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A Decadal Review and Understanding of Light Weight Concrete (LWC) - Its Mechanical Properties, Temperature Effect and Durability Studies

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Abstract: The idea of Light Weight Concrete (LWC) in the construction industry and its technological development is not entirely a new age methodology, it has been a very old technique with enhanced features. This review paper focuses on the evolution of LWC as a mere construction in ship building to bridges and to other forms of construction components. With its wide range of applications, LWC almost fits in a number of challenging construction projects. This review is based on the last decade especially focussing on the materials and the wastes used in the construction industry providing new arena to explore in LWC. Most of the important studies carried out are carefully taken into consideration. There might be number of challenges involved in practical experience especially while handling different LWC in the field. Some of them are discussed on the paper before dwelling to the studies of mechanical properties of LWC, their thermal properties and durability studies when different materials are used to create LWC.

1. Introduction

As the entire globe is looking forward in the direction of sustainable ecological development with new policies and treaties been signed then and there, the construction industry is making an effort to reduce the manufacture and usage of cement in concrete by utilising eco-friendly materials. There have been number of other materials or utilisation of wastes in the construction industry to replace the usage of cement, either in partial or total for preparation of concrete. In addition to that, several other unconventional materials are also used to create concrete and it has yielded successful results in the production of different types of concrete with certain specific properties improved. This significantly improved the utilisation of such newly created concrete which can be used in vast number of applications. One such significant concrete is Light Weight Concrete (LWC).

Light Weight Concrete (LWC) is not a new type of concrete which recently found out. In fact, these types of concrete have been used for a long time and it has come again to limelight due to its advantage in the erection of buildings. One of the best example cited for LWC is The Pantheon in Rome, Italy (built 128 A.D.) (Lamprecht, 1996). Much later, different during the different capacities for the shipbuilding program, LWCs are used in 1918. Huge capacity of concrete were carried out for building such ships and buildings in USA using LWC (Holm, 1980). Technological advancement in the materials industry provided an impetus for the manufacture of LWC later in the 19^{th} and 20^{th} centuries.

This paper focusses on LWC as a prime point discussion with its evolution and significant properties as the next section. Also, it aims at reviewing the past decade's research in utilising different materials and wastes in creating LWC. Further, it focusses on the research made in LWC related to mechanical properties, temperature effect and durability studies and the performance of LWC.

2. Evolution and significant properties of LWC

LWC based on the strength, density and type, definition changes. For instance, structural light weight concrete and high strength light weight concrete differs in the strength parameter. Different guidelines exist among the different types of LWC and its characteristics. After the utilisation of LWC in ship building, its usage is very much concentrated in other types of structural engineering. 1920s have been very fruitful as more number of bridges were constructed with LWC. At the forefront, US has been constantly researching and utilising LWC before Canada enters and identifying the advantages of LWC. During 1970s, several LWC bridges were created in both the countries (Raithby and Lydon, 1981). Even though more number of construction activities were surging in and around the world using LWC, many of the new activities were mainly focussed for the structural reasons.

With its wide range of differences and economy, Germany entered into the market of LWC with prime focus of energy utilisation in buildings. Based on that particular property of efficient use of energy, different types of walls were constructed using LWC focusing on economy and also giving focus on thermal properties. This paved the way for further intensifying the research in LWC for energy utilisation and efficient use of energy in LWCs. Due to changes in the technical policies with respect to building with concrete, a new wave of usage of LWC again surfaced because of the ease in technology and science in utilising the LWC. Strength parameters plays an important role along with the density component in LWC. Some of the important studies carried out in the past to reduce the concrete density has produced some useful results in European countries. LWC gained popularity due to its lowest density and other physical properties such as high fire resistance and durability (Thomas and Bremner., 2012; Lofty et al., 2016; Cavalline et al., 2017; Roberz et al., 2017).

The development of LWC with its full potential evolved into number of stages and development resulting in various other types of concrete. One such type of concrete is called infra-light weight concrete (ILWC). Many researchers are working in this area and specify in different names such as infra light weight concrete or ultra-light weight concrete etc. (Yu et al., 2015). Different properties are to be taken into study in particular structural specifications and thermal insulation properties. These advanced LWCs do not have any required legal permissions from the building regulation authorities and hence it is still at the infant stage.

3. Composition of LWC

As already discussed, there are variety of materials and wastes which were utilised for the manufacture of LWC. Each of the materials due to its composition of various properties are identified and utilised in LWC. The below table will describe the complete details of materials used for LWC and the experimental work carried out by the researchers in the advancement of LWC. Initially, this review discusses the literature in which pumice and EPS beads were used in manufacturing LWC.

