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A Study on mechanical behavior of Eco-friendly Light Weight Concrete (LWC) blocks using industrial wastes

ABSTRACT

In the construction industry, concrete is widely used due to its affordability and extensive applications. However, one of the major drawbacks of conventional concrete is its substantial self-weight, which can make it an uneconomical structural material. To reduce the self-weight, coarse gravel has been partially or substantially replaced by lightweight aggregates. This study aims to investigate the production of lightweight concrete (LWC) using cenosphere and pumice and subsequently evaluate their performance in terms of compressive strength, water absorption, wet density, dry density, and thermal conductivity. Based on a thorough review of the relevant literature, the goal of this study is to determine the optimal volume of cenosphere for fine aggregates and pumice for coarse aggregates in LWC blocks. In this study, cenosphere replaces fine aggregate at a ratio of 30%, as identified in the literature review, and pumice replaces coarse aggregate at varying ratios of 20%, 40%, 60%, 80%, and 100%. The strength and lightweight properties of various cenosphere and pumice concrete mixes were compared, and the mix containing 30% cenosphere and 60% pumice was identified as the optimal combination.The optimal mix achieved a compressive strength of 21.81 N/mm², which is lower than conventional concrete. It also exhibited a water absorption rate of 3.31%, which is higher than that of conventional concrete but greater than the 40% threshold for lightweight blocks (LWB). The results indicate that this mix offers a favorable balance between lightweight properties and strength.

Keywords: *Lightweight Concrete, Density, compression, porous, thermal conductivity*

1. INTRODUCTION

LWC is produced by including a lightweight coarse aggregate, and in some cases, utilizing lightweight fine aggregates that possess a lower density compared to traditional aggregates [1]. The weight of structural lightweight concrete typically falls within the range of 1400 to 1800 kg/m^3. The density of typical weight concretes exhibits a range of 2400 to 2800 kg/m^3, but its strength must surpass 17.0 MPa to meet the requirements for structural applications. Lightweight aggregates commonly consist of shale, or basalt materials, clay that have undergone a process of combustion in a rotary-kiln furnace, resulting in the formation of a structure that exhibits impermeability. Moreover, supplementary materials, such as air-cooled blast furnace slag, are also employed.

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The incorporation of waste materials into concrete results in cost reduction, and this method of addressing garbage disposal is considered environmentally conscientious [2-4]. Figure1 indicated that cenosphere are a major waste product of coal thermal power plants. At that time, the cenosphere in the concrete materials will enable effective and efficient utilization of the products while enriching what is now accessible to produce the concrete materials, such as riversand, M-sand, etc. [5]. As a result, reducing the proportion of fine aggregate has no adverse influence on strength attributes, but has a good impact on sustainability issues with an ideal suggestion of 35% fine aggregate as cenosphere. Perhaps the most valuable parts of coal fly ash are cenosphere is shown in Fig 1. Due to their excellent features, involving as low bulk density, thermal resistance, high workability, and high strength, they have a hollow shape that isspherical and may be used in a extensive set of application. [6-8] This work focuses on the creation of cenosphere, their characterization, and their effect on their strength when mixed with Pumice is shown in Fig 2.

