pre-treatment and long term environmental investigation to broaden its application.

Keywords: *Cement, Compressive Strength, Concrete, Dried Sludge Powder, Flexural Strength, Industrial Sludge, Waste Management*

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Ethiopia is in the midst of rapid urbanization and industrialization; the latter trend has the potential to contribute to urban environmental health and significant due to its huge energy and resource needs. This grow necessitates significant expansion of construction efforts, and in particular of the construction of infrastructure such as roads which in return lead to a high demand for construction materials particularly concrete(Abreha, Yifru et al. 2023). One of the most common structural materials is concrete. Materials and mainly consisting of cement, fine aggregate, coarse aggregate and water. The amount and properties of cement are major factor to define strength of concrete materials as well as its behavior(Sakale, Jain et al. 2015). Cement is a finely ground materials and gains its properties of binding by hydration, a process highly contributed to its silica content.

This reliance on concrete, and there by on cement, has a massive environmental impacts (Chandrasekaran, Vasanth et al. 2018). The manufacturing process of cement is an energy-intensive process with substantial amount of CO_2emissions that contribute to climate change since its one of the greenhouse gases(Zeybek, Özkılıç et al. 2022). Moreover ,raw material extraction like lime stone and clay for cement production can potentially lead to habitat destruction and biodiversity loss(Mohamad, Muthusamy et al. 2022).

In Ethiopia the industrialization intensive is also observed in establishing parks since 2015 as national policy tool to enhance sustainable industrial growth (Guteta and Worku 2024). Besides economic benefits, the industrial park generates a noteworthy waste streams. Of particular note are e the volume of sludge produced from waste water treatment plants within such parks, such as the Adama industrial park, which is processes effluent from a large range of industries. The sludge will likely be harmful since it has the potential for being contaminated with heavy metals, chemicals ,and dyes, especially from textile operations(Kasaw, Adane et al. 2021). Current disposal methods in Ethiopia ,like landfill and incinerations are environmentally unsustainable and stress the weak waste management infrastructure(Kasaw, Adane et al. 2021).

Given the environmental concerns associated with both cement production and disposal of industrial waste, the quest for alternative and sustainable solutions becomes essential. Throughout the globe, there is increasing interest in the utilization of supplementary cementitious materials (SCMs) as a way of partial replacement of cement in concrete mixtures with the objectives of reducing the environmental footprint of the construction sector(Abdelli, Mokrani et al. 2020, Martina, Kinanti et al. 2022). This technique not only minimizes the amount of cement required but can also provide a beneficial use for various waste materials.

International research confirmed that some industrial sludge, if treated suitably, holds potentials to exhibit cementious or pozzolanic properties and hence be suitable to utilize as SCMs in concrete(de Godoy, Rohden et al. 2020, Kasaw, Adane et al. 2021). Successful utilization of such waste materials can contribute towards a stronger circular economy by valorizing waste streams and reducing dependence on virgin materials supply.

Given the specific context in Ethiopia's industrialization and the issue that accompanies the handling of the sludge from industrial parks like the Adama industrial park, analyzing this locally produced dried as a substitute for part of the cement used in the concrete mixes is of great potential. This research is poised to solve environmental concerns in the cement production and industrial waste disposal in the context of Ethiopia. By assessing the prospects of Adama industrial park's sludge as an SCM, this study attempts to contribute to the development of greener building techniques and offer a framework for utilizing an industrial by product in a productive way.

1.2 Statement of the Problem

Rapid urbanization and industrialization in Ethiopia created economic advantages together with environmental issues. In response, the Ethiopian government launched industrial parks in 2015 as a strategic tool to promote sustainable industrialization (Guteta and Worku 2024). Among the key issues, researchers identified sludge generation from wastewater treatment plants within industrial parks such as Adama as a growing concern. The Adama Industrial Park collected effluents from around 19 factories, resulting in a mixed sludge often classified as hazardous due to its content of heavy metals, chemicals, and dyes, particularly from textile industries (Kasaw, Adane et al. 2021). Studies noted that disposal practices in Ethiopia, such as landfilling and incineration, remained environmentally and economically unsustainable, leading to secondary pollution and burdening waste management systems(Kasaw, Adane et al. 2021).

In parallel, the cement industry emerged as a major source of CO_2 emissions globally, accounting for nearly 7% of total emissions (Andrew, 2019). In Ethiopia, cement production has grown rapidly, driven by national infrastructure development. On average, Ethiopia produces approximately 15.1 million tons of cement per year. This significant production volume contributes substantially to environmental burden, as the manufacturing process is highly energy-intensive, requiring about 3.4GJ to produce one ton of cement. Consequently, cement production is a major emitter of greenhouse gases, generating an average of 0.6 to 0.79 tons of CO_2 per ton of cement produced. For instance, in 2019 alone, Ethiopian cement production emitted about 0.16381 metric tons of CO_2, primarily due to fossil fuel use and limestone calcination (Gebrekidan, Gebremedhin et al. 2024). This trend raised serious environmental concerns, especially for a developing country like Ethiopia, where demand for construction materials increased but climate resilience remained limited. Other studies pointed out that various industrial wastes including glass and sludge contributed significantly to land and air pollution. The absence of circular economy practices further worsened the environmental impact (Qin, Hu et al. 2021, Guteta and Worku 2023). Researchers emphasized the urgent need to reduce cement-related emissions and explore sustainable uses for waste materials like industrial sludge. International findings demonstrated that incinerated sludge, especially from textile industries could serve as a supplementary cementitious material (SCM). Researchers reported that up to 20% cement replacement using sludge ash achieved acceptable compressive strength and complied with heavy metal leaching standards (Kasaw, Adane et al. 2021).

Despite these promising results, existing research had not evaluated the potential of dried sludge from Ethiopia’s industrial parks, particularly Adama, as a cement substitute. Without localized data on its chemical, physical, and mechanical properties, Ethiopia risked losing valuable opportunities to reduce hazardous waste, cut cement-related CO_2 emissions, and promote sustainable construction. This study addressed that gap by investigating the suitability of dried sludge from Adama Industrial Park as a partial cement replacement in concrete, aiming to support waste valorization and environmentally responsible construction practices.

1.3 Objective of the Study

1.3.1 General Objective

- To investigate Adama Industrial Park's dried sludge powder utilization as a partial replacement of cement in a concrete mix for green construction and performance evaluation.

1.3.2 Specific Objectives

- To investigate the physicochemical properties of dried sludge powder and prepare concrete mix of varying proportion dried sludge powder with cement.
- To study the mechanical performances of the sludge-blended concrete mixes and evaluate its durability-related properties.
- To investigate the effect of different percentages of dried sludge powder on micro structure properties of concrete.

1.4 Scope of the Study

The scope of this thesis was to identify the effect of replacing cement with industrial sludge, specifically dried sludge from the Adama Industrial Park wastewater treatment plant (AIP-WWTP) in concrete composites. It was limited to produce concrete with strength of C-25 and to a constant water cement ratio of 0.5 and with constant amount fine and coarse aggregate for each sample. The study focused on four levels of dried sludge content: 0%, 5%, 10%, and 15% as partial replacements for cement, in order to determine the optimal substitution percentage. It involved conducting laboratory tests to analyze the workability, mechanical properties (compressive and flexural strength), and durability characteristics (water absorption and sulfate attack) of the concrete samples, both at early and hardened stages. The characterization of the dried sludge material was performed to determine its chemical composition and composition percentage of components. Mix designs of concrete were optimized through partial replacement of cement with quantities of dried sludge specified, for which three samples were prepared per test. Then the experimental studies were conducted on the microstructure of the samples of concrete, considering different amounts of dried sludge, to determine the morphological structure of the samples.

1.5 Significance of the Study

This study explores the application of dried sludge as partial replacement for cement in concrete manufacturing, offering environmental and cost benefits. It contribute to sustainable waste management by reducing sludge disposal that poses potential pollution risks helping to reduce cement consumption, hereby decreasing CO_2 emissions due to cement manufacturing. In addition it proposes the cost saving characteristic for building construction as dried sludge is less expensive to produce compared to cement. By conducting a study of the chemical, mechanical and durability properties of concrete with various percentage of dried sludge, study provides scientific implication for its actual application. Ultimately, this research will serve as an orientation for subsequent academic and applied research in green building materials.

1.6 Limitation of the Study

One of the major constraints encountered in this research was difficulty of obtaining an evenly sized particle of the dried sludge. This was primarily due to the malfunction of the milling ball machine, which was out of service during the research period due to electrical issues. Additionally, the physical and chemical properties of the sludge varied over time, influenced by the operational activities of the industries within Adama Industrial Park. Since wastewater from multiple industrial shades is treated collectively, the composition of the sludge depends on the number and type of industries operating at any given time. For instance, when all industries are actively producing, the sludge characteristics differ significantly from periods of partial or no industrial activity.

Furthermore, there was a lack of specific literature and research focused on the reuse or management of sludge generated by the Adama Industrial Park wastewater treatment plant. This posed a challenge in finding relevant references and comparative studies to support and contextualize the findings of this research.

CHAPTER TWO

LITERACTURE REVIEW

2.1 Introduction

This chapter presents the findings from different reviewed literature on the partial replacement of dried sludge powder into the concrete mixture. Topics addressed include alternative materials for cements , usage of dried sludge powder as a cement replacement their chemical composition (oxides), effects of dried sludge powder and on fresh and hard concrete properties, and the conclusions drawn by the different author related to the topic are over-viewed and its feasibility for use as a replacement for cement. Hence, the literature review tried to highlight these issues with quality requirements with the main focus being on workability, compressive strength and durability of both dried sludge powder in concrete. There is a great motivation worldwide towards using industrial waste by-products. Leaving the waste material to the environment directly can cause environmental problems. Therefore, many countries have still been working on how to use the waste material that gives fewer hazards to the environment. Waste material was found to have either reactive or filler effect in cement and concrete production. Reactive materials are named pozzolanic and have been used widely worldwide where available.

2.2 Concrete in construction Industries

Concrete remains a cornerstone of the construction industry, distinguished for its strength, durability, and versatility across various applications. Its composite nature comprising water, aggregates, and cement provides the foundational material for a vast collection of construction activities, from residential buildings to large-scale infrastructure projects such as bridges and highways(Almusaed, Yitmen et al. 2024). Recent research highlights the successful integration of concrete constituent with waste materials. The findings demonstrated that these recycled materials do not only meet the structural performance requirements, but also significantly reduce the volume of waste sent to landfills, thereby promoting a circular economy within the construction sector. This transition to greener concrete solutions aligns with global efforts to minimize the ecological impacts of construction activities and represents a critical shift toward more responsible building practices. Modern concrete technology is increasingly focused on resilience to climate change and extreme weather conditions, making it essential for future-proofing urban infrastructure.(Shirvani Dastgerdi 2023) examined the incorporation of advanced materials which enhance the durability and longevity of structures against environmental stresses. The thesis posited that these innovations could play a pivotal role in minimizing maintenance costs and improving the overall lifetime of concrete structures. The incorporation of supplementary Cementitious materials, enhance the mechanical properties and reduce the environmental footprint of concrete by lowering carbon dioxide emissions during its production(Leza 2020). This evolution reflects the industry's commitment to both performance and sustainability emphasizing that modern concrete can meet the demands of contemporary construction while addressing climate concerns. The push towards sustainability has driven extensive research on eco-friendly concrete alternatives, leading to innovative approaches in the use of recycled materials and local resources. By prioritizing resilience and sustainability, the construction industry can ensure that concrete remains not only a fundamental material but also a cornerstone of sustainable building practices in an era increasingly defined by environmental challenges.

2.3 Cement Production and its Environmental Impact

The production of Portland cement, a critical component of concrete, involves a multi-stage process that begins with the extraction and processing of raw materials such as limestone and clay (Hewlett and Liska 2019). These materials undergo crushing and grinding to achieve a fine powder, which is then fed into a rotary kiln and heated to extremely high temperatures, approximately 1450°C, to facilitate the formation of clinker (Taylor 1997). Following the cooling of the clinker, it is ground again with a small addition of gypsum to yield the final cement powder. Each of these energy-intensive steps contributes to the significant environmental footprint associated with cement manufacturing.

One of the most pressing environmental concerns related to cement production is its substantial contribution to global carbon dioxide emissions. The cement industry is estimated to account for 5-8% of all anthropogenic CO_2 emissions(Andrew 2018). These emissions arise from two primary sources within the production process: the chemical decomposition of calcium carbonate (limestone) during the clinkering stage, which inherently releases CO_2, and the combustion of fossil fuels necessary to achieve the high temperatures required for the kiln operation (Van Oss and Padovani 2003). For instance, the production of one ton of Ordinary Portland Cement (OPC) is known to generate approximately 0.8-1.0 tons of CO_2, primarily from the calcination of limestone and the combustion of fossil fuels. With the ever-increasing global demand for concrete as a fundamental construction material, addressing and mitigating these emissions is paramount for achieving sustainable development goals. The specific context of carbon emissions from the cement industry within Ethiopia, as explored by (Kedir 2023), will provide valuable insight into the regional impact of this issue.

Beyond carbon emissions, cement production is highly energy-intensive, with an average of 3-6 GJ/ton required to produce one ton of cement. Significant amounts of energy are consumed in various stages, including the crushing and grinding of raw materials, the operation of the high-temperature kilns, and the final grinding of the clinker(Worrell 2008). This substantial energy demand often relies heavily on the combustion of fossil fuels, which not only contributes to greenhouse gas emissions but also raises concerns about resource depletion and energy security. Therefore, efforts aimed at enhancing energy efficiency within cement plants and transitioning towards the use of alternative, more sustainable energy sources are crucial for reducing the environmental burden associated with cement production.

In response to the significant environmental impact of cement production, various regulatory frameworks and sustainability initiatives are being implemented at both global and national levels(Gartner 2004).These may include carbon pricing mechanisms, stricter emission standards for cement plants, and the provision of incentives to encourage the adoption of cleaner technologies and the use of alternative, lower-carbon materials. The broader concept of sustainable construction, as discussed by (Leza 2020), underscores the importance of making environmentally conscious choices regarding building materials and construction practices throughout the entire lifecycle of a structure, from material sourcing to demolition.

2.4 Supplementary Cementitious Material for Cement

In its most basic form concrete is a mixture of Portland cement, sand, coarse aggregate and water. The principal cementitious material in concrete is Portland cement. Today, most concrete mixture contains supplementary cementitious material that makes up a portion of the cementitious component in concrete. These materials are generally by product from other processes or natural materials. They may be or may not be further processed for use in concrete(Biyani, Patil et al. 2020). Some of these materials as called pozzolanic, which by themselves do not have any cementitious properties, when used with Portland cement, react to form cementitious compounds. For use in concrete, supplementary Cementitious materials, need to meet requirements of establish standards. They may be used individually or in combination in concrete. They may be added to the concrete mixture as blended cement or as separately batched ingredient at the ready mixed concrete plant. Now a day ASTM recommend some of cementitious material can use in concrete production such as Coal Fly Ash should conform to standard specification of ASTM C618, Ground Granulated Blast Granulated Blast-Furnace Slag - ASTM C989 and Silica Fume must conform standard specification of ASTM C1240. Supplementary Cementitious Materials are summarized on Figure 2.1 below.

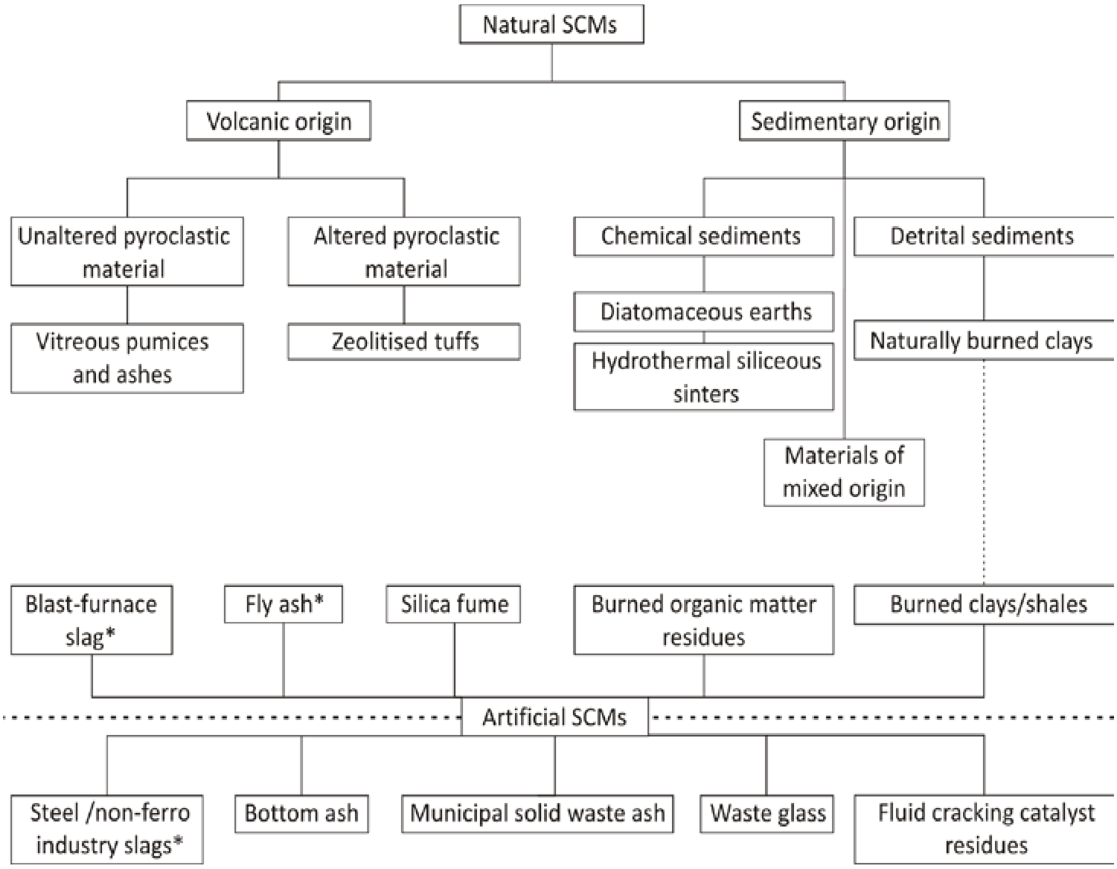


FIGURE 2. 1 Supplementary Cementitious Materials (Snellings, Mertens et al. 2012).

Pozzolanic materials are a siliceous or alumino-siliceous material that chemically reacts with calcium hydroxide released during the hydration of Portland cement to form calcium silicate hydrate and other cementitious compounds. Pozzolanic materials and slags are generally characterized as supplementary Cementitious materials or mineral admixtures(Abreha, Yifru et al. 2023). Supplementary Cementitious Materials of fly ash (F), natural pozzolan (N) and other materials (O) summarized in Table 2.1

Table 2. 1 Supplementary Cementitious Materials (Testing, Concrete et al. 2008)

Constituents	*N*	*F*	*O*
Silicon dioxide (Sio_2) + aluminum oxide (Al_2O_3) + iron oxide (Fe_2O_3), min, %	70	70	50
Sulfur trioxide (Sio_3), max, %	4.0	4.0	5.0
Moisture content, max, %	3.0	3.0	3.0
Loss on ignition, max, %	10.0	6.0	6.0

2.5 Industrial Waste as Supplementary Cementitious Materials

After more than traditional SCMs, the application of varied industrial by-products as partial substitutions for cement constitutes a significant step toward greener building practice (Ramirez, Possan et al. 2017). This adheres to the principle of circular economy in that it strives to create beneficial uses for materials that otherwise would have remained as residues. The range of industrial wastes treated as SCMs is broad, including different types of slag from metal industrial processes, different types of incineration ashes, and many industrial sludge' that are the focal targets of this research.

