

CHAPTER 1 : INTRODUCTION

1.1 General

Cement concrete is regarded as the second most consumed substance after potable water. The global consumption of concrete is estimated at thirty billion tons per year [1]. Cement, the essential and expensive component of concrete, serves as the binding agent. Cement production accounts for around 5–7% of worldwide carbon dioxide (CO₂) emissions, since the manufacture of one ton of Ordinary Portland Cement (OPC) releases one ton of carbon dioxide. This situation is concerning, necessitating an immediate reduction of CO₂ emissions from the cement industry [2,3].

Foamed concrete is a type of mortar or cement paste that has air voids artificially trapped in it. Among its many desirable characteristics are a low specific gravity, good flowability, controlled low strength, and exceptional thermal insulation. It also requires very little aggregate. Use of precisely controlled dosages of foaming agent at different dilution ratios allows to produce foamed concrete with varying density ranging from 400 to 1850 kg/m³; this range can then be applied to structural, partition, insulation, and filler grades [4,5]. Applications as non- and semi-structural material in the construction industry are becoming increasingly popular due to its lightweight and cost-effective character.

Foamed concrete, like conventional concrete, uses cement and sand, two materials that worry about sustainability and environmental difficulties. In particular, the cement sector is a major contributor to global warming due to its high carbon dioxide emissions. Worldwide, 8% of all anthropogenic carbon dioxide emissions came from the cement sector. Cement production is expected to expand, which is driving this percentage growth [6]. Sand, in contrast, is a finite resource that must be preserved to prevent its depletion.

Considering that 60% of the materials recovered from the lithosphere end up in the building industry, it makes sense [7].

Possible alternatives to cement and sand can therefore ease the aforementioned problems and shift the construction industry towards a more sustainable model. To that end, recycling and reusing materials has recently gained popularity as a viable substitute for traditional concrete ingredients like sand and cement [8,9]. Agricultural, mining, industrial, municipal, and construction industry trash are all readily available in plenty globally.

Disposal or recycling has long been the go-to practice for dealing with these types of garbage. Landfilling and incineration are the traditional methods of disposing of these wastes, but they are costly and pose concerns to human and environmental health. Landfills create a lot of problems, the most common of which are liquid waste, windblown debris, and extremely dangerous gas that can harm surface plants and cause greenhouse effects. Burning, on the other hand, releases harmful gas pollutants into the atmosphere. However, complicated products make trash recycling more difficult [10–12].

The idea of using recycled waste in concrete has been around for a while, but it hasn't really taken off due to issues with factors like reduced strength and long-term durability, which make it unsuitable for most concrete constructions. Where strength is not the primary concern, foamed concrete has been seeing a rise in usage for non- and semi-structural applications in recent years [4]. As a result, foamed concrete is a great way to make more sustainable use of materials by replacing cement and sand with a significant volume of different kinds of waste materials. Therefore, a promising strategy for sustainability and environmental concerns related to the building industry CO₂

emissions, resource exploitation, and waste management is the use of waste materials in foamed concrete.

There has been some investigation into using pre-foamed concrete technology to incorporate waste materials; however, this idea has not yet spread. This is a major setback for the cause of promoting and advocating the idea of recycling waste materials from construction and demolition plants into sustainable concrete products. As a result, this research aims to summarize and evaluate the outcomes obtained when employing various forms of waste as cement and aggregate replacement in foamed concrete created using pre-formed foam. The goal is to facilitate the uptake of this technology. Since the availability of different sorts of waste may vary among places, this will be especially helpful as a reference for realizing and embracing the concept overall. Therefore, this study will focus on the various waste types, the dilution ratio of protein based foaming agents, and how they affect the foamed concrete qualities. It will also highlight the benefits and drawbacks of foam concrete and suggest areas for further research.

1.2 Foam Concrete

Foam concrete is a cement mortar composed of cement, water, and stable, homogenous foam injected via an appropriate foaming agent and can be classified as self-compacting materials [13,14]. Foamed concrete is fundamentally defined as "mortar containing air bubbles". The introduction of air bubbles can be accomplished using pre-foaming or mix-foaming techniques. Pre-foaming-type foamed concrete is generated by integrating pre-manufactured foams into cement slurry, while mixed-foaming-type foamed concrete is formed by introducing a surfactant into the cement slurry during the mixing phase [15,16]. The advantages of the prepared foaming method encompass (i) a substantial reduction in the requirement for foaming agents and (ii) a robust correlation between the amount of foaming agent employed and the air concentration in the mixture

