PARTIAL REPLACEMENT OF COARSE AGGREGATE IN PORTLAND CEMENT CONCRETE WITH EXPANDED POLYSTYRENE THERMOCOL (EPT)

Master of Engineering Dissertation

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January 2024.

APPROVED TITLE

PARTIAL REPLACEMENT OF COARSE AGGREGATE IN PORTLAND CEMENT CONCRETE WITH EXPANDED POLYSTYRENE THERMOCOL (EPT).

by

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submitted in accordance with the requirements for

the degree of

MASTER OF ENGINEERING

in the subject

CONSTRUCTION MATERIALS

&

at the

UNIVERSITY OF SOUTH AFRICA

SUPERVISOR: Dr Walied Elsaigh

(Date: January 2024)

DECLARATION

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Publication: Partial Replacement of Coarse Aggregate by Expanded Polystyrene Thermocol in Concrete

Publication Site: Materials Today

Authors: Mashava CT[1] and Elsaigh W.A[2]

08 January 2024

SIGNATURE DATE

DEDICATION

I write my dissertation as a tribute to my family. I want to express my sincere gratitude to my supportive spouse Cassius, who supported me when I thought I could not do it anymore. I also appreciate my kids' patience when I was working on this thesis and unable to be with them, Nhlelo and Nkateko. Since I was a little child, my parents Kaizer and Masingita Makamu have continuously pushed me to be tenacious, and for that, I am grateful. They have done a lot, and I will always be thankful.

ACKNOWLDGEMENTS

Firstly, I want to give thanks and praise to the Lord Jesus Christ for His grace that let me finish my research successfully. I want to convey my profound gratitude to Dr. Walied, my research supervisor, for holding my hand and offering insightful advice during this study. His energy, vision, genuineness, and drive have really motivated me. He has taught me how to conduct research and deliver the results in the most understandable way. Being able to work and study under his direction was a huge honor and privilege. I am incredibly appreciative of what he has given me. I want to thank him for his patience as well. Additionally, I would like to express my gratitude to Mr. Joseph Rametsi of AfriSam for providing the materials I needed for my experimental work. I also pass my thanks to CHRYSO, for donating the plasticizer for my work, I am truly grateful your assistance. I appreciate the help from the Unisa Civil Engineering, Chemical Engineering and Physics Lab team in conducting my studies. I want to express my sincere gratitude to my spouse, son, and daughter for their support and tolerance as I worked on this study. I also Acknowledge Dr Motsa from InanoWS for assisting with SEM images. I am incredibly appreciative of my parents' love, prayers, concern, and sacrifices to raise me and get me ready for the future. Finally, I want to express my gratitude to everyone who has aided me in some way in finishing the research project.

ABSTRACT

Normally, non-biodegradable solid waste material produced in South Africa is disposed off through landfilling, intriguingly, the country has limited landfill space and a high demand for affordable solid waste material for use in construction. The demand for affordable material in the construction industry suggest that there is a need to consider the reuse of solid waste materials. This research aimed to evolve lightweight concrete by partially replacing coarse aggregate with Expanded Polystyrene Thermocol (EPT), hence reducing the amount of EPT that goes to landfills while producing concrete with enhanced properties. In this study, EPT was used to partially replace granite aggregate at varying levels: 0, 5, 10, 15, 20, 25, and 50 % by volume of aggregate. The water to cement ratio adopted was 0.58 and the specimens were cured for 7 and 28 days before testing. The effect of EPT on workability, compressive strength, and flexural strength of concrete was determined. Results showed that incorporation of EPT in concrete reduces the compressive and the flexural strength but increases the workability when compared to the control mix (0% EPT replacement). It was observed that when the percentage of EPT is higher, the compressive and flexural strengths were lower with corresponding improvement in workability. The average compressive strength and flexural strength of 50% replacement was 15.43 and 2.22 MPa, respectively, after 28 days, while that for control mix was 38.63 and 3.78 MPa, respectively, a strength reduction of approximately 40%. The heat conductivity at 50% EPT replacement reduced by 34% from normal concrete. Overall, the results show that one way to dispose EPT is to use it in concrete. It is therefore recommended that it is possible to replace 25% of coarse aggregate by EPT for structural concrete while higher percentage replacement can be deemed for non-structural applications.

Keywords: EPT, EPT concrete, lightweight concrete, compressive strength, flexural strength, workability, drying shrinkage, heat conductivity, low-cost housing.

ABSTRACT

Ngenxa yendawo elinganiselwe yokulahla imfucumfucu eNingizimu Afrika yokulahla imfucuza engaboli kanye nesidingo esikhulu sezinto zokwakha ezithengekayo, kunesidingo esinamandla sokuphinda kusetshenziswe imfucuza eqinile embonini yezokwakha. Lezi zinhloso zocwaningo ziveza ukhonkolo ongasindi ngokufaka ingxenye ehlanganisiwe ye-Expanded Polystyrene Thermocol (EPT), ngaleyo ndlela kwehliswe inani le-EPT eliya ezindaweni zokulahla imfucumfucu futhi ngesikhathi esifanayo kukhiqizwe ukhonkolo onezinto ezithuthukisiwe. Kulolu cwaningo, i-EPT yasetshenziselwa ukufaka ingxenye ye-granite aggregate emazingeni ahlukahlukene: 0, 5, 10, 15, 20, 25 kanye no-50 % ngesisindo, ngokulandelana. Isilinganiso sikasimende samanzi esamukelwe singu-0.58 kanti izibonelo zelashwa izinsuku eziyi-7 nezingama-28 ngaphambi kokuhlolwa. Umphumela we-EPT ekusebenzeni, amandla okucindezela kanye namandla okuguquguquka kwekhonkrithi kwanqunywa. Ucwaningo lubonise ukuthi ukufakwa kwe-EPT kukhonkolo kunciphisa ukucindezela namandla okuguquguqukayo kodwa kwandisa ukusebenza uma kuqhathaniswa nokuxuba kokulawula (i-0% EPT esikhundleni). Kwaphawulwa ukuthi amaphesenti aphezulu e-EPT, aphansi amandla okucindezela nokuguquguquka nokuthuthukiswa okuhambisanayo ekusebenzeni. Amandla acindezelayo amaphakathi namandla aguquguqukayo we-50 % esikhundleni atholwe angu-15.43 no-2.22 MPa ngokulandelana ngemva kwezinsuku ezingu-28, kuyilapho leyo yokuxuba kokulawula ingu-38.63 no-3.78 MPa ngokulandelanayo, ukuncipha kwamandla cishe ku-40%. I-conductivity yokushisa ku-50% EPT esikhundleni sehliswe ngo-34% kusuka kukhonkolo evamile. Ngenhloso yokusebenzisa i-EPT kukhonkolo njengendlela yokulahla futhi isenokhonkolo onezinto ezamukelekayo, ngakho-ke kunconywa ukuthi kuthathelwe indawo u-25 % wesamba esimahhadla nge-EPT ukuze uthole ukhonkolo wesakhiwo kuyilapho ukushintshwa kwamaphesenti aphezulu kungathathwa njengezinhlelo zokusebenza ezingezona ezesakhiwo.

Amagama angukhiye: EPT, Ukhonkolo Ongasindi, Amandla Acindezelayo, amandla aguquguqukayo, Ukusebenza, Ezindlu ezi biza kancane.

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CHAPTER 1

1. INTRODUCTION

1.1. Background

Research relating to beneficial reuse of waste materials in construction has gained momentum in the past few years. The need for such reuse is necessary not only because the world produce markedly more waste materials every year but also because of a shortage of landfill areas. In addition to having environmental benefits, incorporating some waste materials in construction reportedly enhance the properties as well as economical value (Kralj et al. 2005).

About ninety percent of municipal solid waste in South Africa is disposed off in open dumps or landfills (City of Johannesburg, 2015). Of waste that is disposed, part is expanded polystyrene thermocol (EPT) and is among common waste materials found in South African landfills and open dumps. While published literature does not show accurate figures of EPT that is produced in South Africa annually, more than 5500 tons of it were recycled in 2019 (Omnexus, 2021), which is indicative of a relatively large amounts of the waste. Considering the increase in human population and therefore need for conversion of unused land to residential areas, there is rarely sufficient land that can be used to dispose EPT largely because it a health hazard given that it is not biodegradable and not reused (Pack Size International, 2013).

Currently, EPT form constituents of Portland Cement Concrete (PCC) successfully to replace aggregate materials. Also, due to its low density, EPT is used to produce lightweight concrete by partially replacing the aggregates in the concrete mix. In fact, the reuse of EPT as a constituent of building materials is abound in literature. For example, Kaptan, Patroda & Kulkarni (2019) showed that concrete made up of among other constituents, EPT, was advantageous in that it had reduced self-weight and increased thermal conductivity.

Lightweight concrete is light in weight compared to conventional or normal concrete however, it maintains its structural integrity, by incorporating lightweight aggregates in the place of natural coarse or fine aggregates (Shetty, 2005). The density of lightweight concrete ranges from 1600 to

1800 kg/m^3 as compared to 2400 kg/m^3 for normal concrete. It is produced through several techniques, one of which is by using lightweight beads of EPT as aggregate instead of the crushed stone that is used in normal concrete. Concrete that contains a high percentage of EPT is best suitable for non-structural elements and require a compressive strength that range from 20 - 40 MPa and tensile strength ranging from 2 - 4 MPa. Importantly, the compressive and tensile strengths depend on the elements to be constructed, which includes walls, cladding panels, foot path, parapet wall and composite flooring, (Kole et al. 2017).

The focus of this study was to investigate the properties of concrete with coarse aggregates partially replaced by varying percentages of EPT. To achieve this, standard specimens (cubes and beams) were manufactured and tested under compression, flexure, shrinkage, and heat conduction. In general, as EPT increase in volume in a mix, it results in strength reduction, marginal increase in drying shrinkage, and reduction in heat conductivity. Such indicate great potential for application on low-cost housing projects involving labour-intensive construction methods.

1.2. Problem Statement

South Africa has an increased demand for less costly concrete materials given that normal concrete is costly. The increase in the cost of normal concrete is largely caused by scarcity of natural materials used to make it, including sands and aggregates. One way to overcome this challenge is to use alternative materials that can replace natural aggregates, and these include expanded polystyrene thermocol (EPT) which are abundant and considered waste. Producing concrete through using materials that are freely available and abundant could make concrete produced this way affordable, especially for individuals with low income. Indeed Mandlik et al. (2015) and Ganie et al. (2018) confirm that concrete made through using EPT is affordable. Of other benefits associated with EPT concrete is that it exhibits reduced self-weight, which allow for ease of handling (Kuhail, 2003) and thereby suits labour-intensive applications. The latter may make the material favourable and unlock opportunities for small and medium-sized construction companies to thrive and be profitable in the construction industry.

According to literature, decision on the use of EPT in concrete depends on the percentage of EPT used to replace natural materials. Whatever the case, EPT concrete ought to have lower heat conductivity as compared to normal concrete, which is favourable in terms of energy saving. Such kind of concrete is especially recommended to use on construction projects undertaken in some South African provinces where temperatures can reach 48 ºC during the summer season, these include the Northern Cape and Mpumalanga (South Africa Weather Service, 2021). On the other hand, when EPT concrete is used in provinces that experience cold weather on a regular basis, it can help reduce the heating requirements inside buildings as it assist in preventing the heat loss through exterior walls. Intuitively, increasing the percentage of EPT in concrete can positively influence the material's heat conductivity, but may unfavourably affect the mechanical properties such as compressive and flexural strengths. Therefore, it is necessary to keep in mind the balance between percentage EPT replacement, the desired physical, and mechanical properties of EPT concrete.

1.3. Research Questions.

How does expanded polystyrene thermocol (EPT) content in concrete influence the fresh properties of concrete including the workability?

How does the partial replacement of coarse aggregates by EPT affect the mechanical and physical properties of concrete?

Is lightweight concrete with EPT a suitable construction material for low-cost houses in South Africa?

1.4. Research aims and Objectives.

The aim of this research was to characterize expanded polystyrene thermocol (EPT) concrete and evaluate its usage for low-cost housing projects in South Africa.

The main objectives of this research were to:

Investigate the influence of EPT content on workability of EPT concrete.

Determine the effect of EPT content on mechanical properties of concrete. The concerned properties include compressive strength and flexural strength.

Optimising EPT concrete in relation to EPT beads content.

Evaluate the physical properties of EPT beads concrete in relation to drying shrinkage and heat conductivity.

Assess the applicability of EPT concrete for construction of low-cost housing in South Africa.

1.5 Scope and Limitations

The scope of this study covered incorporation of expanded polystyrene thermocol (EPT) in concrete. Natural coarse aggregates were partially replaced with EPT contents of 0, 5, 10, 15, 20, 25, and 50% by volume normal strength concrete of 35 MPa. The water: cement ratio was kept constants for all mixes. The investigated properties included workability, compressive strength, flexural strength, drying shrinkage, and heat conductivity.

The scope included the characterisation of EPT concrete but did not include economic analysis in terms of initial cost or life cycle cost. The cost implications cab be deduced through the incorporation of waste material that is not only available in abundance but also requires cost to manage its disposal. Furthermore, currently, the environmental consequences of EPT usage in concrete is rarely studied. However, the approach has benefits associated with less reliance in natural aggregates while using material that is considered as pollutant.

EPT of a maximum particle size 5 mm is obtained from a single commercial source. The used material is intercepted before reaching the landfill and therefore the beads' surface is clean. EPT taken from landfills is likely contaminated with dirt and dust, as a result, surface treatment is necessary. This study did not include the aspects of treating EPT beads surface before use in concrete.

The investigation involved only laboratory bench-scale experiments and did not expand to include full-scale structural elements or full model building.

1.6 Research methodology

This study followed a comparative approach incorporating test results of fresh and hardened concrete samples. It involved extensive bench-scale testing on concrete specimens containing varying amounts of expanded polystyrene thermocol (EPT) to replace coarse aggregates. Figure 1.1 shows work done on this research.

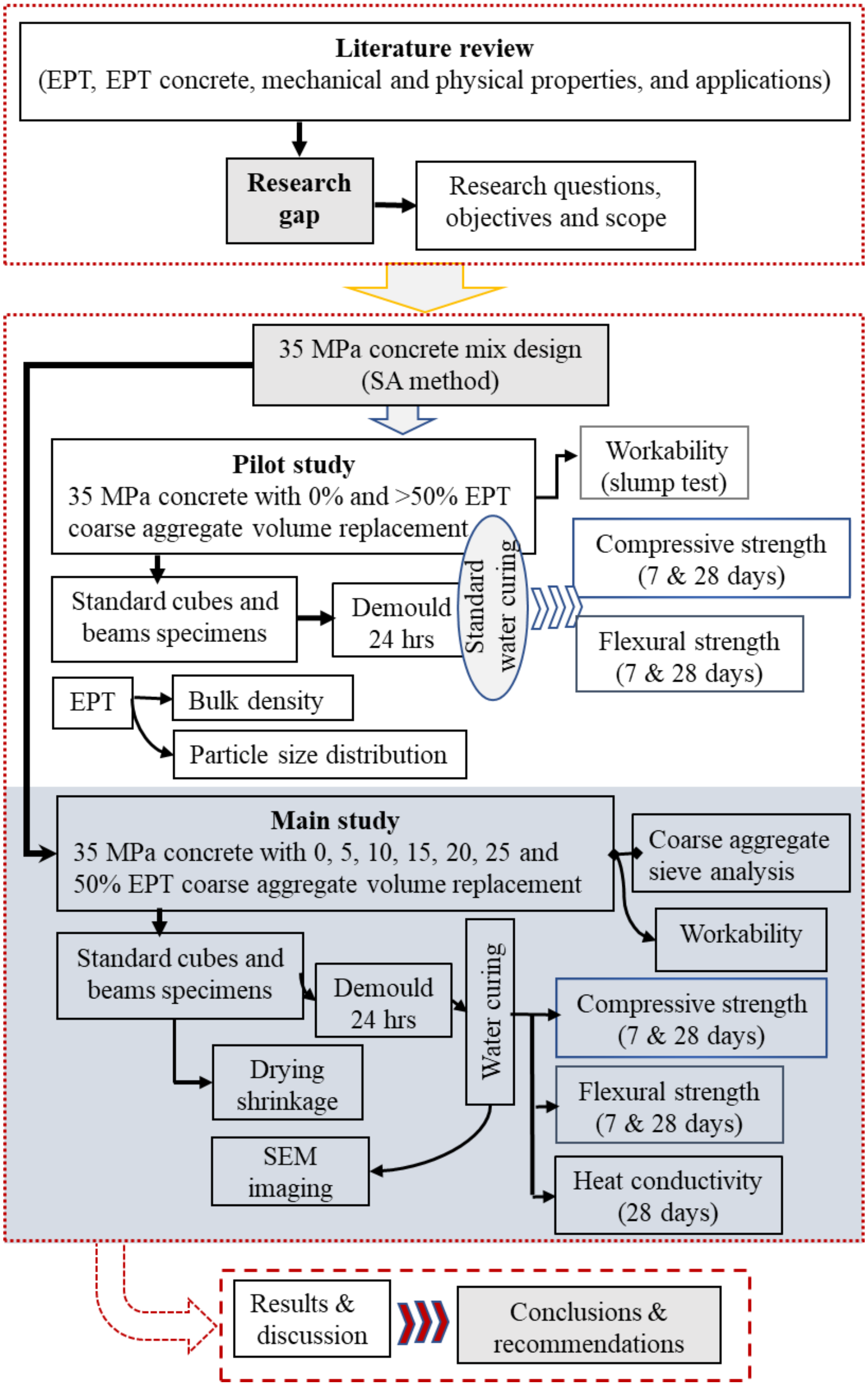


Figure 1-1: Research Flow Chart

1.7 Research Significance

This study evaluated the use of expanded polystyrene thermocol (EPT) in Portland cement concrete. It involved characterization of fresh and hardened properties. Results of the study are expected to contribute to beneficial reuse of materials that are considered waste and therefore abundant and their reuse could reduce the need for landfill area, reduce the dependence on natural aggregates resources, and reduce cost of concrete materials. The use of EPT concrete can enhance labour intensive construction and allow sustainable development in terms of affordable infrastructures.

1.8 Thesis Organisation

Chapter 1: Provides a brief background of the research, objectives of the study, problem statement, scope, and methodology.

Chapter 2: Presents a review of the literature concerning all aspects of the proposed thesis provides expanded polystyrene thermocol (EPT), type of lightweight concrete, application of EPT, fresh properties of EPT concrete, mechanical properties of hardened concrete, physical properties of concrete.

Chapter 3: Explains the research methodology and experimental program.

Chapter 4: Discusses the obtained results.

Chapter 5: Presents the conclusions, recommendations, and necessary future work.

Chapter 6: Provides the reference list.

Chapter 7: Provides appendices.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

This chapter provides a review of literature on expanded polystyrene thermocol beads (EPT) and their reuse in concrete material. Discussion includes the process of mixing EPT in concrete, fresh and hardened properties of EPT concrete, and previous practical use of the material. It is worth pointing that in published literature, concrete containing EPT is referred to as EPS concrete or EPT concrete, among other names, however for this research, EPT concrete was adopted.

2.2. Expanded Polystyrene Thermocol

Expanded polystyrene thermocol (EPT) is produced from styrene and pentane. The material is mostly used in packaging and handling of fragile goods due to its shock absorbing property. EPT used for this purpose is lightweight cellular plastic material, usually found in the shape of beads with diameters ranging from 3 mm to 12 mm and densities ranging from 12 - 50 kg/m^3 (Omnexus, 2021). Furthermore, EPT beads are comprised of about 98% air and 2% polystyrene, making them light in weight (Omnexus, 2021).

According to Omnexus (2021), EPT has low thermal conductivity, low moisture absorption, chemical inertness, and excellent cushioning properties. Its physical properties do not change within its service temperature range of up to 75 ºC even for long-term temperature exposure. In addition, the material is not biodegradable and has been considered as hazard to environment if not properly dumped or reused (City of Johannesburg, 2015). Solung et al. (2019) indicated that when exposed to temperature around 100 °C, EPT softens and deforms. EPT instantly self-ignites at a temperature of roughly 490 °C.

EPT is a cost-effective insulation option when considering the excellent results in achieving the desired thermal insulation in construction projects. Intact EPT beads in the form of panels, were used successfully in the past, without the need for specialized equipment, as heat and sound insulator in building construction (Isowallgroup, 2018).

2.3. Types of Lightweight Concrete

Shifu (2020) note that lightweight concrete can be produced through using several techniques. Among the techniques is foamed concrete (i.e., also called aerated, cellular, foamed or gas concrete) which is produced by introducing larger voids within the concrete or mortar. These voids should be clearly distinguished from the fine voids produced by air entrainment. The second is no fines concrete which is produced by using natural aggregates, but fine aggregates are omitted from the mix, resulting in a relatively large number of voids. The third technique involves producing lightweight concrete by incorporating artificial light weight aggregates, which have low specific gravity, i.e., considerably less than 2.6 lightweight Concrete with EPT beads is the focus of this research.

According to Shifu (2020), when compared to natural aggregates, EPT beads exhibit reduced strength but have lower mass. The latter results in easier handling and transporting of fresh EPT concrete and allows for reduced dead load on a structural element using the material.

2.4. Environmental Benefits of Using EPT in Concrete

So far, there is not much published information on environmental benefits associated with the consumption of EPT in concrete. Of the few scholarly studies, that by Sivakumar et al., (2014) identified several benefits that are linked to usage of EPT in concrete. These include landfill diversion, resource conservation, low carbon footprint, and environmental responsibility. In the South African context, incorporating EPT into concrete ensures that it does not contribute to landfill overcrowding and potential pollution associated with its disposal. Also, re-using EPT reduces the need for new raw materials in concrete production, which pertains well to the sustainability principles by decreasing the demand for natural resources. The process of producing concrete is known to emit a significant percentage of carbon to the atmosphere. However, when EPT is re-used in concrete, it helps lower the overall carbon footprint associated with construction materials by reducing the energy-intensive process of extracting and manufacturing new raw materials. Employing EPT in concrete demonstrates a commitment to environmentally responsible practices, which can be an essential consideration for projects aiming for green building certifications.

2.5. Cost Effectiveness of using EPT Concrete

Apart from meeting the strength requirements and other technical aspects, the option of using EPT as a construction material is considered mainly if it is economically justifiable as compared to the use of other materials. Zhu & Poh, (2003) reported that the cost effectiveness of using EPT in concrete depends on various factors including materials costs, transportation costs, labour costs, project requirements, and construction methods. EPT beads are typically less expensive than natural coarse aggregates, especially if the concrete material is to be utilised in an area where coarse aggregates are scarce. In other words, the cost of EPT concrete is dependent on the geographical location of the project. Due to its light weight (low density), the transportation cost of EPT beads is significantly lower compared to that of coarse aggregates. This is particularly advantageous when the haul distance is relatively long, concerning the labour costs, mixing, and handling EPT concrete requires less labour compared to normal concrete with heavy aggregates. As far as construction speed is considered, EPT concrete can be easier to work with and may allow faster construction which can reduce labour costs and results in project saving costs (Makul & Sahin, 2007).

2.6. Applications of EPT Concrete

EPT concrete is usable in many applications in the construction industry. For example, Mandlik et al. (2013) and RamKumar (2019) revealed that (EPT) concrete offers potential for non-structural uses such as wall panels, partition walls and higher floors of high-rise buildings applications. Also, the use of EPT beads in place of coarse aggregates in construction has proven an alternative material and effective method of disposal for EPT (Vandale et al., 2019a, Mandlik et al., 2013, Vandale et al., 2019b, Karle et al., 2020a, Adhikary & Ashish, 2022 and Thomas et al., 2014).

Studies report that EPT concrete is less expensive compared to normal concrete (Vandale et al. 2019a and Mandlik et al. 2013). In addition, utilizing EPT can help balance the demand for renewable resources, resulting in a step in the right direction for sustainability, the economy, and solid waste management (Adhikary & Ashish, 2022).

Sadrmomtazi et al. (2012) indicated that EPT beads can produce structural grade, moderate strength grade, and insulating lightweight concrete, even though their application typically results in a reduction in the strength qualities.

Sulong et al. (2019) reported that since the 1950s when EPT was discovered as an insulating material, it has made rapid advancements in other novel implementations and currently, is used in numerous building structures due to its benefits for sustainability and enhancements in terms of energy efficiency, durability, and indoor environmental quality. Furthermore, it is used as aggregates in lightweight concrete, in decorative tiles and moulding, in structural insulated panels and composite, and the backfilling of embankments.

The study of Sulong et al. (2019) makes the case that EPT serve as a more environmentally friendly walling material, particularly in areas where natural sand is in low supply. Interestingly, EPT aggregates may replace sand to create lightweight mortar that is less permeable and comparably cheaper. On timber material, protection from water, wind-borne debris, and biological degradation such as mold growth and termite assault can provided by impregnating wood using EPT. Sulong et al. (2019) further indicates that in South Korea, EPT is used as a resilient material in concrete floors to dampen noise and retain heat, which results in greater energy savings.

Mousa et al. (2009) report that heavy filling material used during the construction of an embankment causes several issues including bearing failure and slope instability. Normally, EPT is used as backfilling to lessen the weight of embankments, particularly when they are built on soft soil. Additionally, EPT is utilized as a backfilling material for road shoulders and bridge abutments. EPT therefore seem an appropriate lightweight fill for building low-bearing ground embankments. Additionally, it lessens the lateral forces on the bridge abutment's structural support.

In an experiment carried by Bhutt et al. (2011), EPT waste was mixed with methyl methacrylate solution to create resin, which was then used to make EPT mortar panels. The product outperformed EPT mortar panel in terms of flexibility and load-bearing capability, according to a test of flexural behavior. EPT waste can also be converted into resin using solvents like toluene and acetone to create polymer-cement composite, which has the potential to be used as a deactivator for radioactive waste and a material for commercial construction.

Aabøe et al., (2011) list uses of EPT in Norway and Japan and these include stabilization of steep terrain. Given that it is a lightweight fill, it stabilizes slope by reducing weight and the driving force of sliding mass, according to a study by Arellano et al., (2011). The block's resistance to force from the landslide material boosts the strength of the structure.

Joseph (2018) presents findings of experimental tests conducted to comprehend the behavior of prototype EPT concrete sandwich panels compression. Four alternative panel configurations, each with different thickness and made up of 3 meters long weld mesh were put through axial compression tests until they failed. Concrete wythes were cast using self-compacting concrete and EPT was used as insulation. Focus was on wire mesh with two different mesh sizes - such 50 mm and 100 mm. Results showed that strengthening concrete beams close to the areas of stress and support increased the composite action of the panels and prevented panel failure owing to localized crushing of concrete wythes. Additionally, it was discovered that shear connectors worked well to maintain composite action until the panels failed. In contrast to the panels with higher thickness, which buckled close to the loading location, the panels with relatively less thickness failed by buckling at a cross section away from the loading region. The ultimate load of the panels evaluated is equivalent due to the same area of concrete wythes, despite mesh size and EPT thickness being different.

