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# Lightweight Concrete a Boon in Civil Engineering- Review

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**Abstract—***Lightweight concrete is a very versatile and advantageous material in modern construction industry. It is lighter than normal weight concrete. This paper presents a review on the significant applications and advantages of using lightweight concrete in the field of civil engineering. Also, it focuses on the methods of production and the basic properties of each type. Therefore, the use of lightweight concrete has great impact on developing countries as it permits design flexibility and substantial saving in cost of construction.*

## 1. INTRODUCTION

Lightweight concrete (LWC) is a very versatile material for construction, which offers a range of technical, economic and environment-enhancing and—preserving advantages and is destined to become a dominant material for construction in the new millennium [7]. It has many and varied applications such as multistory building frames and floors, curtain walls, shell roofs, folded plates, bridges, off-shore oil platforms, and precast and pre-stressed or precast elements of all types. LWC has strengths comparable to normal weight concrete, yet is typically 25% to 35% lighter [13].

Concretes are grouped in to three categories according to their unit weights. First category has unit weight in the range of 3200 kg/m$^3$ to 4000 kg/m$^3$. It is called 'Heavy Concrete' and is used mainly in nuclear reactors. Second category is 'Normal weight Concrete' or 'Conventional Concrete' and has unit weight in the range of 2400 kg/m$^3$ to 2600 kg/m$^3$. Third category is the 'Lightweight concrete' having unit weight less than 2000 kg/m$^3$.

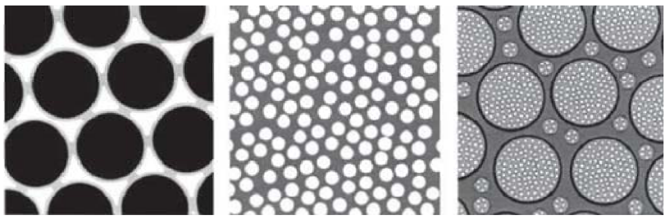
### 1.1 Historical Review

LWC is not a new material in the construction industry, it has been known since ancient times. The use of lightweight concrete can be traced to as early as 3,000 BC, when Mohenjo-Daro and Harappa were built during the Indus Valley civilization. However, in Europe, its use occurred 2,000 years ago when the Romans built Pantheon, the aqua ducts, and the Colosseum in Rome [5]. Some of these magnificent ancient structures still exists, like St. Sofia Cathedral or Hagia Sofia, in Istanbul, in Turkey, built by two engineers, Isidore of Miletus and Anthemius of Tralles, commissioned by the Emperior Justinian in the 4th century A.D.; the Roman temple, Pantheon, which was erected in the years A.D. 118 to 128; the prestigious aqueduct, Pont du Gard, built ca. A.D. 14; and the great Roman amphitheatre, Colosseum, built between A.D. 70 and 82. However, the use of lightweight concrete was limited after the fall of Roman Empire, until 20th century when a new type of manufactured material named expanded shale, which is a lightweight aggregate, became available for commercial use.

Prior to 1917, S. J. Hayde developed a rotary kiln process for heat expansion of shales and clays to form hard, lightweight material which served as aggregates in making concrete of substantial strength and lower weight. At about the same time, F. J. Straub pioneered in the use of bituminous coal cinders as an aggregate for manufacture of concrete masonry units which attained high production volume [7]. The first commercial production took place during World War I for building ships and barges around 1918. This was one of the earliest uses of reinforced lightweight concrete. The U.S. Emergency Fleet Building Corporation found that, for concrete to be effective in ship construction, the concrete would need a maximum density of about 1760 kg/m$^3$ and a compressive strength of approximately 28 MPa. However, the concrete obtained had compressive strength of approximately 34 MPa and a unit weight of 1760 kg/m$^3$ or less using rotary-kiln produced expanded shale and clay aggregate [7].

## 2. PRODUCTION PROCESS AND PROPERTIES

The Lightweight concrete can be produced in three different ways. First technique is produced by eliminating the fine aggregates from the mix completely. This concrete is called 'No-fines Concrete'. The second type is 'Aerated Concrete', sometimes also referred as foamed, gas or cellular concrete. It is produced by the inclusion of bubble voids within the concrete to form a cellular structure containing approximately 30% to 50% voids. It offers varied usages such as Gap filling and thermal and acoustic insulation and in areas like room flooring, RCC roof, sunken slabs, basement filling etc. The third type can be produced by replacing the normal weight aggregate with lightweight aggregate with specific gravity lower than 2.6. This type is known as 'Lightweight Aggregate Concrete' (LWAC). Amongst all the three main groups of LWC, the LWAC and aerated concrete are most often used in the production process. Fig. 1 represents the microscopic view of LWC [9].