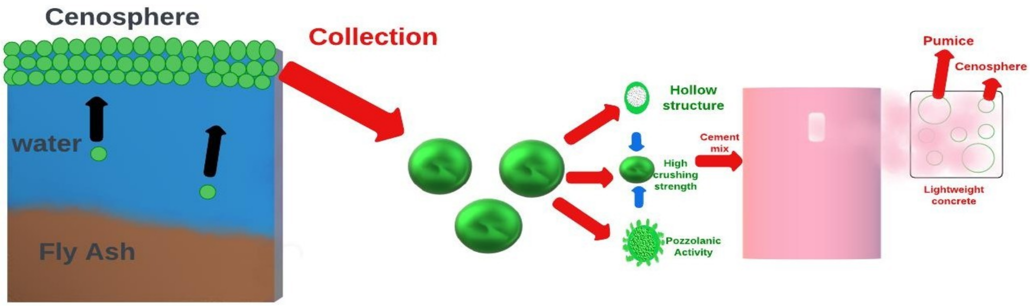

Figure 1. Cenosphere and Pumice in Lightweight Concrete

Pumice aggregates possess the physical characteristics of aggregates made from concrete and can be took advantage of proficiently as lightweight aggregates, and the concrete built with these aggregates meets the demands of low concrete that are lightweight [9]. Furthermore, the resulting concrete can be employed safely in the construction of residences because loads are low and significant durability is not required [10,11]. This country's pumice aggregates can generate commercially low concrete weight, and there is an abundance of naturally generated lightweight gravel for industrial utilization. Pumice is the kind of rock particle used in the concrete in this research, and light weight gravel is a type of material that is lower than aggregate from nature [12,13].The proposed methodology's main goal is to frame a mathematical model using optimization methods. Architectural lightweight concrete is widely employed in the construction industry, especially in skyscrapers [14]. It can only be made with lightweight stones. Pumice is an opaque component and a light porous rock that can be used in place of coarse particles in concrete, and Nanoparticles Silica can be used in substitute of cement [15-18]. Pumice was utilised as a substitute for Coarse Aggregate (CA) in proportions of 0%, 20%, and 30% by amount, and Nano Silica was substitute in 1-3% in various mixtures for estimating three output parameters: compressive force, split tensile capacity (MPa), and bending strength (MPa) [19]. According to test results, incorporating pumice to CA concrete reduces density while also diminishing all mechanical qualities. This is since pumice has a smoother surface texture and a density that is lower than Coarse Aggregate [20,21]. LWC comprising more than 20% pumice, on the other hand, turns into structural lightweight concrete with exceptional strength. Several studies indicated an overall increase in strength as well as a decrease in weight. As a result, lightweight construction has the same strength as heavy- weight concrete [22,23]. Because of its utility and low cost, concrete is the most frequently prefabricated material for construction in the world. One of the drawbacks of traditional building materials is its exceptionally high its own weight. Because of the high self-weight of concrete, structural material will be uneconomical [24-26].

To reduce the own-weight of concrete, coarse material has been mainly substituted by lightweight aggregate. This is lightweight concrete with a low density, reduced dead load, and increased thermal insulation [27]. Natural lightweight gravel and artificial lightweight gravel are two distinct types of lightweight aggregate. Pumice aggregate, one of the most readily accessible natural aggregates, is utilized as a filler for coarse aggregate. Lightweight concrete is made by replacing 50%, 80%, and 100% of the coarse stones with pumice aggregate. Mix M30 with Conplast SP430 additive is used to make conventional concrete together with pumice lightweight aggregate concrete [28-30]. By performing non-destructive assessments, the mechanical and durability qualities of standard concrete as well as pumice aggregate concrete are compared, and a beneficial replacement is identified.

According to IS 1199-2018, the test using a slump cone constitutes one of the more commonly used examines for evaluating the consistency of concrete. In accordance with the outcomes of a slump cone test, pumice is lightweight. The workability of pumice with 50% replacement is very high and in comparison, to the other substitute percentages. Among the most accurate tests is the compacting factor test [31-33]. Using IS 1199-2018 as a guide, determine the mix's workability. When compared to mixes with lower replacement percentages, mixes with 50% replacement also have a high compaction factor. Analysis of the test findings leads to the following conclusions: It proves that aggregate concrete becomes lighter when the percentage of pumice aggregate increases, as the density of the concrete decreases. Using pumice aggregate instead of natural aggregate can make concrete lighter. The reduced strength and increased water absorption of pumice stone aggregate are because of its higher pore content compared to that of regular coarse aggregate. Consequently, superplasticizers are employed.

Comparing pumice with 50%, 80%, and 100% replacement in terms of split tensile strength, compressive strength, and bending strength reveals that 50% replacement provides the most benefit. The tensile, crushing, and bending strengths at 80% and 100% gradually diminish after 50%.

