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“An Experimental Study on the Mechanical and Durability Performance of Steel and Glass Fiber Reinforced Lightweight Concrete”

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Abstract: With the improvement of high-rise buildings, as well as of large-span and large-scale engineering projects, more and more high-performance structural concrete is required in the construction industry to cope with complicate and diverse engineering demands. A significant amount of recent research has focused on high strength, high-toughness, light-weight and economic friendly concrete materials. Among them, the Structural Light Weight Concrete (SLWC) uses high-strength lightweight aggregate instead of natural stone; this change of raw material makes it different from ordinary concrete in many aspects: its density is below two thousands kilograms per meter cube while that of Normal Concrete (NC) is twenty four hundred kilograms per meter cube besides, compared to NC, its strength per weight ratio is higher. SLWC has numerous advantages over NC In this research, the flexural behaviour of light weight aggregate concrete with inclusion of steel and glass fibers were investigated. The methodology consisted of comparing the results of conventional concrete, plain Light Weight Concrete (LWC) and fiber reinforced LWC. The fibers were added in the LWC to reduce the brittleness of the concrete in order to increase the energy absorption capacity and to control the faster rate of crack development. As a result of this study the performance of the lightweight reinforced concrete beam was increased with the inclusion of fibers.

Keywords: High-rise buildings, fiber reinforced, lightweight reinforced concrete, glass fibers, compressive strength

I.INTRODUCTION

To halt global warming, the emission of carbon dioxide into the atmosphere by human activities such as fossil fuel burning, cement production, and deforestation needs to be brought all the way to zero. The longer it takes to do so, the hotter the world will get. Lack of progress towards decarbonization has created justifiable panic about the climate crisis. This has led to an intensified interest in technological climate interventions that involve increasing the reflection of sunlight to space by injecting substances into the stratosphere which lead to the formation of highly reflective particles. Development of Light Weight Concrete (LWC) is one among such materials. Over the last few years, most of the countries like Germany, USA, UK and Russia are producing Light Weight Aggregates (LWA) under different trade High density concrete increases the dead load of the building, which will increase the foundation cost of the building. In order to reduce the density of concrete LWA are utilized to attain LWC.

LIGHT WEIGHT CONCRETE

Light Weight Concrete (LWC) is defined as concrete which has a compressive strength of above 20 MPa at 28 days of age and has a unit weight not surpassing 1842 kg/m³. Due to its lower density there is a reduction in dead load which results in reduced cross section of columns, beams, and foundations. It also decreases the induced seismic loads and minimizes the earthquake damages,

since the quake response is considered to be proportional to the cumulative mass of the structure.

Light Weight Aggregate

Lightweight coarse aggregates are used to produce LWC with reduced unit weight. LWA are wetted before usage in order to avoid water absorption due to the presence of cellular structure. The primary use of structural LWC is to reduce the unit weight of the concrete. In ordinary concrete, different gradation of aggregates affects the necessary amount of water. Increase of water cement ratio affects concrete strength.

Natural Aggregates

- Pumice
- Tuff
- Scoria

Pumice- Pumice is extremely porous igneous rock that forms during the volcanic eruptions. It is used as aggregate in order to produce LWC. Due to reduced density the aggregate floats on water until they are water logged. Pumice is a widely used LWA to produce LWC and low-density cinder blocks. When used as an additive for cement, a fine-grained pumice called pozzolan is mixed with lime to reduce the weight.

Tuff- Locally available fine aggregates (sand) are used for making concrete mix. The fine aggregates are sieved from the set of sieves of size ranges from 4.75 mm to 150 microns, and sand finer than 4.75 mm are used thoroughly over the study. The various properties of fine aggregates sand such as specific gravity, gradation of sand to obtain fineness modulus, are tested as per the IS 2386-1870 code recommendation. Table 3.2 showing the grading of Fine aggregates. The grading observed for sand (fine aggregate) belong to Zone II.