[13–16]. Thus, employing prefabricated foam enables a more efficient attainment of the appropriate air content compared to foaming the mixture [17–19]. Alternative academic terminologies for this material include lightweight cellular concrete, low-density foam concrete, and cellular lightweight concrete. It provides efficient methods to address various challenges and problems faced in construction activities. The lack of coarse aggregates and the predominance of fine aggregates, primarily under 4.75 mm in size, significantly enhance the sustainability and environmental compatibility of the material. This method is consistent with sustainable construction practices, as it minimizes the consumption of natural resources and encourages the use of recycled or finer particles, aligning with contemporary environmental standards for eco-friendly foam concrete production. Its textured surface and microstructural cells render it extensively applicable in thermal insulation, sound absorption, and fire resistance [20–24].

1.3 Historical Background of Foam Concrete

The versatile building material known as lightweight concrete, sometimes called foam concrete or cellular concrete, is characterized by its low density and excellent thermal and acoustic insulation properties. In the more than 100 years after its invention, this material has experienced significant advancements in production techniques and a wide variety of applications. When foam concrete first came out in the 1920s, attempts were made to add air to concrete mixes to reduce their overall weight. The main function of autoclaved aerated concrete at this time was to provide thermal insulation. These early efforts paved the way for modern advancements in foam concrete technology. By the 1950s and 1960s, the initial studies on foam concrete composition and physical properties were finished. Due to professional and scientific inquiries into methods for producing lightweight concrete containing entrained air bubbles, it saw its initial practical applications in Europe and the USA in the 1960s and 1970s [4,5,25]. Foam concrete is

crucial for building, especially for enhancing acoustic absorption, fire safety, and thermal insulation in buildings. At this point, the material was no longer primarily used for research purposes but was instead actively employed in construction applications. Late in the 1970s and early in the 1980s, foam concrete was successfully used in commercial applications due to advancements in foaming agents and production techniques. In the Netherlands, research has greatly expanded its applications, particularly in the fields of ground stability and void filling. During this period, foam concrete was recognized as a lightweight construction material, demonstrating its versatility for a range of building applications. In recent decades, foam concrete has undergone significant improvements in its stability, durability, and manufacturing processes. The innovation of synthetic enzyme-based foaming agents, paired with state-of-the-art mixing technology, has enabled the production of ultra-lightweight foam concretes, reaching densities as low as 75 kg/m^3 [26,27]. The recent developments have expanded their applications to include highways, residential buildings, disaster recovery systems, and various other uses. At present, foam concrete is widely employed globally due to its properties of fire resistance, water resistance, and insect resistance, as well as its ease of handling. Foam concrete has evolved from an experimental lightweight concrete to a well-established construction material, showcasing its adaptability in numerous applications. The historical progression highlights a persistent dedication to advancing innovation aimed at enhancing material characteristics while maintaining cost-effectiveness. As research progresses, foam concrete continues to play a crucial role in advancing sustainable construction practices worldwide.

1.4 Applications of Foam Concrete

Foamed concrete finds application across multiple domains due to its low density and advantageous characteristics that facilitate both placement and production [28–30].

Foam concrete, characterized as cellular concrete, is typically categorized as a lightweight construction material with a significant void content. The air void content is not rigidly defined, with a minimum threshold of around 20% by volume, while the upper limit can exceed 80% [4,5,16]. Foam concrete exhibits a notable high porosity, resulting in a low density that varies from 0.4 to 1.6 g/cm³. The main advantage of foam concrete is its lighter weight, which improves the design of support structures like foundations and lower walls, making it a good choice for buildings that need to withstand earthquakes [13,31,32]. Due to the accessibility of portable foam generators, it is feasible to produce foam concrete directly at the site. The precise control of foam dosage facilitates the production of foamed concrete exhibiting a broad spectrum of specified densities, ranging from 400 to 1800 kg/m³ [33–35]. This feature provides significant versatility in the production of items tailored for applications, encompassing structural, partition, insulation, and filler classifications. Foam concrete exhibits outstanding thermal insulation characteristics attributed to its porous structure, rendering it a highly suitable option for roofing insulation applications. As a result, foam concrete is an energy-efficient solution that is suitable for applications requiring both structural integrity and thermal insulation. Another important advantage of foam concrete is its ability to use industrial waste, such as fly ash, as a principal component in significant quantities. This strategy is a highly effective and efficient way to use waste resources. Furthermore, by serving as a viable alternative to traditional clay bricks, it helps to preserve fertile topsoil that would otherwise be used in brick manufacture [11,36–38].