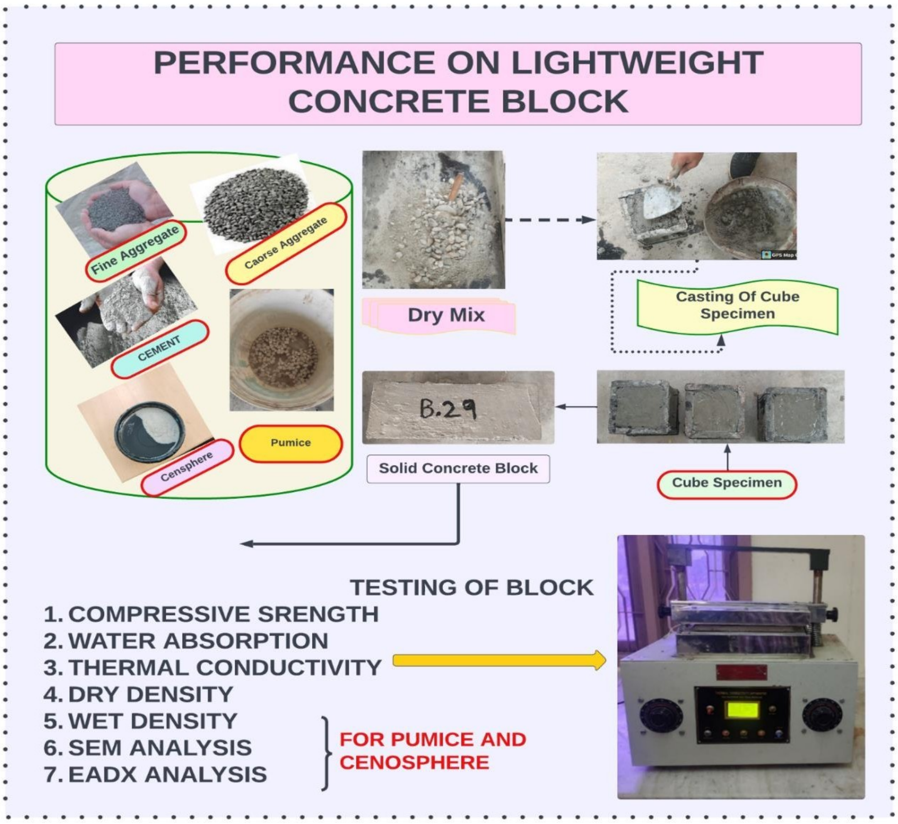

Figure 2. Methodology of LWC block

2. MATERIAL PROPERTIES

Selecting raw materials with sufficient proportioning as well as quality control is crucial for Lightweight Concrete to attain its desired strength and its density. Materials which are used in this work are cement Ordinary Portland Cement (OPC), Cenosphere, Pumice, Fine aggregate, and Coarse aggregate. Energy Dispersive x-ray Spectroscopy (EDS) is a method of analysis to identify the chemical components of a material. For chemical analysis, it utilizes the x-ray spectrum obtained from a specimen sample engaged with an electron beam. The EDS method can identify all elements with an atomic number ranging from 4 through 92. The identification of lines in the spectrum constitutes a component of qualitative analysis. The field emission scan electron microscope is a kind of non-destructive scanning technique which employs high-resolution images to examine the shape and structure of a material.

When a high-energy electron beam strikes a material, , x-rays, as well as scattered electrons are released[34,35]. A detector gathers electrons that are released and converts them into an electrical signal that appears on the screen. It recognizes crystalline formations and displays spatial shifts in chemical structures. Topographical imaging and complete three-dimensional scanning are two of the many uses for an electron microscope scanner. It is capable of approximating particle size within certain limits. Improved spatial resolution with reduced sample charging and damage is achieved by the morphological evaluation technique.

2.1. Cement

OPC cement is main ingredient in making LWC. It also it plays a crucial role in LWC because it offers the chemical reaction required for the curing process. Hydration is the process that occurs when OPC cement is combined with water; during this time, C-S-H and (Ca $(OH)_2$) are formed. The final product's strength and durability can be attributed to these components. By reducing the amount of water needed to reach a workable consistency while yet allowing for proper hydration and hardening, OPC cement plays a crucial part in this process [36,37]. Concrete needs ductile property to increase its breaking strength and strain hardening.

2.2. Pumice

Pumice is one of the most widespread and ancient built-in aggregates used in the manufacturing of lightweight coarse aggregates for the building industry. Pumice is a generic word for porous materials formed during the cooling effect of lava because of igneous activity; fill the gaps are caused by the expulsion of vapors from the magma. Because of the microscopic hollow spaces created by the gases, the resulting particles have an extremely porous structure, which is why pumice has a highly porous structure [38]. Multiple investigations on pumice aggregate for lightweight have been carried out throughout globe, with most studies emphasizing materials that are accessible in specific regions or nations worldwide. The Scanning Electron Microscope (SEM) for pumice was examined in 50μm, shown in Fig 3. The EDS for pumice explained that the elements present inside were O, Si, Al, K and Na which has 67.29%, 21.21%, 4.97%, 3.01% and 2.32 % of composition respectively as shown in Fig 3.

