Preface

Lightweight aggregate concrete (LWAC) has its roots in the ancient period ca. 3000 years before the Christian Era. The aggregates used for making concrete were of volcanic origin. With time, the demand for LWAC increased and technologies were developed to produce the aggregates in factories. The raw materials used for producing lightweight aggregates (LWA) are natural minerals like clays, shales, and slates, as well as industrial by-products like fly ash, bed ash, blast furnace slag, etc. Synthetic organic aggregates, like polystyrene beads, are also used for making insulation concrete.

Today, lightweight aggregates are available in a wide range of densities, strengths, and sizes. This makes it possible to design concrete with a very wide spectrum, a concrete of very low density for insulation and, at the same time, a high strength concrete, more than 80 MPa 15 cm cube compressive strength, for structural purposes. The basic advantage of LWAC is its low density, which reduces the dead load and provides insulating properties. Along with this, it is easy to handle, and heavy duty tools are not required.

In spite of the increasing use and demand, there is still a lack of adequate explanations to understand the mechanisms responsible for the strength and durability properties of LWAC. This book is written to give an overall picture of LWAC, from the historical background, aggregate production, proportioning and production of concrete, to applications in structures.

Physical properties and chemical durability are described in detail. The physical properties include density, strength, shrinkage, and elasticity. Chemical durability includes resistance to acids, chloride ingress, carbonation, and freeze-thaw resistance. Fire resistance is also included, which is seldom considered, but is a very important aspect of the safety of the structure.

Microstructure development and its relation to the durability properties of LWAC generally are not highlighted in the literature. The development of bonds, the microstructure with different binder systems, and different types of lightweight aggregates are explained. They show how lightweight aggregate concrete differs from normal weight concrete. The chapters on chloride ingress and freeze-thaw resistance are detailed because of the use of LWAC in off-shore construction, especially in Norway.

The economical aspects of using LWAC are also reviewed. Emphasis is placed on the fact that although the cost of LWAC is high, the total cost of construction has to be considered, including the cost of transport, reinforcement, etc. When these are considered then LWAC becomes cheaper and attractive. The life cycle cost of the concrete is another consideration for calculating long-term savings on maintenance costs.

Some examples, from different parts of the world where LWAC is used successfully, are also included. This is an illustrative book that explains different phenomena involved in the design and the microstructure development of concrete in a very simple language. A glossary of the terminology and definitions is included to help practicing architects and engineers tailor a concrete that is resistant to the aggressive atmosphere to which it is often exposed.

Satish Chandra — Göteborg, Sweden
Leif Berntsson — 1 June 2001

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Introduction

The use of lightweight aggregate concrete (LWAC) can be traced to as early as 3000 BC, when the famous towns of Mohenjo-Daro and Harappa were built during the Indus Valley civilization. In Europe, earlier use of LWAC occurred about two thousand years ago when the Romans built the Pantheon, the aqueducts, and the Colosseum in Rome. It is interesting to note that pumice is still used today as an aggregate for structural concrete in certain countries such as Germany, Italy, Iceland, and Japan. In some places, like Malaysia, palm oil shells are used for making lightweight aggregate concrete.

Earlier lightweight aggregates (LWAs) were of natural origin, mostly volcanic: pumice, scoria, tuff, etc. These have been used both as fine and coarse aggregates. They function as active pozzolanic materials when used as fine aggregates. These interact with the calcium hydroxide generated from the binder during hydration and produce calcium silicate hydrate which strengthens the structure and modifies the pore structure, enhancing the durability properties.

With the increasing demand and the non-availability of natural LWAs worldwide, techniques have been developed to produce them in factories. These are produced from the natural raw materials like expanded clay, shale, slate, etc., as well as from industrial by-products such as fly ash, bed ash, blast furnace slag, etc. The properties of the aggregates depend upon the raw materials and the process used for producing them.