**No-fines concrete** **Aerated Concrete** **Lightweight Aggregate concrete**

**Fig. 1: Microscopic view of Lightweight Concrete (Newman and Choo, 2003)**

The principal properties desired in materials used as lightweight aggregates vary according to its end use. According to ACI 213, specific properties of aggregate which may affect the properties of the concrete are as follows:

(a) Particle shape and surface texture: Since the sources and methods for producing lightweight aggregates are different, the particle shape and surface texture may vary. Shape may be cubical and reasonably regular, essentially rounded, or angular and irregular. Surface textures may range from relatively smooth with small exposed pores to irregular with small to large exposed pores. Influence proportioning of mixes in such factors as workability, fine-to-coarse aggregate ratio, cement content, and water requirement.
(b) Bulk specific gravity: The specific gravity of lightweight aggregates is lower than that of normal weight aggregates, due to the cellular structure of lightweight aggregate. Bulk specific gravity may also vary with particle size and processing methods.
(c) Unit Weight: Due to the cellular structure of lightweight aggregate, its unit weight is lower than conventional concrete.
(d) Maximum sizes: The maximum size grading designations of lightweight aggregates generally available are 19 mm, 13 mm, or 10 mm. Maximum size of aggregate influences factors such as workability, ratio of fine to coarse aggregate, cement content, optimum air content, potential strength ceiling, and drying shrinkage.
(e) Strength of lightweight aggregates: The strength of aggregate may vary depending upon the source from where it is obtained.
(f) Moisture content and absorption: Lightweight aggregates are capable of absorbing more water than normal weight aggregates, due to their cellular structure. Based on a 24 hr absorption test, lightweight aggregates generally absorb from 5 to 20 percent by weight of dry aggregate, depending on the pore structure of the aggregate.

However the aggregates used for the production of LWAC are either artificial lightweight aggregates or natural lightweight aggregates. The artificial aggregates include aggregates such as brick bats, foamed slag, sintered fly ash, iron blast furnace slag and shale. These are all industrial by-products. Natural lightweight aggregates are not found in many places and they are also not of uniform quality such as saw dust, rick husk, oil palm shell, saw dust and mostly volcanic origin like pumice, scoria, volcanic cinders [3]. Pumice and Scoria are the oldest lightweight aggregate; and are used extensively in Roman construction. Since the source of obtaining lightweight aggregate is different, its property may vary.

Elastic properties, compressive and tensile strength, time dependent properties, durability, fire resistance, and other properties of lightweight aggregate concrete are dependent on the type of lightweight aggregate utilized in the concrete [13]. According to ACI 213R-87, lightweight aggregates can produce concretes with compressive strengths in excess of 35 MPa, a limited number of lightweight aggregates can be used in concretes that develop cylinder strengths from 48 to more than 69 MPa [9]. Most of the lightweight aggregates have a high and raid absorption quality. This is one of the important difficulties in applying the normal mix design procedure to the light- weight concrete. But it is possible to water-proof the light-weight aggregate by coating it with bitumen or such other materials by using a special process. The coating of aggregate by bitumen may reduce the bond strength between aggregate and paste. Coating of aggregate by silicon compounds does not impair the bond characteristics but at the same time makes it non-absorbant. Due to its higher porosity, lightweight concrete is a suitable material for thermal insulation of structures [3].

## 3. APPLICATIONS OF LWC

ACI 213 also classified lightweight aggregate concrete in three categories for the purpose of application in civil engineering[7]. The aggregates that fall under 'Low Density Concrete' have low unit weight (800 kg/m$^3$) and thermal conductivity. Hence, is mostly used for insulation purposes. Aggregates such as pumice and scoria with moderate strength, requires a fair degree of compressive strength, and thus they fall about midway between the structural and low-density concretes. These are sometimes designed as "fill" concretes with compressive strengths approximately equal to 7.0 MPa to 17.0 MPa and are referred as 'Moderate Strength Concrete'. Aggregates falling under structural concrete are used for making load bearing structures, and are popularly used worldwide. These are called Structural concrete or Structural Lightweight Aggregate Concrete (SLWAC) and are usually in the range of 1440 to 1850 kg/m$^3$ and the compressive strength is more than 17.2 MPa. Fig. 2 indicates the approximate 28-day; air-dry unit weight range of various types of lightweight aggregate concretes along with the use to which each type is generally associated.