Karle et al., (2020b), investigated whether a good compressive strength and water absorbing concrete can be produced by placing EPT sheet in the place of some of the sand and coarse aggregates in concrete. The compressive strength of EPT beads concrete blocks was compared to normal concrete. The results show that the compressive strength of sheets that are larger than 30 mm decreases when compared to the normal bricks.

2.7. Mixing of EPT Concrete

The incorporation of EPT beads in concrete does not require a special machinery or changes to the mixing process used for normal concrete (Kumail, 2003 and Ravindrarajah & Tuck, 1994). However, care should be taken when adding the EPT beads that the final EPT concrete mix is homogenous. The latter property requires some adjustment to the mixing sequence. Ravindrarajah & Tuck (1994) recommend that the best method to mix EPT concrete is to first mix the normal concrete until it is properly mixed, then add the EPT beads by portions until it has properly blended with the normal concrete.

In another study, Mahdi & Aljalawi (2019), suggest that for a properly mixed EPT concrete, first, all dry materials ought to be mixed, followed by adding the EPT beads until all the material are completely blended and homogenous. Thereafter, half of the water should be added, and mixing continued for about 6 minutes and the remaining water added. The mixing should continue until the mixture is uniform.

2.8. Fresh Properties of EPT Concrete

wen (2008), posit that concrete is considered fresh from the time it is mixed until it hardens. When in a fresh state, concrete can be transported, placed, compacted, and surface finished. Time during which concrete can be handled in its fresh state depends on the characteristics of the concrete mix but mostly, it is about two hours. The characteristic of fresh concrete is critical and have bearings on its hardened properties such as strength.

Owen (2008), refers to the workability of a mix as how easily concrete it may be poured, compacted, and finished without the need to separate or segregate the aggregates from paste. Concrete mixes formed with different sizes of stone may have different workability even though they have the same slump, the standard test that measures the workability of fresh concrete. In general, concrete with smaller-stone mixes is easier to work with as compared to concrete incorporating larger stone sizes.

Addition of EPT beads to concrete improves the workability of concrete which makes easier compaction and surface finishing as compared to normal concrete (Mbadike & Osadebe, 2012; Thomas et al. 2020). In an experiment conducted by Mbadike & Osadebe (2012), the workability of concrete increased as the EPT beads percentage was increased, this is because the EPT beads do not absorb water when compared to natural aggregates which leaves some free water in the mix. Concrete with EPT replacement of 0%, 5%, 10%, 20%, 30%, and 40% by volume have been shown to have workability results of 10, 15, 22, 40, 49, and 62 mm, respectively while Kan, (2007b) slump values ranged from 8 to 43 mm.

Demirboga & Kan (2012a), conducted research where laboratory heated EPT beads were added in concrete and they found that the fresh concrete from 50% to 70% replacement by volume of aggregates, the mix became rubbery, abrasive, and challenging to put and compact when the heated EPT beads content was increased. From 50% - 70% EPT replacement, the slump was impossible to measure because the concrete was dry.

In contrary, Sabaa et al. (1999), tested the workability of concrete containing 20, 50 and 70 % EPT by volume of coarse aggregates and found that the slump of EPT aggregates concrete is lower than that of normal concrete due to the reduction in unit weight. In order to obtain concrete with a higher workability and prevent the segregation of EPT beads, it was also discovered that super plasticizers can be used to get a satisfactory compaction (Sabaa et al. 1999 & Kan, 2007a). The effect of superplasticizers on workability of EPT concrete is affirmed by Mohammed & Hussein (2021) and further recommended that mixing time to be prolonged for 7 to 8 minutes. Kan (2007a) observed that as vibration duration increased, the EPT beads accumulated over the mould when manufacturing EPT concrete samples.

Gunavel et al. (2020), used fine EPT to replace sand in concrete and found that it aided in the bonding of cements and aggregates, hence a good consistent concrete was achieved. Thomas et al (2014), concluded that the incorporation of EPT in concrete increases the voids and the workability. Kan (2007b), noted that as vibration duration increases, the beads accumulate over the mould and that all concrete mixes were made more workable by the superplasticizer.

Sabaa et al. (1999), compiled a report on how EPT beads can be used to create lightweight EPT beads concrete with a range of densities. They assessed EPT concrete with unit weights of 1600, 1800, and 2000 kg/m^3 and cement concentrations of 350, 420, 490, and 560 kg/m^3, and compared between the compaction index and slump. It was discovered that the compaction index may be used to categorize the workability of EPT aggregate concrete. A compaction index test assumes that the workability of fresh, uncompacted concrete controls its density and that the volume of uncompacted concrete rises as workability falls. In the study by Sabaa et al. (1999), a test was done through using DIN1048 compaction index. The compaction index ranges for high, medium, low, and very low degrees of workability are 1.03 to 1.13, 1.14 to 1.29, 1.30 to 1.40, and 1.41 to 1.52, respectively. The slump of concrete is substantially impacted by its workability for a certain unit weight. The conclusion was that the water to cement ratio, fine aggregates content, and water content, all affect how workable EPT aggregates concrete is, just like they do with regular weight concrete and that when using the DIN1048 compaction index to determine workability, the unit weight has no discernible impact.

Rajamane & Ambily (2012), report that EPT beads concrete is one of many lightweight. However, poor workability and a propensity for segregation make it challenging to maintain quality during manufacturing. Concrete mixtures with 40, 50, and 60 % by volume percent beaded EPT were used, and the properties were investigated. Segregation was prevented in the operation by taking extra precautions, like hand-tamping for compaction and using a superplasticizer to make the material more workable. Sadrmomtazi et al. (2012) states that use of polypropylene on EPT concrete considerably reduced the slump values.

2.9. Mechanical Properties of Hardened Concrete

Sarathy (2016), researched whether abundant waste materials that can be used in industry concrete, as a primary goal. A summary of previous studies' findings about how making lightweight concrete by partially substituting coarse aggregates by EPT beads in concrete is presented. The results of many researchers' studies indicate that partially replacing coarse aggregates by adding EPT beads make concrete less dense and with reduced strength when compared to normal concrete.

2.9.1. Compressive Strength

Owen 2008: The compressive strength of concrete is a measure of the concrete's ability to resist loads and tend to compress it. It is measured by crushing concrete cube specimens in compression testing machine. This is calculated as the maximum compressive load of concrete divided by cross sectional area of the tested specimen.

Considerable research indicates that replacement of natural coarse aggregates by EPT beads reduces compressive strength as compared to normal concrete, (Maaraofi, Younsi & Nouviaire, 2018; Gunavel, Indhumathi, Jalapriya & Kerthi, 2020 and Suhad, Khalil & Ghalib, 2016). At 28 days, it was found that the compressive strength of concrete produced by 5%, 10%, 15%, 20%, 25%, and 30% EPT replacement by volume were 91%, 77%, 71%, 63%, 57%, and 45% respectively when compared to control concrete, i.e., concrete with 0% EPT (Thomas, Rajendra, Katta & Subhash, 2014). Additionally, it was found that EPT beads size significantly influences the compressive strength of EPT concrete; concrete samples with smaller EPT particles exhibited significantly higher compressive strength (Kan 2007b).

Vandale et al. (2019a), studied the effect of partial replacement of coarse aggregates with EPT in concrete by volume. The coarse aggregates were replaced using 20%, 25%, 50%, and 100 %. The main objective was to investigate the properties of the lightweight concrete. After testing standard, concrete cubes of 3, 7, and 28 days old, it was found that the compressive strength and density of the lightweight concrete decreased when large amount of EPT was added.

Mbadike & Osadebe (2012), conducted experiments on lightweight concrete of different densities. It was produced by partially replacing the coarse aggregates with EPT beads in percentages from 5%, 10%, 20%, 30%, and 40 % by volume. The effect of this replacement in the workability, compressive strength, and flexural strength was the studied. A control mix with no EPT beads was also made to compare with the concrete with the EPT beads. Their results revealed lower compressive strength of EPT concrete while there was an increase in the workability compared to normal concrete. Furthermore, as the curing days were increased, the strength of EPT concrete continued to increase, in a similar manner of normal concrete.

Thomas et al. (2014), evaluated alternative construction material for sustainable development. They used EPT beads to replace the coarse aggregates with of 5%, 10%, 20%, 25%, and 30% of EPT by volume, and the properties of the concrete was compared with that of normal concrete. After 28 days, the concrete cubes were tested and found that the compressive strength of 5%, 10%, 15%, 20%, 25%, and 30% EPT replacement were 91%, 77%, 71 %, 63%, 57%, and 43% respectively. However, the density and compressive strength decreased when compared to normal concrete.

Ganie et al. (2018), investigated alternative materials for use to make construction concrete that are less expensive and can cater for the high demand in construction. Due to EPT being less expensive and mostly dumped as waste, it was considered in researching it further as a potential material that can replace the coarse aggregates in concrete. On their experimental study, the coarse aggregates in concrete is partially replaced by different volume percentages of EPT. The percentage used for replacing the coarse aggregates are 5%, 10%, 15%, 20%, and 25% and the property of this concrete is then compared to conventional concrete. After 28 days of curing the concrete cubes with EPT, the compressive strength results of 5%, 10%, 15%, 20% and 25% were 91%, 83%, 77%, 63%, and 57% of the control concrete, respectively. The researchers concluded that the reason for lower strength, and density of the concrete is because the EPT beads are weak in compression and do not chemically react with the concrete to improve the strength.

Gunavel et al. (2020), studied whether the replacement of fine aggregates with EPT beads in concrete could make a lightweight concrete that would be simple in mixing, cheaper, and not need complicated machinery. In their study, the percentages of replacements were 10%, 20%, and 30 % by volume of fine aggregates. It was concluded that 10% of fine aggregates can be replaced by EPT where a strength of 25 MPa after 28 days is desired. Also, their results show that the compressive strength reduces when the EPT beads are added in higher percentages (e.g., >10%). The reduced strength beyond the 10% EPT replacement is deemed to be suitable for some applications. Furthermore, EPT concrete was shown to be cost saving and the dead load due to the mass of concrete is reduced.

Maaraofi et al. (2018), researched to find the properties of cement paste with recycled EPT and compared it to paste without EPT. The reason for the use of recycled EPT was to promote the re-use of waste in construction industry as a proper method of disposal. The percentage of replacement tested were 10, 20, 30, and 50%. Also considered was the fact that EPT on cement-based materials increases the insulation in buildings. Results revealed that the compressive strength decreased when the EPT beads were incorporated. After 28 days of curing, the compressive strength of the normal mortar (i.e., without EPT) was 22 MPa while the one for recycled EPT mortar is 4 MPa.

Bakhshi & Shahbeyk (2019), reports experimental results of concrete containing both low and relatively high volumes of EPT beads. The experiments were conducted with EPT volumes ranging from 15% to 40%, replacing the coarse aggregates by volume. The study concluded that low percentages EPT incorporation had less influence in the compressive strength of the concrete while higher EPT contents (i.e., >10%) showed a noticeable decrease in the compressive strength.

Abdul-Majeed & Al-Lami (2021), examined the density and compressive strength of lightweight concrete, made of EPT beads, cement, sand, and water. Due to its strong compressive strength, low density, and thermal insulation properties. For this, a comprehensive experimental program was put in place. The mix proportions of EPT to cement, sand to cement, and water to cement ratio (W/C) were the variables under investigation. Five EPT beads to cement ratios, 0.02, 0.03, 0.04, 0.05, and 0.06, sixty mixtures were created and tested. The conclusion was drawn that as the EPT ratio rises, the compressive strength decreases. The highest reduction for all mixtures happened when the EPT beads to cement ratio was raised from 0.02 to 0.03. The drop in compressive strength reached by about 82% when the EPT beads to cement ratio was raised from 0.02 to 0.06. Compressive strength is found to be more sensitive to the EPT content than the concrete's dry density.

Xu et al. (2015), aims to describe the mechanical characteristics of lightweight concretes made using EPT that had different amounts of percentages (0, 5, 10, 15, 20, 25, 30, 35 and 40%) as well as two different water-to-cement ratios (0.45 and 0.55). According to the test results, EPT concrete's density and compressive strength dropped as EPT particle content increased. With more EPT aggregates present, the compressive strength considerably decreased. However, lightweight concrete with a high EPT content had its compressive strength boosted by raising the w/c ratio.

Singh (2017), researched on the developed type of structurally light-weight concrete by partially substituting the coarse aggregates by EPT beads. The replacement percentages were 0, 10, 20, 30, 40, and 50% by volume of coarse aggregates. His investigation focused on the properties of EPT concrete with varied percentages of EPT such including compressive strength, split-tensile strength, workability, and flexural strength. Based on the findings, it was determined that light weight concrete with a density of 1812 kg/m^3 and compressive strengths of 20.85 MPa was achieved and the best amount of EPT beads to incorporate was 30% to achieve good compressive strength results. Prolonged curing resulted in an increase in compressive strength. However, the density and strength decreased when EPT beads were increased, when compared to the normal concrete.

Strecker et al. (2016), investigated the effects of adding 5, 10, and 20% of fine-grained sand (1mm) on the concrete made of cement and EPT inclusions of 20, 40, and 60%. To numerically anticipate the impact of particle size and EPT fraction on the compressive strength of the composite materials, finite element analysis was done using the Abaqus software program. After 28 days, the composites were evaluated for density, porosity, and compressive strength. The composites' densities ranged from 1250 to 1600 kg/m^3, and their strengths for 20 and 60% of the EPT inclusions, respectively, were 18 and 9 MPa. Sand's percentage rose from 5 to 20%, causing a rise in bulk density and modulus. After 28 days, the concrete specimens were evaluated for density, porosity, and compressive strength. The specimen densities ranged from 1250 to 1600 kg/m^3, and their strengths for 20 and 60% of the EPT inclusions, respectively. Adding sand had varying effects on the compressive strength, showing that the packing factor of the particles explained the behavior. The amount of stress in the composite increased with increasing particle diameter, according to the finite element analysis. The EPT beads were distributed uniformly throughout the composites under investigation, enabling their use for non-structural purposes. With 60% EPT, the composite with the lowest density 1210 kg/m^3 was created, and it had a compressive strength of 8.38 MPa. The conclusion on this research was that the amount of EPT used has a considerable impact on the compressive strength of concrete.

Rajamane & Ambily (2012), showed that as a specific density grow from 0.8 to 1.30, the compressive strength increases from 3 to 15 MPa. Low strength is a crucial characteristic of effective energy-absorbing materials, as those used to absorb forceful impacts. At maximum strength, EPT aggregates concrete exhibits axial strains that are comparable to those anticipated for normal aggregates concrete with higher strength.

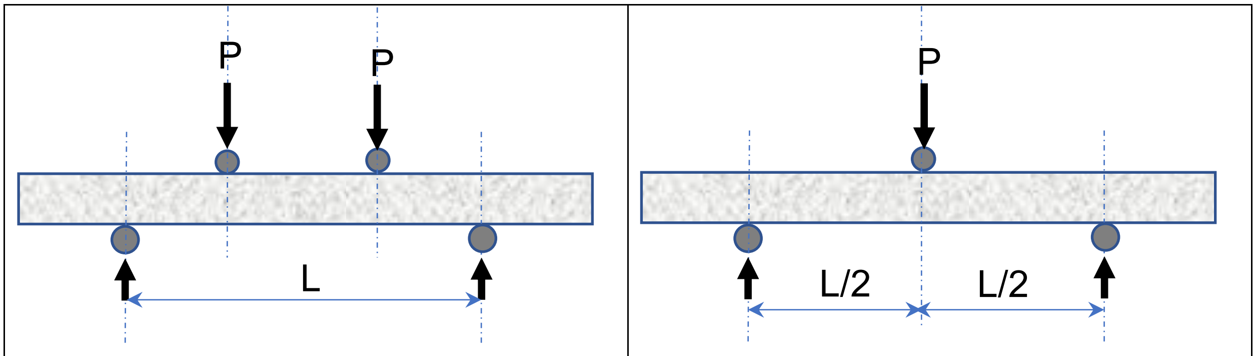
2.9.2. Flexural Strength

EPT concrete's flexural and tensile strengths are usually reported along with the compressive strength with almost similar trends in term of the effect of EPT content in the composite mix. Replacement of normal coarse aggregates by EPT reportedly reduced flexural strength and density as compared to the parent concrete (Mbadike & Osadebe, 2012 and Thomas et al. 2014). A similar effect was shown for tensile strength (Ahmed et al. 2017, Ganie & Prakash, 2018 and Verma & Jain, 2020). When considering flexural properties, concrete with 10% replacement, the flexural strength was determined as of 4.76 MPa, which is lower by 2% than 4.85 MPa of control concrete (Ganie & Prakash, 2018).

In their experimental investigation, Mandlik et al. (2013) found that the flexural strength decreased when EPT beads were used to replace a certain percentage of natural coarse aggregates. The experimental results also showed that the density of the concrete increased when the cement content was increased (keeping the amount of the EPT). The conclusion on this study was that EPT concrete is a good alternative material for use in structures that do not require higher concrete strength.

Gunavel et al. (2020), Flexural strengths are said to decrease with an increase in the EPT content. These authors reported higher flexural strength at 10% of replacement and reduced at 30% replacement, which can still be usable on single floor buildings. This type of concrete has shown to be cost saving and the dead load is reduced. When the fine aggregates were replaced by the EPT, the weight of the concrete became lighter. Haghi et al. (2006b), noted through a flexural strength test that, as the volume of EPT in mixes was increased, the flexural strength reduced, but the use of Polypropylene fiber improved the flexural strength. Sadrmomtazi et al. (2012) also reports the same about the flexural strength being reduced as the volume of EPT in the mixes is increased and that by increasing the volume of utilized polypropylene, flexural strength had increased. Dawood (2015) reported that the findings indicate that using 50% EPT and 50% perlite as a partial replacement for sand, produces lightweight concrete for canoe production that has adequate ranges of compressive and flexural strengths.

Flexural strength gauges a slab or beam of unreinforced concrete's ability to withstand failure when bent. It is determined by loading concrete beams of 750 x 150 x 150 mm until it fails, i.e., fallen apart. This test involves subjecting beam specimens to loading at the two-point or one- point (refer to Figure 2.1). It is often performed on concrete used for floors on the ground or pavement (Owen, 2008).



(a) Four point bending.	(b) Three point bending.

Figure 2-1: Flexural Strength Test Setup

The concrete flexural strength (i.e., maximum stress caused by bending) can be calculated as follows:

For three-point bending: $f_f = \frac{3\,PL}{2bd^2}$ …. (Equation 2.1)

For four-point bending: $f_f = \frac{PL}{2bd^2}$ …. (Equation 2.2)

Where:

f_f = Flexural strength, MPa

P = Breaking load, N

L = Distance between centres of supporting rollers, mm

b = Width of the beam’s cross-section, mm

d = Depth of specimen

2.9.3. Effect of Additives on of EPT Concrete Properties

Several research studies investigated the effect of various additives such as cement extenders and polypropylene fibers, among others, on EPT concrete. The objective is usually to assess whether they can overcome certain shortcomings associated with the EPT concrete.

Abd et al. (2016), investigated EPT concrete by partially replacing river sand through adding fly ash and EPT on PCC concrete. This approach is considered because river sand is extracted from riverbanks and such leaves riverbeds with no sands, posing a risk to the environment. The experiment was conducted with different percentages of fly ash, but the EPT beads were kept at 0.3% by mass. The experimental results show that 60% of fly ash and 0.3% EPT gives strength of 25.62 MPa while the normal concrete gives a strength of 22.70 MPa. It was concluded that concrete with 60% fly ash and 0.3% EPT had higher compressive strength than normal concrete.

Sadrmomtazi et al. (2012), investigated the feasibility of manufacturing lightweight concrete of multiple strengths EPT contents. The aim was to assess the mechanical and durability properties of such concrete. To achieve this, they had different mixtures that were made by replacing 0, 15, 25, 40 and 55% of natural aggregates volume with equivalent EPT bead volumes. In addition, Portland cement was alternately replaced by 10% silica fume or 20% rice husk ash. Also, the tested concrete mixture included waste propylene fibers in the percentage of 0.1%, 0.3%, 0.5% and 1% of Portland cement volume (0.013, 0.038, 0.063 and 0.127% of total concrete volume). Compressive strength, splitting tensile strength, flexural strength, drying shrinkage, and water absorption are among the properties tested and used to evaluate this concrete. For concretes containing up to 25% EPT, the compressive strength was enhanced by substituting 10% of the cement with silica fume. The compressive strength of EPT concrete including silica fume was equivalent and lower than EPT concrete made only of Portland cement for EPT replacement of 40% and 55%, respectively. Due to the rapid reactivity of silica fume, EPT concretes containing silica achieved an average of 70% of their 28-day strength in just 7 days. The compressive strength of rice husk ash contained EPT concrete at later ages, i.e., 90 and 150 days, is almost comparable to that of EPT concrete with Portland cement at 28 days. They found that the addition of propylene to 0.3 % slightly increased the compressive strength, while adding it in higher amount decreased it. They were satisfied with the strength and performance of mixtures with 15% EPT beads, 20% rice husk ash, 25% propylene, and 10% silica fumes. Replacing the coarse aggregates by 40% and 55% EPT beads results in very lightweight concrete and concrete with a moderate strength grade, respectively. The addition of waste fibers rarely improves the qualities of lightweight concrete.

González et al. (2019a), investigates whether the use of lightweight EPT beads can partially replace fine aggregates in a normal concrete mix modified with fly ash (FA). Replacement of 10, 30 and 60 by volume of EPT and 10% FA of cement was adopted. Cylindrical specimens were subjected to destructive and non-destructive testing to evaluate their mechanical and physical characteristics such as density, compressive strength, and dynamic modulus of elasticity. Additionally, scanning electron microscopy, X-Ray diffraction, and Fourier transform infrared spectroscopy were used to investigate the cementing material and EPT. The results showed that a total percentage substitution range between 10 and 30 % guaranteed a significant reduction in density and a minimum drop in compressive strength. A later study by Gunavel et al. (2019b) extended their investigation to include 90 % EPT of fine aggregates volume replacement. It was revealed that EPT concrete did not contain any material that might be considered hazardous.

Haghi et al., (2006b), studied the effect of polypropylene fibers on-the mechanical properties of concrete with EPT. Furthermore, the influence of silica fume and rice husk to replace Portland cement in EPT concrete were also studied. The results revealed the pace at which strength is gained when silica fume is used, however, rice husk ash needs longer time to prove its value as a pozzolanic material than regular cement does compared to using cement. The addition of polypropylene fibers in the concrete did not significantly affect the compressive strength of concretes. Concerning the volume of EPT in the concrete, it was concluded that when the EPT volume was increased, the strength of EPT concretes decreased. Similarly, Sadrmomtazi et al. (2012), investigated the effect of silica fumes and rice husks (i.e., cement extenders) and polypropylene fibers on the characteristics of EPT concrete. The test results were inconclusive in terms of compressive strength since some specimens showed increased compressive strength while others showed decreases. Like the findings of Haghi et al. (2006b), the addition of polypropylene fibers to the concrete had no discernible impact on the compressive strength of the concrete with or without EPT. Silica fume was found to increase the rate of strength growth while rice husk decreased the strength gain.

Wiswamitra et al., (2021), examined the EPT concrete with mineral fillers. According to the researchers, concrete with EPT aggregates and filler had better mechanical properties than concrete with EPT aggregates alone; this has been demonstrated in several previous experiments. As fillers, several minerals including red sand, fly ash, rice husk ash, and cement, have been employed. The production of concrete falls under the category of lightweight concrete since EPT beads is used in place of natural aggregates. Two different kinds of plastic aggregates, which can be distinguished by the filler, were used in the investigation. The second aggregate employs Portland pozzolana cement while the first aggregates are an artificial aggregate created from EPT with rice husk ash filler.

Dawood (2015) examined the characteristics of lightweight concrete made by the addition of perlite and EPT beads, which can be utilized to make canoes. EPT aggregates were utilized in varying amounts 20, 35, 50, and 65%. In addition, the partial EPT beads with varying perlite contents (10, 20, 30, 40, 50, and 60%) sand replacements were made. Tests were done on the mixes' fresh density, compressive strength, flexural strength, an absorption capability. The findings indicate that using 50% EPT and 50% perlite as a partial replacement for sand produced lightweight concrete for canoe production that has adequate ranges of density compressive and flexural strengths. As a result, the canoe created using these EPT and perlite inserts exhibits a definite success in terms of floating. The study concluded that addition of EPT beads reduced the density of lightweight concrete. The density of the concrete decreased by about 50% by using 65% EPT. The presence of EPT beads had an impact on the compressive strength of lightweight concrete inclusion. When 65% EPT was added, the compressive strength dropped from 27.6 MPa to 6.9 MPa.

Herki (2017), studied the combined effects of two types of waste materials EPT and unprocessed fly ash on various concrete characteristics. Novel lightweight aggregates were created by densifying waste EPT using a novel recycling technique. The novel method helped in controlling segregation issue in concrete that has EPT beads with a natural cement and clay binder. A water to cement ratio of 0.8 was employed in nine distinct concrete compositions. EPT beads and unprocessed fly-ash, respectively, were used to partially replace natural aggregates and Portland cement. Evaluation of the combined effects of two types of waste materials of EPT and unprocessed fly ash on compressive strength and density of concrete was done at various curing times. The experimental findings show that as the amount EPT beads in concrete is increased, compressive strength and density decreased. However, it is possible to use these two waste components in concrete using an acceptable recycling approach by employing an appropriate mix design.

Ferrandiz-Mas et al., (2014), evaluated if lightweight cement mortars with good thermal-insulation qualities could be made through using waste EPT and paper sludge ash materials. A mortar mixture containing EPT beads and powdered EPT was made, and properties compared to that of normal mortar (i.e., no EPT added). It was found that the use of resource-efficient mortars in rendering and plastering applications is appropriate when they contain up to 20% paper sludge ash and 60% EPT. The sample with powdered EPT showed a 65% drop in compressive strength compared to normal mortar. In general, mortars made using powdered EPT showed less reduction in compression strength loss, than mortars containing EPT beads. When compared to normal mortars, powdered EPT and EPT beads mortars compressive strength is reduced.

2.9.4. Effect of EPT Treatment on EPT Concrete Properties

EPT beads are water hydrophobic and therefore several attempts have been made to improve its bond to cement paste.