Babu et al., 2006 investigated the use of expanded polystyrene and unexpanded polystyrene beds for their research work. The manufacture of LWC involves the use of cementitious materials such as fly ash in their work. They have steadily organised to check the compressive strength, split tensile strength, absorption, etc., Results clearly show the improvement in compressive strength in unexpanded polystyrene beads. Gradual failure was seen in graded polystyrene beads.

Demirel (2013) worked on the benefits of expanded polystyrene foam and pumice because of low density and thermal property and utilised the same in the manufacture of LWC. It is also checked for the insulation properties with different density values of expanded polystyrene foams. Experimental studies carried out found that the thickness of the blocks played an important role in both heat transfer and maximum compressive strength.

Liu and Chen (2014) worked on adding EPS to prepare LWC which exhibits good mechanical properties. Based on the addition of the EPS in different percentages, different tests were carried out to check compressive strength and tensile strength. Ultrasonic testing reveals the EPS particle size and the granules content.

Karthika et al., 2021 discussed about the disadvantage of conventional concrete due to its self-weight and focussed on making LWC with reducing the self-weight of the concrete. With respect to that, the coarse aggregate was replaced by lightweight aggregate partially. Pumice was used in their study because of its low density and based on that LWC prepared with three different constituents, i.e., 50%, 80% and 100%

replacements were made. Comparison between the conventional concrete and LWC indicates the replacement of conventional concrete with LWC as there seen a considerable improvement in mechanical and durability properties. Different destructive and non-destructive tests confirms the improvment in LWC.

Lehner et al., 2021 noted the high-performance concrete (HPC) which is trending now utilises the Portland cement and other supplementary cementitious materials having desirable mechanical and durable properties. Different supplementary cementitious materials are used: fly ash, slag, metakaolin, volcanic pumice etc., The study carried out the possibility in identifying the chloride penetration into the concrete. Assessment were carried out to check the chloride attack in the concrete but with the change in materials in utilising volcanic pumice and the results were satisfactory.

Rosca (2021) used the recycled brick aggregate and EPS for their research. It is very important being light weight and low density, EPS can be replaced partially or fully. In different percentages of brick aggregate and EPS were added and different parameters were considered for the study. It is found that the concrete manufactured was lighter and enough strength.

Some of the important literature papers in the last decade are briefly discussed in the below table:

Table 1: Materials used in Light Weight Concrete

Author & Year	Material used	Remarks
Kim et al., 2010	Rhyolite powder and slag	Manufacture of light weight aggregate.
Topcu&Uygunoglu (2010)	Pumice, volcanic tuff and diatomite.	
Libre et al., 2011	Pumice, Metallic fibres and polypropylene fibres	Manufacture of light weight aggregate
Herki et al., 2013	Polystyrene aggregate with added heat plant ash	Properties were analysed after mixing.
Rahmani et al., 2013	PET chips	Percentages of 5%, 10% and 15% of PET chips as replacement for sand
Grabois et al., 2016	Metallic fibres	For improving the mechanical characteristics.
Shafigh et al., 2016	Limestone powder, Palm tree bark, fly ash	Dosages of fly ash from 50% to 70% instead of cement
Alqahtani et al., 2017	Recycled plastic.	
Bogas& Cunha (2017)	Reactive powder such as volcanic slag	Volcanic slag is used in different dimensions as aggregate. Compared with expanded clay and polystyrene granules.
Ali et al., 2018	Volcanic slag, Polyethylene waste, Ash	Different characteristics of LWC prepared using volcanic slag, polyethylene waste and ash.
Allahverdi et al., 2018	Blast furnace slag, ultra-smooth silica and polystyrene granules	They were used in dosages of 15%, 30% and 45%
Chung et al., 2018	Limestone powder, expanded clay, heat plant ash, sand	Testing of properties of LWC
Mastali et al., 2018	Metallic fibres, slag	Alkaline activation of slag - with different dosages
Tang & Brouwers (2018)	Artificial light weight aggregates from heat plant ash	For improving the durability characteristics.
Zaleska et al., 2018	Polypropylene, Fiber glass polypropylene	

The above decadal review presents most important studies carried out using alternative materials or utilizing waste materials to prepare LWC. This clearly shows that materials are available in plenty to prepare LWC. Moreover, it is very important to understand the characteristics of such LWC with the ordinary concrete to ascertain the strength, durability and other parameters for huge structures. Some of the important parameters to be ascertained are explained in the later paragraphs with already analyzed researches and literature papers.