Industrial waste as SCMs presents opportunities as well as challenges. On one hand, it has the potential to bring about a radical reduction in the environmental impact associated with the production of cement, lower the cost of production of concrete by manufacturing it employing less costly materials, and prevent substantial amounts of waste from going to landfills(Siddique 2007). Moreover, certain industrial wastes can also contribute to optimizing the properties of performance of concrete, i.e., durability, high strength, and workability. Nevertheless, on the one hand, inherent variability in chemical and physical composition of different industrial wastes is a significant problem, necessitating rigorous characterization and quality control measures (Rashad 2015). Also, the potential contamination of certain industrial wastes with hazardous materials must be carefully evaluated and regulated under environmental regulations to prevent leaching and long-term risks. There is also no standardization of most non-conventional industrial wastes, which acts as a limitation in their mass application.

Despite the above, a number of case studies have shown the successful application of a number of industrial by-products as SCMs. Ground granulated blast furnace slag (GGBFS) is an SCM which has been long proved to be able to enhance the long-term strength and durability of concrete, particularly sulfate attack and chloride ingress resistance (Riyahi, Jebter et al. 2019). Similarly, fly ash has found widespread use due to its beneficial effect on workability and long-term strength gain. Recent research, such as the work of (Kasaw, Adane et al. 2021) on textile sludge ash and (Rodríguez, Ramírez et al. 2010) and (de Godoy, Rohden et al. 2020) on water treatment sludge, indicates the promise of diverse sludge as good partial cement replacements, hence the necessity to investigate the specific properties of the sludge generated in Adama Industrial Park.

2.6 Chemical Properties and Management of Industrial Sludge

2.6.1 Chemical Properties of Industrial Sludge

Industrial sludge, the focused waste stream studied in this thesis, is an industrial by-product which occurs due to wastewater treatment processes of various industrial operations (Kumar, Yadav et al. 2024). It should be noted that the designation "industrial sludge" is used here to describe a wide variety of materials with quite disparate compositions, depending on the specific industry (e.g., textile, food processing, chemical), the specific manufacturing processes employed, and the wastewater treatment processes utilized (e.g., physical settling, chemical coagulation, biological treatment). Thus, industrial sludge potentially contains a complex composition of water, organic matter, inorganic solids, nutrients, and potentially harmful materials such as heavy metals and toxic chemicals. The conventional methods for industrial sludge disposal, i.e., landfill and incineration, carry significant environment liabilities(Tyagi and Lo 2013). Landfilling involves enormous land use and leachate and greenhouse gas production due to biodegradation of organic matter. While incineration reduces waste volume, it also has the potential of releasing air pollutants and it produces ash, which must be disposed of. As more industrial sludge is generated across the globe, there is an increasing need for the development of greener and more sustainable practices of managing it, such as resource recovery and utilization in building material production.

Table 2. 2: Sludge's chemical composition from different papers.

Authors	*(Yagüe, Valls et al. 2005)*	*(Lin, Wu et al. 2006)*	*(Chatveera and Lertwattanaruk 2009)*	*(Chen, Ma et al. 2010)*	*(Rodríguez, Ramírez et al. 2010)*	*(Tartari, Díaz-Mora et al. 2011)*	*(Ramirez 2015)*
Country	Spain	Taiwan	Thailand	China	Spain	Brazil	Brazil
SiO_2	29.70	53.60	25.05	52.10	29.60	24.10	27.25
Al_2O_3	12.90	20.90	7.39	19.90	17.57	31.60	24.15
Fe_2O_3	10.10	6.60	3.99	6.29	5.18	18.60	17.50
CaO	22.7	0.30	31.33	1.68	11.8	–	0.20
MgO	2.73	1.90	1.59	1.38	2.15	–	0.20
K_2O	1.83	2.90	0.85	2.90	2.85	0.30	0.10
Na_2O	0.23	0.97	0.00	0.97	6.09	–	0.10
LOI	–	–	21.07	–	22.00	20.40	27.0

Note: LOI: loss on ignition.

As it is seen from Table 2.2 that the sludge's chemical composition is varied depending on the type and quality of waste water sources where it is generated.

2.6.2 Industrial Sludge's Management system

To view industrial sludge not only as waste but also as a source of valuable resources is among the very essential rules of waste management that is sustainable (Werther and Ogada 1999). Various pathways for the recovery of the resource are under scrutiny, some of which include agricultural applications (as fertilizers), energy production (either through the production of biogas or by direct combustion), and usage as a raw material during building material production such as bricks, ceramics(Teixeira, Santos et al. 2011), and as an additive to cement in concrete (de Godoy, Rohden et al. 2020). The success in employing water treatment sludge as an SCM demonstrates the potential to derive value from this industrial waste.

To properly determine the potential for dried industrial sludge powder as an SCM in concrete, its microstructure properties should be known(Lothenbach, Scrivener et al. 2011). Properties like the particle size distribution, specific surface area, and particle shape can control the sludge's reactivity and how it will interact with the cementitious matrix. Further, microscopic analysis of chemical and mineralogical content, often through techniques like Scanning Electron Microscopy (SEM) and X-ray Diffraction (XRD), can be of crucial significance to identify the likely pozzolanic action of the sludge and its likely contribution towards the strength and durability of concrete. Therefore, the microstructure characterization of the Adama Industrial Park dried sludge is a necessary step towards assessing its viability as a cement substitute.

2.7 Industrial Park in Adama and Its Waste Generation

For the purpose of supplying relative content for this research its curial utilizes the wastewater treatment plant (WWTP) situated in Adama industrial park, Oromia, Ethiopia, where the sludge under investigation is being generated. Overview of industrial sectors being operated in the park was given through the research studies of (Jote and Worku 2024) and (Guteta and Worku 2024). Recognizing the dominant industrial sectors being operated there such as Antenx Textile PLC and Charter Ventures Apparel Ethiopia PLC, very crucial to determine the chemical and physical properties of sludge generated. The potential to uses sludge as cement lies with different industrial processes that may impact with different chemical and physical properties. To assess the probable impact of utilizing Adama industrial park sludge, knowing types and quantities already generated is crucial (Guteta and Worku 2024, Jote and Worku 2024). Quantity of sludge generated changes on a daily basis depending on the wastewater generated on a daily basis by different processes of the company and amount they release produced waste water to WWTP. But approximately 1000kg sludge is generated on a daily basis from primary treatment type on average. Lastly, in Adama industrial park, there is absolutely no sustainable waste management at all, especially now with the way they are trying to handle the generated sludge.

FIGURE 2. 2 Current Adama Industrial Park's Sludge Generation and Management System

2.8 Investigation on the Usage of Sludge in Concrete

Increasing numbers of research studies are carried out on the investigation of the feasibility of using various types of sludge as a partial replacement for Portland cement in the manufacture of concrete. The study attempts to identify the environmental benefits of minimizing waste while evaluating the impact on the performance characteristics of the resulting concrete. These are some of them, such as (Kasaw, Adane et al. 2021), which researched the use of textile sludge ash, and those by (Rodríguez, Ramírez et al. 2010), (Chen, Ma et al. 2010), and (Sales and de Souza 2009), which researched using water treatment sludge. These researches typically involve the manufacture of concrete mixes with the treated sludge replacing different percentages of cement and the subsequent testing of fresh properties (e.g., workability) and hardened properties (e.g., strength and durability) of the concrete.

A major mechanical property to be investigated among those examined in these tests is compressive strength (Tay and Show 1995, Rodríguez, Ramírez et al. 2010). Results are often varying depending on the type of sludge, method of treatment employed, and the percentage of cement replacement. Others show the compressive strength to decrease with increasing sludge, which suggests that the sludge might be inert filler following a certain percentage of replacement. However, certain research indicates that certain pozzolanic sludge types can add strength at later ages, specifically at maximum substitution levels. Similarly, flexural strength, which measures resistance to bending in concrete, is another of the more important mechanical properties that has been tested in terms of sludge addition (Chang, Long et al. 2020). The trends experienced in the flexural strength also generally follow those of compressive strength, with individual sludge properties being significant to the over-all performance.

Apart from mechanical properties, the durability of sludge concrete is another major aspect of research(Yagüe, Valls et al. 2005). Examples include measuring the resistance of the concrete to various degradation mechanisms, like water absorption, permeability, and chemical attacks, such as sulfate attack. The availability of specific compounds in the sludge will enhance or degrade the durability of the concrete exposed to aggressive environmental conditions. Therefore, thorough examination of the properties associated with durability is necessary for evaluating long-term performance of sludge-modified concrete.

One of the extreme durability problems of concrete when one works with new materials is sulfate attack(Mehta and Monteiro 2008). These occur through two major processes: expansive ettringite formation from the reaction between sulfate ions and calcium aluminate hydrated (Atkinson, Hearne et al. 1990), and concrete weakening through gypsum formation from the reaction of sulfate ions with calcium hydroxide (Abba, Ma'aruf et al. 2017). The availability of sulfate ions in the environment (e.g., soil, groundwater) can generate cracking, spalling, and loss of strength of concrete structures and hence sulfate resistance becomes a critical property to be tested (Neville 2011).

Employment of sludge in concrete also poses certain challenges and issues that need to be dealt with most meticulously. The natural heterogeneity of chemical composition of industrial sludge calls for characterization in full and potential pre-treatment processes for concrete in order to act uniformly and in a predictable manner. Besides, the potential availability of heavy metals or other contaminants in the sludge calls for strict evaluation as well as conformity to environmental regulations in order to prevent any damage. Provision for long-term sustainability of the sludge-containing concrete and analysis of potentialities of leaching of harmful components are also vital elements of providing for its safe and sustainable application.

2.9 Review of the Literature and Research Gaps Summary

The reviewed literature indicates traditional cement production's significant environmental impact and to promote sustainability the growing of interests on in using supplementary cementitious materials, including industrial wastes as well. Studies on different types sludge have shown that their use as partial cement replacements, however specific characteristics of sludge affect the concretes properties. Although study exists on using industrial wastes in concrete, specific investigation is needed to check out the potential use of dried sludge from Adama industrial park as SCM. The knowing of this specific sludge's physical, chemical and as well as its influence on workability, durability and mechanical strength is crucial. This research was aimed to address these gaps by giving an assessment of Adama industrial park's sludge as partial cement substitute, contributing more sustainable environment and construction practices in local contexts of Adama, Ethiopia.

The Summary of Researches on the Use of Sludge in Construction Materials is place in Table 2.3.

Table 2. 3: The Summary of Researches on the Use of Sludge in Construction Materials.

Sludge used	**Used levels (%)**	**Main results**	**Writers**
Concrete	0, 2.5, 5, 7.5, 10, 12.5, 15, 17.5	Satisfactory for concrete with additions	(Chatveera and Lertwattanaruk 2009)
Eco-cement	0 to 10%	Satisfactory for levels from 4 to 7%	(Chen, Ma et al. 2010)
Bricks	0, 25 and 50%	Satisfactory	(Hegazy, Fouad et al. 2012)
Concrete	3, 5, 7 and 10%	Satisfactory up to 7%	(Hoppen, Portella et al. 2006)
Light aggregate	0.5 to 15%	Meet minimum standard required	(Huang and Wang 2013)
Bricks	70 to 95%	Satisfactory for high sintering	(Lin, Wu et al. 2006)
Ceramic	0; 1; 2.5; 5; 7.5; 10; 15%	Satisfactory up to 5%	(Martínez-García, Eliche-Quesada et al. 2012)
Ceramic	0, 5, 10 and 15%	Satisfactory up to 15%	(Oliveira and Holanda 2008)
Bricks	5 and 10%	Satisfactory	(Porras, Isaac et al. 2005)
Artistic ceramic	12 and 15%	Feasible after drying and grinding	(Pozzobon, Maran et al. 2010)
Cement and mortar	0, 10, 20, 25 and 30%	Unsatisfactory	(Rodríguez, Ramírez et al. 2010)
LWC, mortar	1 to 5%	Satisfactory	(Sales and de Souza 2009)
Ceramic	4, 8, 12 and 16%	Satisfactory up to 8%	(Tartari, Díaz-Mora et al. 2011)
Ceramic bricks	0, 10, 15 and 20%	Satisfactory	(Teixeira, Santos et al. 2011)
Mortar	10, 25 and 50%	Satisfactory for conventional compressive strength	(Ucker, Barroso et al. 2010)
Concrete	0, 2.5, 5 and 10%	Inappropriate for structural concrete	(Yagüe, Valls et al. 2005)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This experimental study, conducted at Adama Science and Technology University, investigated the mechanical (workability, compressive, and flexural strength) and durability (water absorption, sulfate resistance, and micro-structure) properties of C-25 concrete where cement was partially replaced (up to 15%) with dried sludge powder from the Adama Industrial Park's Wastewater Treatment Plant. The research, an experimental type, utilized primary data from tests and secondary data from literature, aiming to determine the optimal replacement percentage without compromising concrete performance. Material properties, including chemical analysis of the sludge powder, were characterized, and concrete mixes (including a control) were prepared with constant aggregate, sand, and water, varying only the dried sludge powder content. A total of 48 concrete cubes were cast for compressive strength, water absorption, and sulfate resistance tests (following ASTM C-39 and C-172), alongside 24 concrete beams for flexural strength (per ASTM C78/C78M). Workability was assessed immediately, with mechanical strengths tested at 7 and 28 days, and durability properties at 28 and 56 days.

3.2 Materials Used

The study verified all materials used in accordance with the standards set by the American Society for Testing and Materials (ASTM) and the American Concrete Institute (311 2008). The materials employed included fine aggregate (sand), coarse aggregate, Ordinary Portland Cement (OPC), dried sludge powder, and water. All the materials were selected ad tested as per the relevant ASTM specifications: ASTM C33/C33M-11a for fine aggregate (sand) and coarse aggregate and ASTM D4236 for the dried sludge powder.

3.2.1 Coarse Aggregate

The coarse aggregate used in this study were clean, hard durable, and free from dust, friable particles, organic impurities, and other deleterious substances. They possessed high compressive strength and shear strength, good interlocking character, and adequate permeability. From ASTMC33/C33M-11a, the locally produced coarse aggregate were crushed stone with particle size passing through a 20mm sieve and retained on a 14mm sieve. The aggregates used in this research were provided by the construction materials laboratory of Adama and science technology university (ASTU) and were being used by them on a routine basis for instruction purposes. These aggregates were originally obtained from local resources within and around Adama city.

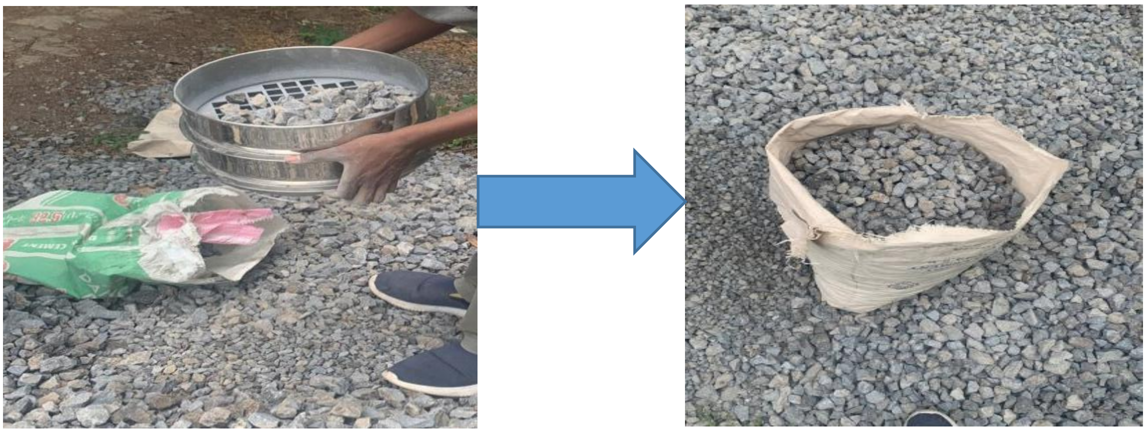


FIGURE 3. 1 Course Aggregates Used for Concrete Production

The coarse aggregate is the primary constituent materials which occupies up to 70%-80% of concrete material properties. The laboratory tests were conducted to identify the physical properties of the coarse aggregate such as gradation, specific gravity and absorption capacity, moisture content, and unit weight.

Table 3. 1 Summary of physical property of coarse aggregates

Type of test	*Test method*	*Test result*	*ASTM Requirement*	*Remark*
Bulk Density	ASTM C29	1606.7	1280 to 1920Kg/m3	Ok
Specific gravity	ASTM C128	2.9	2.4 to 3.0	Ok
Water absorption	ASTM C128	0.76 %	0.2% to 4%	Ok

3.2.2 Fine Aggregate (Sand)

The fine aggregate (sand) used in this research consisted of materials that passed through a 4.75 mm sieve. The study utilized locally available sands, including crushed stone sand and crushed gravel sand, which are typical forms of natural sand deposited by rivers or obtained through mechanical crushing. According to ASTM C33/C33M-11a, aggregates with particle sizes smaller than 4.75 mm were classified as sand and further categorized into fine, medium, or coarse based on grain size. The selection and classification of the sand used adhered to this standard.

FIGURE 3. 2 Fine Aggregate Used for Concrete Production

The objective of fine aggregate is to fill voids in coarse aggregate and to provide workability. Natural river sand is characterized, and qualities such as water absorption, bulk density, specific gravity, and others are assessed using ASTM standards.

Table 3. 2 Summary of physical property of Fine aggregates

Type of test	*Test method*	*Test result*	*ASTM Requirement*	*Remark*
Bulk density of fine aggregate	ASTM C29	1629.5 kg/m^3	1280 to 1920 kg/m^3	Ok
Specific gravity	ASTM C128	2.5	2.4 to 3.0	Ok
Water absorption	ASTM C128	1.6%	0.2% to 4%	Ok

The above result shows that the Fine aggregate physical properties specified by ASTM. Therefore, we can use this aggregate for construction purposes.

The general physical properties of coarse aggregate and fine aggregate like, bulk density, specific gravity and water absorption capacity were determined based on standards. According to ASTM C29, the density of aggregate is the weight of aggregate in a given volume of graded aggregate. Whereas, according to ASTM C128, the specific gravity is the ratio of the mass of a unit volume of material to the mass of the same volume of water. According to ASTM C 128, absorption capacity targeted to test the increase in the weight of aggregate due to water in the pore of the material.

3.2.3 Cement

For this study, Ordinary Portland Cement (OPC) 43 Grade from a single batch was used, satisfying IS: 8112-1989 requirements. This hydraulic cement purchased from a local Adama market, gains strength through hydration and conforms to ASTM C150, EN 197-1, and Ethiopian ES C.D5 201 standards. Its key properties include a fineness of 300–350 m^2/kg (Blaine method), which aids in strength development. Compressive strength meets BIS and ASTM standards at 23 MPa (3 days), 33 MPa (7 days), and 43 MPa (28 days), making it suitable for general structural work. It has a specific gravity of approximately 3.15, essential for mix calculations, and generates a moderate heat of hydration, reducing thermal cracking risks.

3.2.4 Dried Sludge Powder (DSP)

Collection and Preparation of Dried Sludge Powder

The dried sludge powder used in this study was collected from Adama Industrial Park, located about 74 kilometers southeast of Addis Ababa, Ethiopia's capital. A total of 45 kilograms of wet industrial sludge was collected, packaged into three sacks weighing 15 kilograms each. The sludge was partially dried before being transported to Adama Science and Technology University (ASTU), where the laboratory work was conducted.

