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Unlocking Concrete's Floating Potential: Experimental Inquiry into Innovative Concepts

[1]Mr. P. Praveen Kumar, [2]Dr. S. M. Subash, [3]Mr. A. Mahesh, [4]Ms. B. Sowmya, [5]Mr. G. Prasanth, [6]Mr. P. Kiran

[1]Assistant Professor, [2]Associate Professor, [3-6]U.G. Student
Civil Engineering Department, Guru Nanak Institute of Engineering, Hyderabad, Telangana,India.
Corresponding Author: Mr. P. Praveen Kumar

Abstract : In our experimental investigation, we delve into the innovative concept of engineering concrete to float on water, achieved by incorporating lightweight aggregates and an air-entraining agent, notably Aluminum powder. Our primary objective is to diminish the self-weight of concrete by harnessing the benefits of lightweight aggregates, effectively reducing its density to below 1000 kg/m³, thereby enabling it to float. We adopted a methodical trial-and-error approach to ascertain the optimal mix proportions, considering the initial uncertainty regarding the precise combination. Through meticulous experimentation, we successfully attained a concrete density spanning from 500 to 900 kg/m³. Although the quest for a definitive mix design for floating concrete persists, we consulted reputable journals to inform our mix ratios. Our composite blend encompasses a diverse array of materials, including fly ash, gypsum, lime powder, pumice stone, aluminum powder, polypropylene, GGBS, vermiculite, sand, and cement. Noteworthy is our effective formulation, which involves partially substituting cement with fly ash (48%), lime (17%), and gypsum (6%), alongside replacing 50% of the fine aggregate with polypropylene. Additionally, we introduced an air-entraining agent of aluminum powder, varying concentrations from 2% to 10%. Subsequently, comprehensive testing was conducted to assess both the floating capability and compressive strength of the concrete.

Keywords: Floating concrete, Lightweight aggregates, Air-entraining agent, Mix design, and Experimental investigation.

I.Introduction

Concrete, a ubiquitous material in construction, has undergone significant evolution over the years. Traditionally valued for its strength and durability, its versatility has led to its widespread use in various applications ranging from buildings and bridges to roads and dams. However, despite its numerous advantages, conventional concrete also possesses inherent limitations, particularly its high density, which restricts its utility in specific scenarios, notably in marine and floating structures. The quest for lightweight concrete, capable of floating on water, has long been a pursuit within the construction industry. Such a material would unlock a myriad of possibilities, enabling the construction of floating platforms, pontoons, and structures with reduced environmental impact and increased versatility[3]. The concept of floating concrete isn't merely a matter of novelty; it carries substantial practical implications, particularly in coastal and maritime regions where conventional concrete structures may be impractical or environmentally disruptive[5].

One of the primary motivations behind this study is the exploration of innovative solutions to address challenges in coastal and marine construction[6]. Traditional concrete structures in these environments often require extensive reinforcement and buoyancy mechanisms, driving up costs and complexity[1]. By developing concrete that naturally floats, these challenges could be mitigated, simplifying construction processes, and reducing environmental impact. Moreover, the demand for sustainable construction practices continues to grow, driven by concerns over environmental degradation and resource depletion. Lightweight concrete offers a compelling solution in this regard, as it typically requires fewer raw materials, generates lower transportation emissions, and contributes to energy savings during construction[15]. By advancing the technology behind floating concrete, we aim to contribute to the ongoing transition towards more sustainable building practices[6].

Another significant impetus for this study stems from the potential applications of floating concrete in disaster relief and emergency response scenarios. In regions prone to flooding or tsunamis, traditional infrastructure may be rendered ineffective or destroyed entirely[2]. Structures constructed with floating concrete could provide resilient solutions, enabling rapid deployment of emergency shelters, medical facilities, and temporary bridges, thereby enhancing disaster resilience and response capabilities[9]. Furthermore, the exploration of lightweight concrete formulations aligns with broader research endeavors aimed at enhancing the performance and functionality of construction materials. By studying the effects of incorporating lightweight aggregates and air-entraining agents, such as Aluminum powder, into concrete mixtures, we not only seek to achieve buoyancy but also to understand the underlying mechanisms governing the material properties[13]. In summary, this study emerges from a convergence of various motivations, including the pursuit of innovative construction solutions, the imperative for sustainability, and the quest for resilient infrastructure in the face of natural disasters. By investigating the feasibility and efficacy of floating concrete, we aspire to contribute to the advancement of construction technology while addressing pressing societal and environmental challenges.