Mandlik et al. (2013), conducted research on the use of EPT beads to produce a lightweight concrete with a unit weight varying from 1200 to 2000 kg/m^3. Lightweight concrete was achieved by partially replacing the coarse aggregates with the crushed chemically quoted EPT, which is light in weight. The focus was to investigate the properties of lightweight concrete such as compressive strength, tensile strength, and the density. The results showed that concrete's compressive strengths decreased when EPT beads were used to replace a certain percentage of the coarse aggregates. It was also discovered that the compressive strength depends on the size of the EPT beads, that is, the small the beads, the better the results of the compressive strength.

Adhikary & Ashish (2022), determined whether the addition of chemically treated and plain EPT to lightweight concrete altered the mechanical, durability, and thermal insulation properties. Their main contribution lies in the exploration of subsequent additives, to produce modified EPT to improve the performance of EPT concrete. After several experimental studies, the researchers concluded that the mechanical qualities of EPT concrete can be improved by using smaller EPT particles, lowering the water to cement ratio, by adding chemical admixtures and certain pozzolanic ingredients. Furthermore, they showed that the use of specific pozzolanic materials and chemical admixtures helps to improve the mechanical qualities of EPT concrete, as does using smaller EPT beads to reduce the water to cement ratio. The study compared between chemically modified and plain EPT concrete. They concluded that the compressive strength of the concrete with chemically modified EPT significantly increased when compared to EPT concrete that had not been modified chemically. The increase in strength may have been caused by an improvement in interfacial adhesion.

Ravindrarajah & Tuck (1994), reported properties of hardened concrete containing chemically treated EPT beads. The results showed that the compressive strength of EPT concrete with constant density were affected by the water to cement ratio. In other words, the compressive strength of EPT beads concrete increased with an increase in the water to cement ratio.

Mohammed & Hussein (2021), investigated the mechanical properties of treated recycled EPT concrete, treated by two methods, one by heating, and the other by immersed recycled EPT in cement neat. By substituting 0 %, 15 %, 25 %, and 35 % of the coarse aggregates volume with treated recycled EPT, (for both method). Treated recycled EPT concrete ratios are experimentally prepared while the cement is substituted through 10% silica fume. Results from compressive strength tests display the decrease in compressive strength of treated recycled EPT concretes when compared to the normal concrete. When the proportion of treated EPT in the mixes was increased, the compressive strength decreased. This is because, treated EPT is more brittle than natural aggregates. Concrete compressive strength is reduced because of treated EPT mix's more voids and pores compared to normal concrete. Due to the recycled Treated EPT particles' relatively light weight compared to natural aggregates, the density was reduced to meet the lightweight requirements.

Kharun & Svintsov (2017), researched on the possibility of using heat treated EPT beads as aggregates in concrete. The modified heated EPT was done by placing the EPT trash in a closed hot air oven at 1300°C for 15 minutes. Aggregates were both placed individually and collectively for natural coarse aggregates and natural fine aggregates. According to findings of a 28-day testing, the density decreased from 2640 to 846 kg/m^3, compressive strength decreased from 58.51 to 15.85 MPa, and the flexural strength decreased from 4.90 to 2.04 MPa. It was concluded that the density, compressive strength, split-tensile strength, and flexural strength of heat-modified EPT were satisfactory.

2.9.5. Effect of Water to Cement Ratio on Strength Properties of EPT Concrete

Karolina et al. (2019), investigated the mechanical properties of EPT lightweight concretes containing various volumes of EPT with percentages of 0, 5, 10, 15, 20, 25, 30, 35, and 40%, as well as two different water to cement ratios of 0.45 and 0.55. The compressive strength and density were tested, and the outcome of the experiment shows that EPT concrete strength and density decreased as the EPT particle content increased, when comparing with the normal concrete. However, when the water to cement ratio was increased, the EPT concrete increased to a higher strength than that of a lower water to cement ratio. The authors concluded that the addition of EPT to the concrete mixture decreased the value of concrete density and compressive strength however, using a higher water to cement ratio can cater for some of the strength loss.

2.9.6. Effect of EPT Beads Size

Haghi et al. (2006a), investigated the different sizes of EPT beads and adding polyamide-66 yarns in making the latest lightweight concrete. The experimental study was conducted to find out how EPT concrete is influenced by the different sizes of EPT beads. The bigger size EPT beads disintegrate along the contact zone and reduces the bonding strength of the concrete and that adding of polyamide-66 yarns had shown to reduce the cracks of the EPT concrete. From the results, it was stated that when the beads size reduced, EPT concrete's compressive strength improved. They concluded that the size of the EPT beads to be utilized to get the optimum compressive strength is the 3 mm. Even though the 3 mm size is used, when EPT beads are added at higher amount the strength is lessened but is better than when bigger beads are added.

Babu et al. (2006), studied how the compressive strength of lightweight concrete with EPT are affected by the size of EPT beads. Expanded and unexpanded polystyrene beads were used in the study as lightweight aggregates in concrete that also contains fly ash as a cement extender. Lightweight concrete was examined primarily for compressive strength. Concrete densities ranged from 1000 to 1900 kg/m^3. According to the findings, EPT had a 70% lower compressive strength than un-expanded polystyrene thermocol for the same aggregates size and concrete density. Small EPT aggregates in EPT concrete demonstrated better compressive strength. Brittle failure, like that of regular concrete, was seen in the unexpanded polystyrene aggregates concrete, but progressive failure was noticed on aggregates made of EPT.

2.9.7. Ductility of Concrete

Owen (2008) explains that ductility in concrete refers to the ability of concrete to undergo deformation without sudden or catastrophic failure. Concrete with higher ductility can undergo larger deformations and absorb more energy before fracturing. This property is especially crucial in applications where the structure needs to provide warning and accommodate moderate movements before ultimate failure.

Babu et al., (2005), reported that concrete samples with EPT aggregates as a partial replacement of coarse natural aggregates exhibit decreasing flexural strength but potentially improved ductility, because of the plasticity of EPT beads. This suggested that such concrete mixtures might be better suited to structural applications where controlled deformations, energy absorption, and warning signs before failure are important considerations.

2.10. Physical Properties of EPT Concrete

This section discusses the physical properties of EPT concrete, which include the drying shrinkage, heat conductivity, and durability.

2.10.1. Drying Shrinkage

Owen (2008), posit that concrete loses volume because of moisture evaporating from it; this process is known as drying shrinkage. When efficient curing stops, concrete structures begin to lose moisture and shrink, unless they are completely submerged in water. Therefore, joints must be built to accommodate the movement brought on by drying shrinkage. Concrete is put into tension when shrinkage is restrained, and when the tensile stress is equal to or greater than the tensile strength, the concrete cracks. In general, the following measures can be taken to minimize the impacts of drying shrinkage:

Constructing structures with movement joints and appropriately detailing these joints.
Concrete reinforcement to take the tensile forces and prevent cracking.
The correct detailing of components attached to concrete structures.

Maghfouri et al. (2022a), studied the drying shrinkage of EPT concrete. It was found that EPT concrete drying shrinkage is significantly greater than that of control concrete at early age (7 to 28 days) and therefore expected to cause more cracking over time, which would be detrimental to the concrete's durability and longevity. At increasing EPT beads volume, the drying shrinkage in EPT concrete was more than that of normal concrete. At later age of 90 days, EPT beads concrete and control concrete did not exhibit any appreciable drying shrinkage variations, despite early-age shrinkage being significant at increasing EPT content (Maghfouri et al. 2022 & Tang et al. 2008).

According to Maghfouri et al. (2022), drying shrinkage value for lightweight concrete produced by incorporating EPT beads was lower under continuous curing than it was under 7- and 28-day water curing conditions. This may be caused by higher aggregates moisture due to the continuous curing and the higher strength of concrete as hydration continued for longer period. Drying shrinkage has a bigger impact on concrete created with total replacement EPT beads (i.e., coarse aggregates is fully replaced by EPT beads) than concrete made with replacements of 50% or less. Several research attempted to modify the concrete mix to reduce drying shrinkage of EPT concrete.

In their study, Sadrmomtazi et al. (2021) added 0.3 and 0.5 % of Polypropylene fibers on EPT to enhance the drying shrinkage and unexpectedly the drying shrinkage went up. Silica fume was also added and decreased the shrinkage while adding rice husk ash increased drying shrinkage.

Demirboga & Kan (2012a), studied the drying shrinkage of laboratory heated EPT beads concrete and found that the drying shrinkage was reduced as the thermally treated EPT beads content was reduced. Additionally, Demirboga & Kan, (2012b) found that the drying shrinkage of heated EPT concrete was significantly increased by an increase in EPT aggregates. They also found that the natural aggregates concrete shrinks more slowly than heated EPT concrete by up to 30 days, with an abrupt increase of up to 30% occurring after 90 days of curing (Demirboga & Kan 2012a).

Sadrmomtazi et al. (2012), showed that the utilization of EPT beads increases drying shrinkage. While silica fume could partially offset drying shrinkage, the application of 0.3 and 0.5% of Propylene fibers significantly enhanced drying shrinkage. Contrary to silica fume, the addition rice husk ash increased drying shrinkage.

Adhikary & Ashish (2022), investigated drying shrinkage after 84 days of drying for EPT concretes, having 10 mm coarse aggregates and a nominal density of 1300 kg/m^3. Their results indicated that the drying shrinkage value for EPT concrete and conventional concrete was 730 and 655 micro strains, respectively. The higher shrinkage value was attributed to the lower stiffness of the EPT beads, which provide very little restraint to the shrinkage of cement paste.

Sadrmomtazi et al. (2012), suggested that because plastic shrinkage is an issue that happens in all fresh cement-based materials in the first few hours of installation, and it can occasionally be accompanied by unattractive cracks, so prevent this plastic from shrinking, concrete is reinforced with polypropylene and other synthetic fibers. They examined effects of adding polypropylene fibers to EPT concrete at levels of 0.1, 0.3, 0.5, and 1% by volume and, the effects of using Silica fume and Rice husk as two supplementary cementitious materials.

Demirboga & Kan (2012b), researched on whether sustainability in the construction sector can be promoted through using artificial aggregates in place of natural aggregates in the manufacture of concrete. The effect of heat-treated waste EPT shrinkage of concrete was examined. Heat-treated EPT aggregates were substituted for natural aggregates in concrete by percentages of 25, 50, 75, and 100% as lightweight aggregates. After 210 days of ambient curing, the average drying shrinkage was 2.59 10 3 for samples of 25% natural aggregates and 5.08 10 3 for samples of 100% modifies EPT aggregates.

2.10.2. Thermal Conductivity

The term “thermal conductivity” describes a material's capacity to conduct or transfer heat and is represented by the letter “k”. Byjus (2022), indicated that the rate at which heat is transported through a material is proportional to the temperature gradient and is also related to the area through which the heat flows. According to Fourier's law of thermal conduction (also known as the law of heat conduction), each material has a unique ability to conduct heat. The following formula describes a material's thermal conductivity:

$K= \frac{Q\Delta x}{A\Delta t}$ …. (Equation 2.3)

Where:

K = Thermal conductivity (W/m. K)

Q = rate of energy (W), how quickly energy is being transferred or used per unit time.

Δx = Difference between points of temperature measurement (m)

T = Difference of temperature measurement (T1 -T2) (℃).

A = Area of the specimen measured in (m^2) (specimen being concrete cubes measuring 150 x 150 x 150 mm)

Figure 2.2 shows an illustration of a material's thermal conductivity as it relates to the flow of heat through. it. In the sketch, T1 & T2 represent the points where temperature is measured (ΔT =T2-T1), while X1 and X2 represent the distance on which the heat travels (ΔX = X2 - X1).

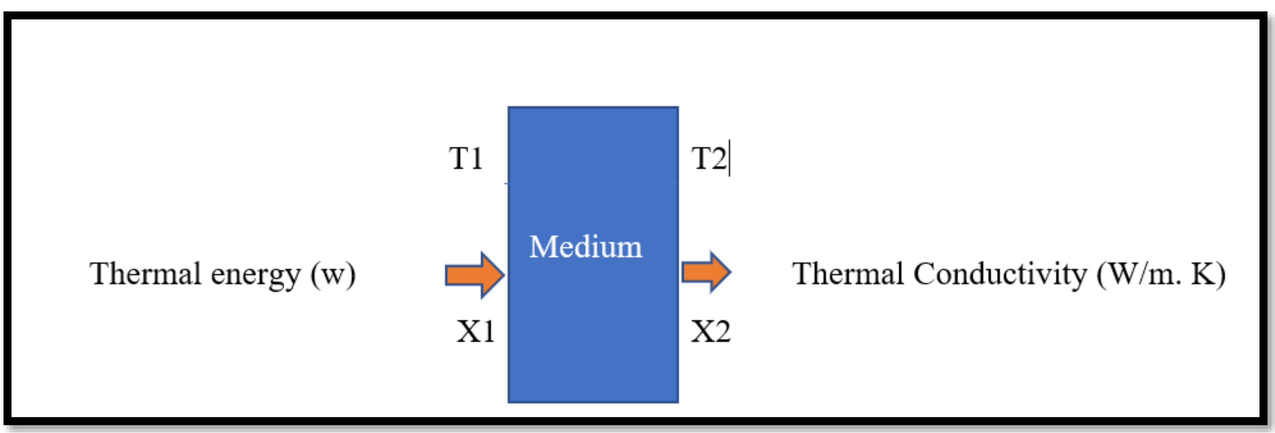


Figure 2-2: Illustration of Thermal Conductivity Test

Byjus (2022), a material's thermal conductivity can vary for reasons other than temperature. Table 2.1 includes the main variables that affect a substance's ability to transfer heat.

Table 2-1: Factors that Influence Heat Conductivity (Byjus, 2022)

Factors Influencing Heat Conductivity	**Effect on Thermal Conductivity**
The chemical phase of the material	A material's heat conductivity may abruptly change when its phase changes. For instance, as ice melts into a liquid phase, its thermal conductivity decreases from 2.18 to 0.56 W.m K.
Thermal Anisotropy	Some materials display varying values of thermal conductivity along various crystal axes due to variations in the coupling of phonons along that crystal axis. Thermal anisotropy suggests that the path of the heat flow might not coincide with the direction of the temperature difference.
The electrical conductivity of the material	Only metals are affected by the Wiedemann-Franz law, which establishes a relationship between electrical conductivity and thermal conductivity. Non-metals' electrical conductivities largely have little impact on how well they conduct heat.
Influence of magnetic fields	The Maggi-Righi-Leduc phenomenon explains how a conductor's thermal conductivity changes when it is exposed to a magnetic field. When magnetic fields are applied, an orthogonal temperature gradient is seen to arise.
Isotopic purity of the crystal	The following illustration shows how isotopic purity affects thermal conductivity: Type II diamonds have a carbon-12 isotope concentration of 98.9%, whereas 99.9% enriched diamonds have a thermal conductivity of 41,000 Wm-1K-1.

Maghfouri et al. (2018), stated that when assessing the quantity of heat transfer by conduction, the thermal conductivity value (k) of cement-based materials like concrete is crucial. Building energy consumption is directly impacted by how much heat is lost via the walls and roofs. The two primary techniques used to determine thermal conductivity are, steady state and transient methods. The thermal conductivity of concrete is influenced by its density, moisture content, aggregates type, and cementitious material type. The lower k value of lightweight concrete compared to normal weight concrete makes it an effective way to reduce the amount of heat transmission and energy consumption in structural and non-structural building.

Though scares, literature on thermal conductivity indicate that EPT concrete has a reduced thermal conductivity as compared to the normal concrete. Investigation conducted by Ferrandiz et al. (2014) on mortars containing EPT suggested that it has lower heat conductivity than control mortars (i.e., mortar without EPT). Furthermore, the heat conductivity was found to decrease with increasing temperature (Maaraofi, Younsi & Nouviaire, 2018). Another study demonstrated that the suitable volume of EPT beads from 30% and more have a noticeable decrease of heat conductivity (Nicholias, 2019). Mortars containing EPT have suggested lower thermal conductivity than control mortars (Ferrandiz-Mas et al. 2014).

Studies reported that the density and thermal conductivity values of EPT concrete decrease with the increase in the volume of beads in concrete (Kharun & Svintsov, 2017). According to the experimental investigation by Mahdi & Aljalawi (2019), the thermal conductivity coefficient of EPT concrete ranges from (0.11- 0.34) and is controlled by the density of the material, where the value increases with the increase in density.

The thermal conductivity tests by Xu et al. (2016a) affirmed that when the volume of EPT increases, the thermal conductivity values of EPT concrete decrease. Moreover, the thermal conductivity of the EPT cement paste is lower than that of the control cement paste mix and this may be due to the insulating properties of the polystyrene beads, (Maaraofi, Younsi & Nouviaire, 2018). It is also stated that the thermal conductivity of lightweight concrete with EPT reduces as temperature rises. Additionally, it was shown that the right amount of EPT particles can lessen thermal conductivity while simultaneously lessening the effect of temperature on thermal conductivity (Nicholias 2019, Joseph & Xu et al., 2016b and Demirboga & Kan, 2012b).

The experimental study was conducted on a control concrete with density of 2510 kg/m^3 and EPT concrete with density of 1835 kg/m^3. Intriguingly, EPT concrete recorded a maximum temperature of 85 ℃ while the control concrete also recorded 85 ℃ (Ravindrarajah & Collins, 1998). With an increase in EPT aggregates, the thermal conductivity of concrete was significantly reduced, with a reduction value of 70% and it is affected by density (Demirboga & Kan, 2012b).

Demirboga & Kan (2012b), concluded that when more heat-treated EPT aggregates are used in place of natural aggregates, the thermal conductivity of the samples drops, with values for 25%, 50%, 75%, and 100% Modified EPT aggregates being 1.990, 1.518, 1.000, and 0.600 W/mK, respectively. The samples made up entirely of modified EPT aggregates showed the greatest thermal conductivity reduction and almost 70% of the original amount was reduced.

Maaraofi et al. (2018), results for thermal conductivity shows that it goes down when the EPT is added. At 23 degrees Celsius, the thermal conductivity shown the results of 383 W/m. K for normal mortar and the one for mortar with EPT is 142 W/m. K, which concludes that the mortar with EPT has a good thermal conductivity. Due to the insulating properties of the polystyrene beads, the thermal conductivity of the polystyrene cement paste is lower than that of the control cement paste mix.

Ravindrarajah & Collins (1998), focused on the effect of EPT beads on temperature development of concrete with EPT beads. EPT beads added to concrete on temperature development in an insulated thick concrete section are the subject of an experimental study, the findings then compared to the once of concrete with no EPT. By replacing some of the coarse aggregates with different amounts of non-heat transmitting EPT beads, the unit weights of 2215, 2100, and 1835 kg/m^3 were achieved. The combinations' cement content and the ratio of water to cement were both held constant at 500 kg/m^3 and 0.30, respectively. The peak temperature of the concrete mixture with the most EPT beads was 85.6 ^{o}C as opposed to 70.6 ^{o}C for the normal concrete mixture. Mixtures 1, 2, 3, and 4 had linear coefficient expansions of 7.35, 7.02, 6.81, and 7.02 x 10-6 per ^{o}C, respectively. According to the findings, the control mix had the highest coefficient of thermal expansion value, because there was only a small amount of insulating EPT beads in the normal concrete, the coefficient of expansion had slightly lower values.

Mahdi & Aljalawi (2019), assessed whether producing lightweight concrete with two densities varying from 350 to 625 kg/m^3 would result in high thermal insulation. Numerous concrete mixes incorporating EPT beads were created. After the casting process, the moulds were covered with polyethylene foil for 24 hours to stop the evaporation of water from the fresh concrete. Following removal from the moulds, the bags of polyethylene were sealed for 28 days. This approach was used in ASTM C-192. The thermal conductive coefficient of EPT concrete was found to rises with density. The conductive coefficient was found to range from (0.11 - 0.34), and it was dependent on the EPT volume incorporated in the concrete mix.

According to the study by Adhikary et al. (2022), thermal conductivity was also evaluated and found that it primarily depends on density, but large increases in thermal resistance can be seen on bulk EPT materials. Also, whether increasing the concentration of natural aggregates and additives such fly ash, paper sludge, foaming agent, and selective resins would have a positive impact on thermal conductivity.

Ferrandiz-Mas et al. (2014) conducted experimental work to compare Portland cement mortar containing powdered EPT and EPT beads. When compared to control samples, the mortars produced using EPT (i.e., powder or beads) showed lower thermal conductivity. Furthermore, mortar containing EPT beads yielded lower thermal conductivity samples with reduced thermal conductivity as compared to mortar with EPT powder.

2.10.3. Durability

Kryton International Inc (2022) posited that durability is important for a sustainable concrete structure. Concrete constructions frequently display severe premature deterioration because of the use of improper materials, inadequate construction techniques, curing, and mix designs. This issue is widespread and cost the public and business sectors large number of resources worldwide, annually. It is challenging to assess concrete's durability to determine how long it would remain in use. However, it is crucial to understand how eventually sustainable structures would be.

How long and well a concrete construction can last is a measure of its durability (Owen, 2008). The chemistry of solidified cement paste, the concrete's ability to transmit fluid, and specific aggregates characteristics all have an impact on how long concrete can last and the exterior deterioration mechanisms affect the concrete surface layer after it has first been influenced by curing (Owen, 2009). When determining the durability of concrete, the tests should consider the special characteristics of the mix design (Kryton International Inc, 2022). The results of having concrete that is not durable include loss of functionality, unpleasant look, risk to people and property, costly repair costs, and negative opinion of concrete as a material (Owen, 2008).

Studies show that when EPT beads are increased in concrete, the concrete exhibit reduced water permeability (Babu & Babu, 2004 and Sadrmomtazi et al. 2012). EPT concretes with higher strength and density from (1500 kg/m^3), function almost similarly to normal concretes in terms of water permeability (Babu & Babu, 2004). Babu & Babu (2004), stated that once a minimum cement paste content is ensured, the chemical attack and corrosion properties, which are greatly impacted by the cement and paste content, show a significant improvement even at the lower densities. A chemical attack's impact was evaluated using methods of assessing weight loss and strength loss and because these concretes contain less cement, the attack was observed to be lessening when the EPT volume was increased. The increase in water permeability in concretes with more EPT beads indicates a rise in internal porosity, which may be due to the existence of more air bubbles and microcracking brought on by compression of the EPT beads during the absorption test (Sadrmomtazi et al., 2012).

Babu (2004), investigated concrete with wide density range from 550 to 2200 kg/m^3, incorporating fly ash and EPT replacements ranging from 0% to 95% EPT mixtures made with fly ash exhibited less water absorption and greater chemical resistance compared to normal concrete. Additionally, these concretes were shown to have a 50 to 65 % reduced chloride permeability than normal concretes with comparable water to cement ratios. On normal concrete, the higher rates of corrosion were seen when compared to EPT concrete and this is because of the non-absorbent properties of the EPT aggregates and the fly ash in the matrix, the behavior of EPT concretes was superior to that of normal concrete.

Ravindrarajah and Tuck (2004), found that other different chemicals solutions such as calcium hydroxide, sodium sulphate, and ammonium sulphate had little effect on EPT aggregates concrete.

But as the water to cement ratio of the EPT aggregates concrete decreased, the resistance to 5 percent hydrochloric acid increased. Adhikary & Ashish (2022) concluded that EPT beads concrete is not affected by calcium hydroxide, sodium sulphate and ammonium sulphate solutions. But the resistance to 5 % hydrochloric acid increased with a decrease in the water to cement ratio of the EPT beads concrete.

According to the evaluation criteria, EPT concrete with fly ash infused, the chloride conductivity was "extremely low". It was noted that all the fly ash infused EPT concretes performed better than the normal aggregates concretes (Babu, 2004). Due to the permeability of EPT aggregates, the addition of EPT beads demonstrated good performance in terms of resistance to chloride conductivity, capillary water absorption, and frost (Adhikary & Ashish, 2022). It was found that the EPT concretes' chloride conductivity was 50 to 65 percent lower than that of normal concretes (Babu, 2004). The overall absorption values likewise exhibit a same downward trend with rising concrete density (Babu & Babu, 2004). Adhikary & Ashish, (2022), concluded that EPT beads concrete is not affected by calcium hydroxide, sodium sulphate and ammonium sulphate solutions. But the resistance to 5 % hydrochloric acid increased with a decrease in the water to cement ratio of the EPT beads concrete.

According to the study by Wiswamitra et al. (2021), the EPT concrete with certain mineral filler's that improves heat resistance. Their test results reveal that concrete made up of EPT aggregates developed fine cracks when subjected to 100 °C, which can only be detected under a digital microscope. By contrast, for normal concrete, fissures show when exposed to about 200 °C. Overall, the mechanical properties of concrete are greatly reduced when cracks are present. The specimens with EPT beads seem burnt at 300 and 400 °C, and there are holes from the EPT decomposition process as well as additional cracks with wide gaps.

2.9 Summary

The following points summarised findings from the literature review on EPT concrete:

- The increase of EPT content in concrete is found to increase the workability of the composite material. However, one study indicated the opposite.

- The increase of EPT content in concrete is found to reduce the compressive, flexural, and tensile strengths of the composite material. The strength reduction varies between the reviewed studies. In addition, key parameters to strength of EPT concrete are the size of EPT beads and water to cement ratio of the concrete mix.
- The increase in EPT content in concrete is found to increase the drying shrinkage of the concrete. The study on the drying shrinkage of EPT concrete is limited when compared to the study done on compressive strength.
- The increase of EPT content in concrete reduce the heat conductivity. All studies consulted came to the same conclusion on this point.
- In general, the increase in EPT content negatively reduces the durability of concrete. Further investigation on durability falls out the scope of this study.

CHAPTER 3

3. RESEARCH METHODOLOGY

3.1. Introduction

The investigation carried out involved extensive laboratory testing on control concrete (plain concrete) and Expanded Polystyrene Thermocol (EPT) concrete with varying dosages of EPT used to replace equal volume of coarse aggregates. This chapter covers the material used, concrete mix design, manufactured specimens, standard methods employed, and testing program in this study. The experimental work mainly included five sets of testing these are workability, compressive strength, flexural strengths, drying shrinkage properties, and thermal properties.

3.2. Pilot Study

A pilot study was conducted to explore possible EPT incorporation in concrete. The initial literature survey indicates a typical range of 0 to 50% replacement. The designed and adjusted control concrete mix, discussed in a later section, was used to manufacture cube and flexure beam specimens containing EPT volumes higher than 50% to replace portions of the coarse aggregates.

The tested EPT dosages were: 0, 0.38, 0.76, 1.13, 1.51 and 1.9 % by mass of aggregates. The data obtained from a pilot study conducted by Mashava & Elsaigh (2023), is presented on Appendix 7-5.