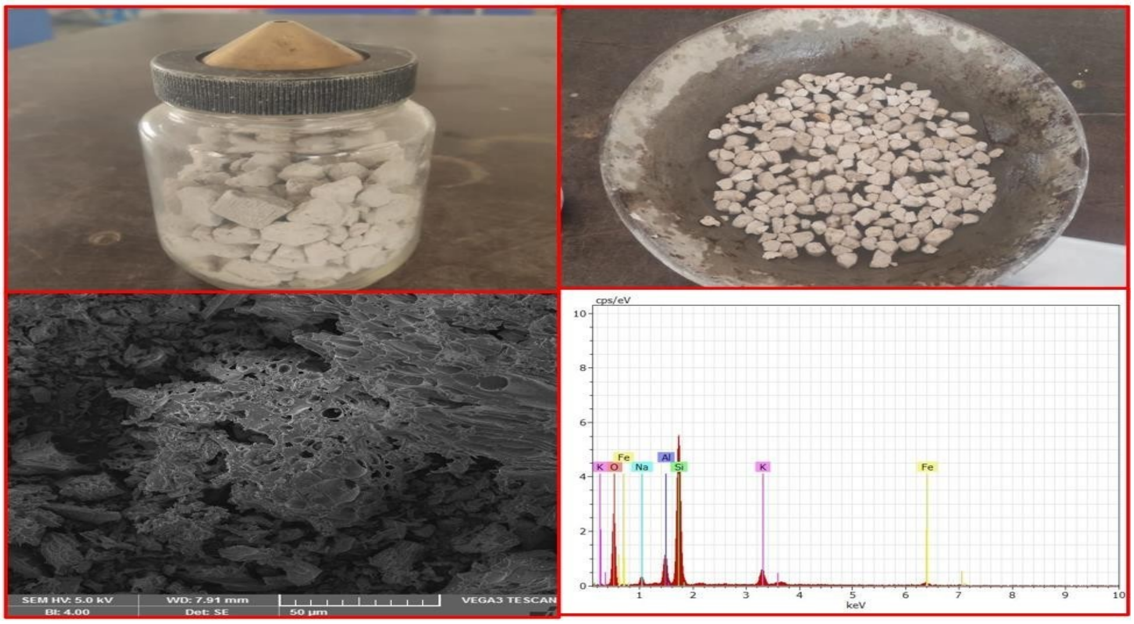

Figure 3. Physical properties and microstructural analysis of Pumice

2.3. Cenosphere

Figure 4 shows that the cenosphere are thin-walled hollow particles with a density to volume ratio of less than 1.0 that float on the water and are retrieved from the float formed by ash removal lagoons in general. They possess chemical characteristics that are comparable to fly ash and are used in a wide range of industries because of their distinctive blend of spherical form, high compression as well, low specific weight, better thermal and acoustical insulating material properties, and inertness in to acids and alkalis [39,40]. EDS is the X-ray emission from an object passing through an electron beam. The SEM for cenosphere of (400-600micron) was examined in 100μm, shown in Fig 4. EDAX for cenosphere of explained that the elements present inside were O, Al, Si, K and Fe which has 61.53%, 17.46%, 16.60%, 3.77%, and 0.64 % of composition respectively as shown in Fig 4.

2.4. Superplasticizer

Benefits of using a superplasticizer in concrete include improved workability at a constant cement concentration, easier placing and compacting, and reduced water content that results in greater strength. Incorporating superplasticizers into concrete improves fresh as well as hardened state. Standard code for Admixtures of Concrete (ASTM C494). Master Glenium SKY 8233, a high-range water-reducing superplasticizer based on a polycarboxylic ether formulation, will be employed. A minimum solids range of 32% and a specific gravity of 1.08 are required for the product.

When compared to conventional superplasticizers, Master Glenium SKY 8233 has a unique chemical structure. It is a polymer of long-chain carboxylic ethers. It starts with the identical electrostatic dispersal mechanism as typical superplasticizers at the initial stage of hydration, but the adjacent chains attached to the polymer backbone provide a steric barrier that substantially regulates the cement particles' ability to split and disperse themselves [41]. In addition to the electrostatic limitation, steric interference creates a physical barrier between the cement grains. Concrete that is flowable and has a significantly reduced amount of water content can be obtained using this technique.