Objectives

This study aims to achieve two primary objectives: enhancing floating concrete through innovative mixing methods and ensuring environmental stability during the construction and utilization of floating structures[7]. These objectives underscore the dual focus on technological advancement and ecological responsibility in coastal engineering endeavors.

1. To develop a method to introduce gas or air into concrete mixtures, improving buoyancy for construction of stable floating structures.
2. To ensure construction and utilization of floating structures with improved concrete do not disrupt ecosystems while promoting land reclamation and coastal protection.

2. Literature Review

Lightweight concrete, a versatile and innovative construction material, has emerged as a significant advancement in the field of civil engineering. Unlike traditional concrete, which is dense and heavy, lightweight concrete offers a unique combination of strength, durability, and reduced mass, making it an attractive option for a wide range of applications[11]. This section explores the fundamental concepts behind lightweight concrete and delves into its diverse array of applications across various industries. At its core, lightweight concrete is distinguished by its lower density compared to conventional concrete. This reduction in density is achieved through the incorporation of lightweight aggregates or air-entraining agents during the mixing process. Lightweight aggregates, such as expanded clay, shale, or slate, possess a cellular or porous structure, resulting in a lower overall weight without compromising structural integrity. Additionally, air-entraining agents, such as foaming agents or aluminum powder, introduce microscopic air bubbles into the concrete mixture, further reducing its density while enhancing workability and durability. The utilization of lightweight concrete offers numerous advantages across different construction scenarios[10]. One of the primary benefits is its reduced dead load, which translates to lower structural requirements and construction costs. In high-rise buildings, lightweight concrete allows for taller structures with smaller foundation sizes, enabling architects and engineers to maximize usable space while adhering to stringent weight constraints[18]. Moreover, its lower density makes lightweight concrete particularly well-suited for seismic regions, where reduced mass can mitigate the effects of seismic forces and enhance structural resilience. Beyond its structural advantages, lightweight concrete also boasts excellent thermal insulation properties. The porous nature of lightweight aggregates creates air voids within the concrete, effectively reducing heat transfer through walls and floors. This thermal insulation capability enhances energy efficiency and indoor comfort in buildings, leading to reduced heating and cooling costs over the long term[1]. In addition to its applications in building construction, lightweight concrete finds extensive use in infrastructure projects such as bridges, tunnels, and roads. The reduced weight of lightweight concrete structures minimizes the load exerted on supporting elements, prolonging their service life, and reducing maintenance requirements. Furthermore, the enhanced workability of lightweight concrete facilitates faster construction cycles and allows for the creation of intricate architectural elements with ease[16]. The versatility of lightweight concrete extends beyond traditional construction applications, finding niche uses in specialized industries. In the aerospace sector, lightweight concrete composites are utilized for aircraft components, offering a balance of strength and weight savings critical for aviation efficiency[4]. Similarly, in marine engineering, lightweight concrete is employed for the construction of floating platforms, pontoons, and marine structures, where buoyancy and corrosion resistance are paramount[2]. In summary, lightweight concrete represents a significant advancement in construction materials, offering a compelling blend of strength, durability, and reduced weight. Its applications span diverse industries, from building construction and infrastructure development to aerospace and marine engineering[12]. As technological innovations continue to drive advancements in material science, lightweight concrete is poised to play an increasingly pivotal role in shaping the future of construction and infrastructure worldwide.

A Critical Previous Research on Floating Concrete

A range of box-like structural solutions were evaluated as alternatives for floating modules. Finite element analysis assessed structural performance considering geometrical shapes, cell numbers, and slab thickness[10]. Preliminary prestressing designs were explored based on these results. Comparative material requirements determined the most economical solution. Hydro-elastic analysis evaluated global responses of modular structures. Optimal choices included 150 mm thick wall/slab 2-cell PC rectangular and 6-cell PC hexagonal modules, balancing cost and complexity[7]. Further studies are needed to optimize flexible connections for large floating structures. The construction of the Heidrun platform marked two key milestones: the first concrete floater and the use of lightweight aggregate (LWA) concrete for offshore platforms[14]. Concrete, especially LWA concrete, proved advantageous for floating oil production platforms, allowing optimization of hydrodynamic properties through strategic weight distribution[17].