Initially, the sludge was sun-dried for three consecutive days to remove surface moisture. After this, it was oven-dried at a temperature of 85°C to eliminate any remaining moisture and to prevent bacterial growth. Once dried, the sludge was ground into a fine powder that could pass through a 75-micrometer ASTM sieve, resulting in a texture similar to that of cement (Taylor 1997). The overall Collection and Preparation of Dried Sludge powder is shown in Figure 3.3 below.

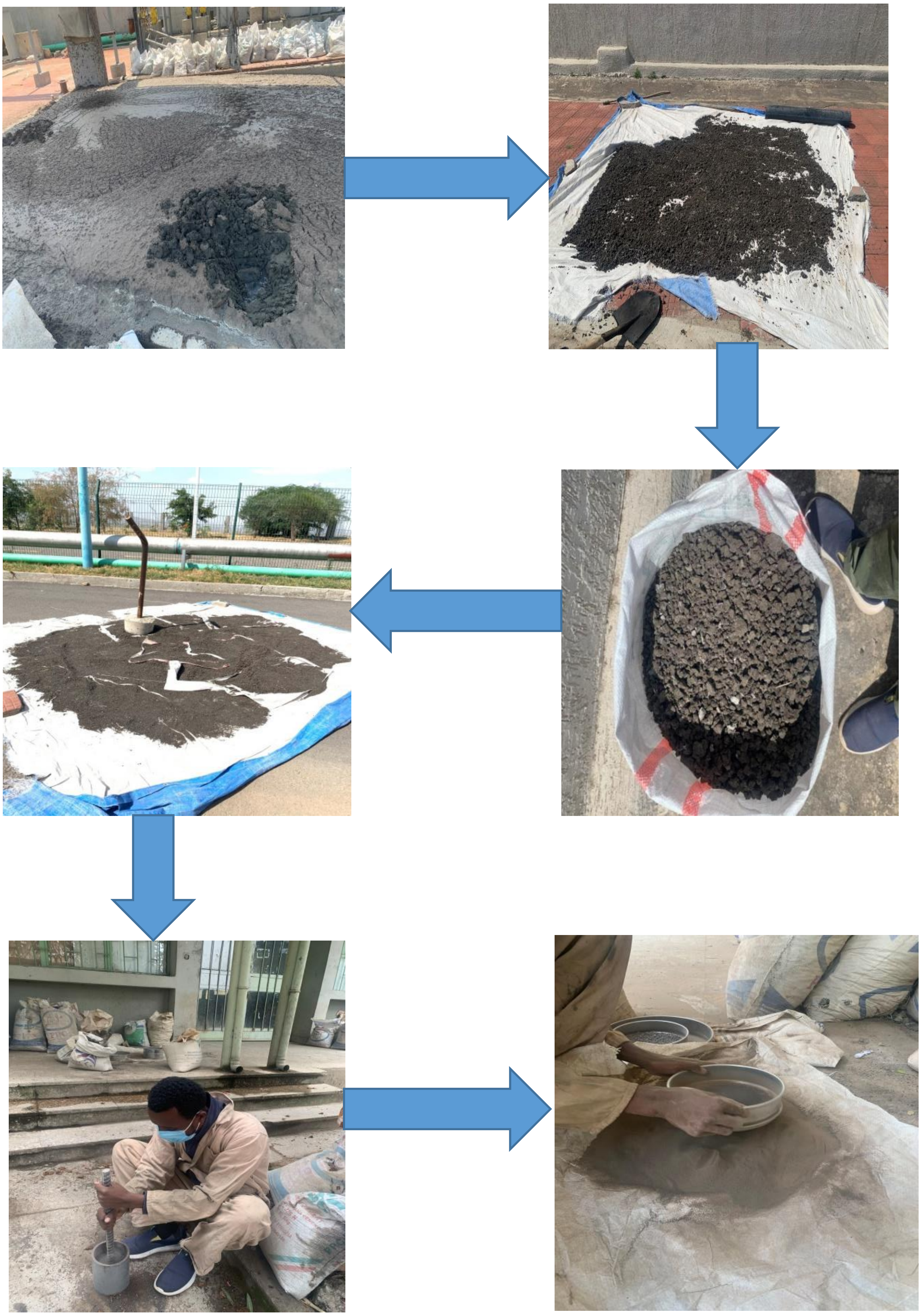


FIGURE 3. 3 Collection and Preparation of Dried Sludge powder

3.2.5 Mixing Water

Drinkable tap water which is free from acids, alkalis, oils and organic materials was used for all concrete mixtures.

3.3 Characterization of the Dried Sludge Powder (DSP)

Characterizing the wastewater sludge was important to determine its chemical composition, particularly the types of oxides it contains. These oxides help assess whether the sludge has potential as a partial substitute for cement in concrete production. Samples were taken and analyzed in coordination with the Ethiopian Geological Laboratory Office through ASTU. From a 10 kg homogenized batch of sludge, 800 grams were sampled from four different spots. These were divided into two sets of 400 grams each for different types of chemical analysis: Complete Silicate Analysis and Trace AAS using $HClO_2$ digestion. The analysis determined the content of key oxides such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, MnO, K_2O, P_2O_5, TiO_2, and H_2O. This chemical composition of Dried Sludge Powder result included different minor and major compounds. According to the chemical analysis result, the major oxides of waste glass powder include: Silicon Oxide (Sio_2), Calcium Oxide (CaO), Aluminum Oxide (Al_2O_3) and Iron Oxide (Fe_2O_3). The minor oxides include Magnesium Oxide (MgO), Sodium Oxide (Na_2O), Potassium Oxide (K_2O), Sulfur trioxide (SO_3), Manganese Oxide (MnO), Phosphorus Oxide (P_2O_3) and Titanium Oxide (Tio_3). Advanced methods such as $LiBO_2$ $LiBO_3$ fusion, HF (hydrofluoric acid) attack, gravimetric analysis, colorimetric techniques, and Atomic Absorption Spectrometry (AAS) were used. These methods are particularly useful for detecting metals and semi-metals, like boron and silicon, as AAS provides accurate measurements for these elements due to their easily readable atomic properties.

3.4 Material Preparation and Tests

3.4.1 Property of Materials

The engineering property of all materials necessary for describing the type of materials used and also properties that can affect the production of concrete were determined before production.

Table 3. 3: ASTM Test Methods and Specifications for Materials

Laboratory tests types	*Test method*
Unit weight of aggregate	ASTM C-29
Specific gravity and water absorption of coarse aggregate	ASTM C127
Specific gravity and water absorption of sand /Fine aggregate	ASTM C-128
Sieve analysis for fine and coarse aggregate	ASTM C-136

3.4.2 Properties of the Concrete

The properties of the concrete at fresh and harden state are slump or workability test, compressive strength test, Flexural, water absorption, Sulphate attack and the micro structure of the cement paste are expected under this study.

Table 3. 4: ASTM Test Methods and Specifications for Concrete Properties

Laboratory tests types	*Test method*
Slump or workability test	ASTM C-136
Compressive strength of concrete after curing	ASTM C-29
Flexural strength of concrete after curing	ASTM C78/C78M
Water absorption of hardened concrete	ASTM C127
Sulfate attack test of hardened concrete	ASTM C-128

3.4.3 Concrete Mixing and Specimen Preparation

The concrete was mixed using a concrete mixing machine, following the procedures outlined in ASTM C-192, *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*. All components were carefully loaded into the mixer, after which the concrete was mixed for three minutes, allowed to rest for three minutes, and then mixed again for two additional minutes. To reduce evaporation during the rest period, the top of the mixer was covered. After completing the slump test, the freshly mixed concrete was poured into molds and compacted in three layers. Each layer was rodded 25 times using a tamping rod, in accordance with ASTM C-192. The concrete specimens were kept in the molds for the first 24 hours. After this initial setting period, specimen were reformed and placed in a 23 ± 1°C water bath for curing up to the designated test age, as per ASTM standards.

FIGURE 3. 4 Concrete Mixing and Specimen Preparation

3.5 Mix Design

Concrete mix design is a systematic approach of determining the right proportion of various concrete ingredients to achieve the desired mechanical and durability properties at minimum cost. In the current work, the concrete mix was optimized for characteristic compressive strength of 25mpa(C-25), with dried sludge powder (DSP) as partial cement replacement by different percentages.

The mix design followed the department of environment (DOE) method, which insures the required strength and workability according to local material conditions. The designed mix included a control mix (0% DSP) and three additional mixes with 5%, 10%, and 15% DSP replacing cement by weight. These percentages were selected from literature suggestion and trial mix observation to study the influence of low to moderate amounts of cement replacement.

3.5.1 Target Strength and Workability

- **Characteristic compressive strength (fck):** 25 MPa
- **Standard deviation (S):** 4 MPa (assumed for general quality control)
- **Target mean strength (f'm):** fck + 1.65 × S = 25 + 1.65 × 4 = 31.6 MPa
- **Maximum aggregate size:** 20 mm
- **Desired slump:** 75–100 mm (medium workability)

3.5.2 Control Mix (0% DSP)

Control mix contained 100% ordinary Portland cement (OPC) with no content of DSP control mix was proportioned for the target strength and was sued as the baseline to compare the performance of the modified mixes.

3.5.3 DSP Replacement Levels

DSP substituted OPC at 5%, 10% and 15% by weight. These are the selected percentage to study the compatibility of DSP as partial cement replacement and to find the optimum substitution percentage that provides s good mechanical characteristics and durability. The other components of the mixes like fine aggregates, coarse aggregates, and water were not altered in any of the mixes except for minimizing cement content to facilitate DSP substitution. The water-to-Cementitious material ratio (W/C) was kept constant at **0.55** to ensure fair comparison between mixes.

3.5.4 Mix Proportion Summary

The mix proportions and number of specimens prepared for each batch are presented in Table 3.4. A total of 72 specimens were cast to evaluate the performance of concrete containing varying percentages of Dried Sludge Powder (DSP) as a partial cement replacement. The four mixes consisted of a control mix (0% DSP) and three replacement levels (5%, 10%, and 15%).

A total of **48 cube specimens** (150 mm × 150 mm × 150 mm) were produced and tested according to **ASTM C39**, following sampling procedures outlined in ASTM C172, for:

- **Compressive strength** (24 cubes),
- **Water absorption** (12 cubes), and
- **Sulfate resistance** (12 cubes).

In addition, **24 beam specimens** (100 mm × 100 mm × 500 mm) were cast and tested for **flexural strength** in accordance with **ASTM C78/C78M**.

The **workability** of each fresh concrete mix was evaluated immediately after mixing by conducting the slump test (ASTM C143). Compressive and flexural strength tests were conducted at **7 and 28 days**, while **water absorption** and **sulfate resistance** were evaluated at **28 and 56 days**, respectively.

Table 3. 5: Mix Proportions and Number of Specimens by Testing Age

Mix Code	*Cement (%)*	*DSP (%)*	*7-Day Cubes*	*28-Day Cubes*	*56-Day Cubes*	*7-Day Beams*	*28-Day Beams*	*Total Specimens*
100C	100	0	3	6	3	3	3	18
95C + 5DSP	95	5	3	6	3	3	3	18
90C + 10DSP	90	10	3	6	3	3	3	18
85C + 15DSP	85	15	3	6	3	3	3	18
Total	–	–	12	24	12	12	12	72

Table 3. 6: Mix Proportions and Amount of Each Raw Materials Needed by Weight.

Sample code	*Cement (kg)*	*DSP (kg)*	*Fine Aggregate(Kg)*	*Coarse Aggregate (Kg)*	*Water Cement ratio*
100C	16.10	0	28.75	42.1	0.55
95C + 5DSP	15.29	0.815	28.75	42.1	0.55
90C + 10DSP	14.49	1.61	28.75	42.1	0.55
85C + 15DSP	13.68	2.42	28.75	42.1	0.55

3.6 Testing of Fresh Concrete

The concrete was prepared using a mixing machine in accordance with ASTM C-192, which outlines the standard procedures for making and curing laboratory test specimens. All ingredients were carefully loaded into the mixer, then combined for three minutes. Afterward, the mixture was allowed to rest for another three minutes, with the open top covered to prevent evaporation. It was then mixed again for an additional two minutes. After we outed the concrete from the mixer the workability of fresh concrete is done using slump test materials.

3.6.1 Slump Test for Workability

Workability is a key property of fresh concrete, indicating how easily it can be placed, compacted, and finished. To evaluate this property, a standard slump test was conducted using a truncated metal cone in accordance with ASTM C143/C, *Standard Test Method for Slump of Hydraulic-Cement Concrete*. The cone, which is 30 cm in height, was filled with fresh concrete in three equal layers. Each layer was compacted by rodding 25 times using a 5/8-inch diameter tamping rod to ensure uniform density. After the cone was completely filled, the excess concrete was leveled off at the top, and the cone was lifted vertically without any lateral or torsional movement. The vertical distance by which the concrete subsided from the original height of the cone was measured as the slump value, which reflects the concrete’s workability.

FIGURE 3. 5: Process of measuring a slump value from Slump Test

3.7 Testing of Hardened Concrete

3.7.1 Compressive Strength Test

Compressive strength is by far the most essential attribute of hardened concrete. This strength is a function of age, which is the time following casting, because it continues to rise with continued cement hydration. The ASTM C-39 "Standard Test Method for

Compressive Strength of Cylindrical Concrete Specimens" was used to conduct the compressive strength test. Twelve compressive strength sample will be tested by pouring concrete into a 150mm*150mm*150mm (L*W*H) cube and curing it with water. After that, after 7 and 28 days of curing, the compressive strength test performed with appropriate machine. Compressive strength test is conducted by placing the cubes in the compression testing machine, using compression test machine with a loading rate of 20N/mm^2/min and a maximum load applied slowly until the specimen fails, and record the maximum load attained. Compressive strength is calculated by dividing the maximum load attained by the cross-sectional area of the specimen and the corresponding unit weight.

$F = \frac{P}{A}$ F=Compressive Strength (MPa or N/mm^2), P=Maximum Applied load (N) and A=Cross Sectional Area of Specimen (mm^2)

FIGURE 3. 6: Machine for tests: Compressive Strengthen

3.7.2 Flexural Strengthen test

The flexural test of concrete, as outlined in ASTM C78/C78M, "Standard Test Method for Flexural Strength of Concrete (Using a Simple Beam with Third-Point Loading)," involves several key steps to assess the material's ability to endure bending stresses. Initially, concrete beam specimens, typically measuring 100 mm x 100 mm x 500 mm, are prepared and cured for 7 and 28 days. These beams are then placed in a universal testing machine, supported at two points, with loading points defined at one-third the length from each end. The setup is designed so that the load is applied incrementally at the center of the beam until failure occurs, with careful measurement of both the maximum load and the deflection at the midpoint. For flexural strength, specimens of concrete beams are prepared with the cross-sectional dimensions and geometry specified in ASTM C78/C78M-17. The specimen's caste in a suitable form and curing would be applied as defined in ASTM C31/C31M- 17a. ASTM C293 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Four-Point Loading) is used for this research as shown below the figure and calculating with

$$\text{Flexural strength} = \frac{\text{Load at failure}}{\text{Beam width x Beam depth}}$$

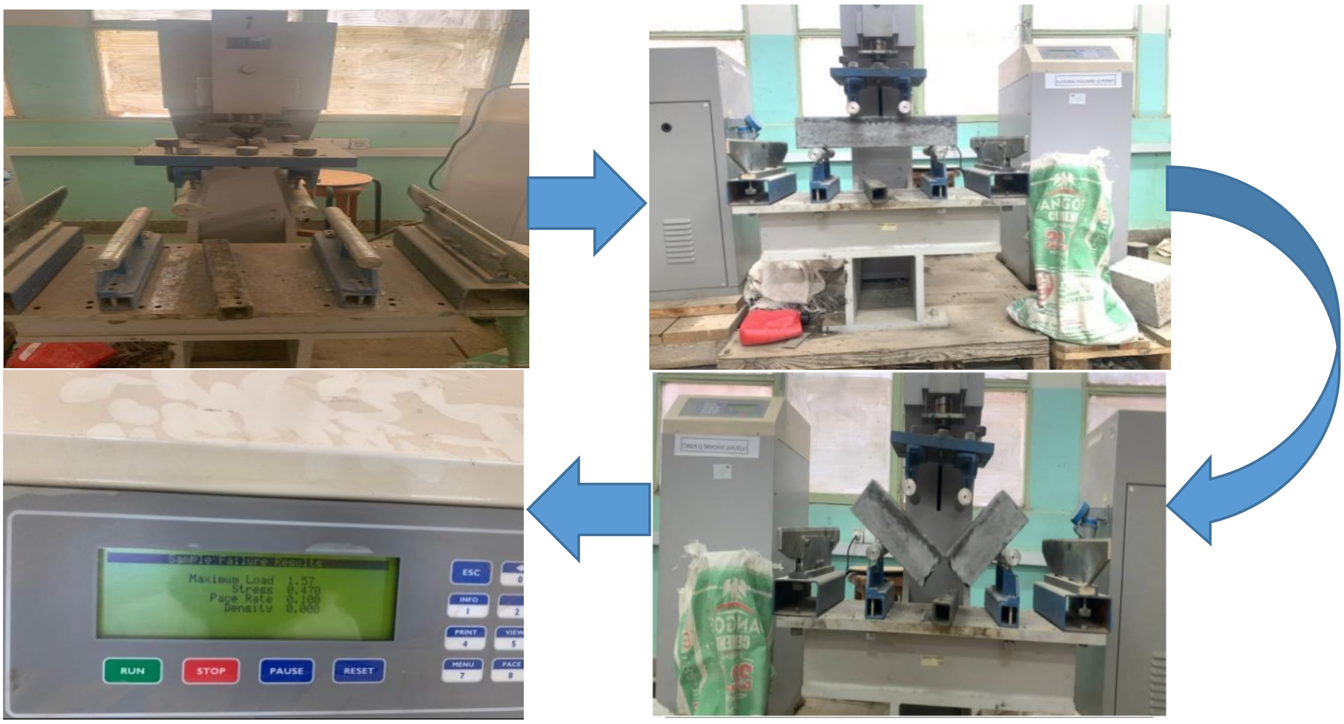


FIGURE 3. 7: Machine for tests: Flexural Strengthen

3.7.3 Water Absorption of Concrete

The water absorption test was conducted in accordance with ASTM C642-13, *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete* (Standard 2006). The test was carried out on 28-day-old concrete specimens prepared with the respective replacement levels of DSP. A total of twelve concrete samples were used for this test. Initially, the samples were placed in an oven at a temperature of 100–105°C for 24 hours to determine their dry weight. The dry samples were then immersed in water for 24 hours, and their wet was determined. The water absorption was determined as a weight increases percentage over dry weight of the sample

$$\text{Water Absorption } = \frac{\text{Wet weight} - \text{Dried weight}}{\text{Wet weight}}$$

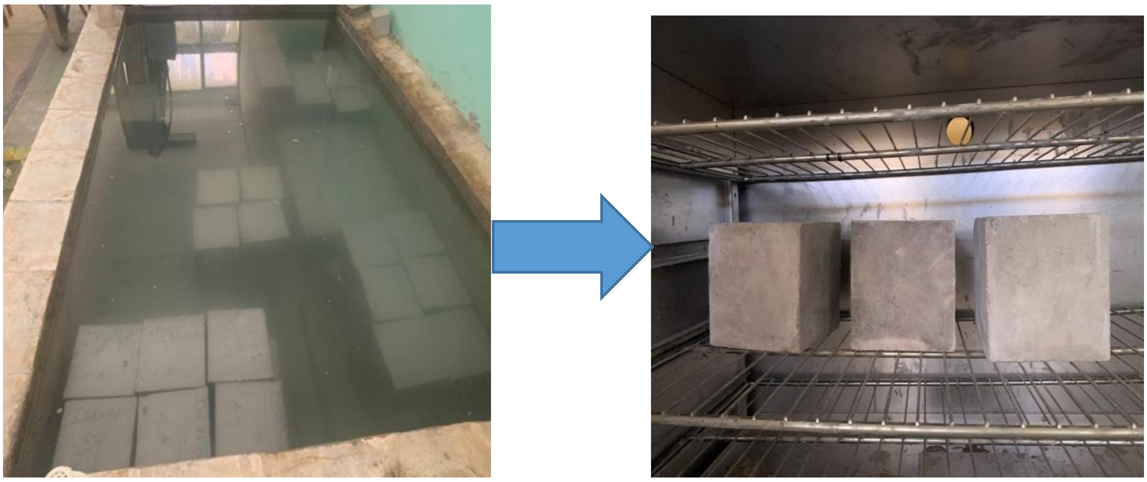


FIGURE 3. 8: Machine for tests: Water Absorption

3.7.4 Sulfate Attack of the Concrete

Concrete resistance against sulfate attack was evaluated according to ASTM C1012, *Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution*. It test the chemical resistance of the concrete by immersing the test specimens in acidic or alkaline solutions for a time specified and comparing the difference in properties with the control specimens(Nadir and Ahmed 2022, Mitikie, Kefa et al. 2024). In this test experiment, cubes of concrete with dimensions 150 mm × 150 mm × 150 mm were cast and cured in water for 28 days. After the curing time, the test specimens were removed from the water, and the surface excess moisture was removed with a standard initial surface cleaning procedure. The cleaned specimens were then weighted in order to obtain their initial weight. After this, the identified specimens were subjected to a solution of 5% aluminium sulfate solution and hardened for the next 28 days. After the end of this time frame, the specimens were taken out of the solution and weighed at the last stage.