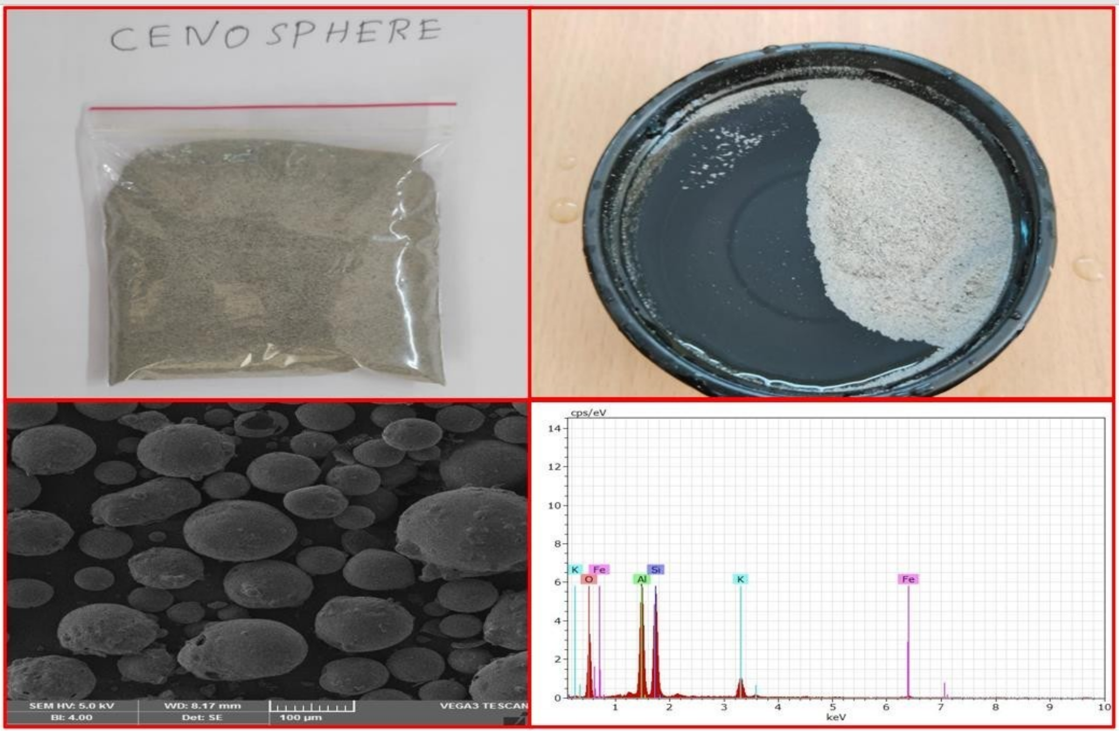

Figure 4 . Physical properties and microstructural analysis of Cenosphere

3. EXPERIMENTAL WORK

Cement was subjected to tests such as the Standard consistency test, beginning and final setting time, and specific gravity test and for zeolite specific gravity test is done as per IS 1124-1974. The specific gravities of zeolite and cement were 2.8 and 3.16 respectively. Particle size distribution for fine aggregate is 0.525 and specific gravity revealed a value of 2.65. Specific gravity of coarse aggregate is found to be 2.74 and water absorption were also conducted. Utilizing the slump conetest, it is possible to determine how workable the fresh concrete is and the value is found to be 3.7 cm. The concrete mix of M35 grade was adopted in this project. Six types of concrete blocks were casted using the materials pumice, cenosphere, cement, fine aggregate, and coarse aggregate is shown in Fig 5. This study aims to investigate the production of lightweight concrete blocks by using cenosphere and pumice and subsequently evaluate their performance in terms of compressive strength, water absorption, wet density, dry density, and thermal conductivity. Based on the findings of the literature review, it was noted that the incorporation of cenosphere in concrete blocks should be limited to a maximum of 30% is indicated in Table 1. Beyond this threshold, adverse effects on both the fresh and hardened properties of the concrete blocks were seen. Based on a thorough review of the relevant literature, the goal of this study is to find the optimal volume of cenosphere for fine aggregates and pumice for coarse aggregates in lightweight concrete (LWC) blocks [42]. Mix design for various proportion for blocks is indicated as Light Weight Block (LWB) with different volume of pumice.