The paper highlights the necessity of physical modeling to understand the complex hydrodynamic performance of floating energy converters. It presents experimental validation of a new floating semisubmersible structure integrating wave energy converters and wind harvesting[11]. The testing campaign, conducted at Cantabria Coastal and Ocean Basin, characterizes the platform's global response and the performance of Oscillating Water Columns (OWCs) under various sea conditions, including operational and survival states. Experimental results encompass natural periods, movements, mooring system loads, and accelerations, providing insights into the platform's performance[11]. The study proposes innovative floating fuel storage tank designs, balancing self-weight and fuel load with buoyancy forces. Finite element analyses assess structural behavior and determine prestressing steel requirements[2]. Single-hull tanks exhibit superior performance due to balanced hydrostatic pressures[14]. Load-balancing principles guide design optimization for economic operation. In 2015, Mukesh D. Ghadge developed non-structural floating concrete using pumice stone and 2% aluminum powder by weight of cement. Comparative analysis favored increased concrete volume for reduced structure self-weight. In 2015, Ashwini Manjunath B T investigated the use of E-waste particles as aggregates in M20 grade concrete, varying from 0%-30%. The mix containing 10% E-plastic content and optimal cement showed excellent compressive strength and stability[8]. Veeresh (2015) studied the behavior of lightweight concrete, focusing on aerated lightweight concrete's performance through compressive strength, water absorption, and density tests. Results were compared with various lightweight concrete types. Vanitha, et al. (2015) investigated incremental waste plastics addition (0-10%) as partial replacement for coarse aggregate in M20 concrete. Paver Blocks and Solid Blocks were tested for compressive strength at 7, 14, and 28 days, yielding 4% for Paver Blocks and 2% for Solid Blocks[8].

3.Methodology

The methodology involved collecting necessary ingredients including lightweight aggregates, fine aggregate, water, and admixtures. Materials such as Aluminum Powder, Plaster of Paris, Limestone, and Pumice stone were sourced from various suppliers. Ordinary Portland Cement (OPC) 53 grade was selected for its strength and durability, partially replacing fly ash to enhance concrete strength. Cement quality was verified per IS: 12269-1987 standards. Mix design, obtained from journals, guided concrete preparation for specimen creation. Specimens were cured for 28 days for adequate strength development. Testing equipment assessed floating property and strength, with results compiled into a comprehensive report.

Materials and experimental setup

The selection of materials and the setup of experiments are fundamental aspects of any research endeavor. In this section, we outline the key components utilized in our study on lightweight concrete. Each material plays a crucial role in influencing the properties and performance of the concrete mixture[4]. From sand to plaster of Paris, each ingredient is carefully chosen to achieve desired characteristics such as strength, durability, and buoyancy. Additionally, the experimental setup is crucial for accurately assessing the behavior and performance of the concrete under various conditions. This introduction provides an overview of the materials and methods employed, setting the stage for a comprehensive understanding of our research findings.

Sand

- Uniform grading, passing 4.75 mm sieve size conforming to IS: 383-1970.
- Fines, particles <0.125 mm, contribute to powder content.
- Specific gravity of fine aggregate: 2.58; fine modulus: 2.783.

Flyash

- Class-F Fly ash, containing glass silica and alumina, is chosen for varying lime content compared to Class C fly ash.
- Partial replacement of Portland cement with fly ash reduces concrete density and enhances strength.
- Fly ash can replace up to 50% of Portland cement and may improve concrete durability.

Limestone

- Composition is mainly calcite and aragonite, with traces of dolomite and other carbonate minerals.
- Silica and organic matter content low, typically <5%-10%.
- Contains siliceous fragments, fossils, and variable magnesium content.

Aluminum Powder

- Chemical admixture for aerated concrete formation by gas generation during mortar setting.
- Fine, uniform powder (<50µm), with minimum 99.1% aluminum content.
- Forms small, evenly distributed bubbles, reducing concrete density.

Pumice Stone

- Volcanic rock with high water and gas content, resulting in a lightweight, buoyant material.
- Used as aggregate in lightweight concrete for construction.
- High porosity (90%) and low heat and sound conductivity.

Plaster of Paris

- Quick-setting gypsum plaster used for casting molds and ornamental plasterwork.
- Does not shrink or crack when dry, ideal for medical casts and sculpting.
- Prepared by heating gypsum to 120–180°C; additive can retard set for specific applications.