Scoria - Scoria is also a type of igneous rock with abundant round bubble-like cavities known as vesicles. The colour of scoria may be black, dark grey or deep reddish brown. Scoria can be used as a material to resist high temperature. It is also utilized in oil well sites to minimize the mud issues with heavy truck traffic

ADVANTAGES AND DISADVANTAGES OF LIGHT WEIGHT CONCRETE

Advantages

- Cost effective in mass construction works.
- Good in energy absorption.
- Good fire resistant and sound insulation material.
- Overall reduction in weight and cost of the structure.

II.LITERATURE REVIEW

Syed Jahanzaib Shah et al. (2024) investigated the demand for lightweight aggregates in concrete compositions for diverse structural and non- structural applications. This is to achieve a controllable low-density lightweight concrete, which reduces the overall structural weight. However, the challenge lies in achieving an appropriate strength in lightweight concrete while maintaining a lower unit weight. This research aims to evaluate the performance of lightweight concrete by integrating expanded polystyrene (EPS) as a partial.

Yaqin Chen et al. (2024) investigated durability properties under severe environmental conditions, which initiate cracks inside and disintegrate it. Randomly distributed short fibers arrest the initiation and propagation of microcracks in the concrete and maintain its integrity. Traditional polypropylene fibers are thin and encounter the problem of balling effects during concrete mixing, leading to uneven fiber distribution. Thus, a new polypropylene fiber is developed by gluing thin ones together, forming macro-polypropylene fibers. Thus, different amounts of fibers, 0–1.5% v/f with an increment of 0.5% v/f, are used in different grades of concrete

Nilesh Zanjad et al. (2024) explored the impact of polypropylene fibers and glass fibers on the mechanical characteristics of lightweight concrete when subjected to elevated temperatures. Different fiber ratios ranging from 0.25% & 0.50% by volume of concrete were tested to evaluate their impact on various concrete mixtures. Cenosphere is lightweight material used with cement as

bonding material. Pumice aggregate, which is known for its lightweight properties, was utilized as the coarse aggregate

Ming Kun Yew et al. (2021) intended to recommend the replacement of conventional coarse aggregates with recycled lightweight expanded clay aggregate (LECA) which offers several advantages such as lightweight, low cost, and easy availability. Lightweight concrete (LWC) offers numerous benefits; therefore, many researchers are using lightweight aggregate to produce lightweight structural concrete to compensate heavy loads by reducing the concrete self-weight due to lower density of lightweight concrete, improving in thermal properties and fire resistance.

PROPERTIES OF MATERIALS

The materials used are cement, fine aggregate, coarse aggregate, pumice aggregate, steel fiber and glass fibers.

Cement- The cement used in this study for all the mixes was Ordinary Portland Cement with 53 grade, conforming to IS 12269:2013. The compressive strength of cement mortar was found to be 29, 42 and 55 N/mm² at 3, 7 and 28 days respectively. The properties of cement used are given in Table 1.

Properties	Experimental Value
Standard Consistency	33%
Specific Gravity	3.15
Initial Setting Time	55 minutes
Final Setting Time	380 minutes

Fine Aggregate- Natural river sand conforming to zone II as per IS 383:2016 was used as the fine aggregate. The sand was air-dried and sieved to remove any foreign particles prior to mixing. The specific gravity, fineness modulus and water absorption were determined

Coarse Aggregate- Crushed granite coarse aggregate of particle size 20 mm having angular shape and conforming to IS 2386 – 2016 was used for this investigation. In all the mixes 20mm size lightweight pumice aggregate was used as the replacement of coarse aggregate.

PROPERTIES OF FRESH CONCRETE

Slump Test

Slump test is the commonly used method for measuring workability of concrete. The mould of 300 mm height, 200 mm base diameter and 100 mm top diameter of frustum cone was filled with four layers of concrete. Each layer was tamped with 16 mm diameter steel rod for 25 times and top surface was levelled. The decrease in height was measured by lifting the frustum cone.