3.3. Materials and Concrete Mix Design

The investigation carried out involved extensive bench-scale testing on control concrete (i.e., 0% EPT, plain concrete) and EPT concrete with 5, 10, 15, 20, 25 and 50% EPT dosage by volume of the natural coarse aggregates. The selection of these percentages is based on the literature review and the results from the pilot study.

This study followed a comparative approach incorporating test results on fresh and hardened concrete samples. Concrete mix design was carried out for the control mix (i.e., 0% EPT) and the proportions of the mix constituents was determined and adjusted for 35 MPa. Thereafter, percentage volumes of coarse aggregates were removed from the concrete mix and replaced with equivalent volumes of EPT to generate six concrete mixtures, beside the control mix. The percent EPT used in each of the mixtures was calculated as volume of EPT and divided by the total volume of coarse natural aggregates used in the mixture. The concrete mixtures were used to manufacture cube samples of 150 x 150 x 150 mm which were used for compressive strength test as well as beam samples of 750 x 150 x 150 mm which were used for shrinkage test. Both samples were tested for the purpose of EPT concrete characterization and comparison to the control mix.

3.3.1. Concrete Mix Composition

A Control concrete mix was designed according to the South African mix design method (Fulton, 2009). The water to cement ratio (W/C) of 0.58 was adopted for all mixes. The design aimed at 35 MPa after 28 days and 75 mm slump workability, which is typical concrete used on low-cost housing and general-purpose applications. The details of the mix design calculations are provided on Appendix 7-1. The blending of coarse aggregates calculations is shown on Appendix 7-2. Grading, chemical impurities, clay & silt content, water absorption and relative density of aggregates are presented on appendix 7-11. After the theoretical calculations, several trial mixes were prepared and used to adjust the mix workability and compressive strength. The final mix constituents and proportioning are shown in Table 3-1 below:

The design strength of a concrete mix must be 35 MPa after 28 days. The cement to be used is a CEM I 42.5 all-purpose cement with relative density of 3.14 from table 11.1 Fulton's Concrete Technology. The stone size to be used is a 22.4 mm with dry compacted bulk density (CBD) of 1660 kg/m^3 and relative density of 2.694. Determination of dry-stone compacted bulk density is shown on Appendix 7-10. A good crusher sand with fineness modulus of 3.1 and relative density of 2.689 is going to be used for the mix. The slump is 75 mm as this is a good workability concrete, especially if it is not going to be transported. The table below shows calculations done in designing the control mix.

Table 3-1: Control Mix Proportion

Materials	**Contents per m^3**
Cement (CEM I- 42.5 N) (kg)	335

Granite coarse aggregate 22.4 (kg)	595
Granite coarse aggregates 14 mm (kg)	595
Granite crusher sand (kg)	539
Riverbed sand (kg)	50
Water (litre)	195
Plasticiser (g) – 0.3 kg per 100 kg of Cement	1173

3.3.2. Cement

Portland cement CEM I with strength class of 42.5 (CEM I- 42.5 N), normal strength all-purpose with relative density of 3.14 was used for concrete mixing. It reaches a compressive strength of 45 MPa at 28 days. It is suitable for elevated structural beams and slabs, columns, water-retaining structures, and other applications where early strength is not required. The cement is sourced from a reputable supplier, whose manufacturing facilities are ISO 9001 certified. The used cement fully complied with the SANS 50197 cement specification for common cements in South Africa.

3.3.3. Natural Aggregates

The granite aggregates were acquired from a local reputable supplier, located in the Johannesburg area. A blended unwashed stone size of 22.4 and 14 mm with a dry compacted bulk density (CBD) of 1660 kg/m^3 and relative density of 2.694 was used. Unwashed Crusher sand with fineness modulus of 3.1 and relative density of 2.689 was used in all mixtures. A small amount (50 kg/m^3) of the crusher sand in the mix was replaced with riverbed sand. Aggregates test results included particle distribution of 14 mm stone, particle distribution of 22.4 mm stone, particle distribution of crusher sand, stone water absorption, clay & silt content and relative density are shown on Appendix 7-11 under figure 7-4, 7-5, 7-6,7-7 and 7-9 respectively.

3.3.4. EPT Beads

EPT beads are round shaped particles, produced from styrene and pentane and comprises of about 98% air and 2% polystyrene (Omnexus, 2021). It is hydrophobic and slow to absorb atmospheric moisture, with relative density of 0.023. The exceptional properties of EPT are its light weight, affordability, thermal insulation, sound insulation, buoyancy, chemical inertness, recyclability, chemical resistance, and aging resistance. Unwashed and untreated EPT beads were acquired from a local supplier in Johannesburg area.

The EPT was characterised in a pilot study conducted by the author. The particle size distribution of the EPT beads was established through standard sieve tests. Refer to Figure 3.1 which shows the EPT beads on the set of sieves used. By visual observation during the EPT beads sieve analysis, most of the beads passed through the 5 mm sieve but few stuck and had to be pushed. All beads were retained at the 2mm sieve. The EPT beads had different sizes, which was possibly anything slightly larger than 5 mm and greater than 2 mm. Figure 3-1 shows the EPT beads size distribution as per standard sieve sizes (SANS 201: 2008) and results are shown on appendix 7-9.

Figure 3-1: Illustration of Particle Size Distribution Test on EPT

The average density of EPT beads is 23 kg/m^{3,} which adheres well to the range reported in the literature for typical EPT beads material (12-50 kg/m^3)

3.3.5. Plasticizer

The plasticizer CHRYSO® Omega 180 ZA, was used as per the product data sheet (CHRYSO, 2020). As indicated in the product data sheet, the plasticizer conforms to the requirements of SANS 50934-2 and sufficiently meets ASTM C494 Type A standard. CHRYSO Data sheet for the admixture used is presented on appendix 7-11. Furthermore, the plasticizer is robust to differences in cement characteristics and can be used with in mixes extended with limestone, Supplementary Cementitious Materials, Ground Granulated Blast Slag, Ground Granulated Copper Slag, fly ash, or/and silica fume. Moreover, the used plasticizer has no or little bearing on the early age strength of concrete. The plasticiser is administered at a rate of 0.3 kg per 100 kg of cementitious material, which makes 1173 g per m^3 of the control concrete mixture. The correct plasticiser amount was added and mixed with water immediately before adding the solution to a concrete mixer. The plasticiser is necessary to aid the workability of concrete because the first trial mixes exhibited a relatively low workability.

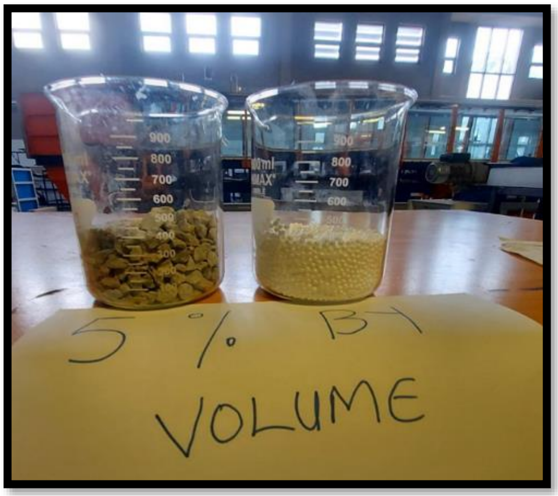
3.3.6. Water

Tap water from the City of Johannesburg municipality was used for all concrete mixing and sample curing. The tap water that was used was collected using a clean bucket and used immediately without any contamination.

3.4. Specimen's Manufacture

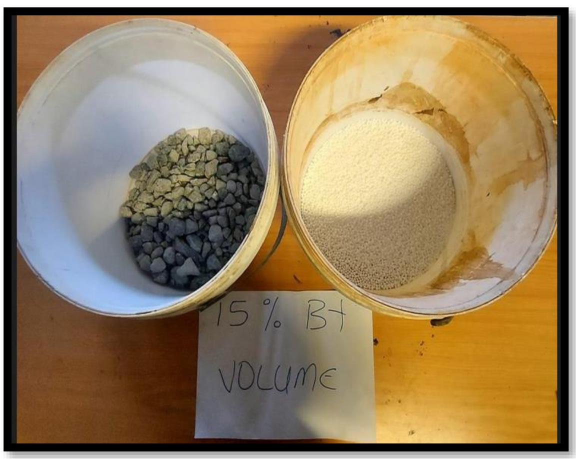
3.4.1. Concrete Mixing

Concrete mixing was done in accordance with SANS 5861-2006. A drum mixture of 20 litre capacity was used. Before the mixer was used, it was clean and dried and then wiped with a damp cloth. The mixer was loaded with approximately half of the coarse aggregates, then with cement, with the fine aggregates and finally with the remainder of the aggregates in such a way as to prevent loss of material. The dry materials were then mixed for not longer than 30 seconds. The water-plasticiser mix was added slowly to mix. Then the concrete constituents were let to mix until the control concrete was uniform in appearance. Lastly, the calculated amount (Refer to Appendix 7-3) of expanded polystyrene thermocol (EPT) beads was added to the rotating mixer portion by portion until properly mixed. Figures 3-2 (a), (b), (c), (d), (e), and (f) show the measured EPT volume used to replace coarse aggregates for each replacement percentage. The EPT volume equivalent to the coarse aggregates is determined theoretically using the densities of the two materials. Refer to Appendix 7-3 for the calculation of equivalent volumes for each percentage replacement.

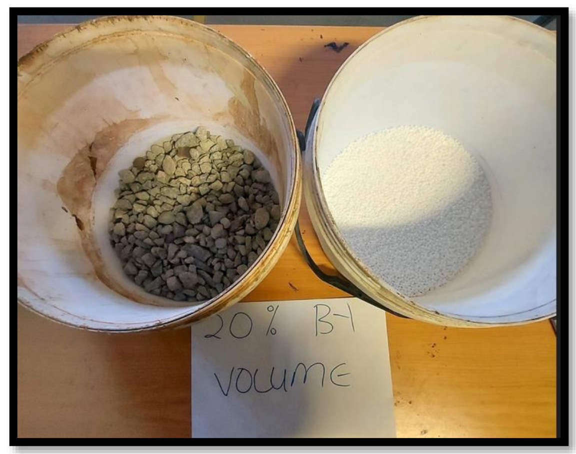


(a) 5% coarse aggregates replacement.

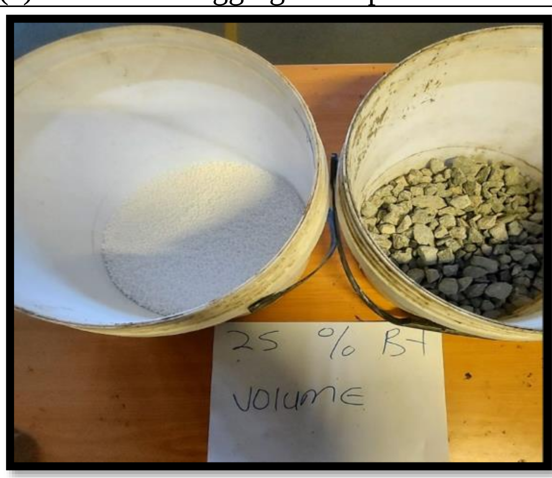
(b) 10% coarse aggregates replacement.



(c) 15% coarse aggregates replacement.



(d) 20% coarse aggregates replacement.



(e) 25% coarse aggregates replacement.

(f) 50% coarse aggregates replacement.

Figure 3-2: Measured Equivalent EPT Volume Used to Replace Coarse Aggregates

3.4.2. Slump Test

Workability of a mix is the relative ease with which concrete can be placed, compacted, and finished without separation or segregation of the individual materials and it is determined by conducting a slump test (Fundamentals of concrete, 2008). The test was done in accordance with SANS 5861-3-2006.

The slump cone secured to the base plate by standing on the foot holds. The cone remained still throughout the test. Using the scoop, 1/3 of the cone was filled with the concrete. The material was tamped 25 times with the steel tamping rod, taking care to distribute rodding evenly over the entire cross-section of the sample. The cone was filled to 2/3 full. The second layer was tamped 25 times, making sure to penetrate the previous layer by about an inch. The final layer was filled, the cone to slightly overflowing. The final layer was tamped 25 times. The excess concrete was stroked off from the top of the cone, using the tamping rod as a screed. The excess concrete was cleaned from the base of the cone. Holding the cone firmly, the u cone was unlocked. The cone was lifted vertically in a constant motion, without any rotational movement, straight up to clear the sample. The cone was inverted, small side down and set it next to, but not touching, the concrete sample on the base. The tamping rod was placed across the cone, the ruler was used to measure the slump from the highest point of concrete to the bottom of the tamping road. The reading was recorded.

3.4.3. Cubes and Beams Manufacturing

Concrete mixing was done in accordance with to SANS 5861-1: 2006. Standard cubes measuring 150 x 150 x 150 mm, flexure beams measuring 750 x 150 x 150 mm, and drying shrinkage beam size of 300 x 100 x 100 mm were manufactured using the control mix and EPT concrete mixtures. The inside of the moulds was cleaned and oiled before filling to prevent the concrete from sticking to the mould’s sides. The moulds were filled with concrete, compacted using vibrating table, surface finished, labelled, and covered with plastic sheets for 24 hours in room temperature before demoulding. Thereafter, specimens were subjected to standard water curing for a desired age. The drying shrinkage specimens are subjected to a slightly different scenario. The drying shrinkage specimens were covered in their moulds with an impervious sheet and stored for 20 to 24 hours in a room that is free from vibration, an atmosphere that has a temperature between 22 °C to 25 °C, and a relative humidity of at least 90%. The specimens were then demoulded in a manner that does not disturb the displacement of the anvils. Table 3-2 shows the tests conducted, % EPT volume replacement, number of tested specimens, curing duration and the standard methods used.

Table 3-2: List of Tests and Their Respective Standards

Tests	No. of Specimen and EPT Dose							Standards Used
	0%	5%	10%	15%	20%	25%	50%	
Slump	One slump test for each mix (immediately)							SANS5861: 2006
Compressive Strength	3 cubes for each % of EPT at 7 and 28 days							SANS5863: 2006
Flexural Strength	3 beams for each % of EPT at 7 and 28 days							SANS5864: 2006
Drying Shrinkage	3 beams for each % of EPT at 7 days							SANS6085: 2006
Heat Conductivity	3 cubes for each % of EPT at 28 days							SANS8301: 2010

3.4.4. Water Curing

After 24 hours from the time of casting, the specimens acquire sufficient strength. Except for the drying shrinkage specimens, the cubes and beams specimens are demoulded and put in a water curing tank for the desired curing period. The temperature of water in the tank was kept between 20 ℃ and 25 ℃ as per standard. The mass of each of the specimens was measured cubes before testing at a particular concrete age.

Immediately after demoulding the drying shrinkage specimens, the gauge length L0 of each specimen were measured, to the nearest mm, as the distance between the innermost faces of the anvils. The specimens were marked and submerge in water for a period of 6 days in clean potable water that had been kept at a temperature of 22 °C to 25 °C.

3.5. Strength Properties Measurement

The specimens were let to cure for 7 days and 28 days. The specimens were taken out of water, the surface water is wiped out, and grit and projecting fins were removed. The mass of each specimen was determined prior to testing. The load was applied on the surface dry saturated specimens.

3.5.1. Compressive Strength Test

The compressive strength of concrete is a measure of the concrete's ability to resist loads which tend to compress it (Owen, 2008). It was measured by crushing a cube of 150 x 150 x 150 mm concrete specimens in compression testing machine. The compression testing machine was wiped to removed foreign material on it, and so position a specimen in the machine that the load was applied to opposite as-cast faces of the specimen. The specimen axis was aligned with the centre of thrust of the spherically seated platen because this platen is brought to bear on the specimen. The compression load was applied without shock and increased continuously at a uniform rate of between 0.3 MPa/s ± 0.1 MPa per second until the specimen fails, or until no greater load can be sustained by the specimen. The maximum load applied was recorded. Figure 3-3 below shows the compressive strength test set up on an EPT concrete cube.

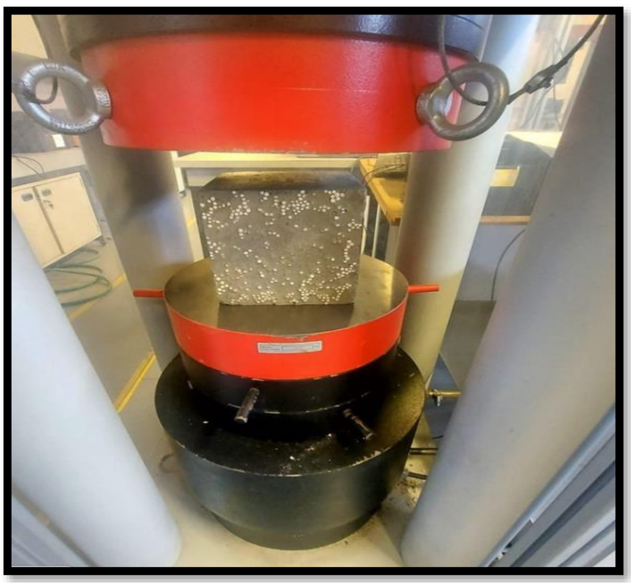


Figure 3-3: Compressive Strength Test Setup

3.5.2. Flexural Strength Test

Flexural strength measures the ability of unreinforced concrete beam or slab to resist failure when subjected to bending. It was measured by loading 750 x 150 x 150 mm concrete beams with a span length of at least three times the depth (e.g., 750 mm for beams with depth of 150 mm). The single point beam test was used for a supported span of 450 mm.

The flexure testing machine was wiped to removed foreign material on it. The rollers' and loading points were marked on each beam specimen before the specimen was placed centrally on the supporting rollers, so orientating it that loading and supporting rollers act on opposite as-cast sides. The specimen axis was aligned with the centre of thrust of the spherically seated top roller holder(s) and ensured that the axes of both the top and the supporting rollers are normal to the longitudinal axis of the specimen. It was ensured that all loading and supporting rollers are evenly in contact with the specimen and the load was applied without shock. The load is set to increase continuously at a constant rate of 0.03 ± 0.01 MPa per second until the specimen fails. The maximum load applied was recorded. Figure 3-4 shows the flexural strength test set up on a concrete beam.

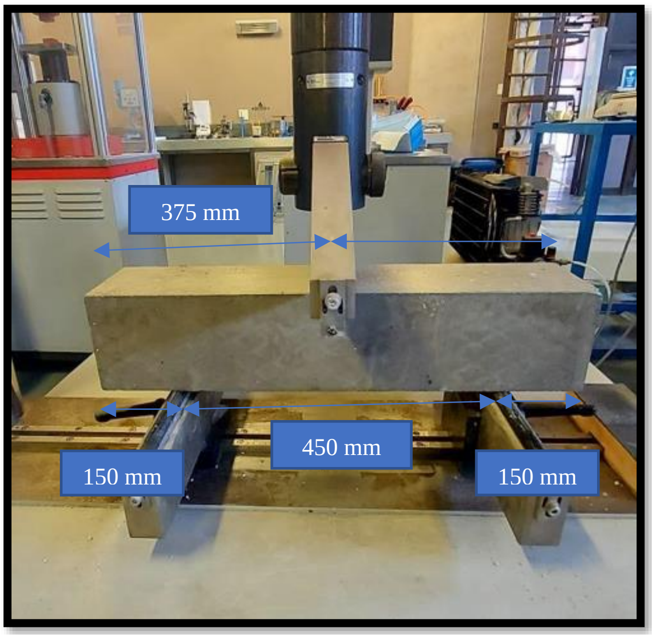


Figure 3-4: Flexural Strength Test Setup

3.6. Physical Properties Measurements

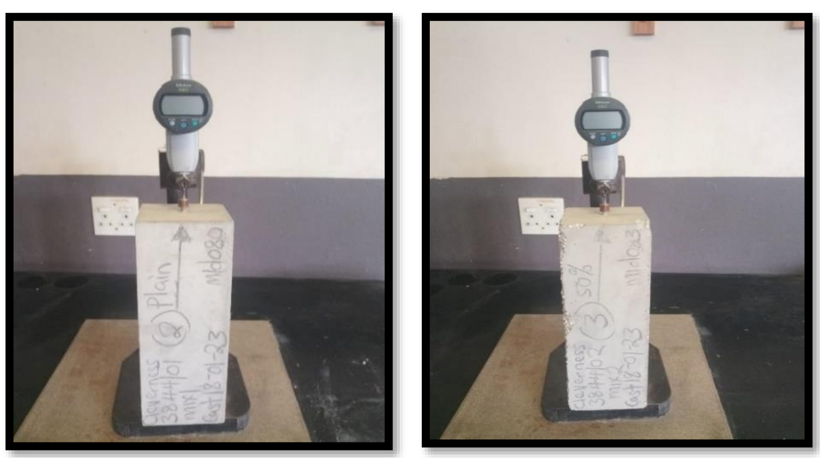
3.6.1. Drying Shrinkage Test

The contraction and expansion of a hardened concrete mixture due to moisture changes in concrete is known as drying shrinkage. With time, the volume of Portland cement concrete changes. For the engineer designing a structure, the volume change in concrete is crucial since it can generate additional stresses in the structural elements. The specimen size of 300 x 100 x 100 mm was adopted as per standard.

The test specimens are covered (in their moulds) with an impervious sheet and stored for 20 h to 24 h in a place that is free from vibration and in an atmosphere that has a temperature of 22 °C to 25 °C and a relative humidity of at least 90 %. The specimen was removed from the water 7 d ± 2 h after molding, the excess water is wiped off and the anvils cleaned. Using the measuring equipment, immediately measurement is done to the nearest 2 μm, the minimum distance between the outer ends of the anvils (measurement $L1$).

The specimens were marked that one end was always orientated in the same direction in relation to the measuring equipment. The specimens were stored in the drying facility (maintained at a temperature of 50 °C to 55 °C and at a relative humidity of 15 % to 25 % for 7 d), thereafter, specimens were removed from the drying facility and allowed to cool to a temperature of 22 °C to 25 °C in the cooling facility. Again, the specimens were measured, making sure that each specimen was orientated in the same direction in relation to the measuring equipment as before.

The drying and measuring as described on the previous paragraph was repeated for further of 48 hours at a time, until the difference between two successive readings did not exceed 2 μm per 100 mm of nominal specimen length, and the lowest reading was taken as the final dry measurement $L2$. Obtained data are shown in table 4-7. Figure 3-5 shows the test set for the drying shrinkage measurements.



(a) 0 % EPT Replacement (b) 50% EPT Replacement

Figure 3-5: Drying Shrinkage Test Setup

3.6.2. Thermal Conductivity Test

The thermal conductivity test in concrete is the measurement of how much heat is lost through the thickness of a wall or through the side length of a concrete cube. A standard approach was applied to obtain thermal conductivity. This approach is called steady-state method and focuses on temperature difference measured between two surfaces of specimen spaced apart. The heat energy is applied on one surface and temperature is measured on the other surface by means of a thermometer.

The thermal conductivity measurements were conducted on standard cubes (150 x 150 x 150 mm) subjected to 28 days water curing. The cubes were allowed to air-dry for 7 days before testing (i.e., prior to application of heat load). Three cubes were tested for the control concrete and for each EPT percentages of replacement. The specimen was then placed for three hours on a hot plate that had been prepared to 50 °C. The temperature 50 °C was chosen based on the highest temperature ever recorded in South Africa, which peaks at 12 p.m. and begins to decline at 3 p.m., or for a period of three hours.

After three hours, the temperatures T1 and T2 were recorded by measuring the temperature at the heating point X1 and the cube's opposite-facing surface X2, Refer to Figure 2-2. The rate of energy was recorded. Fourie's law presented in Equation 2.3 was used to determine the heat conductivity coefficient, k, for each of the tested specimens. Figure 3-6 below shows the setup for cube heating and the chamber housing the test.

Figure 3-6: Heat Conductivity Test Setup

3.6.3. Scanning Electron Imaging

A scanning electron microscope (SEM) is an advanced type of microscope that uses a focused beam of high-energy electrons to examine the surface of a sample. The SEM works on the principle of interaction between the electron beam and the sample, which results in the emission of different signals that are used to form an image.

The concrete sample was cut to at least 2 mm using a grinder to suite the size required by SEM. The sample was cut in a way that it has an EPT bead and natural aggregates bonded by concrete paste. The sample was then coated with a thin layer of carbon as a conductive material to prevent charging of the surface.

The prepared sample was loaded into SEM chamber and secured onto a sample holder. The SEM chamber was then evacuated to create a high vacuum environment, which prevents the electrons in the beam from scattering or colliding with gas molecules. Signal Detection and Processing: Different detectors are used to detect and collect these signals, which are then processed and amplified to create an image of the sample's surface. The signals were used to form an image of the sample's surface, which was displayed on a computer screen. The SEM resolution is typically between 0.5 to 4 nanometers.

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents and discusses the results of slump, compressive strength, flexural strength, drying shrinkage, and heat conductivity tests obtained from laboratory experiments.

4.2. Properties of Fresh Concrete

4.2.1. Slump Test Results

The results are presented in Figure 4-1 show slump value to increase with the expanded polystyrene thermocol (EPT) content. The obtained results indicate slump values of 83, 83, 87, 93, 95 and 109 mm for EPT contents of 0, 5, 10, 15, 20, 25 and 50 % respectively. As compared to the control concrete, replacing coarse aggregates by 5, 10, 15, 20, 25, and 50 % by volume EPT resulted in an increase in the slump value by 0, 4.8, 12, 14.5, 22.7 and 31 %, respectively.