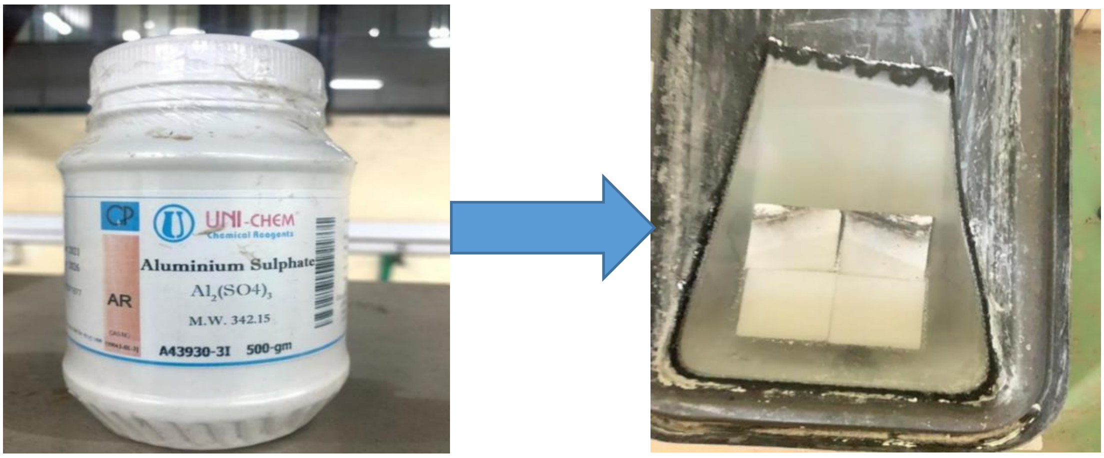


FIGURE 3. 9: Sulfate attack resistance test

3.7.5 Micro-Structural Investigation

Concrete microstructure was tested to observe its properties and behavior at microscopic scale. Scanning Electron Microscopy (SEM) was employed for this purpose with ASTM C457 standards, which offers methods and procedures for testing of the air void system in hardened concrete. During the present analysis, the concrete specimen was placed in the SEM chamber and was scanned at various magnifications to reveal minute details of hydration products, pore morphology, and aggregate particles configuration. Micro graph were captured while the SEM scan was being performed, thus allowing a correct evaluation of pore size, distribution, and other micro structural characteristics. This information was instrumental in establishing the durability and general performance of the concrete

FIGURE 3. 10: Sample used for micro-structural investigation

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Introduction

This Chapter presents and discusses the result obtained from experimental investigation of dried sludge as a partial cement replacement in concrete production. Various concrete tests were performed to assess the material's properties in accordance with established standards and the study's objectives, considering the variability introduced by different cement and dried sludge proportions.

4.2 Chemical Composition of Dried Sludge Powder (DSP)

4.2.1 Dried Sludge Powder (DSP) Chemical Composition Analysis

To determine whether dried sludge powder (DSP) from wastewater treatment in the Adama Industrial Park could be used as a supplementary cementitious material (SCM), its chemical composition was determined. By gravimetric, colorimetric, and AAS analysis, the test was carried out in the Geological Institute of Ethiopia. The findings were referenced against Ordinary Portland Cement's (OPC) general composition and are indicated in Table 4.1.

Table 4.1: Comparison of DSP and OPC's Chemical Composition (% by weight)

Compound	*DSP (%)*	*OPC (%)*
SiO_2	19.44	20.21
Al_2O_3	13.36	6.20
Fe_2O_3	0.92	3.80
CaO	2.51	60.48
MgO	0.96	1.32
Na_2O	1.44	0.21
K_2O	0.19	0.45
MnO	0.02	0.13
P_2O_5	0.90	0.24
TiO_2	0.06	0.36
H_2O	11.66	—
LOI	48.00	—

The DSP sample has high contents of silica (SiO_2) and alumina (Al_2O_3) at 19.44% and 13.36%, respectively. The oxides are most known for increasing pozzolanic activity, which plays a vital role in increasing concrete properties when put to use as an SCM (Jiang, Xiao et al. 2022). Although the SiO_2 content is close to that of OPC (20.21%), the Al_2O_3 content in DSP is over double that for OPC (6.2%). This is to say that DSP may have high pozzolanic activity under the right curing conditions (Celik, Meral et al. 2014).

However, the DSP sample contains only 2.51% calcium oxide (CaO), much less than the 60.48% in OPC. Since CaO is a crucial component of the action of cement's basic hydration reactions, the small amount of CaO in DSP emphasizes its role as a partial substitute and not a full replacement (Neville 2011). DSP possesses a loss on ignition (LOI) of 48%, which indicates a high organic or volatile content that can influence setting time and workability and must be considered cautiously in the formulation of the mix.

Apart from this, DSP contains a notable total alkali content, and calculated as sodium oxide equivalent (Na_2O_{eq}) at approximately 1.565% (1.44% Na_2O and 0.19% K_2O)(In the context of cement and supplementary cementitious materials (SCMs), the total alkali content is usually expressed as sodium oxide equivalent (Na_2O_{eq}), calculated as: $Na_2O_{eq} = Na_2O + 0.658 \times K_2O$)(Leming and Nguyen 2000). DSP contains notable total alkali content, calculated as sodium oxide equivalent. This is higher than the usual 0.60% low-alkali Portland cement limit. High alkali content can potentially enhance alkali-silica reaction (ASR) in the presence of reactive aggregates in the concrete mix, which can lead to long-term durability issues in the form of cracking and expansion(Taylor 1997). Therefore, ASR risk needs to be evaluated with caution, and further tests for alkali-aggregate reactivity may be required, especially if aggregates are not sure of being non-reactive.

Overall, the chemical composition of DSP possesses potential pozzolanic activity based on its high alumina and silica content. However, with the low CaO content and high LOI, mix design and testing should be meticulously conducted before usage in structural concrete. Based on this analysis, DSP is potential suitability for use as a partial cement replacement in C-25 grade concrete under the research parameters (5%, 10%, and 15% by weight).

4.2.2 Heavy Metal Analysis of Dried Sludge Powder

In order to determine the environmental impact of using dried sludge powder (DSP) as a cement replacement, a base metal analysis was conducted to determine the overall concentration of significant heavy metals. The analysis, performed at the Geological Institute of Ethiopia, yielded the results presented in Table 4.2.

Table 4.2. Total Heavy Metal Concentrations in Dried Sludge Powder (DSP)

Metal	*Copper*	*Zinc*	*Lead*	*Cobalt*	*Nickel*
Concentration(ppm)	74.20	206.60	12.60	14.00	28.60

Note: ppm: parts per million

As clear from Table 4.2, DSP consists of various total concentration levels, the highest being Zinc (206.60 ppm) and Copper (74.20 ppm). The total concentration needs to be distinguished from leachable concentration since it is the latter that determines environmental risk. Ranges for reuse of heavy metal-containing materials are typically provided by regulatory bodies on the basis of the leachable fraction (e.g., in mg/L of leachate), not total content. Due to the unavailability of specialized equipment at the local test labs, direct leachate analysis (e.g., TCLP) was not feasible in this study. Hence, a long-term environmental classification of heavy metal mobility cannot be established empirically here. However, the encapsulation of industrial wastes in a concrete matrix is widely recognized for its capability to immobilize heavy metals through physical encapsulation and chemical fixation in the hardened cement paste. This process reduces their potential for release into the environment.

Based on total concentrations determined, the heavy metal concentration of the dried sludge powder appears to be within ranges generally considered for potential beneficial reuse in concrete. While this is suggestive of safe use potential, subsequent study involving direct leachate testing would be required for thorough environmental risk assessment and full verification of DSP-amended concrete.

4.3 Tests for Fresh and Hardened Concrete

In this part of the thesis, the fresh and hardened concrete characteristics such as workability, compressive strength, flexural strength; water absorption, sulfate attack and micro-structure test are presented and described in relation with control concrete samples and relevant ASTM standards. Those characteristics are analyzed under two categories as below.

4.3.1 Tests for Fresh Concrete

4.3.1.1 Workability Test

Workability has a set of properties like cohesion and uniformity common in fresh concrete. It is mainly applied on site, and the slump test is the most convenient way to quantify workability. The slump test is an indication of how much the concrete slumps downward when a cone of the material is raised from about around the concrete. ASTM C143 slump test was used to determine each series mixes workability. Summary of result of slump test is given in the Table below.

Table 4.3: Result of Workability test

Mix Design	*DSP Replacement (%)*	*Water: Cement(W/C)*	*Slump Value(mm)*
Control	0	0.55	50
DSP-5	5	0.55	56
DSP-10	10	0.55	64
DSP-15	15	0.55	70

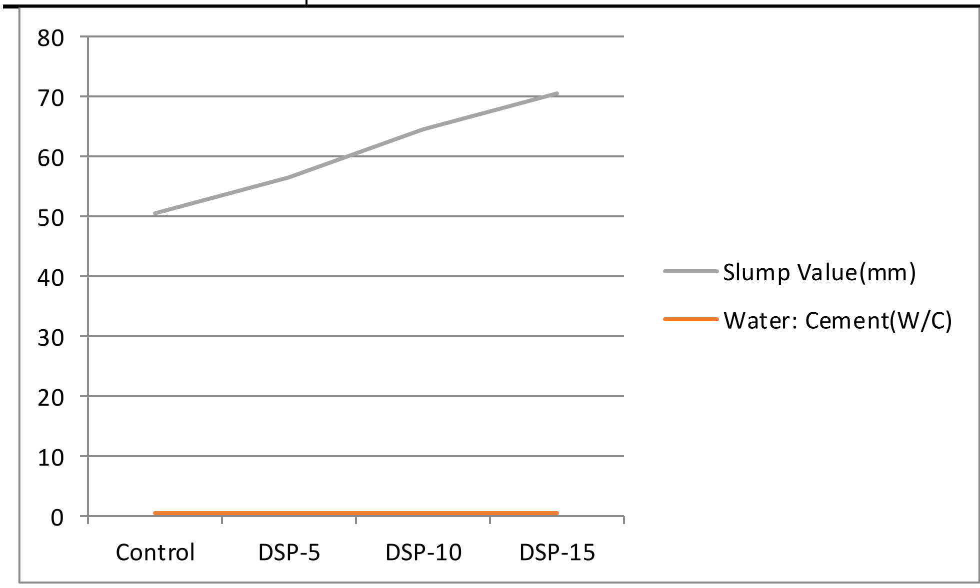


FIGURE 4.1: Graph of Slump test Result

Table 4.2 and Figure 4.1 show the outcome of the slump test, which suggest that workability keeps on improving with rising percentage of dry sludge powder (DSP) used to replace normal Portland cement (OPC). The slump value was 56 mm, 64 mm, and 70 mm for 5%, 10%, and 15% DSP mixes, respectively, compared to 50 mm for control mix (0% DSP).

This observed increase in slump value can be attributed to the physical and chemical properties of the dried sludge powder. DSP typically consists of fine particles, with a maximum size of 75 µm, which is comparable to or finer than cement particles. Due to their fine nature and smooth particle surfaces, these particles can enhance lubrication within the mix and minimize internal friction among aggregate particles. This particle morphology contributes to making the concrete more workable and easier to handle.

Additionally, DSP with unreactive or partially reactive silica can slow down initial hydration reactions, slowing down the stiffening of the mix and prolonging the measured slump in testing. The extremely high loss on ignition (LOI) value of 48.00% also founds in DSP's chemical composition can similarly be a factor in improving workability. This suggests a high proportion of organic or volatile content, which may increase the amount of water available for flow and lubrication and therefore increase the slump.

In applications where high workability is required, the trend finds application in promoting the placing and compaction of fresh concrete. Hardened concrete's strength and hardness may be adversely affected by bleeding or segregation, whose causes may be excessive workability. Thus, while the inclusion of DSP has been noted to enhance flowability, its dose should be carefully designed to align with fresh and hardened material properties.

In conclusion, the evidence that DSP improves the workability of concrete is supported by the fact that the slump value is higher when the content of DSP is increased. This positions DSP as a potentially cement replacing material exhibiting improved fresh concrete properties, particularly in mixtures requiring enhanced flowability.

4.3.2 Tests for Harden Concrete

4.3.2.1 Compressive Strength Test Cured in Water

The compressive strength of concrete is a simple mechanical property that describes the capacity of concrete to withstand axial loads. Compressive strength testing in this study was conducted on a standard cube test size of 150 mm × 150 mm × 150 mm under a digital compression testing machine with a machine crosshead speed of 20 mm/sec according to

ASTM C39 standards. All the specimens were water-cured and prepared according to ASTM C31 procedures in an effort to achieve consistent curing conditions. Compressive strength tests at ages 7 and 28 were performed in an attempt to determine early-age and long-term strength gain. The information for the concrete mixtures of 0% (control), 5%, 10%, and 15% DSP by weight as partial cement replacement is illustrated in Table 4.4 and graphically as Figure 4.2.

Table 4.4: Average Concrete Compressive Strength with DSP Substitution

Mix Design	*DSP Replacement*	*7-Day Strength (MPa)*	*28-Day Strength (MPa)*
Control	0.00	30.06	37.36
DSP-5	0.05	24.05	31.56
DSP-10	0.10	15.90	22.06
DSP-15	0.15	12.86	18.35

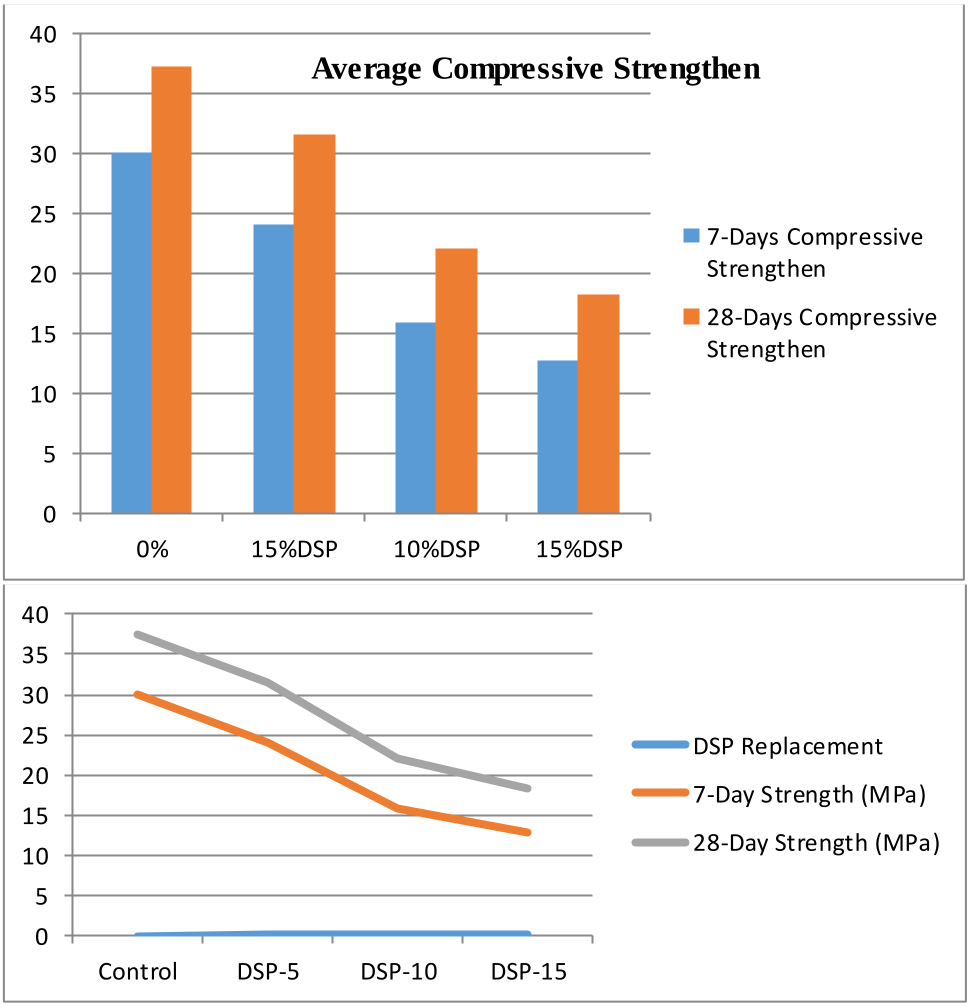


FIGURE 4.2: Average Compressive Strength Graph for Days 7 and 28

In accordance with the data, compressive strength decreases progressively as the rate of DSP replacement is increased. The highest strengths were achieved by the control mix with 100% ordinary Portland cement (OPC). The strengths at 7 and 28 days were 30.06 MPa and 37.36 MPa, respectively, showing that OPC's long history of capability to hydrate and gain strength (Taylor 1997, Neville 2011). On the other hand, the percentage with 5% DSP replacement saw a major drop in strength, which was 24.05 MPa at 7 days and 31.56 MPa at 28 days. The drop, however, was also within acceptable limits for some structural and semi-structural applications (Standard 2017). Nevertheless, the compressive strengths dropped substantially in 10% and 15% DSP replacement percentages, below the minimum demand of plain C-25 concrete in 28 days.

There are a number of reasons why there is a declining trend: ***Low Calcium Oxide (CaO) Content*****:** OPC has about 60.48% CaO, which is needed to produce calcium silicate hydrate (C-S-H), the main substance that gives the strength of hydrated cement paste. In contrast, DSP has only 2.51% CaO, which greatly restricts the production of C-S-H(Hewlett and Liska 2019). ***High Loss on Ignition (LOI)*****:** LOI of DSP is 48%, which means that a large percentage of its components are non-reactive and volatile. For (Siddique 2007), high LOI values weaken the binder matrix and hinder the development of overall strength. *Moderate* ***Pozzolanic Activity*****:** The sum of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) in DSP is approximately 33.72%. This percentage is well below the required minimum of 70% to be considered a Class F pozzolan according to ASTM C618 (2019). Even though the existence of such oxides points towards potential pozzolanic action, their relatively low combined proportion for an SCM and the uncalcined form of the DSP imply that any pozzolanic contribution would be constrained, especially at younger ages. Besides, the pozzolanic reaction requires sufficient calcium hydroxide ($Ca(OH)_2$), which is a byproduct of cement hydration. While the DSP contains $SiO_2$and Al_2O_3, its low pozzolanic reactivity, especially at early ages, and the dilution effect of replacing large amounts of highly reactive cement, result in there not being sufficient C-S-H formation from the pozzolanic reaction to compensate for the decrease in OPC content(Mehta and Monteiro 2008). This limitation in pozzolanic contribution is the cause of the decrease in strength.