MECHANICAL PROPERTIES OF HARDENED CONCRETE

Compressive Strength Test

Compressive strength is defined as the ability of the concrete specimen to resist compressive stress without failure. Cubes of 150 mm size were cast and allowed to cure for the required period. After curing, the cube specimens were removed from the curing tank and cleaned to wipe off the surface water. The cube specimens were tested in accordance with IS:516-1999. The testing was done on a Compression Testing Machine (CTM) of 2000 kN capacity.

Split Tensile Strength: The most commonly used test for estimating the tensile strength of concrete is splitting tensile strength. This test was conducted on cylinder specimen of sizes 150 mm diameter and 300 mm length. The specimens were tested in accordance with IS: 5816-1999. The cylinder specimen was subjected to compressive load along two axial lines which are diametrically opposite.

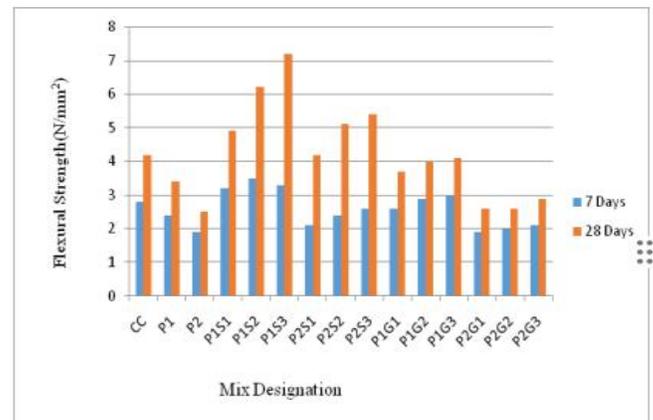
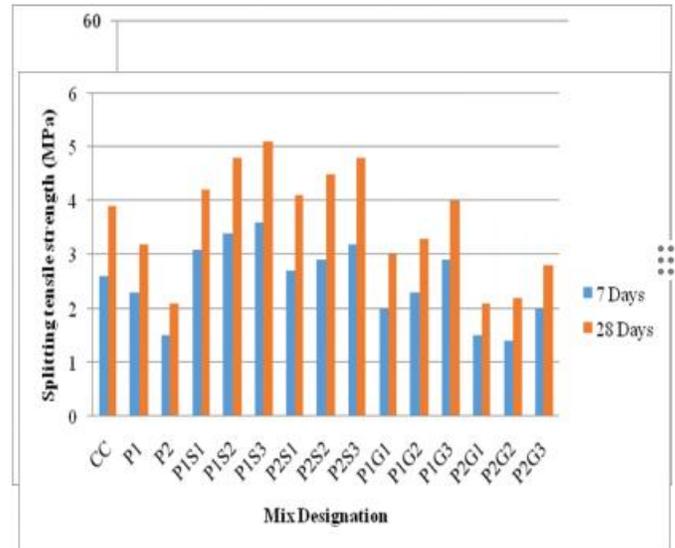
Flexural Strength Test: Flexural strength is expressed in terms of Modulus of Rupture, which is the maximum stress at the extreme fiber in bending. Flexural strength was assessed by testing concrete prism of size 100 mm x 100 mm x 500 mm. The specimens were tested on a Universal Testing Machine (UTM) in accordance with IS: 9399-2013. The loading frame was provided with two rollers 400 mm apart at the base. The load was applied at two similar rollers mounted at the third point of the supporting span spaced 133 mm apart and centrally with respect to the base rollers

1. TEST RESULTS

Compressive, splitting tensile and flexural strength at 7 and 28 days

Mix Designation	Compressive strength(MPa)		Splitting tensile strength (MPa)		Flexural strength(MPa)	
	7 Days	28 Days	7 Days	28 Days	7 Days	28 Days
CC	31.2	47.4	2.6	3.9	2.8	4.2
P1	21.6	33.2	2.3	3.2	2.4	3.4
P2	18.6	27.7	1.5	2.1	1.9	2.5
P1S1	35.2	49.2	3.1	4.2	3.2	4.9
P1S2	33.9	48.2	3.4	4.8	3.5	6.2
P1S3	24.8	33.3	3.6	5.1	3.3	7.2
P2S1	27.9	39.2	2.7	4.1	2.1	4.2
P2S2	26.3	36.2	2.9	4.5	2.4	5.1
P2S3	20.2	28.7	3.2	4.8	2.6	5.4