4. Constituents of LWC

Apart from light weight aggregates and the alternative materials or wastes available, some of the other materials are required in limited proportions. Those details are discussed below briefly:

1. **Regular Aggregate:** Normal coarse aggregate having less weight and sand is more than enough for the preparation of LWC. It depend upon the choice of required properties at the final concrete. Crushed material can be used as the normal aggregate which helps in proper workability characteristics.
2. **Binders**: No specific condition of cement to be used for the preparation of LWC. Important thing to be considered is to use a cement which is having very less thermal release. For instance, cement mixed with the blast furnace slag, fly ash, clay, etc., can be used. These provide additional features for the preparation of LWC.
3. **Water:** One of the biggest advantage is that there is no need of specific water to be used in the preparation of LWC. Normal fresh water can be used for LWC.
4. **Admixtures:** Any type of admixtures can be used for LWC. It can be the same as used in normal concrete preparation. The time of addition of admixtures plays an important role in the preparation of LWC. Since absorption of admixtures by aggregates takes place, it is very important that the admixtures should be added at the later stages of the preparation of LWC.

5. Properties of Light Weight Concrete

Mechanical properties

Topçu and Uygunoglu, 2010 worked on the compressive strength and tensile strength of the LWC. There seems to be an increase in the water cement ration from 0.48 to 0.36 based on the age of concrete. Good relationship was identified based on the material added which in turn improving the compressive strength.

Kim et al., 2010 tried to identify the characteristics of two different LWCs by adding different densities of slag with light weight aggregates. After 28 days, compressive strength was identified to be 75% higher in the light weight aggregate than the normal regular concrete. Slag was added more in proportion to identify the maximum quantity with which it can be replaced, it is found to lower 20% than the normal concrete after a certain content.

Libre et al., 2011, with the addition of pumice, the analysis for the concrete is done. The density was found to be higher compared to the normal concrete. Compressive strength is also found to be very good after the addition of pumice. Different fibres were added to identify the fragile part of LWC. Polyethylene fibres were also tried but the flexural strength was very high reducing the compressive strength.

Herki at al., 2013 worked on a concrete with different polystyrene as a fitting replacement of sand with different percentages along with the addition of fly ash. Different cement was also tried and tested due to which compressive strength decreases.

Rahmani et al., 2013 used different dosage of PET for different concrete samples and started seeing the behaviours related to compressive strength and flexural strength. When the PET percentage is increased to 15%, the flexural strength decreased drastically.

Alqahtani et al., 2017 worked on the effect of synthetic aggregates and investigated the mechanical as well as the durability characteristics. The comparison were made among the synthetic aggregate and the normal concrete which in turn the synthetic aggregate provided a much improved mechanical performance.

Bogas and Cunha, 2017 studied the mechanical characteristics of LWC where the material used is volcanic slag. It was studied to determine the elasticity and the compressive strength of LWC. The material used for the preparation of LWC provided a good result with the different variety of clay added to it boosting the mechanical characteristics of LWC.

Tang and Brouwers, 2018 identified the reduction of compressive strength when more number of artificial aggregates were added. When fresh aggregates were added, the material responded positively and improved the mechanical characteristics

Allahverdi et al., 2018 worked on the experimental study on light weigh concrete which used polystyrene, slag, silica, etc., Compressive strength varies between 20.8 MPa and 85.6 MPa.

Chung et al., 2018 showed an impressive compressive strength of 18 MPa and more than that for all the concretes by adding plastics in LWC. This proved to be one of the important study where good mechanical characteristics where derived from LWC.

Thermal resistance

Topçu and Uygunoglu, 2010 focussed on the concrete which is replaced with stones, volcanic stuff. This is considered to be a very significant study as the materials used in this study has a greater change in the regular materials used. The materials used has a good thermal conductivity than the normal concrete. By increasing the percentages to some extent, the thermal conductivity improved a certain limit thereby providing good assistance in the LWC. Along with this, other properties were also seen to be improved with the materials used in the study.

Grabois et al.,2016 identified the usage of porous aggregate which have better thermal properties. Mixing of porous aggregate was considered to be very important as the quantity plays an important role in the improvement of thermal conductivity. Gradually the property improved to a greater extent by the addition of porous aggregate.

Ali et al., 2018 utilised polyethylene to improve the thermal conductivity. To the astonishment, thermal conductivity improved a lot and it has provided an important analysis that polyethylene can used a substitute for even 100% aggregate replacement.