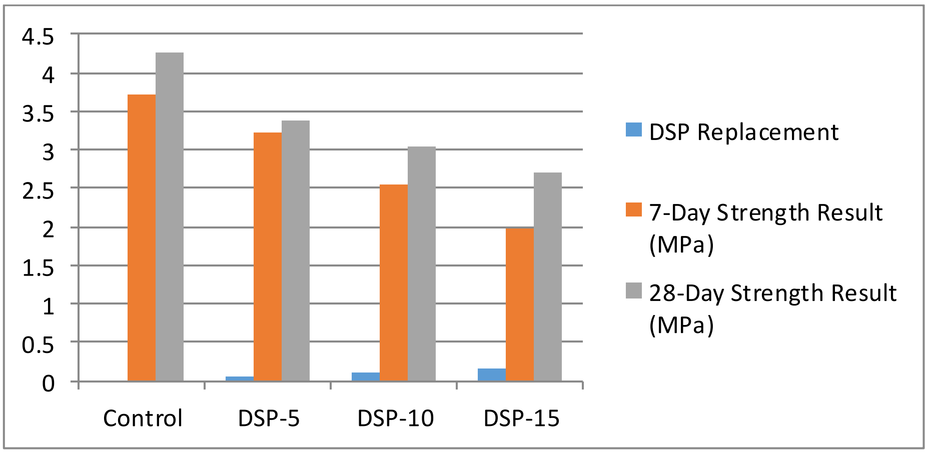
The 5% DSP blend appears to be an appropriate substitute for partial cement replacement, particularly suitable for secondary or non-structural applications, as it still meets the C-25 strength requirement. From these findings, DSP can be incorporated at low percentages (e.g., up to 5%) without excessively compromising early-age mechanical properties, thereby promoting sustainability and waste reduction in cement-based construction while still achieving suitable performance for certain applications.

4.3.2.2 Flexural Strength Test Cured In Water

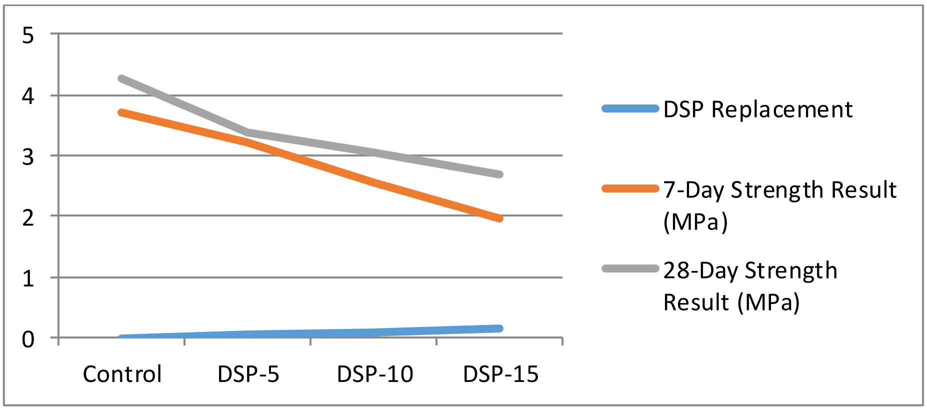
Flexural strength of concrete is one of the most important mechanical properties that define its ability to withstand bending failure. It is of special significance for concrete members subjected to tensile stress, such as pavements, slabs, and beams. In this study, the test was conducted according to ASTM C78/C78M standards, using the Third-Point Loading technique. A rectangular concrete prism resting on two supports and loaded at two points, one-third of the length of span from the two ends is subjected to the maximum load at rupture, which is utilized in the calculation of modulus of rupture, i.e., flexural strength of concrete. Concrete with 0%, 5%, 10%, and 15% dried sludge powder (DSP) as cement partial replacements was tested for flexural strength at 7 and 28 days. The results are presented in Table 4.5 and Figure 4.3.

Table 4.5: Average Concrete Flexural Strength with DSP Substitution

Mix Design	***DSP Replacement***	***7-Day Strength Result (MPa)***	***28-Day Strength Result (MPa)***
Control	0.00	3.71	4.263
DSP-5	0.05	3.221	3.385
DSP-10	0.10	2.549	3.043
DSP-15	0.15	1.982	2.694



(a)



(b)

FIGURE 4. 3 a and b Graph of Average Flexural Strength at 7 and 28 Days for Varying DSP Substitution Levels

As can be observed from the findings, the control mix attained the greatest flexural strength of 3.71 MPa when tested at 7 days and 4.263 MPa at 28 days. This performance can be attributed as consistent with normal behavior of the usual Portland cement (OPC), which provides improved bonding and mechanical strength due to the high calcium oxide (CaO) content and high hydration potential (Chaves, Evangelista et al. 2023). The flexural strength was significantly reduced with the incorporation of DSP. At 5% replacement, the mixture dropped by a minimal amount to 3.221 MPa (7 days) and 3.385 MPa (28 days), which was still quite acceptable for non-structural use. However, when DSP content was increased to 10% and 15%, the flexural strengths dropped lower, with DSP-15 having only 1.982 MPa (7 days) and 2.694 MPa (28 days), which fell by some 35–40% compared to the control mix.

This is attributed to a series of compositional characteristics in DSP. Firstly, low Cementitious content: The DSP used in this study has CaO content of only 2.51%, which significantly limits the formation of calcium silicate hydrate (C-S-H), a key determinant of concrete stiffness as well as strength(Hewlett and Liska 2019). Second, High Loss on Ignition (LOI): The DSP LOI is 48%, which indicates a high proportion of volatile or non-reactive material diluting the real binder content in the mix (Siddique 2007).

Lastly, Limited Pozzolanic Reaction: Although DSP contains a good content of silica (SiO_2 at 19.44%) and alumina (Al_2O_3 at 13.36%), which are usually good pointers to pozzolanic potential; the overall pozzolanic reactivity would appear to be limited. The sum of SiO_2, Al_2O_3, and Fe_2O_3 in DSP (approximately 33.72%) is well below the minimum 70%

required to be a Class F pozzolan as per ASTM C618. While pozzolanic reactions rely on the consumption of calcium hydroxide ($Ca(OH)_2$) produced from cement hydration, the low reactivity of DSP, especially at early ages, makes it unable to compensate for the reduction of OPC content effectively and therefore is liable for the observed strength loss(Ahmed, Kamau et al. 2019).

Flexural strength findings lend support to the conclusion that relatively low concentrations of DSP (e.g., 5%) can be tolerated in concrete mixtures for less challenging applications. At higher replacement levels, however, mechanical performance is drastically impaired and particularly in flexural application with tensile strength being of primary concern.

4.3.2.3 The Water Absorption

Water absorption is an important measure of porosity and durability of concrete. It is directly related to the extent to which water and other aggressive chemicals are able to penetrate into the concrete structure, thus affecting long-term durability and performance. Higher values of absorption typically imply greater connectivity of pores and lower compactness of concrete. For concrete samples with different percentages of dried sludge powder (DSP) replacing normal Portland cement (OPC), water absorption tests were performed in this research according to the procedure specified in ASTM C642, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete." The test was performed on 28 days cured samples. The specimens were cooled and dried in an oven, and then they were immersed in water for 24 hours, and the weight gain prior to and following immersion was used to calculate water absorption. Three samples of each of the replacement ratios of 0%, 5%, 10%, and 15% were tested in order to provide consistency and accuracy. Average results are presented in Table 4.6 and graphically in Figure 4.4.

Table 4.6: Water Absorption Test Results

Mix Design	*DSP Replacement (%)*	*Water: Cement(W/C)*	*Average water absorption test (%)*
Control	0%	0.55	6.055
DSP-5	5%	0.55	6.330
DSP-10	10%	0.55	6.967
DSP-15	15%	0.55	7.514

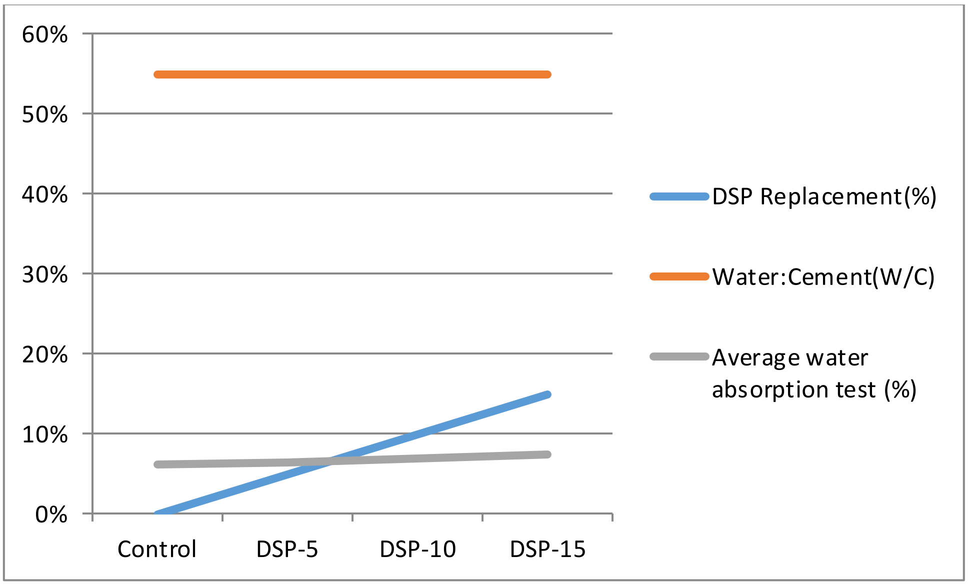


FIGURE 4. 4(a) Graph of Average Water Absorption Test With Respect to DSP Replacement and Water to Cement Ratio.

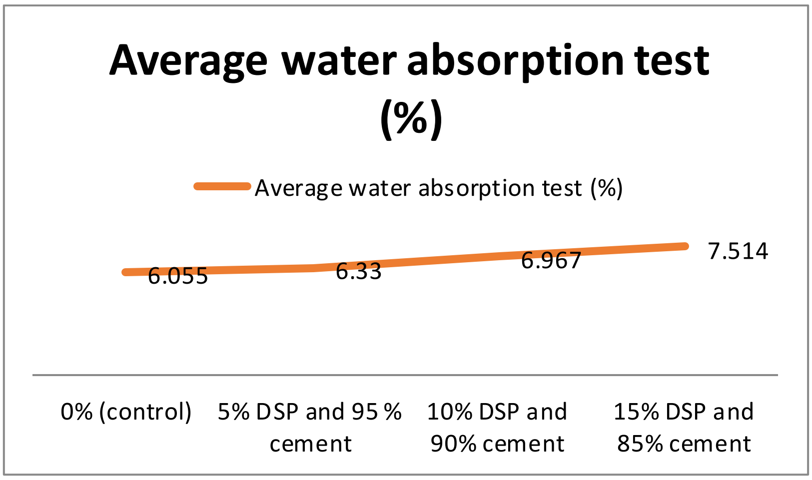


FIGURE 4. 4b: Graph of Average Water Absorption Test only

The results show a consistent increase in water absorption at higher DSP content. The minimum absorption was noted for the control sample (0% DSP) at 6.055%, while the maximum absorption was observed for the 15% DSP substitution at 7.514%. The rising trend indicates that DSP incorporation in concrete increases the porosity and reduces the density. This is primarily due to lower inherent reactivity of DSP at early ages relative to OPC, together with its high LOI (as discussed in Section 4.2), which acts as a non-reactive filler. This would cause dilution of the active cementitious binder and result in incomplete hydration and the formation of less dense, less compact, and more porous microstructure. The diminished C-S-H formation also accounts for the weakened bond at the aggregate-cementitious matrix interface. Higher DSP contents, therefore, result in a more interconnected pore formation and greater water absorption. Although there are environmental and economic advantages in using DSP as a partial substitute of cement, its impact on concrete durability aspects such as water absorption must be properly addressed. Based on the results, the restriction of DSP dosage or its blending with pozzolanic or densifying admixtures would be one method of balancing between sustainability gain and performance requirement for structural applications.

4.3.2.4 Dried Sludge Powder against Sulphate Attack

The sulphate attack experimental investigation assesses the impact of Aluminum Sulphate solution on the concrete structure after an initial 28 days of water curing, by subsequently immersing samples in the sulphate solution until 56 days of total age. The different mix samples cured within water for 28 days and weight of each sample recorded and then the sample kept within aluminium sulphate solution’s until the sample reaches 56 day. Then the loss of weight of each sample calculated. The test follow the standard declared on ASTM C1012 in order to obtain the accurate and precious value. While ASTM C1012 primarily mandates length change measurements, this study utilized weight loss as an alternative/supplementary indicator of sulphate degradation due to equipment availability, focus on mass stability. The dried sludge powder performance against sulphate attack result declared here in below Figure 4. 5 and Table 4.7

Table 4.7: Dried Sludge Powder against Sulphate Attack Result

DSP Replacement (%)	*Mix Design*	*28thDay weight(kg)*	*56thday (weight)kg)*	*Weight Loss (kg)*	*Percentage of Weight Loss (%)*
0%	Control	7.6783	7.6726	0.005	0.0737
5%	DSP-5	7.5316	7.5166	0.015	0.1990
10%	DSP-10	7.4683	7.4480	0.020	0.2724
15%	DSP-15	7.2323	7.2063	0.026	0.3589

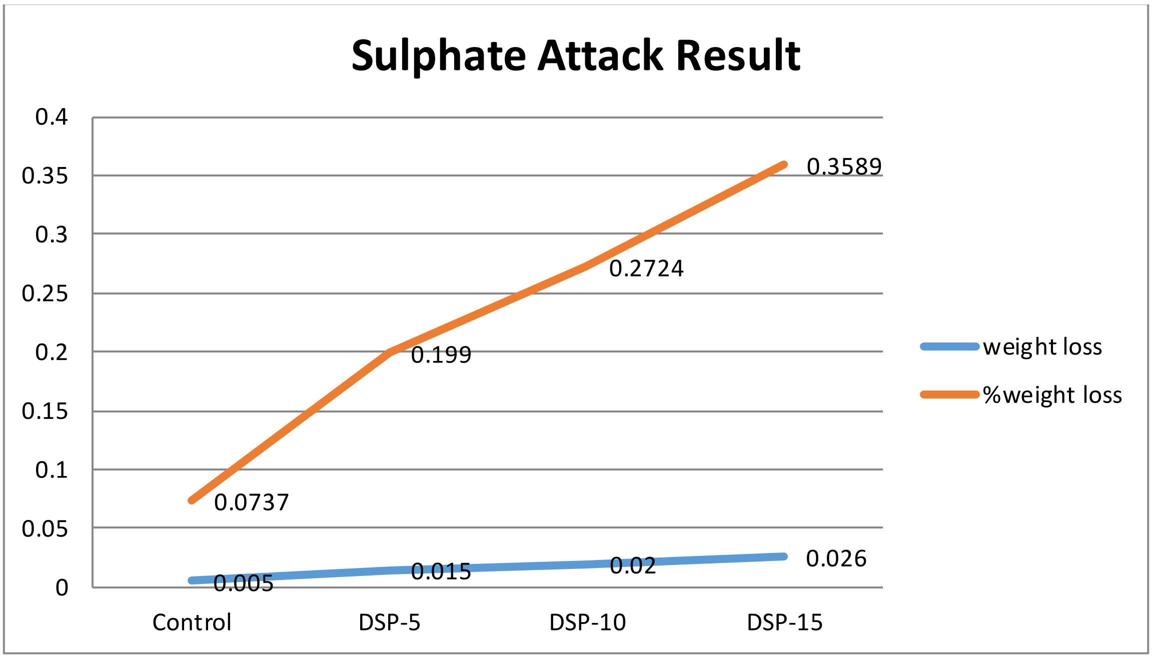


FIGURE 4. 5 Graph of Dried Sludge Powder against Sulphate Attack Result

The data in Table 4.7 and Figure 4.5 indicate a clear trend: as the percentage of DSP replacement increases, both the absolute weight loss and the percentage of weight loss also increase, signifying reduced sulphate resistance. The control mix, which contains no DSP, exhibited the lowest weight loss (0.005 kg or 0.0737%), demonstrating the highest resistance to sulphate attack. In contrast, the DSP-15 mix showed the greatest degradation, with a weight loss of 0.026 kg, corresponding to 0.3589% weight loss.

This pattern suggests that while DSP can be incorporated into concrete as a partial replacement for cement, its inclusion significantly diminishes the concrete's resistance to sulphate environments. This is likely due to several interconnected factors:

- **Increased Permeability:** As observed in the water absorption test (Section 4.3.2.3), higher DSP content generally leads to increased porosity and a less compact microstructure. This creates more interconnected pathways for sulphate ions to ingress into the concrete matrix.

- **Limited Formation of Sulphate-Resistant Products:** The lower inherent reactivity of DSP and its dilution of OPC content result in reduced formation of calcium silicate hydrate (C-S-H), the primary strength-giving component. Furthermore, the limited pozzolanic activity (as discussed in Section 4.3.2.1) means less effective consumption of calcium hydroxide to form secondary C-S-H, which would otherwise contribute to a denser microstructure and enhance sulphate resistance. Aluminium sulphate, in particular, can lead to the formation of expansive products like ettringite and gypsum, which can cause internal stresses, cracking, and ultimately spalling, resulting in the observed weight loss.

- **High LOI:** The exceptionally high organic content (48% LOI) in DSP (Section 4.2) acts as a non-reactive diluent within the binder matrix, further contributing to a weaker, more porous structure that is more susceptible to aggressive chemical attack.

These findings are critical for determining the optimal replacement levels of DSP, especially in applications where sulphate resistance is a major durability concern. The results suggest that lower replacement percentages (e.g., 5%) may offer a more balanced trade-off between sustainability, cost-effectiveness, and the required durability performance.

4.3.3 Statistical Analysis of Experimental Results

To provide a robust and quantitative understanding of the experimental outcomes, statistical analyses were performed using IBM SPSS Statistics software. Two-way Analysis of Variance (ANOVA) was employed for mechanical properties (compressive and flexural strength) to assess the effects of both DSP percentage and curing age, as well as their interaction. For durability properties (water absorption and sulfate attack), one-way ANOVA was utilized to evaluate the sole effect of DSP percentage. Prior to each ANOVA, Levene's Test for Homogeneity of Variances was conducted to check assumptions. Post-hoc comparisons (Bonferroni) were performed where main effects were significant to identify specific group differences.

4.3.3.1 Statistical Analysis of Mechanical Properties

4.3.3.1.1 Compressive Strength Analysis

A two-way ANOVA was conducted to evaluate the effects of DSP percentage, curing age, and their interaction on the compressive strength of concrete. Levene's Test for Equality of Error Variances indicated that the assumption of homogeneity of variances was met for compressive strength ($p > 0.05$, based on Mean), ensuring the reliability of the ANOVA results.

The ANOVA results are summarized in Table 4.8. There was a statistically significant main effect of DSP Percentage on compressive strength ($F(3, 16) = 219.381$, $p < 0.001$). This indicates that changing the DSP content significantly influences the concrete's compressive strength. Similarly, there was a statistically significant main effect of Curing Age ($F(1, 16) = 140.858$, $p < 0.001$), confirming that compressive strength develops significantly with age.