P1G1	22.9	34.4	2	3	2.6	3.7
P1G2	21.2	32	2.3	3.3	2.9	4
P1G3	20.6	31.3	2.9	4	3	4.1
P2G1	20.1	29.4	1.5	2.1	1.9	2.6
P2G2	18.2	26.2	1.4	2.2	2	2.6
P2G3	17.6	26.7	2	2.8	2.1	2.9



Compressive strength of FRLWC at 7 and 28 days

Splitting tensile strength of FRLWC at 7 and 28 days

Flexural strength of FRLWC at 7 and 28 days

II.DISCUSSION ON TEST RESULTS

From the results obtained, it was found that the compressive strength of the concrete was decreased with the presence of pumice aggregate. Pumice aggregates are light weight aggregate replaced for normal weight aggregate but they cannot tolerate considerable compressive force. Although LWC can be achieved with pumice aggregate, it has reduced compressive strength. In order to increase the compressive strength, steel and glass fibers were added by various proportions such as 0.5, 1.0 and 1.5 percentages The rate of strength development was greater at earlier age of 7 days and

decreased at 28 days. However, a comparison of strengths at 7 days revealed that concrete mixes with steel fiber developed almost 70 to 75% of its 28 day strength, while those mixes with glass fiber developed almost 65 to 70% of its 28 day strength.

From the results, it was found that the P1 mix exhibited decrease in compressive strength by 29.9% and the P2 mix exhibited decrease in compressive strength by 41.6% as compared to the control concrete at 28 days. This decrease in compressive strength is due to the presence of cellular structure of light weight concrete and lesser density as compared to the normal weight concrete.

III.CONCLUSIONS:

From the above research work the conclusion are as follows:

1. Addition of fibers decreases the slump of concrete which is very dominant in steel fiber than glass fiber. The slump value for all the mix was in the range of 85 mm to 120 mm which is sufficient for good workability in the case of FRLWC.

2. The mixes with 20% and 40% replacement of normal aggregate with pumice have the density of 1985 kg/m³ and 1820 kg/m³ respectively. The mixes developed with the inclusion of fibers in lightweight concrete have the density varying from 1830 kg/m³ to 2200 kg/m³. The density of Fiber Reinforced LightWeight Concrete is lower compared to that of control concrete.

3. Steel fiber inclusion of 1.5% on mix with 20% LWA significantly increases the flexural strength by 72% as compared to control concrete at 28 days but it has much smaller effect on compressive and splitting tensile strength.

4. Inclusion of glass fiber has relatively lower effect on the compressive strength. The splitting tensile strength seems to increase by 28.2% with the inclusion of 1% of glass fiber in mix with 20% LWA as compared to control concrete at 28 days. The flexural behaviour of Glass Fiber Reinforced Lightweight Concrete seems to have insignificant effect as compared to that of Steel Fiber Reinforced Lightweight Concrete.

5. The modulus of elasticity seems to increase by 9.87% with inclusion of 0.5% of steel fiber with 20% LWA as compared to control concrete.

6. The bond strength decreases with the increase in LWA content but increases with increase in steel fiber content indicating good bonding behavior between concrete and steel fiber. But glass fibers are ineffective in improving the bond strength.

All the mix proportions with fibers show good resistance to chloride ion penetration except lightweight aggregate concrete without fibers.

SUGGESTIONS FOR FUTURE WORK

1. The present study can be extended to explore the use of hybrid fibers combining steel and glass fibers at different proportion.
2. The research study can be conducted on the performance of light weight structural concrete reinforced with recycled or bio-based fibers.
3. The study of creep and shrinkage of light weight structural concrete can be carried out to understand the long-term performance of structural light weight concrete. Analytical study can be done to develop appropriate models for structural light weight concrete.

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