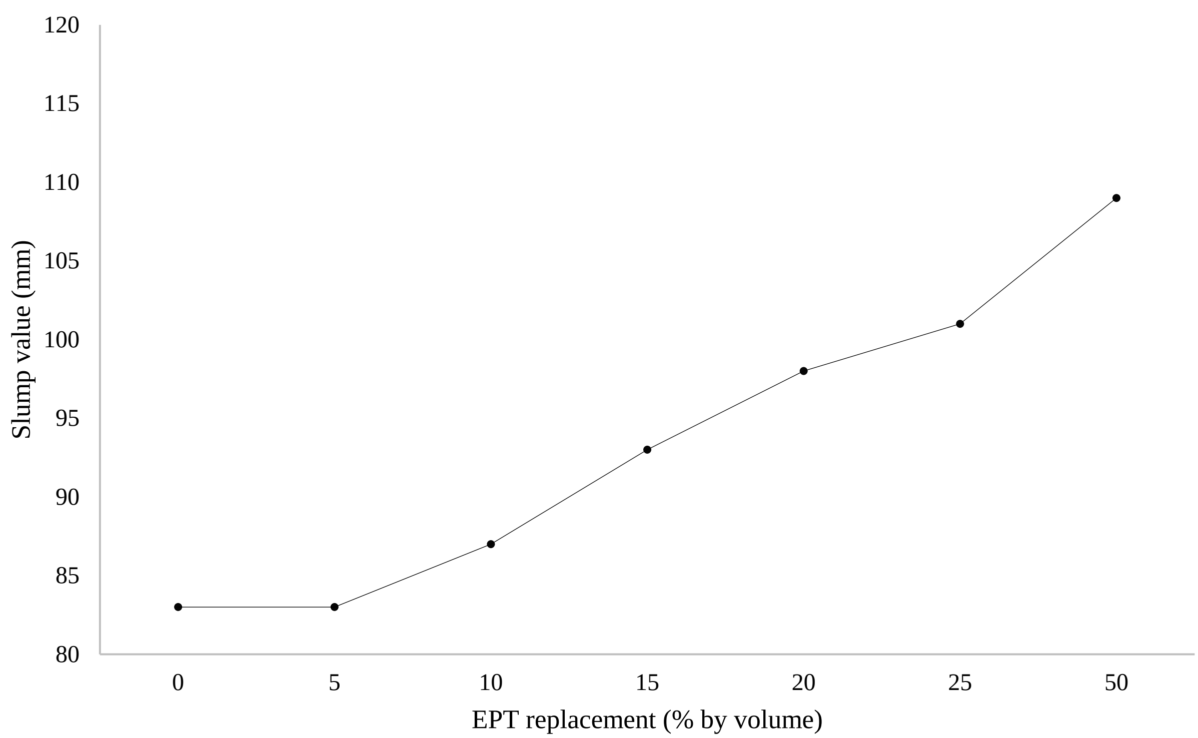


Figure 4-1: Effect of EPT Content on Slump Value

Figure 4-2 show visual presentation in terms of the effect of EPT content increase on concrete workability as measured by the slump test. The pictures show that replacing the coarse aggregates by the same volume of EPT beads in concrete had a significant effect on slump value.

(a) 5% coarse aggregates replacement.	(b) 50% coarse aggregates replacement.

Figure 4-2: Effect of EPT Content on Workability

Refer to Figure 4-1, three stages can be identified, the first stage (0 to 5% EPT), the second stage (5 to 25% EPT), and the third stage (>25% EPT). The first stage shows EPT content had little or no effect on the slump value while a significant increase of approximately 22% (i.e., [101/83] - 1) was obtained at between in the second stage. In the third stage (beyond 25% EPT replacement), a slump increase seems to be less pronounced than stage 2 since the curve flattened. The increase in the slump value was due to higher EPT content in concrete conforms well to findings by Mbadike & Osadebe (2012), Thomas et al. (2020), and Kan (2007b).

Although only 5 % of coarse aggregate is replaced by EPT, the slump tends to show some form of failure. However, at 0% EPT replacement, the concrete was shown to be cohesive. This invites for thoughts and further research.

The author opines that the increase in the slump value could be associated with the higher EPT content in the concrete mix, which is attributed to the spherical shape and the hydrophobic nature of EPT beads. Replacing natural aggregates that are angular in shape with spherical shape aggregates is expected to reduce friction between mix constituents and eventually promotes workability. The use of a hydrophobic material to replace natural aggregates with absorption of 0.3% releases some water which aid workability of the concrete mix. Future EPT concrete mixtures can be proportioned considering the effect of EPT content on workability. Reduction of water content in concrete mixes is favourable which would allow lower water to cement ratio and less voids which should eventually result in higher strength or use of less cement content. The latter is beneficial to the cost of material and environment.

4.2.2 EPT Concrete Compaction and Finishing

It has been observed that EPT beads migrate to the surface during the compaction of EPT concrete using vibrating table. Though this was observed for all tested EPT percentages, it was more pronounced at higher EPT percentages (e.g., > 20%). However, manual compaction using tamping rod was found to be effective in pushing back the EPT beads into the mix. EPT beads migrating to the top also prevent adequate finishing of the surface. Figure 4-3 shows EPT beads on the surface of hardened EPT concrete specimen.

Figure 4-3: EPT Beads Escaping to The Surface

The migration of EPT beads to the surface seems to occur because of the significantly lower mass of EPT beads as compared to the rest of concrete constituents. The low mass causes the EPT beads to buoy on the surface of a relatively fluid concrete. In addition, the hydrophobic nature of EPT beads could have an influence on this behaviour. However, this should remain speculation until verified by further research.

4.3. Compressive Strength Results

Table 4-1 and Table 4-2 show the measured results of cube compression test at 7 days and 28 days, respectively. The values between the parenthesis represent the averages while values between the square brackets represent the standard deviations.

Table 4-1: Cube Compression Strength on Control Mix and EPT Concrete: 7 - Day Results

EPT Replacement (%)	Mass (kg)		Density (kg/m^3)	7 Days Cube Strength (MPa)	
0	8.00	(7.98) [0.05]	2364	26.21	(26.45) [0.22]
	7.94			26.48	
	8.03			26.65	
5	7.95	(7.92) [0.09]	2346	25.77	(24.85) [0.83]
	7.84			24.62	
	7.97			24.15	
10	7.92	(7.88) [0.03]	2335	23.69	(23.91) [0.45]
	7.87			23.62	
	7.84			24.43	
15	7.46	(7.65) [0.18]	2267	21.31	(21.89) [0.89]
	7.82			22.92	
	7.66			21.45	
20	7.55	(7.50) [0.06]	2222	19.09	(18.31) [0.75]
	7.43			18.25	
	7.51			17.60	
25	7.38	(7.27)	2157	16.66	(16.34)

	7.23	[0.1]		15.94	[0.37]
	7.20			16.43	
50	6.45	(6.48) [0.07]	1920	10.80	(10.78) [0.02]
	6.56			10.78	
	6.43			10.77	

Table 4-2: Cube Compression Strength on Control Mix and EPT Concrete: 28 - Day Results

EPT Replacement (%)	Mass (kg)		Density (kg/m^3)	28 Days Cube Strength (MPa)	
0	8.00	(8.00) [0]	2370	39.46	(38.63) [0.47]
	8.00			38.38	
	8.00			38.06	
5	7.90	(7.80) [0.07]	2311	38.45	(38.30) [1.16]
	7.76			38.56	
	7.81			38.34	
10	7.90	(7.79) [0.1]	2308	39.40	(38.12) [1.62]
	7.75			38.60	
	7.72			37.11	
15	7.62	(7.59) [0.03]	2249	35.07	(34.21) [0.74]
	7.57			33.81	
	7.58			33.75	
20	7.25	(7.32) [0.06]	2169	24.49	(25.00) [0.83]
	7.33			24.46	
	7.37			25.91	
25	7.31	(7.28) [0.12]	2157	25.33	(25.05) [0.87]
	7.39			25.76	
	7.15			24.07	
50	6.51	(6.39) [0.2]	1893	15.85	(15.43) [0.85]
	6.13			14.54	

	6.55			15.90	

Table 4-1 and 4-2 show the compressive strength results of 5, 10, 15, 20, 25 and 50% EPT replacement indicate that at 28 days the compressive strength was found to be 99, 98, 89, 65, 55 and 40 % respectively, when compared to the normal concrete. The normal concrete had the strength of 26.45 MPa and the concrete with 50% replacement had the strength of 10.78 MPa after 7 days. The percentage of strength decrease between 0 and 50% replacement was 59%.

The result's trend pertains well to the findings by Tamut et al. (2014), where they had replacements of 5, 10, 15, 20, 25 and 30% and found the compressive strength to be 91, 77, 71, 63, 56 and 45% respectively as compared to the control concrete. However, it appears that EPT replacement larger than 25% has a significant impact on concrete compressive strength. As a result of EPT beads being hydrophobic, there exist no strong bond between them and the cement paste, which results in weak spots on concrete and thereby decreased strength. The reduction in compressive strength may attribute to the bond characteristics in the paste-EPT beads interface.

Results on observations made over 28 days on compressive strength shows no significant differences while the other three analysis were significantly different. The latter results means that there is strong evidence that suggest that the difference between the means is not due to random chance or sampling variability. Rather, it indicates that the compressive strength decreased with an increase in percentages of EPT replacement and this does not affect the quality of the results. See the statistically analysis calculations on appendix 7-12.

Figure 4-4 shows the compressive strength of concrete with varying EPT content. Also, the standard deviations obtained from sets of three cubes is indicated on the graph below.

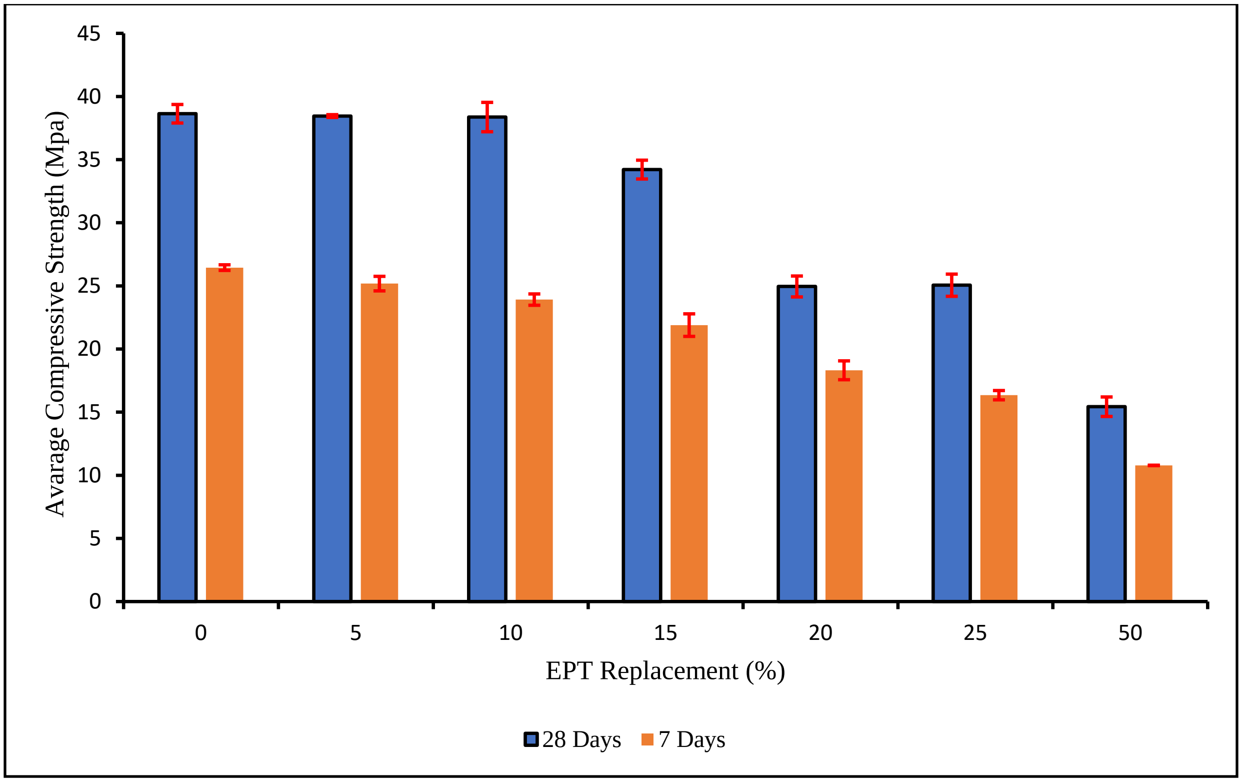


Figure 4-4: Effect of EPT on Compressive Strength

Figure 4-4 presents that the 7-day results follow the same trend of the 28 days results in terms of compressive strength reduction associated with the increase in EPT content in the mix. The 7-day strength ranged from 63 to 73% of the 28 days strength. This is typical for normal concrete growth because a 7-day strength is about 65%. This result indicates that incorporation of EPT in concrete did not influence the strength growth of concrete. This was expected since the EPT does not chemically react with the cement materials.

As indicated by the standard deviation values for each set of cubes, the presence of EPT beads in concrete seems to have minimal effect on variability of the hardened mix. It is worth pointing out that high variable concrete is not desirable because it influences how well the results from samples can be generalized to represent the population.

A pilot study conducted by Mashava & Elsaigh (2023), with a higher percentage of replacement greater than 50% of coarse aggregates by volume and the results are presented in Appendix 7-7. The result indicates that strength significantly reduced to a point where it becomes negligible. The benefits of incorporating EPT beads (e.g., reduced density and consumption of the waste EPT) at dosages greater than 25% may not justify the amount of Portland cement used in the mixtures (335 kg/m^3 for the used concrete mix), let alone the relatively high reduction in strength.

4.3.1. Effect of EPT Aggregates Gradation

The natural coarse aggregates used to generate the control mix was blended in conformance with the recommended upper and lower limit particle size distribution according to SANS 1083-2017. Thereafter, the particle size distribution was established for the coarse aggregates used in each of the tested EPT concrete mixtures (mixtures containing 5 to 50% EPT) and the results are shown on Appendix 7-8. The purpose is to evaluate the influence of the EPT beads on the blend between EPT and coarse aggregates. The particle size distribution for all aggregates blends is shown in Figure 4-5.

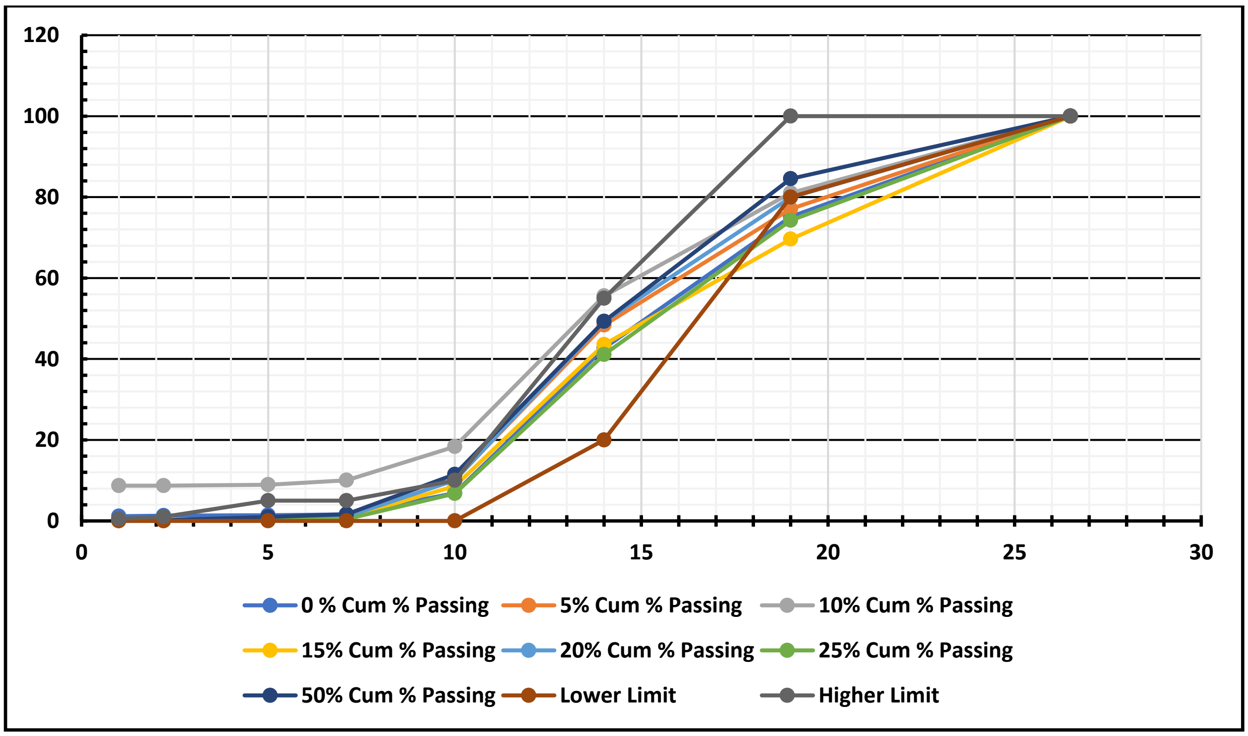


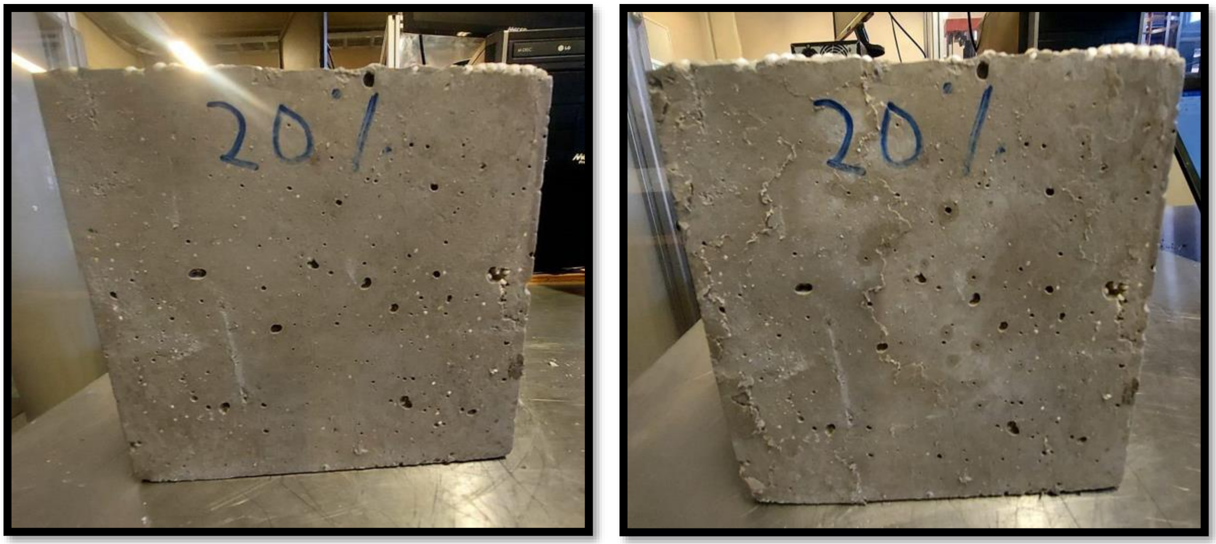
Figure 4-5: Particle Distribution for All Percentages of Replacement

Replacing coarse aggregates that have well graded particle distribution with EPT beads that are gap graded, affects the packing density, and eventually negatively influences the strength. The grading results of the 0% replacement falls well within the specification, while the ones with EPT falls in and out of the specification. These results indicate concrete with EPT does not perform according to the expectations in terms of its strength properties. The deviation of the size particle distribution from the recommended envelop can be one of the explanations of the loss of strength on concrete with EPT. A well-graded aggregates has a good distribution particle size and can produce a dense and strong concrete mix. In contrast, a poorly graded aggregates can result in voids in the mix and a weaker concrete. This can be one of the explanations of the loss of strength on concrete with EPT. Moreover, Herki et al., 2013 investigated the compressive strength of EPT concrete and attributed decrease in compressive strength to increase in the surface area, caused by replacing coarse aggregate material with that which is finer and thereby weaken the interfacial zone between the aggregates and the cement paste. Similar argument has been reported by Tang et al., (2008) and Kan and Demirboga, (2009).

Salih et al., (2023) and Shi et al., (2015) reported that the use of EPT beads of size between 1 to 1.2 and 1 to 3 mm to replace coarse aggregates was effective as a partial replacement of coarse aggregates. Herki et al., (2013) confirmed that early results reported by Miled et al. (2007) that EPT beads made of smaller size increase the strength development and therefore enhance the concrete compressive strength. Furthermore, Salih et al., (2023), Parant et al., (1999) and Puram & Nikhar, (2003) affirmed Herki et al. (2023) stated in their results that the strength of concrete reduces when fine or coarse aggregates are replaced by EPT. Therefore, there is a need for studies that can compare the percentages of strength reduction when equal volumes of EPT beads are used to replace coarse and/or fine aggregates.

4.3.2. Cube Failure Mode

The failure pattern of a concrete cube under compression load decides the correctness of the testing setup and the validity of the obtained results. Figure 4-7 shows the failure pattern on EPT concrete cube before and after the compressive force is applied. According to Owen (2008), the failure pattern on the figure below is normal/satisfactory. The observed failure patterns of EPT concrete cubes correlate well with the observations of Babu et al. (2006). Figures of other percentages of replacement are presented on appendix 7-7.



(a) (b)

Figure 4-6:20% EPT Replacement Cube (a) Before and (b)After compressive force

4.4. Flexural Strength Results

Table 4-3 and Table 4-4 show the measured results of beam flexure test at 7 days and 28 days, respectively. The results given by the crushing machine were confirmed by calculations using the formula presented on appendix 7-4. The values between the parenthesis represent the averages while values between the square brackets represent the standard deviations.

Table 4-3: Flexural Strength on Control Mix and EPT Concrete: 7 - Day Results

EPT Replacement (%)	Mass (kg)		Density (kg/m^3)	7 Day Flexural Strength (MPa)	
0	37.97	(37.95) [0.03]	2248	4.55	(4.79) [0.36]
	37.95			4.61	
	37.92			5.20	
5	37.82	(37.81) [0.04]	2241	4.20	(4.29) [0.09]
	37.84			4.37	
	37.77			4.29	
10	37.82	(37.47)	2220	3.58	(4.29)

	37.84	[0.07]		3.62	[0.09]
	37.23			3.58	
15	36.57	(36.42)	2158	3.27	(3.30)
	36.30	[0.14]		3.34	[0.04]
	36.38			3.29	
20	34.95	(34.68)	2110	2.83	(2.83)
	35.92	[0.41]		2.88	[0.05]
	34.97			2.79	
25	34.84	(34.68)	2055	2.78	(2.68)
	35.00	[0.41]		2.64	[0.09]
	34.22			2.62	
50	30.73	(30.68)	1818	1.87	(1.89)
	30.60	[0.07]		1.92	[0.03]
	30.71			1.87	

Table 4-4: Flexural Strength on Control Mix and EPT Concrete: 28 - Day Results

EPT Replacement (%)	**Mass (kg)**		**Density (kg/m^3)**	**28 Day Flexural Strength (MPa)**	
0	37.78	(37.71)	2335	5.50	(5.53)
	37.65	[0.07]		5.68	[0.14]
	37.70			5.41	
5	36.57	(37.09)	2198	5.46	(5.37)
	37.21	[0.48]		5.37	[0.09]
	37.50			5.29	
10	37.58	(37.10)	2198	4.65	(4.62)
	36.40	[0.50]		4.62	[0.05]
	37.22			4.58	
15	36.51	(36.65)	2172	4.25	(4.29)
	36.44	[0.31]		4.34	[0.04]

	37.00			4.28	
20	35.13	(35.8) [0.63]	2121	3.68	(3.78) [0.10]
	36.39			3.88	
	35.87			3.79	
25	34.81	(34.11) [0.04]	2021	3.64	(3.57) [0.06]
	33.98			3.54	
	33.54			3.52	
50	33.54	(30.60) [0.15]	1813	2.03	(2.22) [0.17]
	30.65			2.26	
	30.72			2.36	

Refer to Tables 4-3 and 4-4, the normal concrete had the strength of 4.79 MPa and the concrete with 50% replacement had the strength of 1.89 MPa after 7 days. The percentage of strength decrease between 0 and 50% replacement is 39%. The flexural strength results of 0, 5, 10, 15, 20, 25 and 50 % replacement indicate that 7-day strength was reduced by 10, 25, 31, 41, 44 and 61%, respectively as compared to control mix while at 28 days, the flexural strength was reduced by 3, 16, 22, 32, 35 and 60%, respectively. Regardless of other design factors, it appears that EPT replacement of up to 25% result in flexural strength that is within the typical range of values used for floor slab applications. However, further investigation is required to evaluate other key properties such as shrinkage, curling and warping, fatigue endurance and abrasion resistance. Figure 4-8 shows the flexural strength of concrete with varying EPT content. Also, the standard deviations obtained from sets of three cubes is indicated on the graph below.

Observations made on EPT replacement over the 28 days revealed no significance different between 0 and 5%, while the rest of the percentages were significantly different. Also, the flexural strength is expected to decrease with an increase in percentage of replacement and this does not affect the quality of the study. See the statistically analysis calculations on appendix 7-12.