The production of foam concrete is typically characterized as cement paste or mortar with precursor foam. The composition of the mortar includes Portland cement, water, fine aggregates, along with various mineral and chemical admixtures. The precursor foam is produced through the vigorous agitation of a foaming agent combined

with the appropriate quantities of water. Upon setting, the significant volume fraction of closely arranged pores within the solid matrix imparts foam concrete with several distinctive material characteristics, including exceptional ductility when subjected to compressive forces. In contrast to autoclaved cellular concrete, foam concrete can be produced and cured without the need for a specialized facility[4,5,14,39]. Consequently, the cast-in-place characteristic holds significant practical value as it can minimize the expenses associated with material transportation during construction. This feature provides flexibility for field engineers to modify the material characteristics as required for a particular project. The properties of foam concrete render it a strong contender for various applications in civil engineering. These include energy-absorbing pavements like Engineered Material Arresting Systems (EMAS), filtration media for water treatment, construction materials suitable for temporary landfilling, and isolation layers such as acoustic barriers [40–43].

1.5 Objective of the study

Although the use of CD-RFA aggregates helps to reduce the use of natural aggregates, there are still certain challenges with their effective and maximum utilization in FC mixes at different dilution ratio of foaming agents. To examine the feasibility of ceramic waste tile powder (CWTP) as a partial substitute for cement in foam concrete (FC), with an emphasis on optimizing mechanical, microstructural, and durability characteristics while promoting environmental sustainability. This study performed a comprehensive analysis of the application of sustainable foam concrete, which incorporates recycled fine aggregates derived from building and demolition waste as natural sand replacement and ceramic waste tile powder as OPC replacement. It analyzed the differences in these properties by utilizing three different dilution ratios of foaming

chemicals in sustainable foam. The following sub-objectives were created to help achieve this set of goals.

- Determining the mix design proportion based on the density as a controlling factor to produce foam concrete mixes
- Replacing the natural river aggregate with recycled fine aggregates (CD-RFA) to select the optimum percent replacement level of natural river sand in the mix design
- Evaluating the impact of different CWTP replacement percentages (0%, 10 %, 30 %, 50 %, 70 %, and 90 %) on the mechanical characteristics (compressive, flexural, and tensile strengths) of foam concrete
- Assessing the microstructural properties of FC, including CWTP, by methodologies such as SEM, XRD, and XRF. Assessing the durability of FC mixes by analysing their resistance to environmental conditions such as sulphate and salt exposure, water absorption, porosity, and abrasion
- Formulating and executing a novel Durability Index (DI) approach to evaluate the long-term performance of FC blends with CWTP under adverse circumstances
- Advancing sustainable building methodologies by advocating for the repurposing of ceramic waste in FC, diminishing dependence on conventional raw materials, and alleviating environmental repercussions

1.6 Scope of the study

This thesis aims to determine the best possible sustainable solution for utilizing CD-RFA and CWTP in FC mixes. To achieve this target, firstly, (i) an optimum mix design gradation is selected based on three different dilution ratios of foaming agent. (ii) Now, utilizing the similar mix design criteria, multiple proportions of CD-FRA aggregates and CWTP are added as a partial replacement of natural river sand and cement

in the ratios 10, 30, 50, 70, and 100% and 10, 30, 50, 70, and 90%, respectively. (iii) CD-RFA aggregates and CWTP were characterized accordingly to determine their suitability in foam concrete mixes.

It may be recognized that the literature considers foam concrete as having non-structural applications that don't bear loads by admixing foam with cement and sand. For structural applications such as reinforced foam concrete beams, sub-base layer in pavement and railway bed construction to avoid settlement. Sand has been either completely eliminated or replaced with manufactured silica sand and recycled materials. In these mixes, foaming agents are directly admixed with the cement to produce a homogeneous foam concrete suitable for structural use [44–47]. All varieties of foaming agents (synthetic or protein based) have dilution ratio with water as recommended by their manufacturers. In the present experimental pursuit, this dilution ratio is varied once to the lower and once to the higher side of the recommendation to study the changes in the mechanical and durability properties for each. The appropriate dilution ratio of the foaming agent is determined by its specific kind, since each type has a distinct dilution ratio that is most effective. The dosage and dilution ratio of foaming agent significantly affects the dry density and compressive strength of foam concrete. According to Wang and Tang [48], they state that changing the dilution ratio of the foaming ingredient can vary the microstructure of the foam, which in turn impacts its mechanical properties. Consequently, having knowledge of and making adjustments to the dilution ratio is crucial for achieving the desired level of performance. The dry aggregate consisted of sand replaced with similar fine proportions sourced from construction and demolition waste (CD-RFA). Secondly, sand was replaced previously by investigators with CD-RFA to a maximum of 50%. In the present work, sand is replaced up to 100% by CD-RFA to study its effect on the mechanical and durability properties. Based on the results, the

possible usage of foam concrete would be determined, and an optimized dilution ratio is recommended, which stands as the novelty of this work.