Table 1. Mix ratio LWC using Cenosphere and Pumice

Mix name	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate(Kg/m^3)	Water (Kg/m^3)	Super plasticizer(By its weight of cement)	Cenosphere (Kg/m^3)	Pumice (Kg/m^3)
LWB 0%	437.77	710.22	1150	197	0%	0	0
LWB 20%	437.77	568.176	920	220	1%	142	230
LWB 40%	437.77	426.132	690	220	1%	213	460
LWB 60%	437.77	284.08	460	220	1.5%	355	690
LWB 80%	437.77	142.06	230	220	2%	497	920
LWB 100%	437.77	0	0	220	2%	639	1150

Figure 5. Casting of Conventional Block and LWC block

The Pumice and Cenosphere LWC block were cased on varying ratios as shown in Table-1. Control specimens were also casted. The casted specimens were kept in curing tank for curing and their 28th day compressive strength, water absorption, wet density, dry density, and thermal conductivity were done for all the six ratios and for the conventional blocks. Where mineral-based additives or blended cement are included in the concrete, it is advised that the following minimum periods be increased to 28 days: Specimens are demolded after 24 hours and then submerged under water for 28 days to achieve the target crushing strength.

3. RESULTS AND DISCUSSION

3.1. Compressive strength

Compressive strength commences with the preparation of concrete samples. These specimens are typically cubical in shape, with a size of 400 mmx200mmx100mm. The specimens are then placed in a mould and aged in preparation for testing by curing them under a wide range of curing condition. After a suitable period has passed, the specimens' compressive strength is evaluated is mentioned in Table 2. Typically, a hydraulic press is used to apply a force to the top of the specimen and press down until failure occurs. The load is applied at a steady rate until the specimen fails, typically at a rate of 0.6MPa per second. It is calculated by recording the highest load applied to the specimen [43]. By dividing the highest load exerted on the specimen by its c/s area, researchers may determine the concrete's compressive strength in units of megapascals (MPa). Table 2 indicates that the crushing strength of the LWB 60% mix is 21.81 MPa, which is higher compared to LWB 20% and LWB 40% due to cenosphere and because the incorporation of pumice reduce the strength and make concrete as lighter. Due to the high pumice content in LWB 80%, itdoes not attain an enormous amount of strength compared to LWB 40% is indicated in Fig 6.

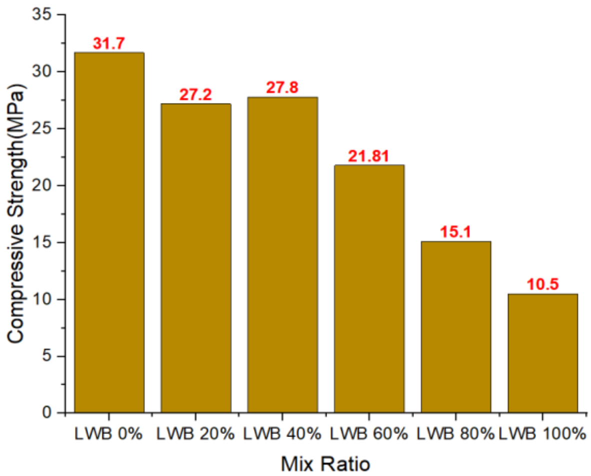

Figure 6. Compressive strength (MPa) of LWB

3.2. Water Absorption

Concrete's ability to absorb water is one of its most essential properties, and it is one of the ways that its strength and resistance to weathering are evaluated. After being cured, the specimens are weighed again, and this time the initial weight is noted. The samples are stored in water in a sealed container to prevent loss due to evaporation. After that, the samples are left to soak for a certain amount of time, usually 60 days. After the allotted time has passed, the samples are taken out of the water and wiped off with a towel [44]. The percentage of water absorbed is found by taking the difference in weight before and after soaking and dividing it by the weight before soaking. The result of this calculation is the percentage of water that the concrete has absorbed in graphical manner in Fig 7. In addition, mix LWB 80% and LWB 100% had water absorption values lower than that of the control mix samples (mix LWB 20% and LWB 40%) is shown in Table 2.

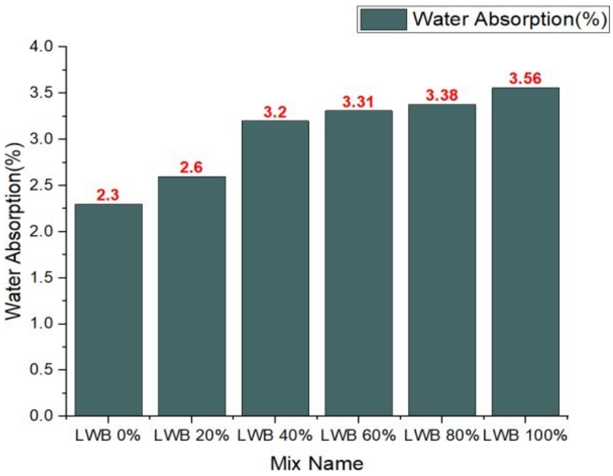

Figure 7. Water Absorption (%) of LWB

3.3. Wet density

The wet density of LWC is the mass of the mix of concrete per unit volume when it is fresh, and itis usually measured in kg/m^3. It is a critical parameter in the design of concrete mixtures and the building industry. The wet density is affected by a wide variety of things like the ratios of the concrete mix's ingredients, the volume of water utilized, and the stage of consolidation.