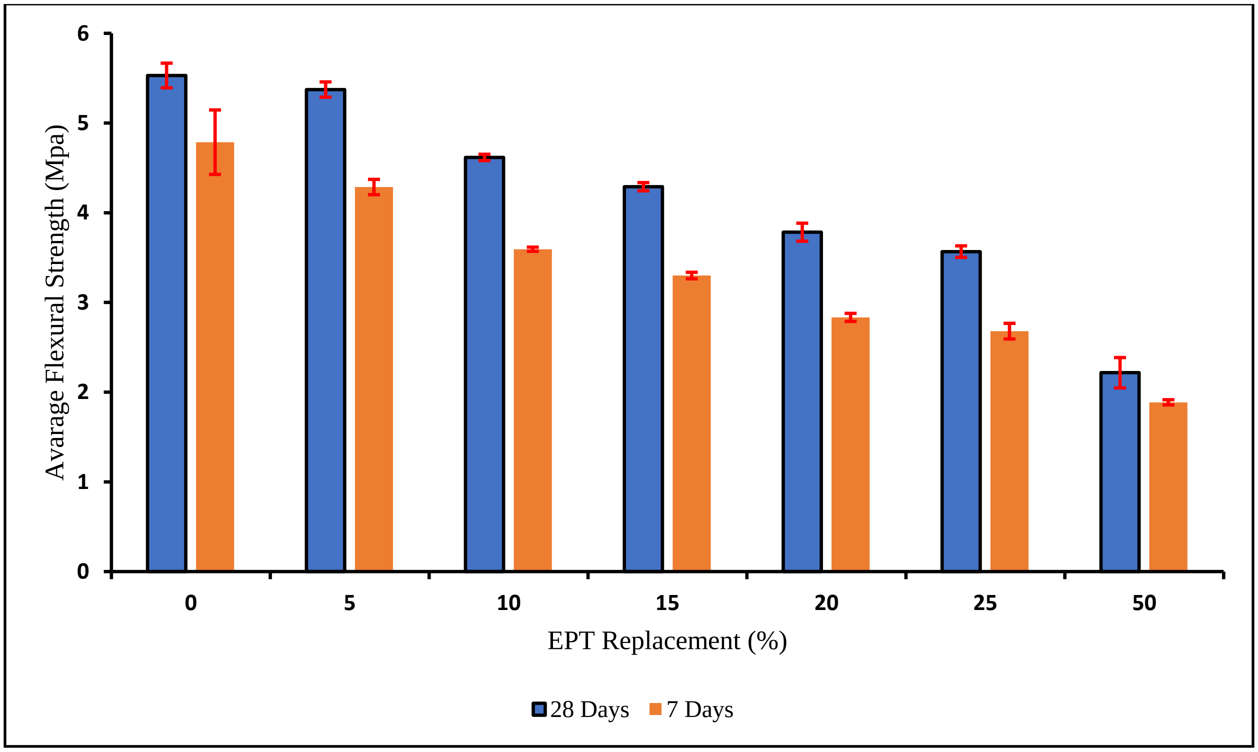
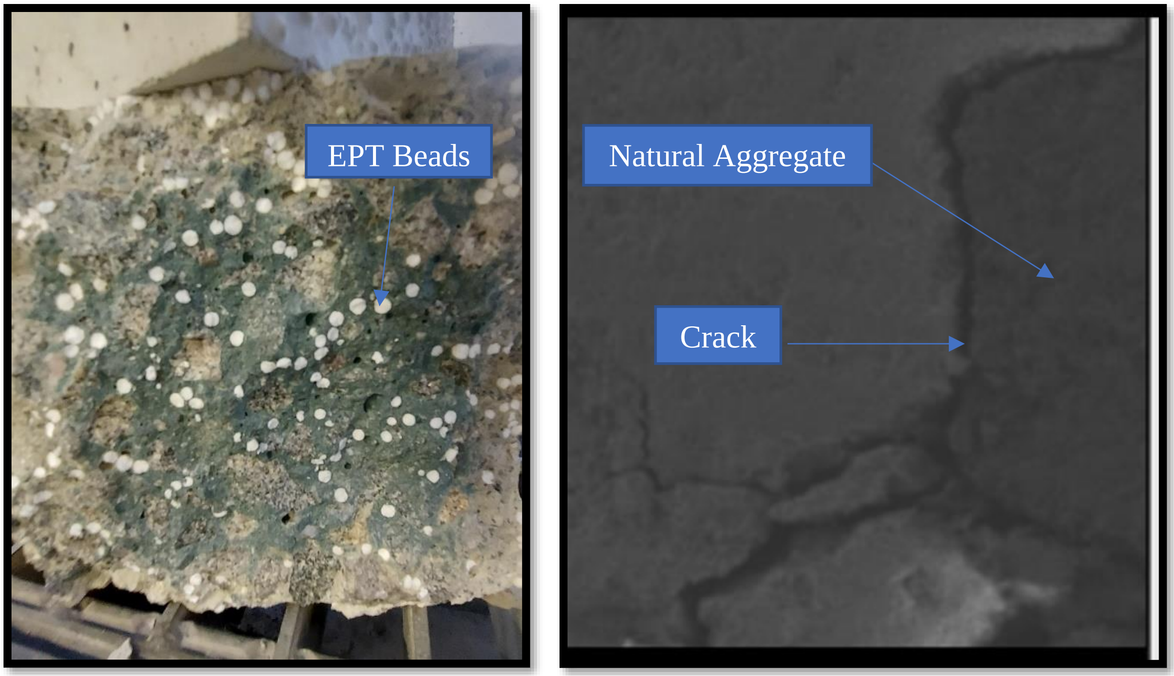


Figure 4-7: Effect of EPT on Flexural Strength

Figure 4-8 indicate resemblance regarding the effect of EPT content on the 7-day and 28-day flexural strength. The result affirms the findings of compressive in in terms of the effect of EPT on the strength growth. However, the 7-day strength is about 80% of the 28 days, which invites for thoughts. This figure affirms the findings for average flexural strength presented on table 4-3 and 4-4.

4.4.1 Fracture Surface

Concrete beam was subjected to a force until to the breaking point was reached. Refer to Figure 4-9, by visualising and pattern of breaking of the beam cross-section, it was observed that, for the normal concrete, the cracking occurred around the natural coarse aggregates however, for EPT concrete, the cracks were observed along the EPT beads. This may be attributed to the low hardness of EPT beads, which can also explain the strength reduction while increasing EPT content in concrete. The observation regarding the fracture surface correlates well with the findings of Ganie & Prakash (2018), who attributed the strength reduction to the weak EPT beads. This has also been affirmed by the work reported by Haghi et al. (2006a), who stated that larger size EPT beads disintegrate along the contact zone.



(a) (b)

Figure 4-8: Illustration of crack going through (a) EPT beads and (b) around the natural aggregates.

4.4.1. Strength Conversion

In some applications such as on-ground floor slabs, which are designed relying on flexural strength, cube samples are taken on-site for the purpose of quality assurance. The flexural strength is estimated from the cube strength results obtained at 28 days. A formula below from British Concrete Society (2016) was used to relate 28 days flexural and compressive strength:

$$f_f = 0.393\,(f_u)^{2/3}$$

where:

f_f = Flexural strength

f_u = Compressive strength

Table 4-5 shown below reveal a comparison of flexural strength obtained through formula and the one obtained through the test machine was done. Results show that on 0, 5, 10, 15, 20, 25 and 50 % replacement, the deviation was found to be 18, 17, 3, 3, 11, 6 and 9 % respectively. The deviation was greater on 0 and 5% replacement. The equation is found to be reliable and can be used in estimating flexural strength in the sense that compressive strength test equipment is readily available, easy to conduct and cost effective when compared to the flexural strength equipment.

Table 4-5: Relationship of Compressive and Flexural Strength

EPT Replacement (%)	Average measured Compressive Strength (MPa) at 28 Days	Flexural Strength (MPa) at 28 Days from: $f_{f\,=\,0.393}\,(f_u)^{2/3}$	Average Measured Flexural Strength (MPa) at 28 Days
0	38.63	4.50	5.53
5	38.30	4.47	5.37
10	38.12	4.46	4.62
15	34.21	4.15	4.29
20	25.00	3.36	3.78
25	25.05	3.36	3.57
50	15.43	2.44	2.22

4.5. Concrete Density Results

Figure 4-10 shows the effect of EPT replacement percentage on density of concrete. The average measured values of cubes and beams tested at 7 days and 28 days are plotted. As compared to the control concrete, replacement of coarse aggregates by EPT percentages of 5, 10, 15, 20, 25 and 50 % resulted in density reductions by approximately 17, 33, 44, 57 and 64% respectively.

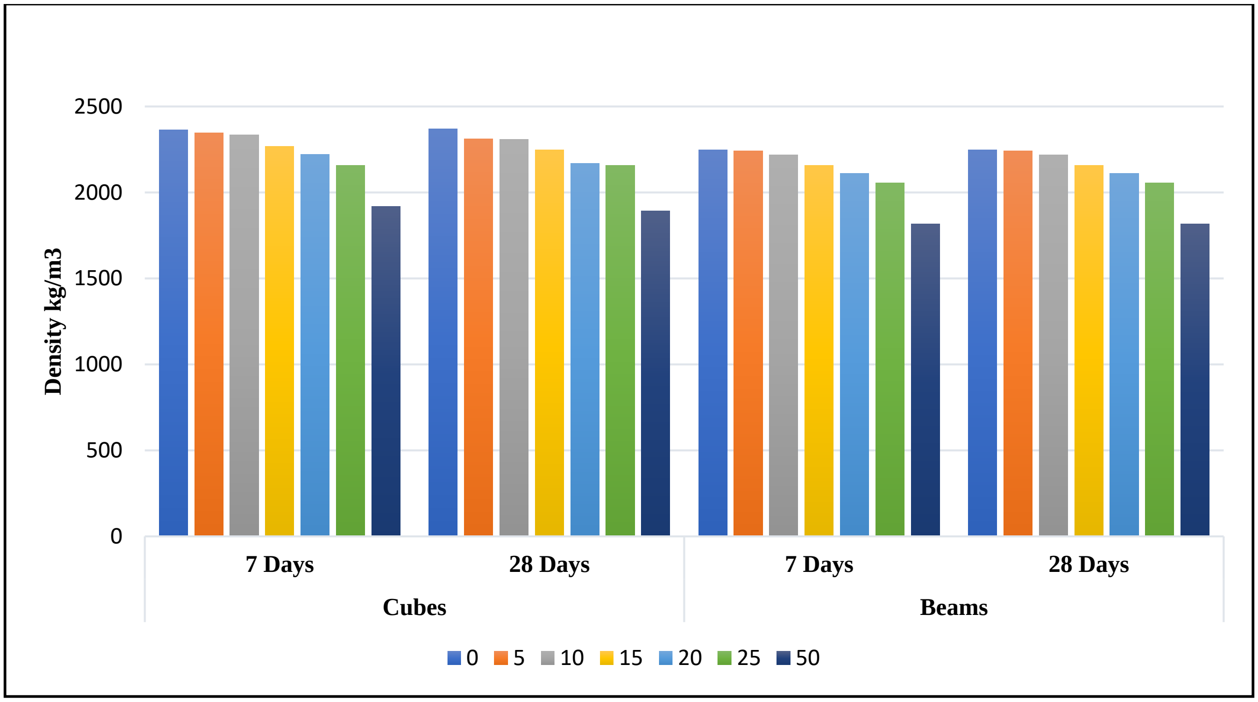


Figure 4-9: Effect of EPT Replacement on Concrete Density

As compared to the control concrete, EPT replacement of 5, 10, 15, 20, 25, and 50% resulted in density reductions of 2.5, 2.6, 5, 8.5, 9 and 20%, respectively. The least density of concrete was observed at 5, 10 and 15% replacement while that from 20% replacement exhibited a noticeable reduction.

It is worth pointing that, for normal concrete mixes, reduction in density usually relates to the number and size of voids in the mix and often accompanied with reduction of strength. However, the lower density with higher EPT content in concrete attributes to the significantly lower density of EPT beads compared to natural aggregates. Therefore, the lower density of EPT-concrete should not be used to explain the reduction in strength associated with increase in EPT content.

4.6. Thermal Conductivity Results

Table 4-6 depict results of the heat conductivity tests on control concrete and concretes with expanded polystyrene thermocol (EPT) beads. As the EPT content increased, the thermal conductivity capability decreased. The EPT concrete showed improved thermal insulation when compared to normal concrete, according to the results. Concrete's thermal conductivity capacity dropped from 0.31 W/m. K to 0.21 W/m. K when EPT content was added in increments of 0 to 50 %. Thermal conductivity decreases by 32% between 0 and 50% EPT replacement.

The effect of concrete density seems to play a significant role in this regard. Thermal conductivity values for 0 and 50% EPT replacement with densities of 2335 and 1813 kg/m^3 are 0.31 and 0.21 W/m. K, respectively. Concrete's thermal conductivity decreased along with its density.
This type of concrete is energy efficient as it would reduce the need for air conditioning for in areas with high and low temperature weather conditions. Cold storerooms can also be constructed from EPT concrete. Appendix 7-6 presents the calculations of the value of (k) heat conductivity.

Table 4-6: Results of Heat Conductivity on EPT Concrete

T1 and T2 represent temperature 1 and 2, while SD represents standard deviation.

% EPT Replacement	T1 (°C)	T2 (°C)	T1 SD	T2 SD	Average		Heat Conductivity (W/m. K)
					T1	T2	
0	42.72	34.84	[0.11]	[0]	(42.62)	(34.84)	0.31
	42.63	34.84					
	42.50	34.84					
5	42.48	34.20	[0.04]	[0.18]	(42.45)	(34.00)	0.28
	42.41	33.90					
	42.45	33.87					
10	42.36	33.20	[0.11]	[0.35]	(42.41)	(33.17)	0.28
	42.54	32.80					
	42.34	33.50					
15	42.40	32.66	[0.09]	[0.14]	(42.31)	(32.78)	0.26
	42.22	32.76					
	42.31	32.93					
20	41.70	32.03	[0.11]	[0.36]	(41.72)	(32.11)	0.25
	41.62	32.50					
	41.83	31.80					
25	41.15	31.00	[0.07]	[0.22]	(41.17)	(31.24)	0.24
	41.24	31.30					

	41.11	31.42					
50	40.21	29.00	[0.11]	[0.10]	(40.22)	(29.00)	0.21
	40.33	29.09					
	40.11	28.89					

According to a study published in the Journal of Energy in Southern Africa (2020), the thermal conductivity of normal concrete in South Africa ranges from 0.8 to 1.6 W/m. K. The study indicates that these values can vary depending on factors such as the water to cement ratio, the aggregates type, and the curing conditions used for the concrete. From the results obtained in this study, normal concrete has lower heat conductivity than what is stated in the study published in the journal mentioned above, and this could be because of the mentioned factors, but the general trend still show that the thermal conductivity decreases as EPT beads increases in an in a concrete mix.

To compare the results obtained in this study with previous studies, Kan & Demirboga (2012) found that the thermal conductivity of EPT concrete containing 0 – 40% EPT is 1.14 – 0.20 W/m. K respectively. Another study by Almusallam et al. (2000) reported thermal conductivity values of 0.45 of normal concrete and 0.15 on 50% EPT replacement. The results obtained from this study are comparable to the results of (Wongkvanklom et al. 2021), where the concrete with density of 1200-1000 kg/m^3 had the thermal conductivity of 0.35-0.26 W/m. K.

EPT is a lightweight closed-cell foam material that has a high resistance to heat flow, making it an effective insulator. When EPT is added to concrete, they create pockets of trapped air within the concrete, which act as insulating voids, slowing down the transfer of heat through the material. The heat conductivity is shown to drop with increasing porosity and pore size, which implies that if these parameters increased, more air would fill the pores in concrete, thereby decreasing the heat conductivity, as the heat conductivity of gas is far less than the solid. The percentage of EPT beads incorporated also affects the heat conductivity. As the EPT beads increase in concrete mix, the heat conductivity reduces.

In contrast, normal concrete is a dense material with a high thermal conductivity, meaning that it readily conducts heat. This is because the main ingredients in normal concrete such as cement, sand, and stone, are all materials that have high thermal conductivity. The exact heat conductivity of EPT concrete would depend on factors such as density and size of EPT beads, the amount of EPT used in the mix, and other factors such as the type and amount of cement used.

4.7. Drying Shrinkage

Table 4-7 below show results on the drying shrinkage of normal and expanded polystyrene Thermocol (EPT) concrete with different percentages. The results indicate that the drying shrinkage increased as EPT content increased in concrete, however, the mean values were statistically similar. This means that the observed differences between the means are unlikely be due to the random variation. The slight numerical differences between the mean values could be due to the difference in the percentages of EPT replacement. See the statistically analysis calculations on appendix 7-12.

A maximum increase of 13% is found for concrete with 50% EPT replacement. The drying shrinkage findings are in line with relevant literature such as the work by Maghfouri et al. (2022).

Table 4-7: Drying Shrinkage Results

% of Replacement	Drying Shrinkage %	Average Shrinkage %	Standard Deviation
0	0.018 0.019 0.019	0.019	[0.001]
5	0.018 0.019 0.018	0.018	[0.001]
10	0.019 0.020 0.017	0.019	[0.002]
15	0.020 0.021 0.019	0.020	[0.001]
20	0.021 0.020 0.020	0.020	[0.001]
25	0.020 0.022	0.021	[0.001]

	0.022		
50	0.023 0.023 0.022	0.022	[0.001]

The increase in drying shrinkage can be explained as the difference in elastic modulus on EPT beads and natural coarse aggregates. Concrete with natural aggregates that have higher elastic modulus and rougher surfaces when compared to EPT beads tend to be more resistant to shrinkage.

Extreme concrete drying shrinkage may result in the development of microcracks and subsequent cracks, allowing toxic substances to enter the concrete and cause corrosion of the reinforcing which lead to reduction in the durability of the concrete. Figure 4-11 below presents the microscopic view of the EPT bead and reveal compressible in relation to its elastic modulus. And, when literally being pressed, it deforms and come back to its original shape when released.

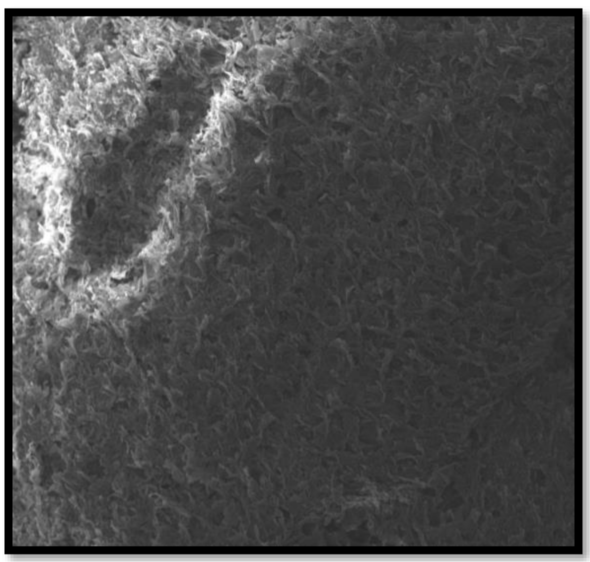


Figure 4-10: Microscopic View of EPT Bead

In South Africa, the acceptable drying shrinkage limit for normal concrete is determined by the South African National Standard (SANS) 5861-2:2016. According to this standard, the acceptable drying shrinkage limit for normal weight concrete (NWC) is 0.006 % of the member length for restrained shrinkage and 0.10% for unrestrained shrinkage. The concrete on study falls on unrestrained shrinkage, as it is not supported by anything but just a block. From the results obtained, concrete from 0 to 50% replacement falls within the acceptable shrinkage limit of 0.10%.

Restrained shrinkage refers to shrinkage that is restrained by adjacent elements, such as in concrete slab restrained by walls or columns. Unrestrained shrinkage refers to shrinkage that is not restrained, such as in a free-standing concrete wall or column.

It is important to note that the acceptable shrinkage limit may vary depending on the specific application and requirements of the project. In some cases, a lower shrinkage limit may be required to meet the structural or aesthetic needs of the project. Proper curing, reinforcement detailing, and material selection can help minimize shrinkage.

4.8. Potential Use of Expanded Polystyrene Thermocol (EPT)-concrete in Low-cost Housing

The strive towards affordable infrastructure such as low-cost housing continues to be a subject of debate for some time in South Africa and in other countries within the African continent. Studies involving research that assess alternative low-cost construction materials have been highlighted on many occasions as a priority and are considered as a drive for sustainable development and a means of poverty alleviation. In general, the use of EPT concrete in low-cost housing can provide a cost-effective and sustainable solution that can improve the living conditions of low-income households. The material's lightweight and insulating properties, makes it an attractive option for low-cost housing projects.

4.8.1. EPT Concrete Houses

Among possible applications of EPT concrete in low-cost housing projects is strip foundation, floor slab, wall panels, concrete blocks, bricks, and roof panels.

Typical strip foundation requires concrete materials which are characterized by a cube compressive strength of about 25 MPa. Referring to Figure 4-4, coarse aggregate replacement by EPT of up to 25 percent seems to provide an EPT concrete suitable for foundation applications. It is worth pointing out that the lower dead load applied on the foundation, because of the lighter weight of other building components, can generate savings in terms of the strip foundation size and reinforcement requirements. However, due to the interaction of the foundation's concrete with soil chemical composition, the assessment of EPT concrete durability or foundation protections is crucial.

Considering the floor slab component of a typical masonry brick house, concrete with 20 percent EPT is revealed to have about 4 MPa flexural strength at 28 days, refer to Figure 4-8, which is equivalent to plain concrete usually used for such applications. In addition, Table 4-7 indicates that the laboratory-scale drying shrinkage property of the EPT concrete is within the ranges of counterpart plain concrete, meaning that shrinkage cracks on the floor slab is not expected to be a compromising factor for the material use.

EPT concrete can be molded into wall panels, blocks, or bricks which can be used to construct the exterior and interior walls of the house. As per AfriSam bricks and blocks guide 2007, the masonry blocks or bricks is required to have minimum compressive strength range between 3.5 and 21 Mpa, considering the other physical properties stated in the standard specification by SANS 1215. Revisiting Figure 4-4, EPT concrete can provide some liberty in terms of meeting the strength requirements for masonry block and bricks. This can be done by selecting the amount of EPT incorporation based on the strength requirement. The same above discussion applies to in-situ slabs, panels, or tiles that can be manufactured using EPT concrete to construct the roof of the low-cost house.

It should be noted that when the EPT content is higher, the compressive strength becomes lower but lighter material providing easy handling and with better insulation property of constructed wall as compared to traditional similar ones. Apart from the EPT concrete heat insulation capabilities, hollow block can be produced by incorporating EPT material in the mixture to obtain higher control on heat exchange between the interior and the exterior of the house.

In the recent past, South Africa has had numerous fires breaking incidences, especially for settlements where there are shacks built using metal-wood. It should be noted that EPT in the form of loose beads is flammable and therefore not a fireproof material. Therefore, the fire resistance of EPT concrete is considered to play a significant role in terms of the material acceptance for low-cost houses. In other words, strength properties may not be the only factor to consider but also the fire resistance of EPT concrete. Further investigation is required to qualify the inclusion of EPT in a concrete mix meant for use in building construction as per the SANS 428 fire performance requirements.

4.8.2. Air Conditioning Efficiency with EPT Concrete Houses

Normally, a building which comprises of a floor, walls, and roof, controls heat gain in summer and heat loss in winter. Ideally, the building material is required to maximise the exclusion of heat in summer, and trap and store warmth in winter to increase the effectiveness of the building, creating much more comfortable and less expensive to maintain living environments. Such a structure is advantageous because it mitigates high electrical consumption due to air conditioning. As per SANS 10400 XA, South Africa will be implementing laws with the gool to establish Energy Efficiency Standards for Buildings. To this end, South Africa's building code is expected to include sections that talks to energy efficiency requirements, and thermal insulation will be required in all new construction projects. Refer to the discussion presented in section 4.6, the insulation capabilities of EPT concrete as inferred by the decrease of conductivity factor ranging from 0.03 to 0.04 W/m. K has the potential and can play a significant role and contribute to the adherence in terms of these requirements.

4.8.3. Construction of Low-cost houses

In the context of low-cost housing in South Africa, the construction of houses in a manner that is efficient in terms of cost and labour-intensive construction is encouraged by the government and other non-governmental organisations. The reduced labour intensity and construction time associated with EPT concrete can help expedite housing projects, meeting the demand for affordable housing within shorter timeframes. An experiment of a full-scale house that was conducted for the Expanded Polystyrene Association of Southern Africa, EPSASA (2009). In the study, an example house was built using intact EPT in the form of panels as insulation for the floor slab and hollow EPT block filled with concrete. The walls were then plastered to cover the relatively weak EPT surface. The study revealed that a complete two-bedroom house can be constructed using EPT materials in about Fourteen (14) days by a trained team. It is worth noting that EPT beads were not used as part of the concrete mix, the subject investigated in the previous sections of this dissertation.

Labour-intensive construction approach is often employed in low-cost housing projects in South Africa. Concrete with low density, i.e., lighter in weight for the same volume as compared to normal concrete, pertains well to this application as it generates savings in terms of manpower required for handling concrete mix. For example, once rural women are trained on it, they would be able to build these houses themselves, as the materials are mostly lightweight and manageable. Using EPT concrete for low-cost houses can reduce construction costs (cost analysis needs to be done for every project). The material itself is perceived to be cost-effective, and its lightweight nature can potentially speed up construction since it can be handled by a smaller number of workers, leading to further cost savings. This is in addition to the savings in terms of materials cost.

4.8.4. Sustainability of EPT concrete

Concerning sustainability, the use of EPT as a component in concrete is meant to replace natural aggregates. Building of low-cost houses is well in line with the United Nation's Sustainable Development goal no 9 - "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", goal no 11 - "Make cities and human settlements inclusive, safe, resilient and sustainable", and goal no 12 - "Ensure sustainable consumption and production patterns".

Using recycled EPT in concrete reduces environmental impact and supports eco-friendly construction methods. Also, EPT concrete offers benefits, its usage might need to be combined with other construction techniques or materials to ensure structural integrity and longevity. EPT is a recyclable material, which aligns with the growing emphasis on sustainable building practices. The production of EPT concrete typically generates fewer greenhouse gases compared to traditional concrete production, contributing to a lower carbon footprint. Additionally. By incorporating locally accessible waste materials such as EPT, the adverse environmental effects of the infrastructure being constructed in the area are mitigated. The ability of sustainable building materials and structures to withstand natural disasters and climate fluctuation can be used to assess their suitability. In every circumstance, there is a need for technological advancements and information sharing with local populations. To produce more sustainable building materials, locals can be made aware of these resources and possibly educated on how to build their own affordable homes, that way, they could use EPT to replace flammable material used to build metal-wood shacks. It is worth pointing out that the appropriate technology to use must not ignore factors such as location, climate, local requirements, available resources, and cultural considerations. Future study must be conducted in this regard.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

This study set out to identify the fresh and the hardened properties of lightweight concrete with EPT. This was carried out empirically and based on the findings, the conclusions follow below.

5.2. Conclusion

The first objective was to investigate the influence of expanded polystyrene thermocol (EPT) content on fresh properties of EPT concrete including workability, consistency, and self-weight. It is concluded that the workability and consistency of EPT concrete is improved when compared to the normal concrete. Good consistency and workability were clearly noticed on 50% replacement. The weight and density of concrete also decrease as the percentage of replacement went high and it was evident that the concrete became easier to work with as the weight was reduced.

The conclusion is also drawn from the effect of EPT content on mechanical properties of concrete, focusing on compressive strength and flexural strength. The compressive and flexural strength reduced as EPT content increased in concrete. 25% EPT replacement with compressive strength of 25 MPa was found to be the maximum replacement for structural concrete while higher percentages of replacement can be used for non-structural purposes. Replacement of more than 50% still has good strength of 15 MPa depending on the application of concrete.

Expected results were also achieved on drying shrinkage and heat conductivity of EPT concrete. It was concluded that EPT concrete can be used temperature regulator in places with high and low weather temperatures.

It is concluded that the incorporation of EPT into concrete lead to a marginal (depending on the percentage of EPT incorporated) reduction in strength due to these factors: Firstly, the gradation of EPT beads particles can cause voids and weak points in the concrete, reducing its strength. Secondly, the breakage of EPT particles on the crack surface can create microcracks and further weaken the structure. It is important to consider these factors when designing and using EPT in concrete applications.

EPT concrete compaction with vibration machines can course beads to escape to the surface, care must be taken to stop vibration when more beads are starting to show on the surface and other manual compaction can be used to finish off the compaction, if necessary. Further investigation is required to investigate suitable scenarios for compaction of EPT concrete.

5.3. Recommendations

Future studies can explore various ways to enhance the expanded polystyrene thermocol (EPT) matrix bond, including admixtures as the use of chemical admixtures such as bonding agents, which can improve the bond between EPT beads and the matrix. Surface treatment can also be investigated as the surface of EPT beads can be treated with chemicals or mechanical methods to increase their surface area and improve the bond. Different sizes of EPT beads should be explored as the effect of using different sizes of EPT beads on the bond strength and overall properties of EPT concrete. Varying the water to cement ratio is essential as it affects the bond strength between EPT beads and the matrix. Studies can investigate the optimal ratio for achieving maximum bond strength.