As previous studies have investigated the use of ceramic powder as a substitute for cement and aggregates in both conventional and aerated concrete mixtures, there is a paucity of literature addressing its application in foam concrete (FC). Most earlier studies mainly looked at the fresh and mechanical properties using synthetic foaming agents diluted at a 1:20 ratio and ceramic powder from tile polishing. However, there hasn't been much research on how ceramic waste tile powder (CWTP) from construction debris affects the strength, structure, and durability of foamed concrete (FC), especially when using a natural protein-based foaming agent at a 1:40 dilution ratio and river sand that goes through a 1.18 mm sieve. The impact of different foam concrete densities (1200–1800 kg/m³) on the performance of CWTP-integrated FC has not been extensively examined. This research seeks to elucidate the potential of CWTP as a sustainable alternative to cement in FC, hence addressing existing gaps in knowledge. Our research is innovative in employing a natural protein based foaming agent, which is more ecologically sustainable than synthetic alternatives, and in utilizing CWTP as a cement substitute at replacement levels of 0%, 10%, 30%, 50%, 70%, and 90%. The examination encompasses not only fresh and mechanical qualities but also a thorough review of durability parameters, including resistance to sulphates, chlorides, and abrasion. This work presents a novel durability index (DI) particularly formulated to evaluate FC blends under severe environmental conditions, a consideration overlooked in prior studies. The examined parameters encompass compressive strength, flexural strength, split tensile strength, density, porosity, sorptivity, water absorption, volume of permeable voids, Cantabro abrasion, and acid resistance. The results fill gaps in current research and show that CWTP can be a practical and eco-friendly alternative to cement in FC, which could

help protect the environment and support sustainable building practices. This research considerably enhances the durability and performance of sustainable construction materials by optimizing CWTP use in FC.

1.7 Scientific Novelty of study

To the author's knowledge, no specific study has evaluated the impact of varying foaming dilution ratio (1:20, 1:40, and 1:60) for a given density, arising from the use of CWTP and CD-RFA aggregate, on the mechanical, microstructural, and durable characteristics of foam concrete. This trial is the inaugural investigation into the formation of voids during mixing, achieved by assessing and contrasting the size distributions of air voids in hardened foamed concrete mixes with those of bubbles in pre-formed foam, based on both the quantity and area of bubbles/voids, as well as examining the circularity of the voids within the mixes. This study has been done to look at how CWTP and CD-RFA affect the strength of foamed concrete by analyzing the size and shape of air voids and understanding how these factors change the cement paste structure and influence its strength.

The merit of this research is to comprehend the behavior of foamed concrete in relation to alterations in its microstructure and to analyze that link between the microstructure and the mechanical and durable properties of foamed concrete at different dilution ratio of foaming agent.

1.8 Organization of the thesis

To achieve the set of research objectives mentioned in Section 1.6, the thesis has been divided into 8 chapters, which are explained below:

Chapter 1: This chapter presents the novelty of the research effort, the need for the study, as well as its breadth, along with a set of research objectives.

Chapter 2: This chapter presents a thorough examination of the use of CD-RFA and CWTP in FC mixtures. We established the objectives of this thesis based on the gaps identified in this chapter.

Chapter 3: This chapter discussed the materials, and their characterization used in the thesis. And discusses the FC mix design and the experimental methods for testing the hardened specimens.

Chapter 4: This chapter discusses the preliminary investigation of FC mix design admixed with CD-RFA and CWTP at different dilution ratio of foaming agent.

Chapter 5: This chapter investigates the optimization of the foaming agent dilution ratio and the generation of CD-RFA aggregates in a cleaner way, focusing on their mechanical, durability, and microstructural properties.

Chapter 6: This chapter investigates the suitability of CWTP as a cement substitution based on the mechanical, durability, and microstructural properties.

Chapter 7: In this chapter, the main conclusions of this study are made, and recommendations for future work are made.