Zaleska et al., 2018 did a study to including plastic materials to boost the thermal conductivity in the concrete. By varying the percentage of adding plastics upto 50% can boost up the thermal conductivity.

Durability studies

Alqahtani et al., 2017highlighted the importance of synthetic materials along with LWC provided a good durability. In addition to that, the absorption of water and the allowability of waster along with chlorines is much reversed in LWC compared to normal concrete and the aggregates.

Ali et al., 2018 also focussed on the leaching of chlorine which in turn affecting the concrete. Polyethylene was added as an replacement in order to control the attack of chlorine to the concrete. Slowly different percentages of polyethylene was added in the studies to control the chlorine attack. The study saw variable and improved results in LWC.

Some other important studies focussed on the effects of other chemicals and found it very interesting to add PET, silica, ash, slag and other materials to arrest the damage caused to the LWC. One of the important chemical was sulfuric acid which was arrested by replacing PET and comparison with normal concrete was done. This showed improved durability when those materials were used in different studies.

AmirrezaBahrami, 2021, Lightweight concrete (LWC) with a pumice coarse aggregate and rock wool waste (composed of mineral fibres) was investigated for its mechanical characteristics and residual stress- strain behaviour before and after thermal loading. Exposure temperature (20C, 200C, 400C, and 600C) and rock wool waste volume percentage (0%, 2.5%, 5%, 7.5%, and 10%) were also significant factors. In this study, we examined how changing a few variables affected the compressive strength of LWC that had been strengthened with rock wool scraps. The stress-strain relationship, mode of failure, and values of elastic modulus, compressive strength, peak strain, and ultimate strain were all taken into account. Then, various empirical relationships were proposed to predict the varied mechanical features of rock wool based on the ratio of its volume and temperature.

Quang Tran, 2020, In this study, 37 unique concrete combinations were tested. In addition to ordinary Portland cement (OPC), these mixtures also made use of fly ash, slag, silica fume, and metakaolin, as well as ultrafine VPP as a key supplementary cementitious material (SCM). Two important performance indicators, corrosion and compressive strength, were the focus of this research. In a short length of time, a 4-point Wenner

Probe and a Merlin metre were used to explore the surface resistivity (SR), the bulk resistivity (BR), and the charge passed, respectively, utilising nondestructive testing methods. These properties of hardened concrete are essential to the longevity of reinforced concrete structures in the face of corrosion. The results demonstrated that the binary and ternary based VPP combinations had significantly higher compressive strength and permeability than OPC and other SCM based binary mixtures from an early age to a long-term period (up to 91 days).

Prof. Ashish S. Moon, et.al, 2020, This research provides a possible method for reusing a byproduct in building projects. This research necessitates the utilisation of alternative waste materials and the inspection of recent building activity. As the total area to bearing area ratio of polystyrene aggregate concrete rises, so does the bearing strength. The ratio of bearing strength to compressive strength improved with the addition of polystyrene aggregate.

Zrar Safari, et.al, 2020, Sustainable building practises include geopolymerization, in which large amounts of by-product materials are used into construction materials. Other research have focused on common additional cementitious materials as a precursor for this purpose, such as fly ash and metakaolin. The geopolymerization process, however, is not limited to just one type of precursor. In this study, geopolymer paste was made using pumice powder, which is rich in both Silica and Aluminium. For activation by alkali solution, the components were determined to be 2.50 parts sodium silicate to 0.35 parts sodium hydroxide. Pastes were made with 8, 10, 12, 14, 16, and 18 M of alkali and cured at room temperature, 60, 80, and 100 °C for 24, 48, 72, and 120 hours to find the optimal molarity, curing temperature, and curing time. The results showed that the highest flexural and compressive strengths were achieved by mixes treated in an oven at 60 °C with a 12 M alkali solution for 120 hours.

6. Lightweight Concrete by the Inclusion of Expanded Polystyrene(EPS)

M. Gunavel, 2020, This study explores the use of polystyrene, sand, cement, coarse aggregate, and water to create a new kind of lightweight concrete. The goal of this study was to find the ideal dosage of Expanded Polystyrene Beads to use in lightweight concrete, which is a relatively new area of study due to the ease, low cost, and lack of complexity of the mixing procedure. Here, 10%, 20%, and 30% by volume of Expanded Polystyrene beads are used. Compressive, split tensile, and flexural strengths are among the ones investigated. The results indicated that fine aggregate could successfully substitute for up to 10% of the volume of Expanded Polystyrene beads. It can be utilised in places where M25 concrete is called for to create a simple building.