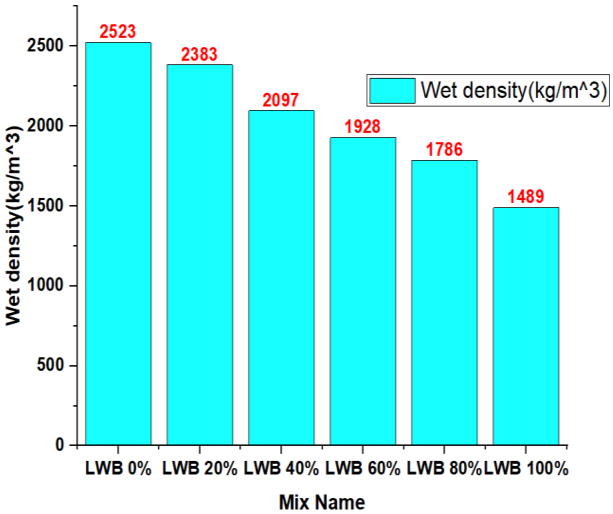

Figure 8. Wet Density (Kg/m^3) of LWB

Table 2 indicated that depend on its requirements, density, and strength wise produce a lightweight block because incorporation of pumice is above permissible limit it will affect the strength characteristics but it will drastically reduce the density of structure. Simultaneously 60% of pumice and 30% of cenosphere it will satisfy both strength and density criteria as shown in Fig 8.

3.4. Dry Density

The dry density of concrete, an important construction parameter, is the mass per volume of hardened concrete. identifying dry density requires measuring the mass and volume of the concrete after curing. When the concrete has hardened, the excess water has dissipated, and its composition has attained its dried state, the dry density can be determined using the following equation: Dry density = Mass of concrete/Volume of Concrete.

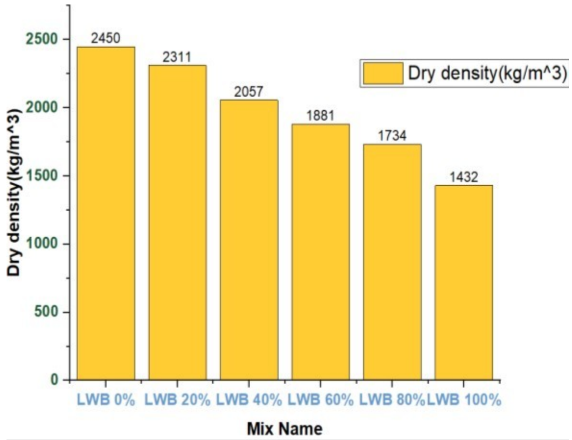

Figure 9. Dry Density (Kg/m^3) of LWB

The density of a material is critical for determining structural strength and durability. Table 2 indicated that depend on its requirements desired density lightweight blocks because incorporation of pumice within limit it will affect the strength characteristics but it will drastically reduce the density of structure. Simultaneously 60% of pumice and 30% of cenosphere it will satisfy both strength and density criteria as shown in Fig 9.

3.5. Thermal Conductivity

Thermal analysis is a branch within experimental condensed matter science that studies material properties as a function of temperature. There are plenty of thermal analysis methods accessible that offer data on different characteristics of materials such as phase changes, shift temperature, heat of response, oxidative resistance, purity, thermal endurance, creep/stress tranquilly, flexural modulus, as well dissipation of energy, permeability, and loss factor, between others. Thermal analysis yields properties such as energy density, heat capacity, mass modifications, and the ratio of heat contraction in practice. Thermal analysis is employed in solid state chemistry to examine solid-state processes, such as thermal responses, phase transitions, and diagrams of phase. When vital, the thermal conductivity of LWA in the air state of dryness shall be assessed in accordance with EN 12664 in the event of dry LWA with a thermal conductivity value less than 0.4 W/(mK) is shown in Fig 2.