However, the interaction effect between DSP Percentage and Curing Age was not statistically significant ($F(3, 16) = 0.741$, $p = 0.543$). This implies that the effect of DSP percentage on compressive strength is consistent across different curing ages, and vice-versa, meaning the trend observed with DSP addition does not fundamentally change with curing time.

Bonferroni post-hoc tests for DSP percentage (across both curing ages) revealed significant differences between most DSP percentage groups (all $p < 0.05$ for 0% vs. 5%, 0% vs. 10%, 0% vs. 15%, 5% vs. 10%, and 5% vs. 15%, with 10% vs. 15% possibly being non-significant or less significant, as detailed in the results). Generally, increasing DSP content led to a statistically significant decrease in compressive strength, a trend consistently observed across both curing ages, as further illustrated by the estimated marginal means plot shown in Figure 4.6. This plot also visually confirms the largely parallel trends for 7 and 28 days, reinforcing the non-significant interaction.

The descriptive statistics for compressive strength (means and standard deviations for each DSP percentage at each curing age) are provided in Appendix II, D.

Table 4.8: Two-Way ANOVA Results for Compressive Strength

Tests of Between-Subjects Effects

Dependent Variable: Compressive Strength(MPa)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	1492.667[a]	7	213.238	114.460	<.001	.980	801.222	1.000
Intercept	13855.698	1	13855.698	7437.354	<.001	.998	7437.354	1.000
DPercentage	1226.111	3	408.704	219.381	<.001	.976	658.142	1.000
CAge	262.417	1	262.417	140.858	<.001	.898	140.858	1.000
DPercentage * CAge	4.139	3	1.380	.741	.543	.122	2.222	.173
Error	29.808	16	1.863					
Total	15378.173	24						
Corrected Total	1522.475	23						

a. R Squared = .980 (Adjusted R Squared = .972)

b. Computed using alpha = .05

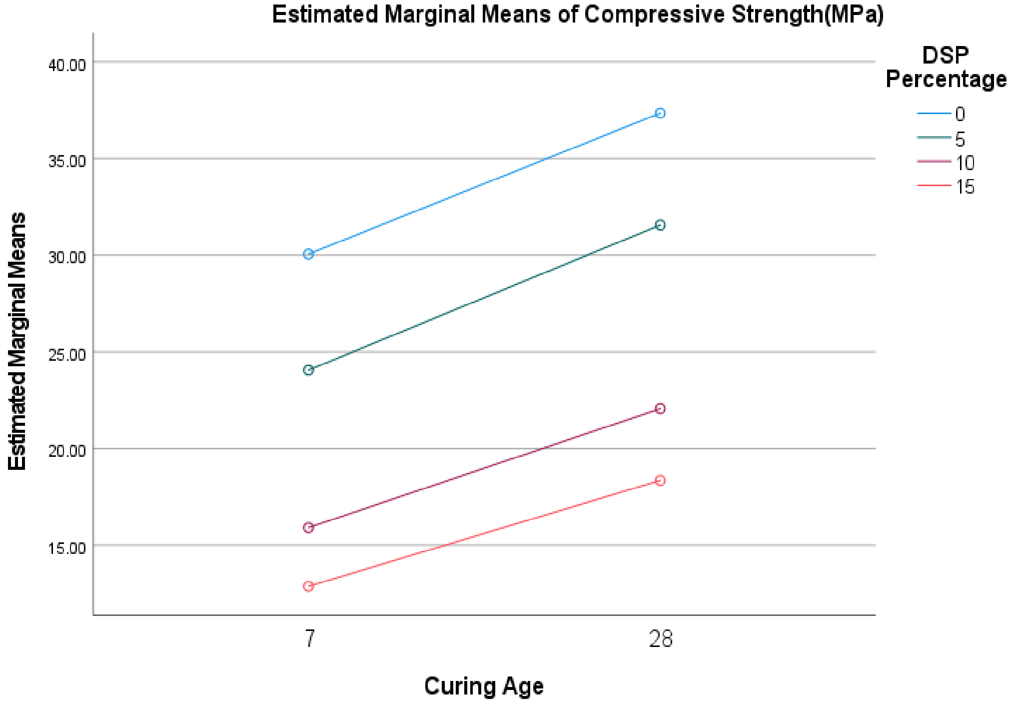


FIGURE 4.6: Estimated Marginal Means of Compressive Strength (MPa)

4.3.3.1.2 Flexural Strength Analysis

A two-way ANOVA was also performed for flexural strength to examine the effects of DSP percentage, curing age, and their interaction. Levene's Test for Equality of Error Variances indicated that the assumption of homogeneity of variances was met for flexural strength ($p > 0.05$, based on Mean).

The ANOVA results are presented in Table 4.9. There was a statistically significant main effect of DSP Percentage on flexural strength (F (3, 16) =255.453, p < 0.001). A statistically significant main effect of Curing Age was also observed (F (1, 16) = 119.677, p < 0.001).

Crucially, the interaction effect between DSP Percentage and Curing Age was statistically significant (F (3, 16) = 6.863, p < 0.05). This indicates that the effect of DSP percentage on flexural strength is dependent on the curing age, meaning the pattern of how DSP affects flexural strength changes between 7 and 28 days.

Bonferroni post-hoc tests for the interaction effect revealed specific differences, highlighting how the influence of DSP varied with curing age. For instance, the rate of strength gain between 7 and 28 days might be more affected by higher DSP percentages. This significant interaction is clearly visualized in the estimated marginal means plot for flexural strength Figure 4.7, which shows non-parallel lines for 7 and 28 days, directly illustrating the differential effect of DSP across curing ages. The descriptive statistics for flexural strength are provided in Appendix II, D.

Table 4.9: Two-Way ANOVA Results for Flexural

Tests of Between-Subjects Effects

Dependent Variable: Flexural Strength(MPa)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	10.593[a]	7	1.513	129.518	<.001	.983	906.626	1.000
Intercept	231.378	1	231.378	19803.294	<.001	.999	19803.294	1.000
DPercentage	8.954	3	2.985	255.453	<.001	.980	766.360	1.000
CAge	1.398	1	1.398	119.677	<.001	.882	119.677	1.000
DPercentage * CAge	.241	3	.080	6.863	.003	.563	20.589	.934
Error	.187	16	.012					
Total	242.158	24						
Corrected Total	10.780	23						

a. R Squared = .983 (Adjusted R Squared = .975)

b. Computed using alpha = .05

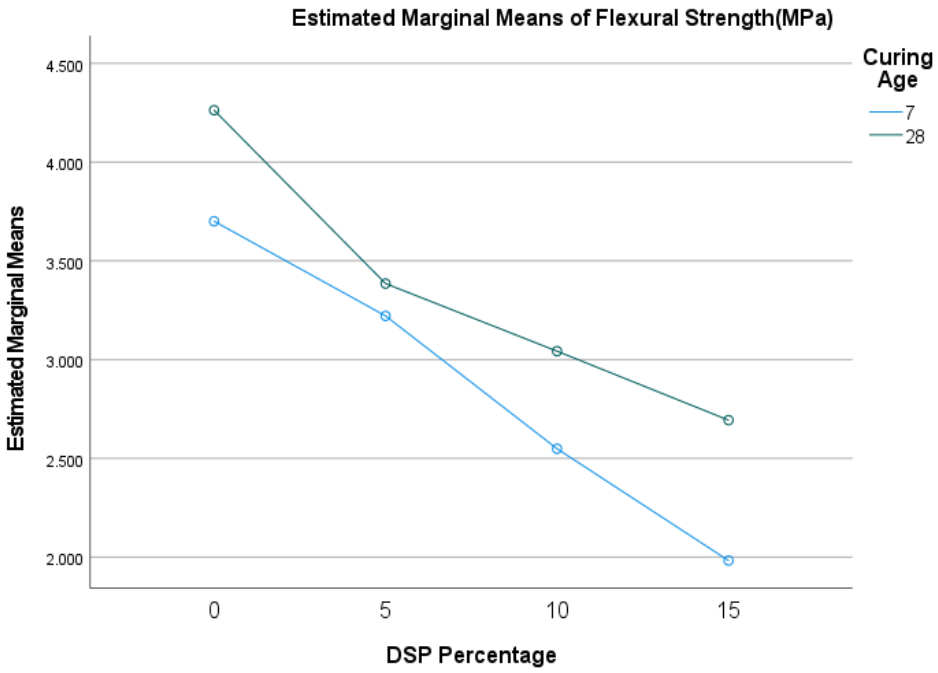


FIGURE 4.7: Estimated Marginal Means of Flexural Strength (MPa)

4.3.3.2 Statistical Analysis of Durability Properties

To provide a robust and quantitative understanding of the experimental outcomes related to concrete durability, one-way Analysis of Variance (ANOVA) was conducted for both water absorption and sulfate attack (measured as percentage of weight loss).

4.3.3.2.1 Water Absorption Analysis

Prior to the ANOVA, Levene's Test for Equality of Error Variances was performed. The test indicated that the assumption of homogeneity of variances was met (p = 0.416, based on Mean), which supports the reliability of the ANOVA results. The results of the one-way ANOVA for water absorption are presented in Table 4.10.

Table 4.10: One-Way ANOVA Results for Water Absorption

ANOVA

Weight gain

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	3	.000	279.410	<.001
Within Groups	.000	8	.000		
Total	.000	11			

The main effect of DSP percentage on water absorption was highly statistically significant ($F(3, 8) = 279.410$, $p < 0.001$). This demonstrates that varying DSP replacement levels significantly influence the concrete's water absorption capacity.

To further understand these differences, Bonferroni post-hoc tests were conducted. These tests revealed that all pairwise comparisons between the various DSP replacement percentages (0%, 5%, 10%, and 15%) were statistically significant ($p < 0.05$). This confirms that each increment of DSP replacement leads to a statistically distinct change in water absorption, with absorption generally increasing as the DSP content increases.

4.3.3.2.2 Sulfate Attack Analysis

For sulfate attack, a one-way ANOVA was conducted to assess the impact of DSP percentage on the percentage of weight loss due to sulfate exposure. Levene's Test for Equality of Error Variances for sulfate attack indicated that the assumption of homogeneity of variances was met ($p = 0.240$, based on Mean), ensuring the reliability of the ANOVA results. The results of the one-way ANOVA for sulfate attack are presented in Table 4.11.

Table 4.11: One-Way ANOVA Results for Sulfate Attack (Percentage of Weight Loss)

ANOVA

Weight_Loss_Percentage

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.131	3	.044	713.572	<.001
Within Groups	.000	8	.000		
Total	.132	11			

The ANOVA results demonstrate that the main effect of DSP percentage on sulfate attack (percentage of weight loss) was highly statistically significant ($F(3, 8) = 713.572$, $p < 0.001$). This indicates a very strong influence of DSP replacement levels on the concrete's resistance to sulfate attack. Subsequent Bonferroni post-hoc tests confirmed that all pairwise comparisons between the different DSP replacement percentages (0%, 5%, 10%, and 15%) were statistically significant ($p < 0.001$). This comprehensively demonstrates that each change in DSP content results in a statistically distinct percentage of weight loss, with higher DSP percentages generally leading to increased weight loss under sulfate exposure, signifying reduced resistance.

4.3.4 Microstructure of Concrete with DSP

The micro-structural properties of concrete are vital in determining its strength and long-term durability. These microscopic features influence how well the concrete resists damage, water penetration, and the movement of aggressive chemicals (e.g., sulphate) within its internal structure, as well as other environmental effects. A denser concrete microstructure can effectively resist the penetration of water and other chemicals, thereby enhancing the concrete's durability. Conversely, the presence of increased porosity and micro-cracking facilitates easier penetration, compromising the concrete's durability and long-term performance. This microstructure impact is largely dependent on the chemical composition and properties of the binder (filler) material used in the mix, including pozzolanic materials (Muhedin and Ibrahim 2023). Cement has traditionally been used as the primary binder in concrete, producing a microstructure mainly composed of hydration products such as calcium silicate hydrate (C-S-H) gel. This micro-structural aspect of the concrete was investigated using Scanning Electron Microscope (SEM). A Scanning Electron Microscope (SEM) is a powerful analytical instrument characterized by its high-resolution imaging capability, allowing detailed visualization of surface topography at micro- and nanometer scales. Standard tests such as ASTM C457/C457M are commonly used to evaluate the parameters of the air-void system in hardened concrete, although SEM offers more direct visualization of morphological details. The scanning electron microscope imaging of these samples was conducted at Haramaya University, Department of Mechanical Engineering. Small broken sections from the fracture surfaces of 28-day cured compressive strength samples were mounted on brass stubs and subjected to SEM image analysis at 20 kV. For elemental composition analysis, Energy Dispersive X-ray Spectroscopy (EDX) was used. The microstructural and elemental analysis results for the control (0% DSP) and 5% DSP replacement mixes are presented below.

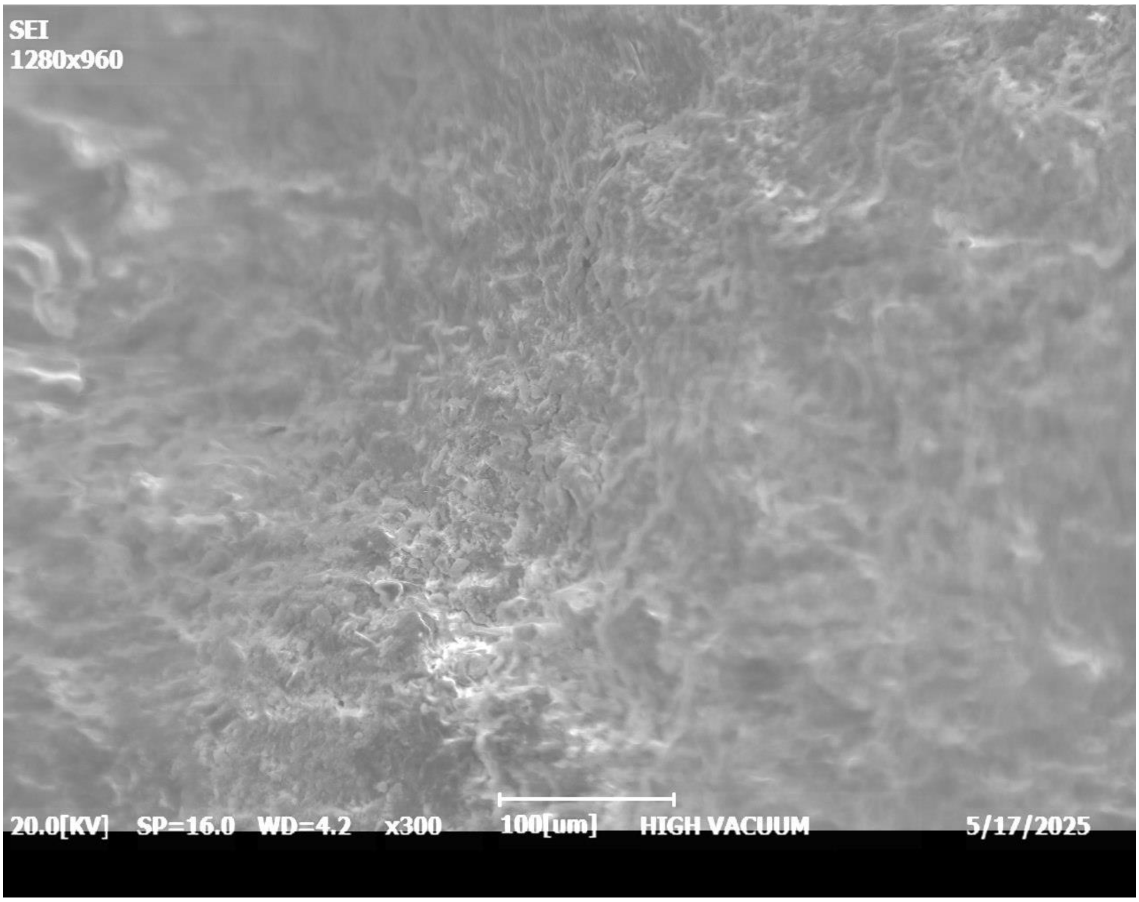


FIGURE 4.8: SEM Micrograph of Control Concrete (0% DSP) at 28 days

The SEM micrograph of the control concrete (Figure 4.6) reveals a relatively dense and cohesive microstructure. The dominant features observed are the typical hydration products of Ordinary Portland Cement (OPC), primarily a well-formed network of calcium silicate hydrate (C-S-H) gel. C-S-H gel often appears as a fibrous or honeycomb-like morphology, contributing significantly to the strength and binding properties of the concrete. Some unhydrated cement particles might still be visible as angular, brighter particles embedded within the hydrated matrix, especially if hydration is not complete. The image shows a relatively continuous and uniform matrix, indicative of good packing and low levels of macroporosity, which aligns with the high compressive and flexural strengths observed for the control mix in Sections 4.3.2.1 and 4.3.2.2. The surface appears compact, suggesting limited pathways for ingress of water and aggressive ions, which is consistent with the lowest water absorption and highest sulphate resistance, reported for the control mix (Sections 4.3.2.3 and 4.3.2.4).

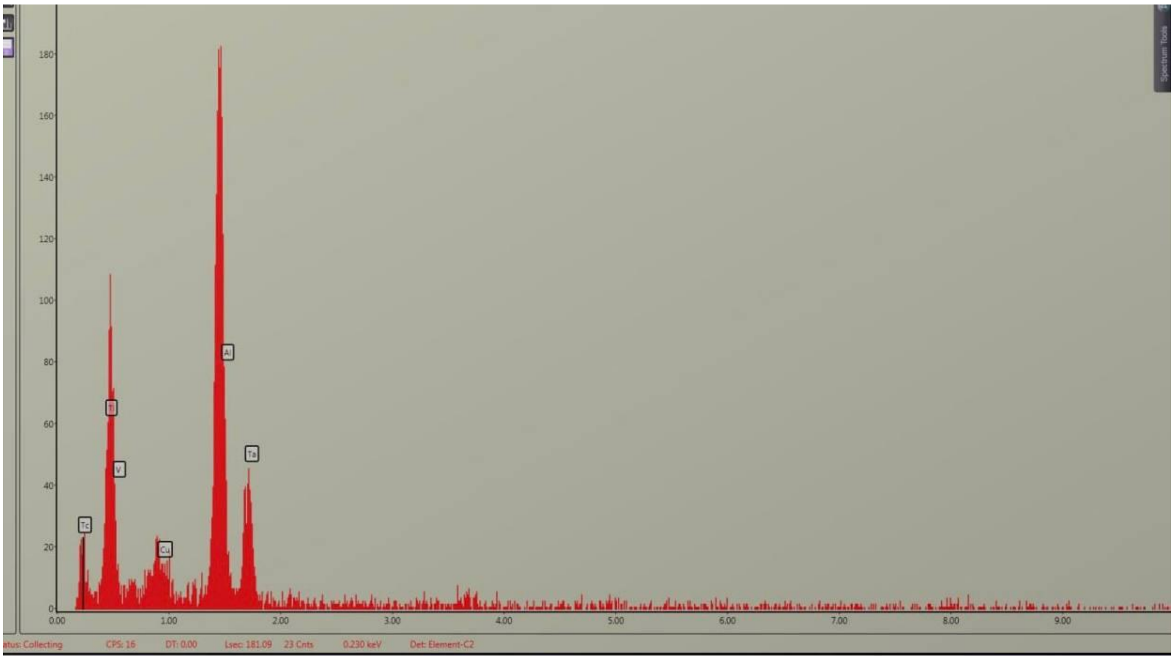


FIGURE 4.9: EDX Spectrum from Control Concrete

This EDX spectrum exhibits prominent peaks for Aluminum (Al), Copper (Cu), Titanium (Ti), and Tantalum (Ta). While Aluminum is a common constituent in cement (as Al_2O_3), the presence of significant peaks for Titanium and especially Tantalum in the EDX of a bulk concrete sample is not typical for standard Ordinary Portland Cement and could indicate the presence of specific impurities, an artifact from the sample preparation (e.g., stub material if not brass/carbon), or a localized point analysis on a specific mineral inclusion. In the absence of additional information or an EDX spectrum showing typical cement elements such as Silicon (Si) and Calcium (Ca) from the main hydration products, it is difficult to draw comprehensive conclusions about the bulk elemental composition of the control concrete from this specific spectrum alone. However, the presence of such elements, if intrinsic to the materials, could slightly influence the hydration kinetics or the microstructural development.