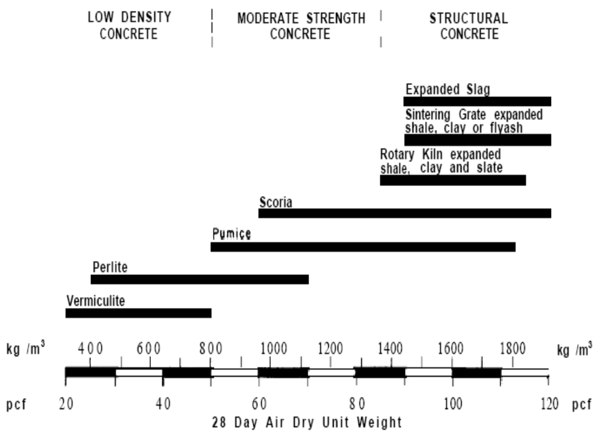



**Fig. 2:Approximate unit weights and use classification of lightweight aggregate concretes (ACI-213)**

In India lightweight aggregate is used in the form of masonry blocks. Most popularly used material is Fly ash or Sintered Fly for the production of blocks. The use of lightweight aggregate in masonry blocks permits increased labor productivity because the decreased weight makes for greater speed and ease of handling. The general characteristics of the lightweight masonry unit were that it provided a high degree of insulation, light weight, nominal shrinkage, and a uniform compressive strength equal to a heavyweight block with equal cement content. Lightweight masonry blocks are ideal for all types of exterior and interior walls, both load bearing and non load bearing.

## 4. ADVANTAGES OF LWC

The primary use of LWC is to reduce the dead load of a concrete structure thus making it well suited for seismic design. The lateral forces acting upon a structure during an earthquake are directly proportional to the inertia or weight of the structure. If, by using structural lightweight concrete, a structure can be built so it weighs less, then during an earthquake any resultant lateral forces will be smaller [12]. Many authors in their investigation reported that that structural lightweight concrete has its obvious advantages of higher strength/weight ratio, better tensile strain capacity, lower coefficient of thermal expansion, and superior heat and sound insulation characteristics due to air voids of the lightweight aggregate.

A 1982 study by the National Science Foundation showed that lightweight concrete columns performed under seismic conditions in much the same way that same strength, normal weight concrete columns did. Therefore, a concrete which combines strength and lightness will have unquestionable economic advantage. The flowchart in Fig. 3 summarizes the advantages of using LWC from economic perspective.

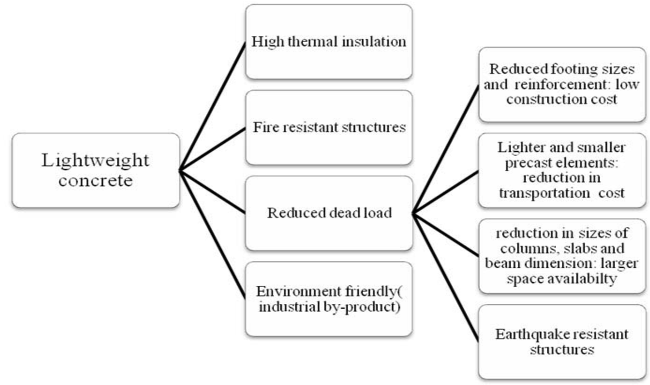



**Fig. 3: Flowchart showing advantages of using lightweight concrete**

## 5. LITERATURE REVIEW

An exhaustive research has been carried out to study the various properties of lightweight concrete, which are as follows:

**Yasar et.al.** [6] have performed a study on the design of structural lightweight concrete (SLWC) made with basaltic pumice (scoria) as aggregate and fly ash as mineral admixtures that will provide an advantage of reduction in dead weight of a structure, and to obtain a more economical and greener mixture with the use of fly ash. The compressive and flexural tensile strengths of hardened concrete, the properties of fresh concrete including density, and slump workability were measured. Laboratory compressive and tensile strength tests results showed that SLWC can be produced by the use of scoria. However, the use of fly ash seems to be necessary for the production of cheaper and environment-friendly SLWC with the compressive and tensile strengths similar to control SLWC containing only NPC. Results showed that SLWC has an advantage of the reduction of the dead weight of the structure at an average of 20% since the dry weight unit of NWC is about 2300 kg/m$^3$.

**H. Al-Khaiat and M.N. Haque** [8] investigated the effect of initial curing on early strength and physical properties of a lightweight concrete. They have used a high strength structural lightweight concrete using Lytag LWA with a slump of about 100 mm, fresh unit weight of 1800 kg/m$^3$ and 28 day cube compressive strength of approximately 50 MPa. The specimens initially cured as; full curing, 1day curing, 3 day curing and 7 day curing. According to test results the compressive strengths of SLWC seems to be less sensitive to lack of curing than the NWC, at least in the first month of exposure. However, lack of curing seems to affect long-term strength development of SLWC.