The mix design of EPT concrete can be adjusted to achieve the required workability while maintaining the desired bond strength between EPT beads and the matrix. The environmental implications of using EPT in concrete in the place of normal concrete and analysis of EPT concrete cost, comparing it to the cost of normal concrete can be added in the future studies. Overall, further research in this area can help to optimize the properties of EPT concrete to make it a more viable alternative to normal concrete in various construction applications.

The recommended suitable percentage of EPT replacement for use in low-cost housing is found at 25% where the compressive and flexural strength at 28 days is 25 and 2.68

MPa respectively. Replacement up to 50% can also be considered, as compressive strength of 15 MPa was obtained after 28 days, depending on the structure needed.

The tested EPT was obtained from a source before it was taken to a landfill. The later may bring dirt to the surfaces of EPT beads, which certainly has an influence in terms of the EPT percentage incorporation and the properties of EPT-concrete. Future research is recommended to study the effect of dirt on EPT surfaces and possible treatments. In addition, in some cases, EPT is found in an intact form. Further research can explore the possibility of incorporating such material in concrete. Future research can delve into the environmental implications of using EPT in concrete to assess whether it has a discernible impact on environment.

CHAPTER 7

7. APPENDIX

Appendix 7-1: Control Mix Design Calculations C&CI

The design strength of a concrete mix must be 35 MPa after 28 days. The cement to be used is a CEM I 42.5 N all-purpose cement with a relative density of 3.14 from table 11.1 Fulton's Concrete Technology. The stone size to be used is a 22.4 mm with a dry compacted bulk density (CBD) of 1660 kg/m^3 and relative density of 2.694. A good crusher sand with fineness modulus of 3.1 and relative density of 2.689 is going to be used for the mix. The slump is 75 mm as this is a good workability concrete, especially if it is not going to be transported. The table below shows calculations done in designing the control mix.

Table 7-1: Mix Design Calculations

Step 1: Select water to cement ratio
W:C = 0.583 from the w:c graph, using the concrete desired strength at 28 days of 35 MPA and the cement strength of 42.5 N.
Step 2: Determine water requirements
Table 11.2 Fulton's Concrete Technology Aggregates quality is good and natural, hence water required is = 195 l/m^3
Step 3: Calculate cement content
Cement content = water requirement/ w:c= $\frac{195}{0.583}$ = 335 kg
Step 4: Determine K value
Table 11.4 Fulton's Concrete Technology Slump range of 25-100 mm (typical for general purpose applications) Moderate vibration as a method of compaction Interpolation was done to get K value for 22.4 mm stone. K value = 1.027
Step 5: Determine stone content

$St = CBD_{st} (K – 0.1\ FM)$ = 1660 (1.027 – 0.1 x 3.1) = 1190 kg/m^3 St = mass of stone in one cubic metre of concrete, kg. CBD_{st}= dry compacted bulk density of stone kg/m$^{3.}$ K = a factor that depends on nominal size of the stone and the workability of concrete. FM = Fineness Modulus
Step 6: Determine sand content
$Vol_s = 1000 - (\frac{335}{3.14} + \frac{1190}{2.694} + \frac{195}{1})$ = 256.61 l $Mass_s$ = 256.61 x 2.689 = 690 kg
Material requirement per m^3 for concrete mix design per cubic m of concrete:
Cement = 335 kg Stone = 1190 kg Sand = 690 kg + 50 kg adjustment River sand = 50 kg Water = 1955 kg Admixture = at 0.3 application 1173 g The initial trail mix indicate low slump value and therefore, plasticiser was used as per the supplier's recommendations.

The calculations above are for a cubic meter volume and they were converted to a 10 L to suite the mixing pan in the laboratory by dividing each material by 100.

Appendix 7-2: Grading and Blending of Coarse Aggregates Calculations

This process of blending aggregates was done to combine two coarse aggregates (maximum sizes of 22.4 and 14 mm), to create a blend with improved grading qualities, that meets the requirements known as Fuller envelope. The table below shows how the blending was done. Trail -and – error procedure is used to determine the percentage of from each aggregates size.

Trial 1 = 50% of material A which is 22.4 mm aggregates and 50 % of material B which is 14 mm

Table 7-2: Grading and Blending of Aggregates Calculations

Sieve Size (mm)	37.5	26.5	19	13.2	9.5
Aggregates A (% passing)	100	100	72	4	1
Aggregates B (% passing)	100	100	100	86	2
Specification	100	100	85-100	0-50	
Blend Calculations	0.5x100+ 0.5x100 = 100	0.5x100+ 0.5x100 = 100	0.5x55+ 0.5x100 = 86	0.5x4+ 0.5x86 = 45	0.5x 1+ 0.5x2 = 1.5

Specification is met at 50% blend.

Proportion of aggregates A (maximum size 22.4 mm) = 50%

Proportion of aggregates B (maximum size 14 mm) = 50%

Aggregates with the calculated percentages were measured and subjected to sieve analysis test. The resulting blend conforms well with the graduation requirements.

Appendix 7-3: Calculations of Aggregates Replacement Volume

Specific amounts of natural aggregates were replaced by equivalent volumes of EPT beads. The sections show the calculated volume for each percentage replacement. The coarse aggregate density is 2694 kg/m^3. The volume of course aggregate in the mixture is 1190 kg per cubic m of the total concrete mix. EPT with density of 23 kg/m^3 and relative density of 0.023. Table 7-3 below shows the sample calculations.

Table 7-3: Calculations of Replacement Volumes

Coarse aggregate replacement by EPT (%)	Coarse aggregate volume (m^3)	Mass of EPT beads (Per cubic m) (kg)	Mass EPT per trial mix of 10 litre (g)	Mass of coarse aggregate replaced for the trial mix. (g)
5	0.0221 [(a)]	0.508 [(b)]	5.08 [(c)]	595 [(d)]
10	0.0442	1.017	10.17	1190
15	0.0664	1.527	15.27	1785
20	0.0885	2.036	20.36	2380
25	0.1106	2.544	25.44	2970
50	0.2212	5.088	50.88	5950

[(a)] The volume of coarse aggregates = mass/ density = (1190/ 2690) *(5/100) = 0.0221 m^3. The same volume is replaced by EPT beads.

[(b)] The mass of EPT beads = EPT density * mass = 23*0.0221 = 0.508 kg

[(c)] EPT mass in the trial mix = mass required for m^3 of concrete / 100 = 0.508/100 = 0.508x10^{-3}kg (508 g)

[(d)] Coarse aggregate mass in the trial mix = (1190/100) *(5/100) = 0.595 kg (595 g)

Appendix 7-4: Flexural Strength Results Calculations

Figure 7-1 below shows the flexural test setup. Three beams on each % of replacement for 7 and 28 days were calculated using the formula below. The calculated values were then presented in table 4-3 and 4-4 of chapter 4.

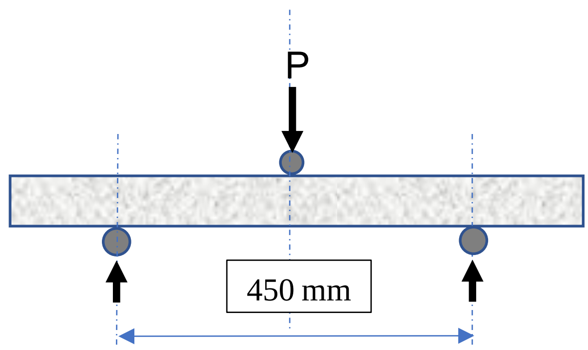


Figure 7-1: Flexural Test Setup

$F = (3*P*L)/(2*b*d^2)$

P = failure load (N)

L = tested span (450 mm)

b = d = 150 (mm)

Appendix 7-5: Pilot Study Results

A pilot study was conducted at the start for the following purposes:

- To test the mix design and make further adjustments.
- To get the feel on how EPT mixes to concrete.
- To verify the best mixing sequence for the various constituents of EPT concrete.
- To test the effect of EPT contents greater than the values tested and reported in the literature (i.e., >50% replacement).

Sets of three tests were conducted for this purpose, including, slump test, cube compressive strength test and beam flexure tests. Coarse aggregates were replaced with equivalent mass of EPT beads (i.e., provide the masses here). This results in volume replacements of 60% and greater. The following sections will provide the data obtained; however, the full analysis is published in a conference paper by Makamu and Walied (2023) Table 7.5, 7.6 and Table7.7 show the obtained results.

Table 7-4: Slump Test Results

EPT of Replacement (%)	Slump (mm)
0	120
5	127
10	140
15	150
20	164
25	170

Table 7-5: 7- and 28-Days Compressive Strength Results

Values between the parenthesis represent the averages while values between the square brackets represent the standard deviations.

7 days Compressive Strength (MPa)				28 Days Compressive Strength (MPa)		
% of Replacement	Average Mass (kg) And SD	Density (kg/m^3)	Average 7 Days Compressive Strength (MPa)	Average Mass (kg) And SD	Density (kg/m^3)	Average 7 Days Compressive Strength (MPa)
0	(7.69) [0.49]	2259	(21.45) [0.23]	(8.00) [0]	2370	(38.00) [0.47]
0.38	(6.81) [0.04]	2018	(10.85) [0.16]	(6.65) [0.03]	1970	(21.66) [0.32]
0.76	(4.89) [0.12]	1449	(5.69) [0.60]	(5.39) [0.57]	1597	(9.89) [0.29]
1.13	(4.35) [0.22]	1289	(3.45) [0.28]	(4.44) [0.13]	1316	(4.51) [0.04]
1.51	(3.62) [0.25]	1073	(1.29) [0.04]	(3.47) [0.19]	1028	(2.08) [0.13]
1.90	(2.87) [0.02]	850	(0.25) [0.032]	(2.92) [0.04]	865	(0.95) [0.06]

Table 7-6: 7- and 28-Days Flexural Strength Results

Values between the parenthesis represent the averages while values between the square brackets represent the standard deviations.

7 days Flexural Strength (MPa)				28 Days Flexural Strength (MPa)		
% of Replacement	Average Mass (kg) and SD	Density (kg/m^3)	Average 7 Days Flexural Strength (MPa)	Average Mass (kg) and SD	Density (kg/m^3)	Average 7 Days Flexural Strength (MPa)
0	(36.57) [0.51]	2167	(3.53) [0.04]	(36.71) [0.21]	2175	(4.59) [0.12]
0.38	(31.22) [0.21]	1850	(1.96) [0.14]	(30.65) [0.48]	1816	(2.55) [0.10]
0.76	(25.77) [0.11]	1527	(1.17) [0.10]	(23.85) [0.22]	1413	(1.52) [0.11]
1.13	(20.73) [0.10]	1228	(0.84) [0.08]	(20.48) [0.85]	1214	(1.09) [0.01]
1.51	(17.13) [0.22]	1015	(0.13) [0.23]	(17.55) [0.14]	1040	(0.17) [0.05]
1.90	(14.63) [0.07]	867	(0.03) [0.21]	(15.02) [0.50]	890	(0.04) [0.2]

The lesson drawn from the study includes:

- Workability increases significantly and linearly.
- Difficulties observed in compacting and finishing the surface of concrete.
- Strengths reduce significantly to a level that excludes the use of the EPT concrete materials in general purpose application.

Appendix 7-6: Heat Conductivity Results Calculations

Table below shows the calculations done to determine the heat conductivity of concrete.

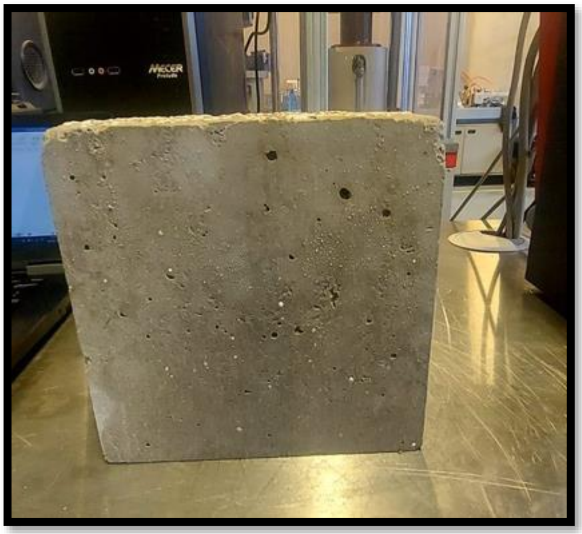
Table 7-7: Heat Conductivity Calculations

0% Replacement	**5% Replacement**
Q = 64 watts at 50℃ ΔT = Kelvin 315.56 -306.32 = 7.7 Δx = 150 mm – 0 mm = 150 mm A= 0.15 x 0.15 = 0.0225 m^2 t= 180 mins K= $\frac{Q\Delta x}{Ax\Delta Txt}$ = $\frac{64\ x\ 0.150}{0.0225\ x\ 7.7x\ 180}$ = 0.31 W/m. K	Q = 64 watts at 50℃ ΔT = Kelvin 315.77 -307.32 =8.45 Δx = 150 mm – 0 mm = 150 mm A= 0.15 x 0.15 = 0.0225 m^2 t = 180 mins K= $\frac{Q\Delta x}{Ax\Delta Txt}$ = $\frac{64\ x\ 0.150}{0.0225\ x\ 8.45x\ 180}$ = 0.28 W/m. K
15% Replacement	**20% Replacement**
Q = 64 watts at 50℃ ΔT = Kelvin 315.56 -306.32 =9.24 Δx = 150 mm – 0 mm = 150 mm A= 0.15 x 0.15 = 0.0225 m^2 t = 180 mins K= $\frac{Q\Delta x}{Ax\Delta Txt}$ = $\frac{64\ x\ 0.150}{0.0225\ x\ 9..24x\ 180}$ = 0.26 W/m. K	Q = 64 watts at 50℃ ΔT = Kelvin 314.87 -305.26 =9.61 Δx = 150 mm – 0 mm = 150 mm A= 0.15 x 0.15 = 0.0225 m^2 t = 180 mins K= $\frac{Q\Delta x}{Ax\Delta Txt}$ = $\frac{64\ x\ 0.150}{0.0225\ x\ 9.61x180}$ = 0.25 W/m. K
25% Replacement	**50% Replacement**

Q = 64 watts at 50℃ ΔT =Kelvin 314.32 -304.39 =9.93 Δx = 150 mm – 0 mm = 150 mm A= 0.15 x 0.15 = 0.0225 m^2 t = 180 mins K= $\frac{Q\Delta x}{Ax\Delta Txt}$ = $\frac{64\ x\ 0.150}{0.0225\ x\ 9.93x180}$ = 0.24 W/m. K	Q = 64 watts at 50℃ ΔT = Kelvin 313.3 -302.36 =11.01 Δx = 150 mm – 0 mm = 150 mm A= 0.15 x 0.15 = 0.0225 m^2 t = 180 mins K= $\frac{Q\Delta x}{Ax\Delta Txt}$ = $\frac{64\ x\ 0.150}{0.0225\ x\ 11.01x180}$ = 0.21 W/m. K

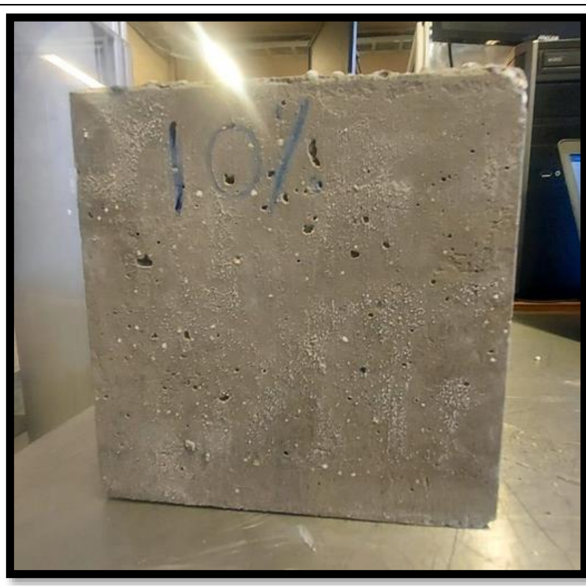
Appendix 7-7: Figures Showing Cubes Before and After Crushing

Figures below show the concrete cubes before and after crushing. The figures after crushing show the pattern on how the cube failed.



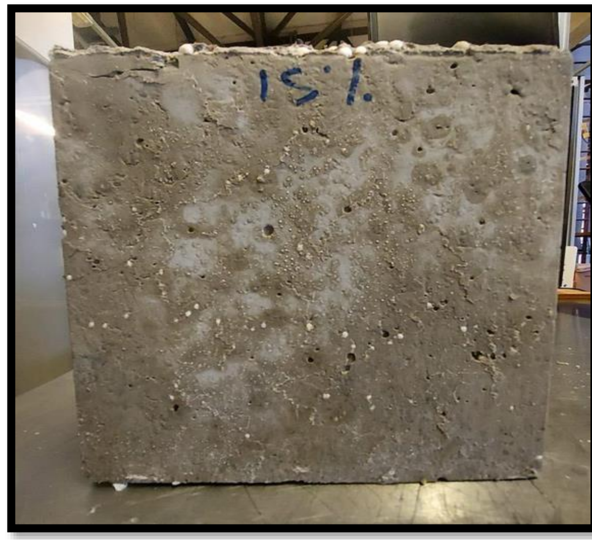
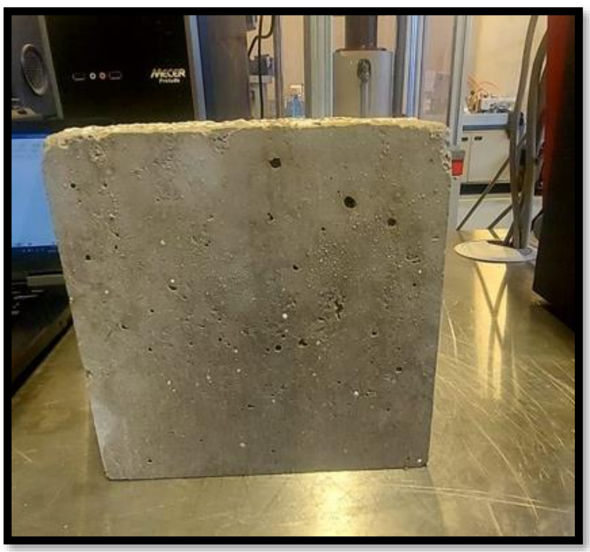
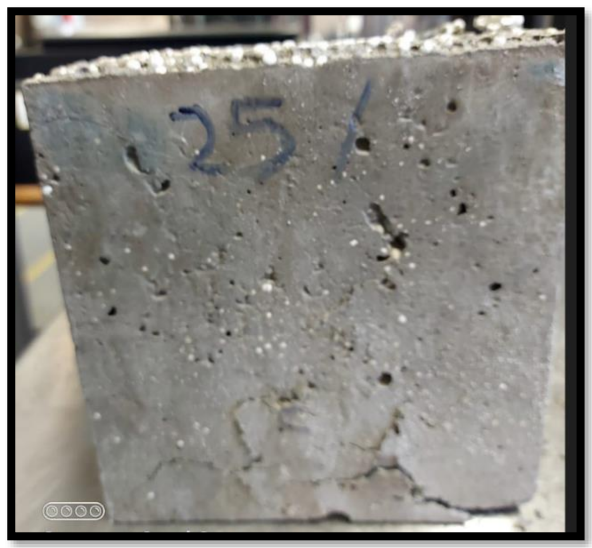
Before crushing

After crushing



Before crushing

After crushing

 Before crushing	 After crushing
 Before crushing	 After crushing

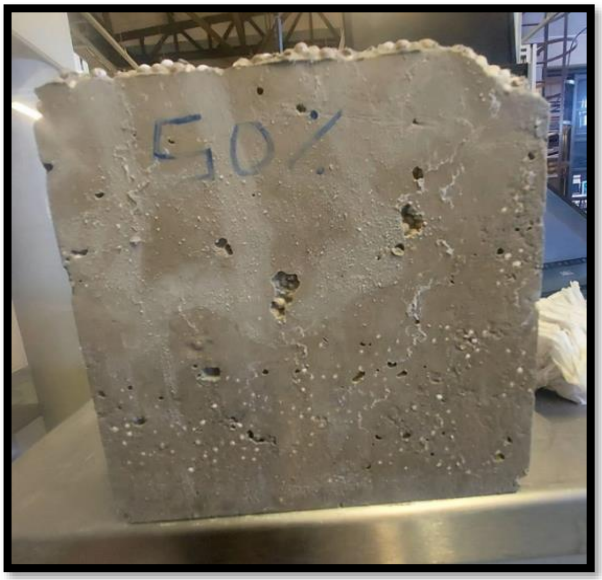
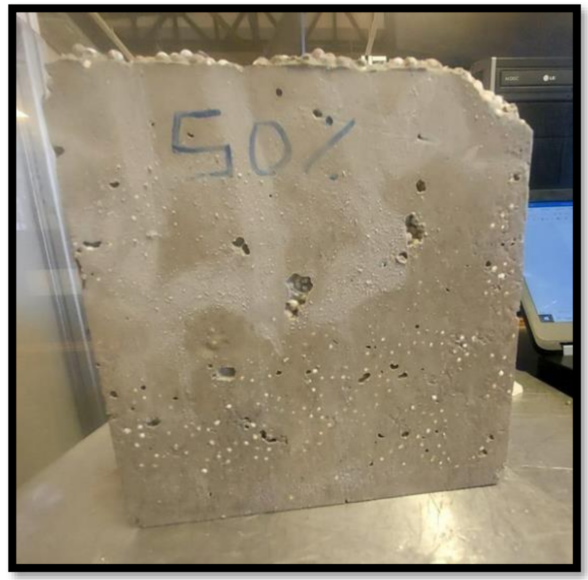
	
Before crushing	After crushing

Figure 7-2: Figures of Cubes Before and After Crushing

Appendix 7-8: Grading Analysis for All Percentages of Replacement

In South Africa, the grading limits for coarse aggregates are specified in the South African National Standard for aggregates, SANS 1083. The standard specifies limits for the percentage passing each sieve size for both single sized and graded aggregates. The table below shows the grading analysis of all percentages of replacement.

Table 7-8: Grading Analysis for All Percentages of Replacement

Sieve Size (mm)	Lower Limit	Higher Limit	0 % Cum % Passing	5% Cum % Passing	10% Cum % Passing	15% Cum % Passing	20% Cum % Passing	25% Cum % Passing	50% Cum % Passing
Pan			0.83	0.07	0.61	0.15	0.24	0.16	0.12
1	0	0.05	1.17	0.16	0.71	0.01	0.09	0.12	0.17
2.2	0	1	1.3	0.16	0.71	0.01	0.08	0.12	0.17
5	0	5	1.43	0.27	0.93	0.25	0.25	0.17	0.99
7.1	0	5	1.62	0.79	1.04	0.85	1.09	0.48	1.65
10	0	10	6.88	10.2	18.35	8.57	10.03	6.77	11.5
14	20	55	42.68	48.37	55.58	43.57	49.27	41.1	49.31
19	80	100	75.16	77.08	81	69.61	79.95	74.24	84.53
26.5	100	100	100	100	100	100	100	100	100

Appendix 7-9: EPT Particle Distribution Results

The table below presents the results obtained when EPT was put on sieves to determine its particle distribution.

Table 7-9: EPT Particle Distribution Results

Initial Mass = 18.5 g			
Sieve Size (mm)	**Mass Retained (g)**	**% Retained**	**% Passing**
7.1		-	100
5.0		-	100
2.0	18.5	100	0
1.0	-	-	0
Pan	-	-	0

Appendix 7-10: Determination of CBD of EPT and the coarse aggregates blend (50% 22.4 mm and 50% 14 mm) and EPT.

Table 7-10 shows the measurements and CBD values. Volume of the CBD container = 3 kg

CBD (EPT) $=\frac{0.0421\ \text{kg}}{0.003\ \text{m3}} = 14\ \text{kg/m}^3$

CBD (Coarse Aggregates) $= \frac{4.8\ \text{kg}}{0.003\ \text{m3}} = 1660\ \text{kg/m}^3$

Table 7-10: Measurements and CBD Values

Property	EPT Beads	Coarse Aggregates Blend
Mass in CBD container (kg)	3	3
CBD (kg/m^3)	14	1660

Figure 7-2 below demonstrate of how EPT beads bulk density was determined.