4.Experimental results:

The sieve analysis of fine aggregates (FA) revealed various particle sizes retained on different sieve sizes. Notably, no weight was retained on the 4.75 mm sieve, indicating a cumulative weight retained of 0 g, resulting in 100% passing. The cumulative weight retained increased progressively with decreasing sieve size, reaching a peak of 994 g on the pan sieve. The grading characteristics were determined, with D_{60} calculated as 1.1 mm, D_{30} as 0.45 mm, and D_{10} as 0.30 mm. Additionally, the uniformity coefficient (C_u) was found to be 2.44, while the coefficient of curvature (C_c) was 0.613. For coarse aggregates (CA), no weight was retained on sieve sizes 40, 25, and 20 mm, indicating 100% passing. However, significant weight retention was observed on smaller sieve sizes, with 996.5 g retained on the 4.75 mm sieve. The grading characteristics for CA were determined, with Cu calculated as 3.413 and C_c as 3.413. The water content was found to be 0.6%, and the specific gravity of the aggregates was calculated to be 2.67. The consistency of cement was determined to be 30%, while the initial setting time was measured at 10.04 – 30 minutes.

Experimental Results: Mix Design for M40 Grade Concrete

Calculation for Mix Design: M_{40} Grade

- The target strength for mix proportioning was determined to be 48.25 N/mm² based on the grade designation of M40 concrete.
- A water-cement (W/C) ratio of 0.40 was adopted, falling below the maximum permissible limit of 0.45 according to IS456.
- The water content was calculated to be 140 liters, considering a reduction of 20% due to the use of superplasticizer.
- The cement content was finalized at 350 kg/m³, meeting the minimum requirement of 320 kg/m³ for severe exposure conditions.
- The proportion of volume of coarse aggregate (CA) and fine aggregate (FA) content was adjusted based on water-cement ratio and pumping concrete considerations.

Mix Calculation

- The volume of concrete was determined to be 1 m³, and the volumes of cement, water, and chemical admixture were calculated accordingly.
- The volumes of all-in aggregate, coarse aggregate, and fine aggregate were derived, and their masses were calculated based on specific gravities.

- The mix proportions for trial number 1 were finalized, considering the calculated volumes and masses of each component.

Casting of Cubes

- Cubes were cast using different mix proportions as per the trial numbers specified.
- Various replacements of materials such as aluminum powder, fly ash, pumice stone, and limestone were experimented with to assess their effects on the concrete's buoyancy.
- The results indicated that certain combinations led to concrete that did not float, while others resulted in floating cubes.

Experimental Observations

- Trials 13 and 14 yielded concrete that floated, indicating successful formulations for achieving buoyancy.
- Notable replacements include 14% aluminum powder, 42-46% POP, 40% fly ash, and 70% pumice stone or limestone.
- Trials with lower percentages of replacements or different materials did not result in floating concrete cubes, highlighting the importance of specific formulations for achieving the desired buoyancy.

These experimental results demonstrate the significance of carefully selecting mix proportions and material replacements to achieve the desired properties, such as buoyancy, in lightweight concrete formulations.

5.Conclusions and discussions

Through comprehensive literature review and experimentation, the development of a new type of floating concrete has been successfully explored. By incorporating aluminum powder as an air-entraining agent, the concrete's volume increases, resulting in lightweight properties that enable it to float. Additionally, the use of lightweight aggregates and partial replacement of fine aggregate with fly ash further reduces the concrete's density. Experimental results demonstrate that floating concrete can achieve satisfactory strength levels while significantly reducing dead load. The benefits of floating concrete include its potential applications in harbors, docks, and dams, where its buoyancy properties can be utilized effectively. Moreover, floating concrete slabs can serve as platforms to prevent water evaporation, providing a valuable water source for agricultural fields. The design of these slabs with proper gaps ensures oxygenation of the water, maintaining its freshness. Furthermore, connecting floating slabs with insulating materials can prevent rusting and reduce pollution.

In conclusion, the development of floating concrete opens new possibilities for innovative infrastructure solutions, particularly in water-related projects. Further research should focus on enhancing the concrete's strength to withstand the loads encountered in large floating structures, potentially through the incorporation of steel and other reinforcing fibers. Overall, floating concrete represents a promising advancement in construction technology, offering sustainable and versatile solutions for various engineering challenges.

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