Today, lightweight aggregates are produced in a very wide range of densities varying from 50 kg/m^3 for expanded perlite to 1000 kg/m^3 for clinkers. With these aggregates and high range water reducers, it is possible to make LWAC of 80 MPa 15 cm cube compressive strength.

Because of the practical advantages which it possesses, LWAC has, in recent years, become an important structural material and the demand for it is increasing. A savings in the weight of the superstructure means that foundations can be reduced in bulk, and time and expenses saved in erection and handling of components, so that smaller lifting equipment can be employed or larger precast units can be handled.

The low density results in high thermal insulation of buildings and, in some instances, the thickness of roofs and walls can be reduced. Where there is reduction in weight, a higher degree of thermal insulation will be achieved.

Nearly all LWACs are inherently fire resistant. In addition, depending upon the density and strength, the concrete can be easily cut, nailed, drilled, and chased with ordinary wood-working tools. One such example is 3L concrete developed at the Chalmers University of Technology, Göteborg, Sweden. The name is given on the basis of three properties: lightweight aggregate concrete, low density, and strength less than 20 MPa.

In the UK, clinker aggregate concrete was used in the construction of the British Museum in the early part of the 20^{th} century. The output of clinker aggregates increased enormously in the ensuing decades, but its manufacture is now declining since oil and other fuels are more widely used for firing the furnaces. This trend is likely to continue and, as a result, the use of sintered pulverized fuel ash (fly ash) has been steadily increasing over the last decades. Besides this, other types of ashes have also been used for producing aggregates like bed ashes from boilers, etc.

In 1918, Stephen J. Hayde patented the lightweight aggregate "Haydite," the first one made by the expansion of shale, which came into production in the US. Synthetic aggregates of this type have been universally accepted, making satisfactory reinforced or prestressed concrete.

Other early applications are the ships built with the LWAC at the end of World War I, 1917. One of the famous ships was named *Selma*. After so many years of service in harsh climates, it is still in satisfactory condition. This speaks of the durability of lightweight aggregate concrete. In addition to the materials, the techniques adopted by the ship builders to construct the ship is equally important. It was so well constructed that some of the factors have become specifications for ship making.

The first building frame of reinforced LWAC in Great Britain was a three story office block at Bentford, near London, built in 1958. Since then, many structures have been built of precast, in-situ prestressed, or reinforced lightweight aggregate concrete.

With an increase in off-shore construction, and the general reluctance for using LWAC due to its low density and strength, the demand for improved strength has increased. This has led to the development of high strength structural lightweight aggregate concrete (HSLAC), specifically in Norway. The low strength of the aggregate has been balanced by using high strength cement mortar. Because this high strength matrix has a dense pore structure, it may decrease the insulating properties in comparison to the normal strength lightweight aggregate concrete.

The dense cement mortar matrix of the high strength LWAC also decreases fire resistance. However, this can be improved by modifying the pore structure using polymers, air-entraining agents, or polymer fibers. By the use of industrial by-products like fly ash, slag, and other types of ashes in making LWA, ecological and environmental problems are solved to some extent.

Lightweight aggregate is expensive, but the cost is calculated not just on the basis of aggregates or LWAC. Other costs involved are taken into consideration also, like working cost, reinforcement cost, transport cost, etc. Being lightweight, it is easy for the workers to handle and they complain less of back pain. The biggest advantage, which is generally not raised, is the enormous expenditure involved in medical aid to workers. Consequently, the contractor has to find substitute workers to avoid project delays. Another advantage is in the demolition cost. It takes less energy to demolish LWAC compared to normal concrete, as smaller equipment can be used. Apart from this, since it contains air, the amount of the waste will be less than when using normal concrete.

The bond between the aggregate and the matrix is stronger in the case of LWAC than in normal weight concrete. Cement paste penetrates inside the aggregates due to their porous nature. Thus, there is very little or no interfacial transition zone between the aggregates and the matrix, the weakest zone. It is a very important feature from the durability aspect of LWAC.

The use of lightweight aggregate concrete is increasing and research and development are going on worldwide to develop high performance structural lightweight aggregate concrete.