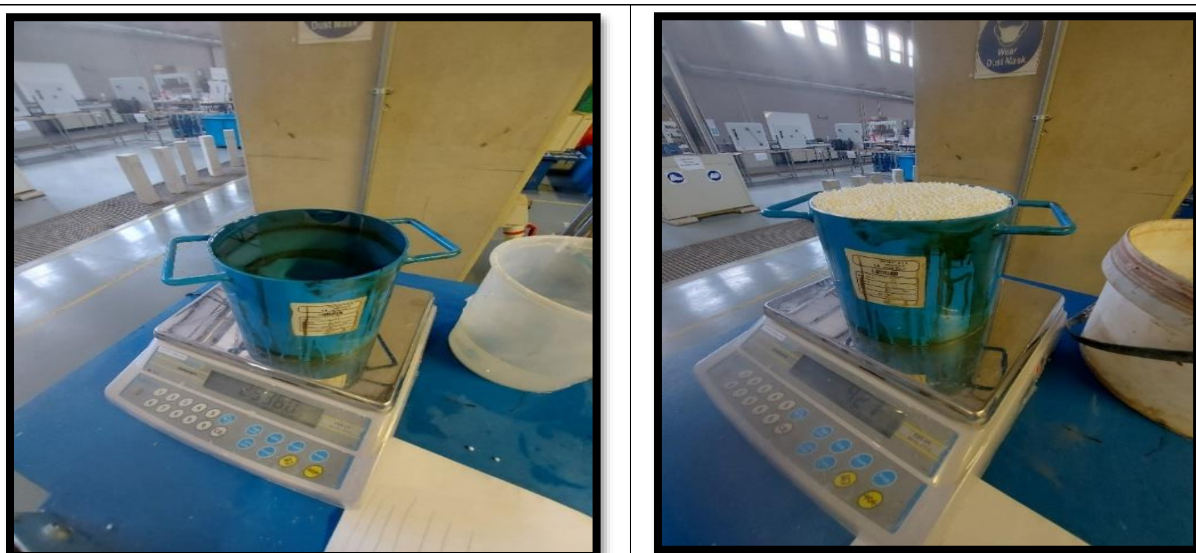


Figure 7-3: Determination of EPT Density

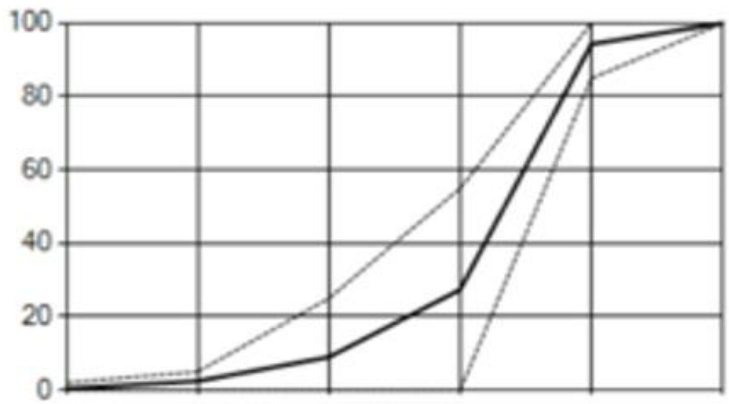
Appendix 7-11: Aggregates Tests Results

AGGREGATE TEST SHEET
Standard From SF 1a

AfriSam

Plant	0309 Jukskei	Sample ID	AA030921567
Rock Type	Granite	Date	16.08.2021 13:17
Product code	004M 14.0mm Concrete	Time	13:17
Sample Point	Stockpile	Sampled By	MALE
Plant Section	Main plant 1	Tested By	MALE
SAP Inc. No		Captured By	ZAF-GTN-HQ\MALE
Specification	SANS:1083	Weather	Dry and windy

GRADING						Flakiness Index
Sieve Size (mm)	Mass Retained (g)	Individual % Retained	Cumulative % Retained	Total % Passing	Specification %Passing	Mass Passing Slots (g)
20.0		0.0	0.0	100.0	100	
14.0	88.0	5.7	5.7	94.3	85-100	0.0
10.0	1043.0	67.0	72.6	27.4	0-55	97.0
7.1	286.0	18.4	91.0	9.0	0-25	57.0
5.0	102.0	6.6	97.6	2.4	0-5	
0.075	32.0	2.1	99.6	0.4	0-2	SANS5847
PAN (c)	4.0	0.3	99.9			9.9
TOTAL (B)	1557.0					Spec:0-35%



GRADING CALCULATIONS		
Total Mass (A)	1562.0	
Dry Mass (B)	1557.0	
Washed Mass (C)	1554.0	
PAN (B-C)	3.0	(a)
PAN (Actual)	1.0	(b)
Total PAN (a+b)	4.0	(c)

MOISTURE CONTENT %	
(A-B)/B*100	0.3

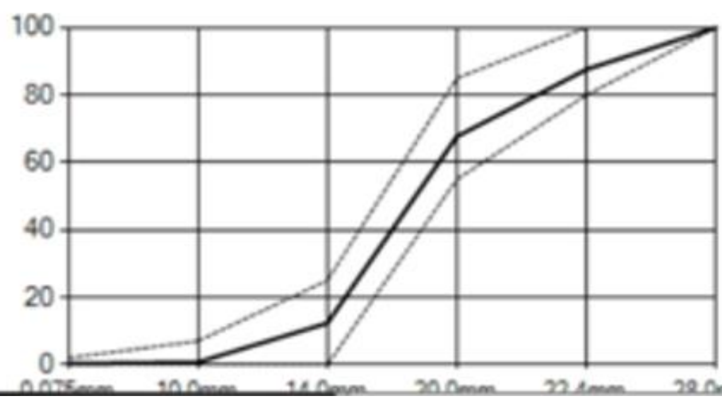
Figure 7-4: 14 mm Stone Grading Results

AGGREGATE TEST SHEET
Standard From SF 1a

AfriSam

Plant	0309 Jukskei	Sample ID	AA030921566
Rock Type	Granite	Date	16.08.2021
Product code	506M 22.4mm Concrete	Time	13:16
Sample Point	Stockpile	Sampled By	MALE
Plant Section	Main plant 1	Tested By	MALE
SAP Inc. No		Captured By	ZAF-GTN-HQ\MALE
Specification	AfriSam	Weather	Dry and windy

GRADING						Flakiness Index
Sieve Size (mm)	Mass Retained (g)	Individual % Retained	Cumulative % Retained	Total % Passing	Specification % Passing	Mass Passing Slots (g)
28.0	0.0	0.0	0.0	100.0	100	
22.4	314.0	12.4	12.4	87.6	80-100	89.0
20.0	505.0	19.9	32.3	67.7	55-85	123.0
14.0	1404.0	55.4	87.7	12.3	0-25	304.0
10.0	293.0	11.6	99.3	0.7	0-7	
0.075	11.0	0.4	99.7	0.3	0-2	SANS 5847
PAN (c)	4.0	0.2	99.8			20.4
TOTAL (B)	2535.0					Spec:0-35%



GRADING CALCULATIONS		
Total Mass (A)	2540.0	
Dry Mass (B)	2535.0	
Washed Mass (C)	2533.0	
PAN (B-C)	2.0	(a)
PAN (Actual)	2.0	(b)
Total PAN (a+b)	4.0	(c)

MOISTURE CONTENT %	
(A-B)/B*100	0.2

Figure 7-5: 22.4 mm Stone Grading Results

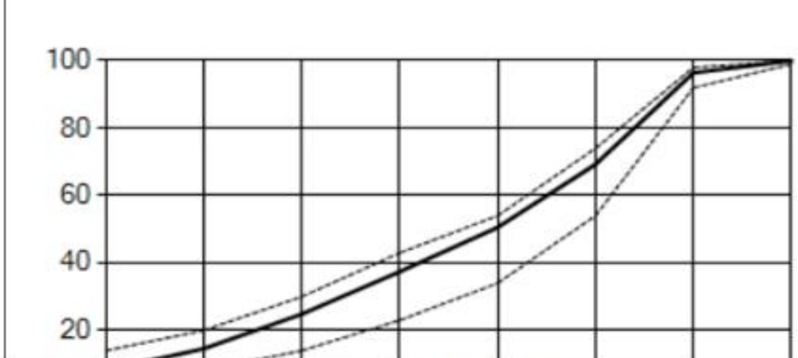
AGGREGATE TEST SHEET
Standard From SF 1a

AfriSam

Plant	0309 Jukskei	Sample ID	AA030921561
Rock Type	Granite	Date	13.08.2021
Product code	0309120M UWCS	Time	10:24
Sample Point	Stockpile	Sampled By	MALE
Plant Section	Main plant 1	Tested By	MALE
SAP Inc. No		Captured By	ZAF-GTN-HQ\MALE
Specification	AfriSam	Weather	Cold and dry

GRADING

Sieve Size (mm)	Mass Retained (g)	Individual % Retained	Cumulative % Retained	Total % Passing	Specification % Passing	FINENESS MODULUS (FM)
7.1	0.0	0.0	0.0	100.0	99-100	F.M.= 3.1
5.0	20.0	3.6	3.6	96.4	92-98	
2.00	151.0	27.2	30.8	69.2	54-74	Upper Limit 3.75
1.00	104.0	18.7	49.5	50.5	34-54	
0.600	73.0	13.1	62.6	37.4	23-43	Lower Limit 2.81
0.300	70.0	12.6	75.2	24.8	14-30	
0.150	57.0	10.3	85.4	14.6	8-20	FM=600-(sum of % passing 5.0mm to 0.150mm sieves)/100
0.075	36.0	6.5	91.9	8.1	6-14	
PAN (c)	42.0	7.6	99.5			
TOTAL (B)	556.0					



GRADING CALCULATIONS

Total Mass (A)	576.0	
Dry Mass (B)	556.0	
Washed Mass (C)	521.0	
PAN (B-C)	35.0	(a)
PAN (Actual)	7.0	(b)
Total PAN (a+b)	42.0	(c)

MOISTURE CONTENT %

AA030921567 0309 Jukskei

Figure 7-6: Crusher Sand Grading Results

Beton-Lab cc

Tel: 011-979-1422 | Fax: 011-979-1430
e-mail: betonlab@absamail.co.za
32a Third Road, Bredell
PO Box 10583, Aston Manor, 1630

AfriSam (South Africa) (Pty) Ltd
P.O. Box 6367
Weltevredenpark
Email: joseph.rametsi@za.afrisam.com

Report Ref: BLM3315 (final)
Date: 6th April 2021

TEST REPORT

1. **Sample description:**
   The following sample was received on the 8th March 2021 for testing as per your Purchase Order Number: 4501622316.

   - **Unwashed sand**

   Project: Jukskei

   The sample was received in a sealed plastic bag and deemed suitable for testing.

2. **Test required and test method:**
   Organic impurities in fine aggregate (limit test) - SANS 5832;2006
   Detection of sugar in fine aggregate – SANS 5833:2006
   Water soluble sulphates in fines in aggregates – SANS 850-1:1998
   Chloride content of aggregates – SANS 202:2006
   Deleterious clay content of the fines in aggregates (methylene blue absorption indicator test) – SANS 6243:2008
   Clay and silt content (out sourced)
   Particle and relative density of aggregates – SANS 5844:2006
   Water absorption of aggregates – SANS 5843:2006
   Potential reactivity of aggregate with alkalis (accelerated mortar prim method) – SANS 6245:2006
   Sand equivalent of fine aggregate – SANS 5838:2006

3. **Results**

   3.1 Organic impurities in fine aggregate (limit test) - SANS 5832;2006
   Unwashed crusher sand = Passed

   3.2 Detection of sugar in fine aggregate – SANS 5833:2006
   Unwashed crusher sand = No sugar present

   3.3 Water soluble sulphates in fines in aggregates – SANS 850-1:1998
   Unwashed crusher sand = 0.066%

   3.4 Chloride content of aggregates – SANS 202:2006
   Unwashed crusher sand = 0.007%

Figure 7-7: Chemical Impurities Tests on Aggregates

Report no: BLM3315
Date: 6th April 2021

3.5 Deleterious clay content of the fines in aggregates (methylene blue absorption indicator test) SANS 6243:20085

Unwashed crusher sand = 0.25%

3.6 Clay & silt content (see attached report)

3.7 Particle and relative density of aggregates – SANS 5844:2006

Unwashed crusher sand = 2.63

3.8 Water absorption of aggregates – SANS 5843:2006

Unwashed crusher sand = 0.56%

3.9 Potential reactivity of aggregate with alkalis (accelerated mortar prim method) – SANS 6245:2006

Unwashed Crusher Sand:

Specimen		Linear expansion %:
1		0.034
2		0.034
3		0.034
	Avr	0.034
	Range	0.000

Comments:

According to Fulton's Concrete Technology, (Eighth Edition – pg 171) the most widely accepted criteria for expansion after 14 days (12 days in South Africa) are:

- Less than 0,10%: aggregate innocuous.
- More than 0,10% but less than 0,20%: aggregate slowly reactive or inconclusive.
- Equal to or more than 0,20%: aggregate deleteriously reactive, rapidly expansive.

3.10 Sand equivalent of fine aggregate – SANS 5838:2006

Unwashed crusher sand = 80.1%

A.D.R de Kock
Member

R de Lange
Report compiled by:

Figure 7-8: Water Absorption, Clay and Silt Content, Relative density Tests on Aggregates.

Revision number: 1
Date: 2020/04/09

Technical data sheet

CHRYSO® Omega 180 ZA

New generation, multi-dose, water reducing plasticiser

Description

CHRYSO® Omega 180 ZA is classified as a water reducing plasticiser. The admixture thus induces the following major effects in a concrete mix:

- Without affecting the consistence (workability), permits a reduction in the water content of a given concrete or
- Without affecting the water content, increases the slump/flow or
- Produces both of the above effects simultaneously.

- **CHRYSO®Omega 180 ZA** conforms to the requirements of SANS 50934-2 (EN 934-2) Table 2). These requirements are approximate equivalents of ASTM C494 Type A.

Advantages

- **CHRYSO®Omega 180 ZA** is a multi-dose admixture, allowing a wide range of dosages to be applied, without any excessive retardation at the higher dosages.
- The multi-dose characteristic of **CHRYSO®Omega 180 ZA** allows concrete to exhibit extended workability characteristics.
- When used to reduce the water content of a concrete mix (lower the w/b ratio) **CHRYSO® Omega 180 ZA** may potentially reduce the rate of bleeding.
- **CHRYSO®Omega 180 ZA** improves the cohesion and lowers the viscosity of a concrete mix. This results in an improved homogeneity and compaction, allowing for superior off-shutter finishes.
- By reducing the need to add extra water, **CHRYSO®Omega 180 ZA** increases the durability of concrete, by reducing permeability.

Physical and chemical properties

- Physical state(@25°C): liquid
- Specific gravity (@25°C): 1.098 (±0.013)
- Colour: brown
- pH: 6.0 (±1.0)
- Viscosity(@25°C): 15 -25 secs (ford#4 cup)
- Cl^- ions content < 0,1%
- Na_2O equivalent: ≤ 2%
- Solubility in water: miscible

- **CHRYSO®Omega 180 ZA** is robust to differences in cement characteristics. Based on aesthetic requirements, its suitability for use with white cement, should be ascertained prior to use.
- **CHRYSO®Omega 180 ZA** may be used with in mixes extended with limestone and/or typically used SCMs - GGBS, GGCS, Fly Ash and Silica Fume.
- **CHRYSO®Omega 180 ZA** does not undermine the early age strength of concrete and in certain cases, may be used to improve it.
- Depending on the dosage, **CHRYSO®Omega 180 ZA** will cause a relative increase of mechanical strength after 24 hours.

Application guidelines

Use

- Typically ready-mix concrete and mechanically mixed site concrete.
- Low to high workability concrete.
- Conventionally placed concrete.
- Pumped concrete.
- Highly reinforced concrete.

CHRYSO® Omega 180 ZA

New generation, multi-dose, water reducing plasticiser

Dosage

- The optimum dosage of **CHRYSO®Omega 180 ZA** can only be established by using trial tests, taking into account local conditions affecting the workability of the fresh mix and the mechanical properties required of the concrete.
- Range:
  - By volume: 0.3 to 1.5 litres per 100 kg of cementitious material (including extenders)
  - By weight: 0.33 to 1.65 kg per 100 kg cementitious material (including extenders)
- Typical:
  - By volume: 0.6 to 0.8 litres per 100 kg of cementitious material (including extenders)
  - By weight: 0.66 to 0.88 kg per 100 kg cementitious material (including

- As a component of the mixing process: Should be added simultaneously with approximately 90% of the concrete's total gauge water requirement.
- To freshly mixed concrete in a ready-mix truck drum: Reverse the ready-mix truck drum to discharge at very slow revolutions. When the concrete reaches the mouth of the drum, stop the drum. Place **CHRYSO®Omega 180 ZA** on the concrete and not onto any exposed surface of the drum interior. Change the direction of the drum to mixing and ensure that all material has moved to the bottom of the drum. Repeat a minimum of 2 more times (preferably 3), the reverse to discharge at very slow revolutions, until the concrete reaches the mouth of the drum and then change to mixing until the concrete has moved to the bottom of the drum - to ensure that all of the internal upper drum surfaces have been cleared of admixture and to

CHRYSO® Omega 180 ZA

New generation, multi-dose, water reducing plasticiser

Dosage

- The optimum dosage of **CHRYSO®Omega 180 ZA** can only be established by using trial tests, taking into account local conditions affecting the workability of the fresh mix and the mechanical properties required of the concrete.
- Range:
  - By volume: 0.3 to 1.5 litres per 100 kg of cementitious material (including extenders)
  - By weight: 0.33 to 1.65 kg per 100 kg cementitious material (including extenders)
- Typical:
  - By volume: 0.6 to 0.8 litres per 100 kg of cementitious material (including extenders)
  - By weight: 0.66 to 0.88 kg per 100 kg cementitious material (including

- As a component of the mixing process: Should be added simultaneously with approximately 90% of the concrete's total gauge water requirement.
- To freshly mixed concrete in a ready-mix truck drum: Reverse the ready-mix truck drum to discharge at very slow revolutions. When the concrete reaches the mouth of the drum, stop the drum. Place **CHRYSO®Omega 180 ZA** on the concrete and not onto any exposed surface of the drum interior. Change the direction of the drum to mixing and ensure that all material has moved to the bottom of the drum. Repeat a minimum of 2 more times (preferably 3), the reverse to discharge at very slow revolutions, until the concrete reaches the mouth of the drum and then change to mixing until the concrete has moved to the bottom of the drum - to ensure that all of the internal upper drum surfaces have been cleared of admixture and to

Technical data sheet

CHRYSO® Omega 180 ZA

New generation, multi-dose, water reducing plasticiser

Packaging

- 25 ℓ jerry can
- 200 ℓ drum
- 1000 ℓ flow bin
- Bulk delivery on request

Health and safety

- This product is classified as harmless. CHRYSO will provide onsite assistance when requested.
- For more information, please refer to the material safety data sheet.

Figure 7-9:CHRYSO Admixture Information Sheet

Appendix 7-12: Statical Analysis Calculations

Calculations procedure

This procedure calculates the difference between the observed means in two independent samples. A significance value (P-value) and 95% Confidence Interval (CI) of the difference is reported. The P-value is the probability of obtaining the observed difference between the samples if the null hypothesis were true. The null hypothesis is the hypothesis that the difference is 0.

For both samples, you enter:

- **Mean**: the observed arithmetic mean.
- **Standard deviation**: the observed standard deviation.
- **Sample size**: the number of observations in the sample.

Step 1:

$$s = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

where s_1 and s_2 are the standard deviations of the two samples with sample sizes n_1 and n_2.

Step 2:

The standard error *se* of the difference between the two means is calculated as:

$$se(\bar{x}_1 - \bar{x}_2) = s \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

Step 3:

between the two means is calculated as:

$$se(\bar{x}_1 - \bar{x}_2) = s \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

Step 4:

The significance level, or P-value, is calculated using the *t*-test, with the value *t* calculated as:

$$t = \frac{\bar{x_1} - \bar{x_2}}{se(\bar{x_1} - \bar{x_2})}$$

The P-value is the area of the *t* distribution with $n_1 + n_2 - 2$ degrees of freedom, that falls outside ± *t* (see Values of the *t* distribution table).

When the P-value is less than 0.05 (P<0.05), the conclusion is that the two means are significantly different.

Table 7-11: Statistically Difference Calculations of Compressive Strength in Table 4.2

0-5 % Replacement	**5 -10% Replacement**
CALCULATIONS BETWEEN 0 AND 5% **0 % Replacement** Mean =38.63 Standard deviation=0.47 Sample size =3 **5% Replacement** Mean= 38.30 Standard deviation= 1.16 Sample size=3 **Results** Difference = -0.180 Standard Error= 0.723 95% CI = -2.1863 to 1.8263 t-Statistics= -0.249 DF= 4 Significance level (P) = 0.8156 The results between 0 and 5% are significantly the same.	**CALCULATIONS BETWEEN 5 AND 10%** **5 % Replacement** Mean =38.3 Standard deviation=1.16 Sample size =3 **10% Replacement** Mean= 38.12 Standard deviation= 1.62 Sample size=3 **Results** Difference = -0.180 Standard Error= 1.150 95% CI = -3.3739 to 3.0139 t-Statistics= -0.156 DF= 4 Significance level (P) = P = 0.8832 The results between 5 and 10% are significantly the same.
10 -15% Replacement	**15 -20% Replacement**

CALCULATIONS BETWEEN 10 AND 15%	CALCULATIONS BETWEEN 15 AND 20%
10% Replacement Mean =38.12 Standard deviation=1.62 Sample size =3 **15% Replacement** Mean= 34.21 Standard deviation= 0.74 Sample size=3 **Results** Difference = -3.910 Standard Error= 1.028 95% CI = -6.7649 to -1.0551 t-Statistics= -3.803 DF= 4 Significance level (P) = P = 0.0191 The results between 10 and 15% are significantly the different.	**15% Replacement** Mean= 34.21 Standard deviation= 0.74 Sample size=3 **20% Replacement** Mean= 25 Standard deviation= 0.83 Sample size=3 **Results** Difference = -9.210 Standard Error= 0.642 95% CI = -10.9925 to -7.4275 t-Statistics= -14.346 DF= 4 Significance level (P) = P = 0.0001 The results between 15 and 20% are significantly different.
20- 25% Replacement	**25- 50% Replacement**
CALCULATIONS BETWEEN 20 AND 25% **20% Replacement** Mean= 25 Standard deviation= 0.83 Sample size=3 **25% Replacement** Mean= 25.05 Standard deviation= 0.87 Sample size=3 **Results**	**CALCULATIONS BETWEEN 25 AND 50%** **25% Replacement** Mean= 25.05 Standard deviation= 0.87 Sample size=3 **50% Replacement** Mean= 15.43 Standard deviation= 0.85 Sample size=3 **Results**

Difference = 0.050 Standard Error= 0.694 95% CI = -1.8774 to 1.9774 t-Statistics= 0.072 DF= 4 Significance level (P) = P = 0.9460 The results between 20 and 25% are significantly the same.	Difference = -9.620 Standard Error= 0.702 95% CI = -11.5697 to -7.6703 t-Statistics= -13.699 DF= 4 Significance level (P) = P = 0.0002 The results between 25 and 50% are significantly different.

Table 7-12: Statistically Difference Calculations of Flexural Strength in Table 4.4

0-5 % Replacement	**5 -10% Replacement**
CALCULATIONS BETWEEN 0 AND 5% **0% Replacement** Mean= 5.53 Standard deviation= 0.14 Sample size=3 **5% Replacement** Mean= 5.37 Standard deviation=0.09 Sample size=3 **Results** Difference = -0.160 Standard Error= 0.096 95% CI = -0.4268 to 0.1068 t-Statistics= -1.665 DF= 4 Significance level (P) = P = 0.1712 The results between 0 and 5% are statistically the same.	**CALCULATIONS BETWEEN 5 AND 10%** **5% Replacement** Mean= 5.37 Standard deviation= 0.09 Sample size=3 **10% Replacement** Mean= 4.62 Standard deviation=0.09 Sample size=3 **Results** Difference = -0.160 Standard Error= 0.05 95% CI = -0.9150 to -0.5850 t-Statistics= -12.67 DF= 4 Significance level (P) = P = 0.0002 The results between 5 and 10% are statistically different.

10 -15% Replacement	**15 -20% Replacement**
CALCULATIONS BETWEEN 10 AND 15% **10% Replacement** Mean= 4.62 Standard deviation= 0.09 Sample size=3 **15% Replacement** Mean= 4.29 Standard deviation=0.04 Sample size=3 **Results** Difference = -0.330 Standard Error= 0.037 95% CI = -4.4326 to -0.2274 t-Statistics= -8.927 DF= 4 Significance level (P) = P = 0.0009 The results between 10 and 15% are statistically different.	**CALCULATIONS BETWEEN 15 AND 20%** **15% Replacement** Mean= 4.29 Standard deviation= 0.04 Sample size=3 **20% Replacement** Mean= 3.78 Standard deviation=0.1 Sample size=3 **Results** Difference = -0.510 Standard Error= 0.062 95% CI = -0.6826 to -0.3374 t-Statistics= -8.202 DF= 4 Significance level (P) = P = 0.0012 The results between 15 and 20% are statistically different.
20- 25% Replacement	**25- 50% Replacement**
CALCULATIONS BETWEEN 20 AND 25% **20% Replacement** Mean= 3.57 Standard deviation= 0.06 Sample size=3 **25% Replacement** Mean= 2.22 Standard deviation=0.17	**CALCULATIONS BETWEEN 25 AND 50%** **25% Replacement** Mean= 3.57 Standard deviation= 0.06 Sample size=3 **50% Replacement** Mean= 2.22 Standard deviation=0.17

Sample size=3 **Results** Difference = -1.350 Standard Error= 0.104 95% CI = -1.6390 to -1.0610 t-Statistics= -12.970 DF= 4 Significance level (P) = P = 0.0002 The results between 25 and 50% are significantly different.	Sample size=3 **Results** Difference = -1.350 Standard Error= 0.104 95% CI = -1.6390 to -1.0610 t-Statistics= -12.970 DF= 4 Significance level (P) = P = 0.0002 The results between 25 and 50% are significantly different.

Table 7-13: Statistically Difference Calculations of Drying Shrinkage in Table 4.7

0-5 % Replacement	5-10 % Replacement
CALCULATIONS BETWEEN 0 AND 5% **0% Replacement** Mean=0.018 Standard deviation=0.001 Sample size=3 **5% Replacement** Mean=0.019 Standard deviation=0.002 Sample size=3 **Results** Difference =-0.001 Standard error= 0.001 95% CI= -0.0026 to 0.0046 t-statistic=0.775	**CALCULATIONS BETWEEN 5 AND 10%** **5% Replacement** Mean=0.019 Standard deviation=0.002 Sample size=3 **10% Replacement** Mean=0.019 Standard deviation=0.002 Sample size=3 **Results** Difference =-0.001 Standard error= 0.001 95% CI= -0.0026 to 0.0046 t-statistic=0.775

DF=4 Significance level= P=0.4818 The results between 0 and 5% are significantly the same. Top of Form	DF=4 Significance level= P=0.4818 The results between 5 and 10% are significantly the same.
10 -15% Replacement	**15 -20% Replacement**
CALCULATIONS BETWEEN 10 AND 15% **10% Replacement** Mean=0.019 Standard deviation=0.002 Sample size=3 **15% Replacement** Mean=0.02 Standard deviation=0.001 Sample size=3 **Results** Difference =-0.001 Standard error= 0.001 95% CI= -0.0026 to 0.0046 t-statistic=0.775 DF=4 Significance level= P=0.4818 The results between 10 and 15% are significantly the same.	**CALCULATIONS BETWEEN 15 AND 20%** **15% Replacement** Mean=0.02 Standard deviation=0.001 Sample size=3 **20% Replacement** Mean=0.02 Standard deviation=0.001 Sample size=3 **Results** Difference =-0.000 Standard error= 0.001 95% CI= -0.0023 to 0.0023 t-statistic=0.000 DF=4 Significance level= P=1.0000 The results between 15 and 20% are significantly the same.
20- 25% Replacement	**25- 50% Replacement**

CALCULATIONS BETWEEN 20 AND 25%	**CALCULATIONS BETWEEN 25 AND 50%**
20% Replacement Mean=0.02 Standard deviation=0.001 Sample size=3 **25% Replacement** Mean=0.021 Standard deviation=0.001 Sample size=3 **Results** Difference =0.001 Standard error= 0.001 95% CI= -0.0013 to 0.0033 t-statistic=1.225 DF=4 Significance level= P=0.2879 The results between 20 and 25% are significantly the same.	**25 % Replacement** Mean=0.021 Standard deviation=0.001 Sample size=3 **50% Replacement** Mean=0.022 Standard deviation=0.001 Sample size=3 **Results** Difference =0.001 Standard error= 0.001 95% CI= -0.0013 to 0.0033 t-statistic= 1.225 DF=4 Significance level= P=0.2879 The results between 25 and 50% are significantly the same.