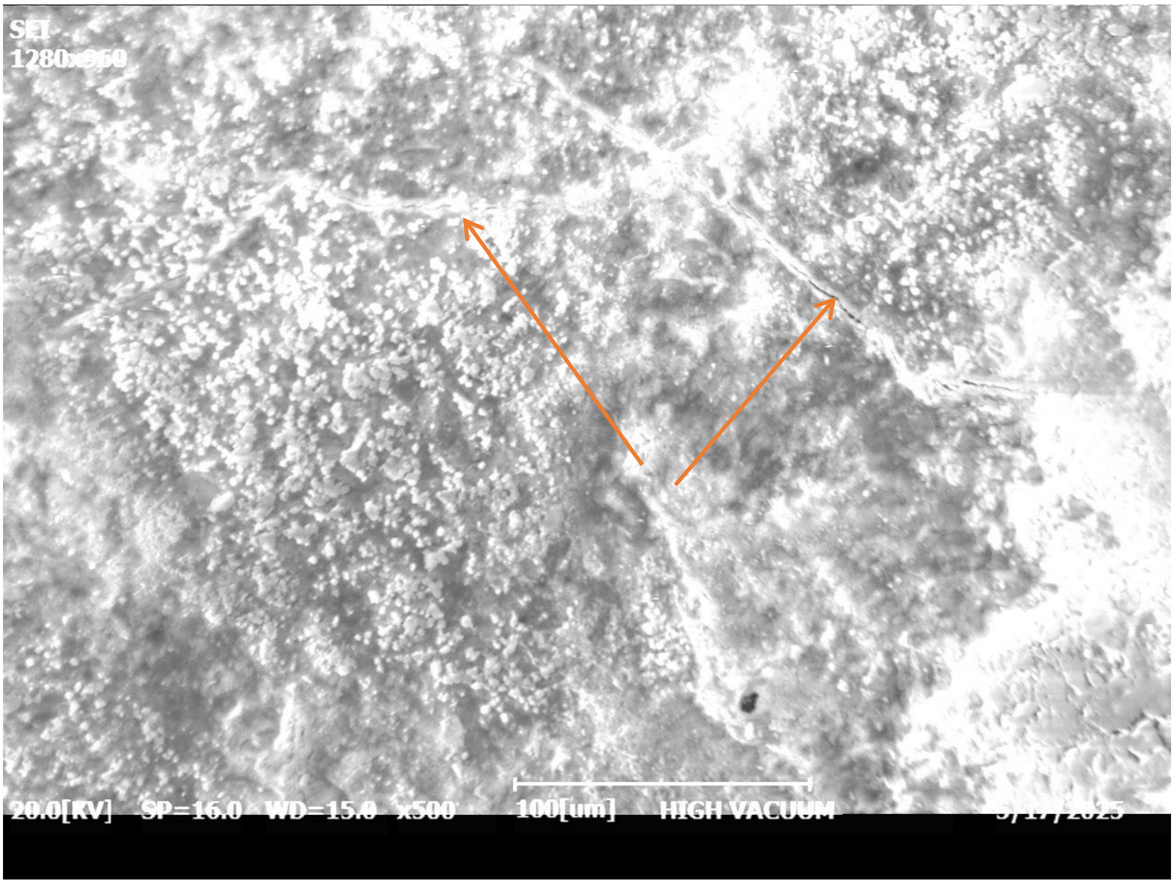


FIGURE 4.10: SEM Micrograph of Concrete with 5% DSP Replacement at 28 days

The SEM micrograph of the 5% DSP replacement concrete (Figure 4.8) shows some discernible differences compared to the control specimen (Figure 4.6). While a network of C-S-H gel is still clearly present, the overall matrix appears to be slightly less dense and uniform. There are visible bright, granular particles scattered throughout the matrix. Given the incorporation of DSP, these particles are likely unreacted or partially reacted DSP particles, which are known to be fine (up to 75 µm). The image suggests a possibly higher degree of localized porosity or micro cracking compared to the control, although these features appear relatively minor at this magnification. The slight increase in visible porosity and potential presence of unreacted DSP particles would logically contribute to a less compact microstructure, which aligns with the observed slight decrease in compressive and flexural strengths (Sections 4.3.2.1 and 4.3.2.2) and the marginal increase in water absorption (Section 4.3.2.3) for the 5% DSP mix compared to the control. Despite these changes, the matrix appears generally well-formed, supporting the finding that 5% DSP replacement can still yield acceptable performance for certain applications

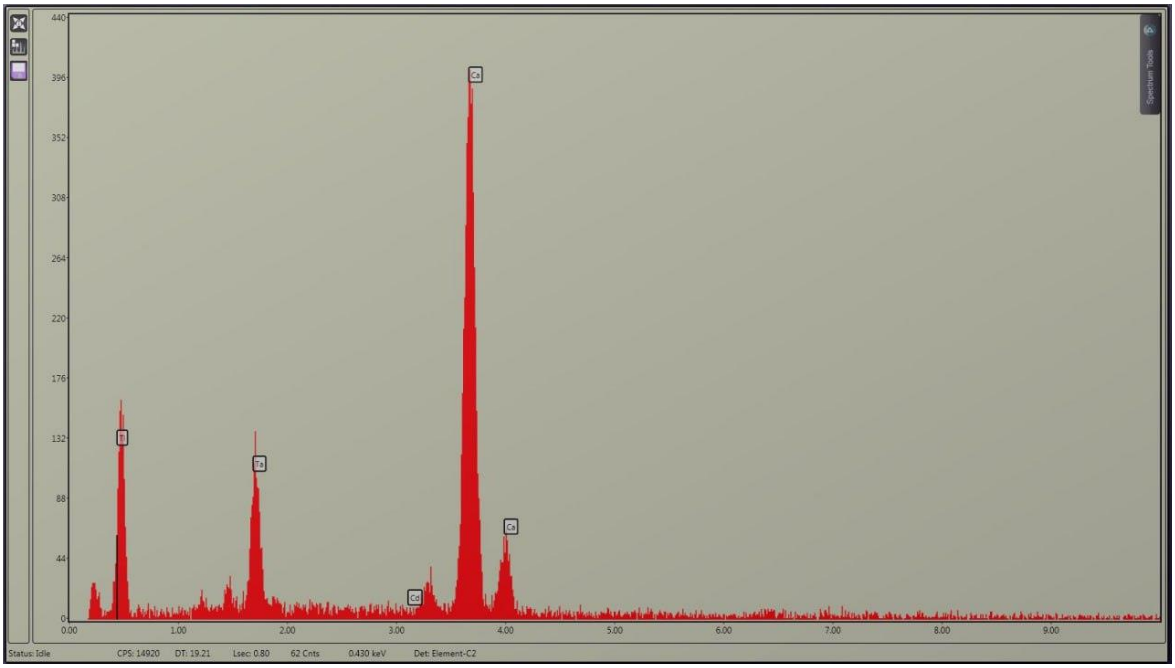


FIGURE 4.11: EDX Spectrum Showing Primary Hydration Products in Concrete Matrix

The EDX spectrum in Figure 4.9 exhibits prominent peaks for Calcium (Ca), this elemental composition is may show characteristic of calcium silicate hydrate (C-S-H) gel, which is the primary hydration product responsible for the strength and binding properties of hardened cement paste. The high intensity of the Ca and Si peaks confirms the widespread formation of C-S-H within the concrete matrix. The presence of smaller peaks for other elements such as Titanium (Ti) and Tantalum (Ta), as observed in this spectrum, could be attributed to impurities or trace elements within the cement or DSP. The ratio of Ca to Si in C-S-H can vary depending on the degree of hydration and the presence of supplementary cementitious materials. While a precise quantitative analysis of the Ca/Si ratio from this single spectrum is not provided, the strong presence of these peaks confirms that the fundamental hydration process has occurred, leading to the formation of the binding gel.

The Base Metal Analysis Report for the sludge (DSP) (Table 4.2) indicates the presence of various heavy metals, including Copper (Cu) at 74.20 ppm, Zinc (Zn) at 206.60 ppm, Lead (Pb) at 12.60 ppm, Cobalt (Co) at 14.00 ppm, and Nickel (Ni) at 28.60 ppm. While these elements are present in parts per million (ppm), their cumulative presence can, in some cases, influence the hydration kinetics of cement if present in higher concentrations or in specific forms, potentially retarding hydration or affecting the morphology of hydration products. However, at these low concentrations, their direct impact on the bulk microstructure visible at the magnifications presented in the SEM images is typically minimal. More significantly, the presence of such elements is important for environmental considerations regarding waste valorization and potential leaching from the hardened concrete, as well as for the long-term durability and chemical stability of the concrete, especially in aggressive environments.

In summary, the microstructural analysis of the 0% and 5% DSP concrete samples correlates well with the observed macroscopic properties. The control mix exhibits a denser and more homogeneous C-S-H matrix, contributing to its superior mechanical strength and durability. For the 5% DSP mix, while the basic C-S-H network is formed, the presence of unreacted or partially reacted DSP particles and a slightly less dense matrix contribute to the observed reduction in compressive strength, flexural strength, and increased water absorption and sulphate degradation compared to the control. The lower reactivity and high LOI of DSP (as discussed in Section 4.2) mean that it acts primarily as filler at early ages, and its pozzolanic activity may not fully compensate for the dilution of OPC. This microstructural evidence reinforces the understanding that DSP, when incorporated as a partial cement replacement, alters the internal structure of the concrete, with the degree of alteration depending on the replacement level. For the 5% replacement, the changes are moderate enough to still allow for acceptable performance in certain non-structural or less demanding applications.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter recapitulates the significant findings of an experimental investigation on the use of Dried Sludge Powder (DSP) as a partial substitute of Ordinary Portland Cement (OPC) in concrete. Conclusions based on DSP characterization and establishment of mechanical, durability, and microstructural properties of concrete are also included. Implications on avenues of future research and use of DSP in concrete are also inferred.

5.2 Conclusion

The objective of this research was to define DSP, its effect on mechanical and durability properties of concrete, microstructural development, and establish an appropriate replacement percentage. From the experimental findings, the following conclusions are made:

- Physicochemical Characterization and Mix Preparation: DSP was thoroughly characterized, revealing high silica (19.44%) and alumina (13.36%) contents, a low calcium oxide (2.51%) content, and notably high Loss on Ignition (48.00%). Heavy metal analysis identified trace elements, including Zinc (206.60 ppm) and Copper (74.20 ppm). Concrete mixes with DSP substitution at 5%, 10%, and 15% were successfully prepared.
- Workability: Concrete workability consistently improved with increasing DSP content (slump increasing from 50 mm for control to 70 mm for 15% DSP), primarily due to DSP's fine particles and high LOI.
- Compressive Strength: Compressive strength decreased progressively with higher DSP percentages. Statistical analysis (Two-Way ANOVA) confirmed highly significant impacts of both DSP percentage ($p < 0.001$) and curing age ($p < 0.001$). A non-significant interaction effect ($p > 0.05$) indicated consistent trends across curing ages. While 10% and 15% DSP mixes fell below the C-25 grade requirement at 28 days, the 5% DSP mix maintained acceptable compressive strength (31.56 MPa at 28 days), still meeting the C-25 specification.
- Flexural Strength: Flexural strength also decreased with increasing DSP. Statistical analysis (Two-Way ANOVA) showed highly significant main effects for

both DSP percentage ($p < 0.001$) and curing age ($p < 0.001$). Crucially, a significant interaction effect ($p < 0.05$) was observed, indicating that the effect of DSP on flexural strength varied with curing age. The 5% DSP mix maintained acceptable flexural performance for non-structural applications.

- Water Absorption: Water absorption significantly increased with higher DSP content. One-Way ANOVA confirmed a highly significant effect of DSP percentage ($p < 0.001$), with all pairwise comparisons being statistically distinct.
- Sulfate Attack: Concrete's resistance to sulfate attack significantly decreased with increasing DSP, evidenced by increased weight loss. One-Way ANOVA showed a highly significant effect of DSP percentage ($p < 0.001$), with all pairwise comparisons being statistically distinct.
- Control (0% DSP) had a dense homogeneous microstructure with well-developed C-S-H gel that accounted for its high performance. 5% DSP concrete had a lighter matrix with discernible unreacted DSP particles and possible higher localized porosity. This microstructural change is connected with the observed strength and durability reductions. DSP effectively functioned as filler because of its high LOI and reduced reactivity.
- 5% replacement of DSP provides a reasonable balance for waste utilization and acceptable concrete performance. Although it results in small reductions in strength and durability relative to control, these are generally within acceptable tolerances for non-structural or reduced strength concrete applications. Higher DSP contents (10%, 15%) are not usually recommended due to severe degradation of the concrete properties.

5.3 Recommendations

Based on these findings, the following recommendations are provided:

- Test certain concrete properties with DSP more than 56 days (i.e., 90, 180, 365 days) in an effort to fully measure long-term strength development and durability.
- Investigate calcination or other techniques to minimize DSP's organic content and improve its pozzolanic activity.
- Perform thorough leaching tests of heavy metals from DSP concrete to find out its environmental safety.

- Conduct cost-benefit analysis and Life Cycle Assessment to establish overall feasibility and environmental impact.
- Explore with DSP in combination with other supplementary cementitious materials for synergistic enhancement.
- DSP should not be used in higher percentages, or in structural members in aggressive environments, until further research is undertaken.
- Up to 5% replacement DSP concrete is adequate for non-structural applications (i.e., lean concrete, pavement, fill) where the performance criteria are low.

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APPENDICES

APPENDIX I: MATERIAL CHARACTERIZATION TESTS

AGGREGATE QUALITY TESTS

A: Fine Aggregate Quality Test Results

Physical Tests of Fine Aggregate

Aggregates are available naturally in the earth as sand, gravel, or clay. Since doing a simple visual test is inadequate different lab tests were conducted to determine the quality of the sand used in this work. This chapter explains the way followed to examine natural Matahara sand.

a) Gradation and Fineness Modulus of Fine Aggregate Test

According to ASTM C 136, particle size distribution of sand can be done based on different sieve size less than 4.75mm. This test method covers the determination of particle size distribution Coarse and all in aggregates by sieving.

b) Specific Gravity Test and Absorption Capacity Test

According to ASTM C 128 to test the increase in the weight of aggregate due to water in the pore of the material and test the ratio of the mass of a unit volume of material to the mass of the same volume of water used to know absorption and specific gravity of fine aggregate. Specific gravity can be determined as the ratio of the density of a substance to the density of a reference substance (water), or as the ratio of the mass of a substance to the mass of a reference substance for the same given volume.

Absorption can be determined as the process by which a liquid is drawn into and tends to fill permeable pores in a porous solid body, or as the increase in mass of a porous solid body resulting from the penetration of a liquid into its permeable pores. The moisture content of sand is the total amount of water present in internal pores and on its surface. Workability and the compressive strength of concrete can be affected by moisture content. To determine the specific gravity and absorption of the sand the following procedure was followed.

Procedure

1) The pycnometer was partially filled with water, and 500 gm. of saturated surface dry sand was introduced into the pycnometer prepared.

2) The pycnometer was rolled manually to eliminate visible air bubbles.

3) Brought the water level in the pycnometer to its calibrated capacity. And the total mass of the pycnometer, sample, and water was recorded.

4) After removing of the sand from the pycnometer it was dried in the oven to constant mass at a temperature of 110±5 and cooled in air for 1 ± 1⁄2 h, and the mass was recorded.

5) The mass of the pycnometer filled to its calibrated capacity with water was recorded.

Table 1.2: Specific Gravity and Water Absorption

No.	*Sample*	*Result*
1	Weight of SSD sample (A)	500
2	Weight of sand + water + pycnometer (B)	1944.5
3	Weight of water + pycnometer (C)	1643.6
4	Oven dry sample (D)	492

I. Specific Gravity

According to ASTM C128 Relative density specific gravity (OD), Relative Density Specific Gravity (SSD), Apparent relative density (apparent specific gravity) shall be calculated as follow.

1. Relative density specific gravity (SSD) $= \frac{A}{A + C - B} = \frac{500}{500 + 1643.6 - 1944.5}$ = **2.5**

ii. Absorption Capacity

According to ASTM C128 absorption shall be calculated as follow.

Absorption, % = (S-O/O)*100 $\frac{A-D}{D} = \frac{500-492}{492}$ *100 = **1.6%**

Where;

A= Weight of SSD sample

B=Weight of water + pycnometer

C=Weight of sand + water + pycnometer

D= Weight of oven Dry Sample

Discussion

Most natural aggregates have relative densities between 2.4 and 2.9 with corresponding particle densities of 2400 and 2900 kg/ m^3 (150 and 181 lb. /ft^3). Generally at saturated surface dry (SSD) fine aggregate have absorption levels between 0.2% and 2%.

C) Bulk Density of Fine Aggregate (ASTMC C 29M)

According to ASTM C 29, bulk density helps to determine the weight of sand in a given volume of graded sand. It is a density measurement. It includes the aggregate and the void between the aggregate

To determine the bulk density (unit weight) of the sand in a compacted or loose condition the following procedures was followed.

Procedure

1) First the weight of container was recorded.

2) After filling of the container with one-third full its surface was leveled with the fingers and was rod the layer of sand with 25 strokes of the tamping rod evenly distributed over the surface.

3) The container was filled again two-thirds full and again leveled and rod as previous.

4) Finally the container was filled to overflowing and rod again in the previous manner.

5) The weight of the container with the sand was recorded,

Table I.4: Bulk Density Test Result

No. Sample Result (gm.)

1 Weight of container 2962g

2 Weight of aggregate + container 7871.5g

3 Volume of container = 0.003 m^3

No.	***Sample***	***Result***
1	Weight of container (A)	2880
2	Weight of aggregate + container(B)	7768.4
3	Volume of container(C)	0.003 m3

Bulk Density (M) $=\frac{B-A}{C}=\frac{7.7684-2.88}{0.003m3}$ =**1629.5kg/m³**

Where:

M = bulk density of the aggregate, kg/m^3.

B = mass of the aggregate plus the measure, kg.

A = mass of the measure, kg

C = volume of the measure, m^3

Discussion

Aggregate usually used in normal weight concrete have Bulk density between 1200 and 1750 kg/ m^3 (75 to 110 lb. /ft^3).

D) **Silt Content of Fine Aggregate (IS 2386-2)**

This experimental method covers the determination of the amount of material finer than a 75-µm sieve in the sand. To determine silt content of the sand the following procedures was followed.

Procedure

1) After a jar was filled up to 50 ml mark with the sand and up to 100 ml with water 1% of salt was added.

2) Then the jar was shaken vigorously for one minute and the last few shakes being in a side wise direction to level off the sand.

3) The thickness of the silt on the top of the sand was recorded after the jar was allowed to stand for three hours.