Abhishek Kumar Singh, et.al, 2022, Impact of coarse aggregate partial replacement with light weight coarse material (LECA) is studied. LECA shares several characteristics with coarse aggregate. Since self-weight contributes significantly to the total load applied to a concrete building, LECA is utilised in concrete to lessen the need for coarse aggregate and in the construction of concrete structures. This is especially important when dealing with issues like rocky ground or a very high building. Significant benefits in terms of reduced concrete density, which enhances productivity, are also provided. Lightweight concrete is more insulating and has a lower density than regular concrete.

N. Ramanjaneyulu, et.al, 2021, The study looks into the viability of replacing natural coarse aggregate (NCA) with sintered fly ash aggregate (SFA) in structural lightweight concrete (LWC). Here, adding sintered fly ash aggregates reduces the volume of the natural aggregates by 0%, 10%, 15%, 20%, 25%, and 30%. Mechanical properties (such as Compressive strength and split tensile strengths) and durability qualities (such as water absorption test and permeability) on 40MPa concrete were carried out for this investigation in order to assess its effectiveness. The results of the present study indicated that the LWSCC mixture containing 20% sintered fly ash aggregates had the highest strength (i.e., 56.88MPa), hence this was the formulation that was ultimately selected. Sintered fly ash aggregates, which may be used to replace up to 20% of the aggregates in a mix, have been demonstrated to significantly improve both strength and durability.

S. Kavipriya, et.al, 2021, In most cases, the use of lightweight concrete is preferred for structural purposes because it reduces the overall cost of a project relative to regular weight concrete. Given its heft, it would be too expensive to use as a building material. To improve concrete's productivity as a structural material, earlier efforts have been made to lessen its self-weight. In this study, bamboo sticks are utilised as coarse aggregate in concrete, with varying percentages of bamboo to cement. The qualities of a naturally occurring fibre known as sisal fibre are also being investigated. The primary goal of this experimental investigation is to determine the effect of adding sisal fibres and bamboo sticks to lightweight geopolymer concrete on its strength. In recent years, there has been widespread excitement about the prospects for natural fibre reinforced cement-based composites and lightweight concrete. Casting lightweight geopolymer concrete with bamboo aggregates as a 10%, 20%, and 30% replacement for coarse aggregate will also be used to examine concrete strength qualities. In addition, Sisal fibres are mixed in at concentrations of 0.25%, 0.50%, 0.750%, and 1% by volume of concrete.

SerminPolat, 2021, As an organic aggregate, maize cobs were investigated for their possible use in creating lightweight concrete. To begin, the maize cob's crucial physical features have been analysed in detail. These characteristics include granulometric analysis, water absorption rate, and weight-to-volume ratio (unit weight). In the end, four different batches of concrete were made, each tailored to the workability of concrete and the requirements set forth by Turkey. Machines measuring unit weight, heat transmissibility coefficient, and 28-day pressure strength were then applied to these four samples of concrete.

Fahad K. Alqahtani, 2021, A comparison was made between the produced plastic-based green lightweight aggregates (PGLAs) and the reference aggregates in terms of their physical and mechanical qualities. PET plastic scrap and by-products were included in the PGLAs. We next replaced all of the standard weight and low-density coarse aggregate with PGLAs and compared the resulting mix to the control mix in terms of its fresh, hardened, microscopic, and durability-related characteristics. PGLAs were found to have a unit weight that is 21–29% less than that of regular coarse aggregate. Water absorption was also modest for PGLAs, ranging from 1.2% to 1.6%. The aggregates developed were 45% stronger than standard lightweight coarse aggregate. The studies demonstrated that dry density, compressive, and splitting tensile strength requirements of ASTM C330 could be reached in structural green lightweight aggregate concretes (GLACs). Last but not least, ASTM C1202 found that GLACs had low to moderate chloride penetration, permitting their use in areas prone to chloride assault.

7. Conclusions

It is very significant to note that the LWC can be applied to a wide variety of applications. The paper discusses about the usage of LWC from a very long time since ages applied in ship building, bridges and construction in structural buildings. Even though there exists some doubts in the usage of LWC due to its different properties which were tested at different stages. Also, there are some areas such as mixing, testing using different materials added in the preparation of LWC proves little challenging at times. Manufacturing of LWC pose a significant challenge even though regular materials are used. Important properties such as mechanical properties, thermal resistance and durability studies proves to be an additional advantage in the usage of LWC. Several studies are still carried out and they are in different stages to further provide an insight into the usage of LWC in the future.

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