Table 2. Lightweight Concrete Block Test results

Mix name	Compressive strength(N/mm^2)	Water absorption (%)	Wet density(kg/m^3)	Dry density (kg/m^3)	Thermal Conductivity W/(mK).
LWB 0%	31.7	2.3	2523	2450	1.82
LWB 20%	27.2	2.6	2383	2311	0.38
LWB 40%	27.8	3.2	2097	2057	0.36
LWB 60%	21.81	3.31	1928	1881	0.34
LWB 80%	15.10	3.38	1786	1734	0.22
LWB 100%	10.5	3.56	1489	1432	0.18

5. CONCLUSION

Cenospheres are often mixed into concrete to make lightweight composites. Large levels of cenosphere reduce concrete weight but increase consistency, reducing hard composite strength and porosity. When pumice replaces coarse aggregate to 60% or more, compressive strength drops because load bearing capacity diminishes. Instead of cenosphere, 30% fine aggregate was used. Due to its greater aluminium and silica content, cenosphere increases heat conductivity. Compare LWB 20%, 40%, and 60%, the latter has the highest compressive strength at 31.7 N/mm^2. LWB 100% had the maximum compressive strength at 15.10 N/mm^2, surpassing ordinary concrete. Lightweight concrete with all pumice and cenosphere mixes percentages absorbs water within limits. Other ratios have higher wet density than LWB 100%. A hollow sphere is generated when cenosphere is added to a cement matrix form, indicating that axial breaking microstructures occur when compressed [45,46]. Crack form parallel to compression. Cenosphere/cement composite materials have closed porosity from cenosphere capsules and exposed permeability from inadequate packing [47].

The compressive strength of the LWB 60% mix is lower than that of the LWB 20% and LWB 40% mixes. This reduction in strength can be attributed to the higher proportion of lightweight aggregates, such as cenosphere and pumice, which, although advantageous for decreasing density and thermal conductivity, generally result in diminished strength. Here According to literature, 30% cenosphere replaces fine aggregate while 20%, 40%, 60%, 80%, and 100% pumice replaces coarse aggregate. The best blend of 30% cenosphere and 60% pumice concrete was established by comparing the strength and lightweight. For concrete density reduction, compressive strength, wet density, dry density, water absorption, and thermal conductivity determine the best combination. The compressive strength of this ideal mix is 21.81 N/mm^2, lower than ordinary concrete, while the water absorption is 3.31%, higher than LWB 40%.

Acknowledgments

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IZVOD

STUDIJA O MEHANIČKOM PONAŠANJU EKOLOŠKI PRIHVATLJIVIH LAKIH BETONSKIH BLOKOVA (LVC) KOJI KORISTE INDUSTRIJSKI OTPAD

U građevinskoj industriji beton se koristi zbog svoje pristupačnosti i široke primene . Jedan od nedostataka normalnog betona je njegova velika sopstvena težina . Ova velika sopstvena težina konstrukcije će dovesti do neisplativosti konstrukcijskog materijala . Da bi se smanjila sopstvena težina, krupni šljunak je delimično/značajno zamenjen lakim agregatom. Ova studija ima za cilj da istraži proizvodnju LVC-a (Light Veight Concrete) korišćenjem cenosfere i plovućca i zatim proceni njihove performanse u smislu čvrstoće na pritisak , upijanja vode, gustine mokre, suve gustine i toplotne provodljivosti. Na osnovu detaljnog pregleda relevantnih literaturi , cilj ovog istraživanja je pronalaženje optimalne zapremine cenosfere za fine agregate i plovućca za krupne agregate u LVC blokovima. Ovde je cenosfera zamenjena finim agregatom u razmerama od 30% iz pregleda literature, a plovućac je zamenjen krupnim agregatom u odnosima od 20%, 40%, 60%, 80%,100%. Upoređene su osobine čvrstoće i lake težine različitih odnosa cenosfere i plovca betona i beton sa 30% cenosfere i 60% plovućca je pronađen kao optimalna mešavina. Optimalna mešavina se nalazi na osnovu čvrstoće na pritisak , vlažne gustine, suve gustine, upijanja vode, toplotne provodljivosti za količinu smanjene gustine u betonu. Ova optimalna mešavina ima čvrstoću na pritisak od 21,81 N/mm^2 koja je niža od konvencionalnog betona i ima apsorpciju vode od 3,31% što je više od konvencionalnog betona i takođe veće od LVB (Lightveight Block) 40%. Takođe pokazuje bolje rezultate u laganoj težini i snazi.
Ključne reči: laki beton, gustina, kompresija, porozna, toplotna provodljivost.

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