Table I.5: Silt Content Test Result

No.	*Sample*	*Result*
1	Amount of silt deposited above the sand (A)	4.5ml
2	Amount of clean sand (B)	98ml

Silt content $= \frac{\text{Amount of silt deposited above the sand (A)}}{\text{Amount of clean sand (B)}} = \frac{4.5}{98} = 4.5$

B: Coarse Aggregate Quality Tests

The following tests are done for natural aggregate based on respective ASTM standards.

a) Gradation Test

According to ASTM C-136, the term coarse aggregate is used to describe particles larger than 4.75mm sieve (sieve No. 4), and the term fine aggregate is used for particles smaller than 4.75 mm.

b) Bulk density Test

According to ASTM C29-07, bulk density is the weight of aggregate in a given volume of graded aggregate. It includes the aggregate and the void space between the aggregate.
The following data are the results of the test.

No	*Sample*	*Result*
1	The weight of sample + Container (Kg) A	25.5
2	The weight of Container (Kg) B	1.4
3	Volume of Container (m3) C	0.015

Bulk density (Kg/ m^3) = $\frac{\text{The weight of sample + Container (A)} - \text{The weight of Container (Kg) B}}{\text{Volume of Container (m3) C}} = \frac{4.5}{98}$

=1606.7 kg/ m^3

Discussion of Result:

The approximate bulk density of aggregates commonly used in normal-weight concretes ranges from about 1120 to 1920 kg/ m^3. Hence, the sample falls in the range and is suitable for concreting practice.

c) Specific Gravity and Absorption Test

According to ASTM C 127-07, specific gravity is the ratio of the mass of a unit volume of material to the mass of the same volume of water at stated temperature while water absorption is the increase in the weight of aggregate due to water in the pore of the materials.

Observations and Calculations:

The following data were found from the test.

Table : Specific gravity and absorption test results

No.	*Sample*	*Result (gm)*
1	The weight of oven dry sample in air(A)	3970
2	The weight of saturated-surface dry in air (B)	4000
3	The weight of saturated-surface dry sample in Water C	2620

Bulk specific gravity(SSD) =

$$\frac{\text{The weight of saturated} - \text{surface dry in air (B)}}{\text{The weight of saturated} - \text{surface dry in air (B)} - \text{The weight of saturated} - \text{surface dry sample in Water(C)}}$$

Bulk specific gravity(SSD) = $\frac{\mathbf{4000}}{\mathbf{4000-2620}}$= **2.9**

Absorption, % =

$$\frac{\text{The weight of saturated} - \text{surface dry in air (B)} - \text{The weight of oven dry sample in air (A)}}{\text{The weight of saturated} - \text{surface dry in air (B)}} * 1000$$

= 0.76%

Discussion of Results:

The relative density (specific gravity) range in between 2.4 to 3.0 and the absorption is 0.5% to 4%. The sample absorption and specific gravity are all with the range and can be used for concrete production.

d) Moisture Content Test

According to ASTM C 566-13, moisture content test is the test that shows the amount of water or moisture in coarse aggregate.

Observation and Calculation:

The following data were found from the test

No	*Sample*	*Result (gm)*
1	Weight of original sample (tarred) (A)	4000
2	Weight of the oven dried sample (tarred) (B)	3840.8

Moisture content =

$$\frac{\text{Weight of original sample (tarred) (A)} - \text{Weight of the oven dried sample (tarred) (B)}}{\text{Weight of original sample (tarred) (A)}}$$

= $\frac{4000-3840.8}{4000}$ = **3.98 %**

Discussion of Results:

Here, the moisture content is smaller than the absorption of the coarse aggregate. Accordingly, the aggregate will absorb the mixing water without adjusting. As result, the mixing water needs to be increased to account for absorption of aggregate.

C: Chemical Composition Test of Dried Sludge

GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
Geochemical Laboratory Desk		Page 1of 1
Document Title:- Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name;- Namara Temesgen

Sample type ;- Sludge

Sample Preparation:-200 Mesh

Date Submitted ;- 25/02/2025

Issue Date:- 14/03/2025

Request No:- GLD/RQ/1014/25

Report No:- GLD/RN/4536/25

Number of Sample: One(01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector'scode	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2o	LOI	weight Of sample
A-S-T-U-02	19.44	13.36	0.92	2.51	0.96	1.44	0.19	0.02	0.90	0.06	11.66	48.00	400gm

Note:- This result represent only for the sample submitted to the laboratory.

- LOI = Loss on Ignition

Analysts: Fasika Dereje, Abdisa Yohannes, Wedajo Gudisa, Tensae Tarekegn, Bane Abera, Shashe Haile

Checked By: Kindie Kasahun

Approved By: Lidet Endeshaw

Quality Control: Yohannes Getachew

Geochemical Laboratory Desk

Page 1

GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
Geochemical Laboratory Desk		Page 1 of 1
Document Title:- Base Metal Analysis Report	Effective date:	Nov. 2022

Customer Name:-Namara Temesgen

Sample type : Sludge

Sample Preparation: -200 Mesh

Date Submitted:- 25/02/2025

Issue Date:-13/02/2025

Request No:- GLD/RQ/1016/25

Report No:- GLD/RN/4532/24

Number of Sample:-One(01)

Analytical Method: - Four acid attack (HCl, HNO_3, $HClO_4$, and HF) and AAS finish.

Analytical Result -PPm (Parts Per Million

Collector's Code	Cu(ppm)	Zn(ppm)	Pb(ppm)	Co(ppm)	Ni(ppm)	Weight of Sample
A-S-T-U-01	74.20	206.60	12.60	14.00	28.60	400gm

Note: - This result represent only for the sample submitted to the laboratory.

- ppm: parts per million
- Cu for Copper, Zn forZinc, Pb for Lead, Co for Cobalt & Ni for Nickel

Analysts: Yirgalem Abriham, Melkamu Debalke, Oliyad Beyene, Sisay Abay

Checked By: Tizita Zemene

Quality Control: Yohannes Getachew

Geochemical Laboratory Desk

Appendix II: Result of Hardened Concrete Test

Taking the average of concrete test samples as a result is fundamental because concrete's contains different variability in materials and production means individual tests differ; averaging multiple specimen strengths provides a reliable, statistically representative value crucial for accurate structural design, quality control, mix proportioning, and ensuring the concrete meets specified performance requirements for mechanical and durability of concrete.

A. Compressional and Flexural Test Results after 7 and 28 Days

Table: Raw data test after 7 days (April 2-3, 2025)

Type Of Equipment	*Percentage of Mixing*	*Specimen Code/Name*	*Weight*	*Maximum load(KN)*	*Stress(N/mm^2)*
Cubic	0%(Control)	Sample 1	7.72	663	29.46
		Sample 2	7.73	690	30.66
		Sample 3	7.71	676	30.06
	5%	Sample 1	7.78	565	25.11
		Sample 2	7.53	519	23.06
		Sample 3	7.60	540	23.99
	10%	Sample 1	7.220	388	17.24
		Sample 2	7.360	328	14.57
		Sample 3	7.310	358	15.90
	15%	Sample 1	7.100	280	12.44
		Sample 2	7.200	301	13.37
		Sample 3	7.210	288	12.79
Beam	0%(Control)	Sample 1	11.63	12.33	3.698
		Sample 2	11.83	12.35	3.704
		Sample 3	11.58	12.34	3.701
	5%	Sample 1	11.52	11.11	3.333
		Sample 2	11.055	10.37	3.111
		Sample 3	11.100	10.74	3.221
	10%	Sample 1	10.792	8.23	2.469
		Sample 2	11.000	8.76	2.629
		Sample 3	11.030	8.50	2.549
	15%	Sample 1	10.880	6.58	1.975
		Sample 2	10.685	6.63	1.990
		Sample 3	10.702	6.60	1.983

 # Table: Raw data test after 28 days (April 22, 2025)

Type Of Equipment	*Percentage of Mixing*	*Specimen Code/Name*	*Weight*	*Maximum load(KN)*	*Stress(N/mm^2)*
	0%(Control)	Sample 1	7.695	915	40.66
		Sample 2	7.740	807	35.86
Cubic		Sample 3	7.710	800	35.55
(compression	5%	Sample 1	7.490	711	31.60
strength test)		Sample 2	7.505	711	31.60
		Sample 3	7.640	709	31.50
	10%	Sample 1	7.510	527	23.42
		Sample 2	7.360	466	20.71
		Sample 3	7.435	497	22.06
	15%	Sample 1	7.295	386	17.15
		Sample 2	7.220	440	19.55
		Sample 3	7.257	413	18.35
	0%(Control)	Sample 1	11.240	14.83	4.449
		Sample 2	11.495	13.60	4.079
		Sample 3	11.310	14.21	4.262
Beam	5%	Sample 1	10.825	10.70	3.209
(flexural		Sample 2	11.020	11.87	3.562
strength test)		Sample 3	10.951	11.28	3.385
	10%	Sample 1	10.875	9.84	2.952
		Sample 2	10.685	10.45	3.134
		Sample 3	10.732	10.145	3.043
	15%	Sample 1	10.820	8.87	2.662
		Sample 2	10.485	9.09	2.726
		Sample 3	10.572	8.98	2.693

Table: Result of Compressive Strengthen sample tests

Sample Code	**7th day Compressive Strengthen result**	**Average Compressive Strengthen**	**28th day Compressive Strengthen result**	**Average Compressive Strengthen**
Conventional	29.46	30.06	40.66	37.36
	30.66		35.86	
	30.06		35.55	
5 percent	25.11	24.05	31.60	31.56
	23.06		31.60	
	23.99		31.50	
10 percent	17.24	15.90	23.42	22.06
	14.57		20.71	
	15.90		22.06	
15 percent	12.44	12.86	17.15	18.35
	13.37		19.55	
	12.79		18.35	

Table: Result of Flexural Strengthen sample Tests

Sample Code	7th day Flexural Strengthen result	Average Flexural Strengthen	28th Flexural Strengthen result	Average Flexural Strengthen
conventional	3.698	3.701	4.449	4.263
	3.704		4.079	
	3.701		4.262	
5 percent	3.333	3.221	3.209	3.385
	3.111		3.562	
	3.221		3.385	
10percent	2.469		2.952	
	2.629	2.549	3.134	3.043
	2.549		3.043	

15 percent	1.975	1.982	2.662	2.694
	1.990		2.726	
	1.983		2.693	

B. Water Absorption Test (28 Days)

 # Table: Raw data test after 28 days (April 22, 2025)

Mix Design	*Specimen Code/Name*	*Weight one(kg)*	*Weight two(kg)*
0%(Controller)	Sample 1	7.855	7.385
	Sample 2	7.740	7.269
	Sample 3	7.710	7.240
5%	Sample 1	7.510	7.035
	Sample 2	7.505	7.026
	Sample 3	7.640	7.160
10%	Sample 1	7.310	6.800
	Sample 2	7.360	6.840
	Sample 3	7.435	6.925
15%	Sample 1	7.215	6.670
	Sample 2	7.220	6.680
	Sample 3	7.257	6.712

Note: Weight one is weight before the sample was treated in oven.

Weight two is weight after it was taken from oven.

$$\text{Water Absorption} = \frac{\text{Wet weight} - \text{Dried weight}}{\text{Wet weight}}$$

Table : Result of Water absorption of concrete sample tests

Sample Code	*Weight one(kg)*	*Weight two(kg)*	*percentage of water absorption*	*Average Result*	*Percentage (%)*
Conventional	7.855	7.385	0.0598345	0.060541	6.055
	7.740	7.269	0.0608527		
	7.710	7.240	0.0609598		
5 percent	7.510	7.035	0.0632490	0.063300	6.330
	7.505	7.026	0.0628272		
	7.640	7.160	0.0638241		
10 percent	7.310	6.800	0.0697674	0.069671	6.967
	7.360	6.840	0.0706521		
	7.435	6.925	0.0685945		
15 percent	7.215	6.670	0.0755370	0.075143	7.514
	7.220	6.680	0.0747922		
	7.257	6.712	0.0750999		

C. Sulphate attack test after 56 days (May 20, 2025)

 # Table: Raw data test (May 20, 2025)

Percentage of Mixing	*Specimen Code/Name*	*28^{th} Day weight(kg)*	*56^{th} day (weight)kg)*	*Weight Loss (kg)*	*Percentage of Weight Loss (%)*
0%(Controller)	Sample 1	7.630	7.625	0.005	0.0655
	Sample 2	7.695	7.689	0.006	0.0779
	Sample 3	7.710	7.704	0.006	0.0778
5%	Sample 1	7.465	7.450	0.015	0.2015
	Sample 2	7.490	7.475	0.015	0.2003
	Sample 3	7.640	7.625	0.015	0.1963
10%	Sample 1	7.460	7.440	0.020	0.2685
	Sample 2	7.510	7.490	0.020	0.2664
	Sample 3	7.435	7.414	0.021	0.2823
15%	Sample 1	7.145	7.120	0.025	0.3494
	Sample 2	7.295	7.269	0.026	0.3569
	Sample 3	7.257	7.230	0.027	0.3703

Table: Average Weight and Weight Loss

Percentage of Mixing	*Average Weight at 28 Days (kg)*	*Average Weight at 56 Days (kg)*	*Average Weight Loss (kg)*	*Average Percentage of Weight Loss (%)*
0%	7.6783	7.6723	0.005	0.0737
5%	7.5983	7.5750	0.015	0.1990
10%	7.5483	7.5477	0.020	0.2724
15%	7.2323	7.2063	0.026	0.3589

D. Statistical Analysis of Experimental Results

1. Compressive Strength

Descriptive Statistics

Dependent Variable: Compressive Strength(MPa)

DSP Percentage	Curing Age	Mean	Std. Deviation	N
0	7	30.0600	.60000	3
	28	37.3567	2.86497	3
	Total	33.7083	4.40450	6
5	7	24.0533	1.02647	3
	28	31.5667	.05774	3
	Total	27.8100	4.16627	6
10	7	15.9033	1.33500	3
	28	22.0633	1.35500	3
	Total	18.9833	3.58204	6
15	7	12.8667	.46972	3
	28	18.3500	1.20000	3
	Total	15.6083	3.11197	6
Total	7	20.7208	7.11272	12
	28	27.3342	7.99750	12
	Total	24.0275	8.13600	24

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Compressive Strength (MPa)	Based on Mean	3.256	7	16	.024
	Based on Median	.644	7	16	.714
	Based on Median and with adjusted df	.644	7	3.373	.715
	Based on trimmed mean	2.983	7	16	.033

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Compressive Strength(MPa)

b. Design: Intercept + DPercentage + CAge + DPercentage * CAge

Pairwise Comparisons

Dependent Variable: Compressive Strength(MPa)

(I) DSP Percentage	(J) DSP Percentage	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
0	5	5.898*	.788	<.001	3.528	8.269
	10	14.725*	.788	<.001	12.354	17.096
	15	18.100*	.788	<.001	15.729	20.471
5	0	-5.898*	.788	<.001	-8.269	-3.528
	10	8.827*	.788	<.001	6.456	11.197
	15	12.202*	.788	<.001	9.831	14.572
10	0	-14.725*	.788	<.001	-17.096	-12.354
	5	-8.827*	.788	<.001	-11.197	-6.456
	15	3.375*	.788	.003	1.004	5.746
15	0	-18.100*	.788	<.001	-20.471	-15.729
	5	-12.202*	.788	<.001	-14.572	-9.831
	10	-3.375*	.788	.003	-5.746	-1.004

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

2. Flexural Strength

Descriptive Statistics

Dependent Variable: Flexural Strength(MPa)

DSP Percentage	Curing Age	Mean	Std. Deviation	N
0	7	3.70100	.003000	3
	28	4.26333	.185004	3
	Total	3.98217	.329484	6
5	7	3.22167	.111002	3
	28	3.38533	.176500	3
	Total	3.30350	.159454	6
10	7	2.54900	.080000	3
	28	3.04300	.091000	3
	Total	2.79600	.281217	6
15	7	1.98267	.007506	3
	28	2.69367	.032005	3
	Total	2.33817	.389985	6
Total	7	2.86358	.684303	12
	28	3.34633	.620158	12
	Total	3.10496	.684608	24

Pairwise Comparisons

Dependent Variable: Flexural Strength(MPa)

(I) DSP Percentage	(J) DSP Percentage	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
0	5	.679*	.062	<.001	.491	.866
	10	1.186*	.062	<.001	.998	1.374
	15	1.644*	.062	<.001	1.456	1.832
5	0	-.679*	.062	<.001	-.866	-.491
	10	.507*	.062	<.001	.320	.695
	15	.965*	.062	<.001	.778	1.153
10	0	-1.186*	.062	<.001	-1.374	-.998
	5	-.507*	.062	<.001	-.695	-.320
	15	.458*	.062	<.001	.270	.646
15	0	-1.644*	.062	<.001	-1.832	-1.456
	5	-.965*	.062	<.001	-1.153	-.778
	10	-.458*	.062	<.001	-.646	-.270

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

3. Water Absorption

Descriptives

Weight gain

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0	3	.060549000	.0006210880	.0003585853	.059006132	.062091868	.0598345	.0609598
5	3	.063300100	.0005004106	.0002889122	.062057011	.064543189	.0628272	.0638241
10	3	.069671333	.0010321584	.0005959170	.067107310	.072235357	.0685945	.0706521
15	3	.075143033	.0003742688	.0002160842	.074213298	.076072769	.0747922	.0755370
Total	12	.067165867	.0059513334	.0017180020	.063384570	.070947164	.0598345	.0755370

Multiple Comparisons

Dependent Variable: Weight gain

Bonferroni

(I) DSP_Percentage	(J) DSP_Percentage	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-.002751100*	.0005540140	.007	-.004678448	-.000823752
	10	-.009122333*	.0005540140	<.001	-.011049681	-.007194985
	15	-.014594033*	.0005540140	<.001	-.016521381	-.012666685
5	0	.0027511000*	.0005540140	.007	.000823752	.004678448
	10	-.006371233*	.0005540140	<.001	-.008298581	-.004443885
	15	-.011842933*	.0005540140	<.001	-.013770281	-.009915585
10	0	.0091223333*	.0005540140	<.001	.007194985	.011049681
	5	.0063712333*	.0005540140	<.001	.004443885	.008298581
	15	-.005471700*	.0005540140	<.001	-.007399048	-.003544352
15	0	.0145940333*	.0005540140	<.001	.012666685	.016521381
	5	.0118429333*	.0005540140	<.001	.009915585	.013770281
	10	.0054717000*	.0005540140	<.001	.003544352	.007399048

*. The mean difference is significant at the 0.05 level.

4. Sulfate Attack

Descriptives

Weight_Loss_Percentage

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0	3	.073733	.0071305	.0041168	.056020	.091446	.0655	.0779
5	3	.199367	.0027227	.0015720	.192603	.206130	.1963	.2015
10	3	.272400	.0086377	.0049870	.250943	.293857	.2664	.2823
15	3	.358867	.0105879	.0061129	.332565	.385168	.3494	.3703
Total	12	.226092	.1093754	.0315740	.156598	.295585	.0655	.3703

Multiple Comparisons

Dependent Variable: Weight_Loss_Percentage

Bonferroni

(I) DSP_Percentage	(J) DSP_Percentage	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	5	-.1256333*	.0063897	<.001	-.147862	-.103404
	10	-.1986667*	.0063897	<.001	-.220896	-.176438
	15	-.2851333*	.0063897	<.001	-.307362	-.262904
5	0	.1256333*	.0063897	<.001	.103404	.147862
	10	-.0730333*	.0063897	<.001	-.095262	-.050804
	15	-.1595000*	.0063897	<.001	-.181729	-.137271
10	0	.1986667*	.0063897	<.001	.176438	.220896
	5	.0730333*	.0063897	<.001	.050804	.095262
	15	-.0864667*	.0063897	<.001	-.108696	-.064238
15	0	.2851333*	.0063897	<.001	.262904	.307362
	5	.1595000*	.0063897	<.001	.137271	.181729
	10	.0864667*	.0063897	<.001	.064238	.108696

*. The mean difference is significant at the 0.05 level.

Research Fund Acknowledgment

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