**Khandaker M. Anwar Hossain** [10] carried out an investigation on the suitability of using volcanic pumice (VP) as cement replacement material and as coarse aggregate in lightweight concrete production. Tests were conducted on cement by replacing 0% to 25% of cement by weight and on concrete by replacing 0% to 100% of coarse aggregate by volume. The properties of volcanic pumice concrete (VPC) using different percentages of volcanic pumice aggregate (VPA) were evaluated by conducting comprehensive series of tests on workability, strength, drying shrinkage, surface absorption and water permeability. The results showed that the VPC has sufficient strength and adequate density to be accepted as structural lightweight concrete. However, compared to control concrete, the VPC has lower modulus of elasticity and has more permeability and initial surface absorption.

**T. Parhizkar et.al.** [14] presented experimental investigation on the properties of volcanic pumice lightweight aggregates concretes. To this end, two groups of lightweight concretes (lightweight coarse with natural fine aggregates concrete and lightweight coarse and fine aggregates concrete) are built and the physical/mechanical and durability aspects of them are studied. The results of compressive strength, tensile strength and drying shrinkage show that these lightweight concretes meet the requirements of the structural lightweight concrete.

**P.C.Taylor**[10] presently a professor at Wuhan University of Technology has said that mineral admixtures affect the physical and mechanical properties of High Strength Structural Light Concrete. Addition of Fly Ash enhances the compressive strength and splitting tensile strength of HSSLC when FA was more than 20% in cementitious materials, its 28 days compressive strength and splitting tensile strengths are less than those of the concrete without FA. Addition of silica fume enhances the compressive strength about 25% and splitting tensile strength also.

**Banthia, N. and Trottier,J**.[1] conducted research on concrete reinforced with deformed steel fibers and suggested that in lightweight fiber reinforced concrete the addition of fibers produces an increase in compressive strength.

**Compione, G., et.al.** [4] suggested that brittle nature of lightweight aggregate can be overcome by increasing the ordinary confinement of transverse reinforcement and/or by adding reinforcing fibers to the concrete matrix. Also they have suggested that the presence of fibbers reduces material decay in the field of the strains exceeding that corresponding to the peak value of strength.

**Campione G., Mindess S., and Zingone G.** [2] suggested that in the case of normal weight or light weight high strength concrete fibers in combination with traditional steel reinforcements reduce the brittleness characterizing these advanced materials. Fibers improve ductility of concrete and avoid congestion of secondary reinforcements required in critical regions of structures designed in seismic zones. Lightweight concrete, which was largely utilized for its non-structural properties (as lagging or soundproofing material), has also been employed more recently to make structural elements, in particular in the field of precast concrete structures.

**Arunachalam et.al.** [14] investigated the compressive and tensile strengths of lightweight concrete (LWC) of density 1700 kg/m$^3$ to 1800 kg/m$^3$ with different aluminium powder content using cube and cylinder specimens. Based on an earlier investigation of the first two authors, cement to combined aggregate ratios of 1:6, 1:8, and 1:10 have been selected. Both sand and quarry dust have been tried as fine aggregate. Aluminium powder was added at 0.2% to 0.8% by weight of cement. The strength related tests were carried out on hardened cement concrete at the age of 7 days and 28 days. Hence, the results showed that 1:6 mix proportions gives more compressive strength than the other two mix proportions in both the cases with quarry dust and sand. However, compared with quarry dust mixes, sand mixes gave more strength.

Since lightweight concrete has the potential to produce commercial concrete with many advantages, various experimental investigations and analysis have been made by researchers to determine different properties and aspects of this new material. However, its progress is hampered due to lack of knowledge in many developing countries like India. To overcome this gap, there is a need to introduce the results drawn from these researches in the standard code so that further experiments can be carried out, as there is a lot of scope of development in construction industry.

## 6. CONCLUSION

Concrete has undergone rapid and phenomenal development in the past few years and is of utmost importance to the construction industry. As a result, lightweight concrete has emerged as the concrete which serves both economical and environmental concerns. Since lightweight aggregate can be used in cast in place, load bearing and non-load bearing structures, it can be an alternative for normal weight coarse aggregate, which are depleting due to fast pace of construction activity. At present, in India standard codes are only specified for construction of lightweight concrete masonry blocks. For the scope of more development, there is a need to introduce standard codes for lightweight concrete. Therefore, for a successful project the use of lightweight concrete will provide an economical solution for various engineering applications.

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