Employment and Characterization of Lightweight Concrete

Gustavo H. M. Serqueira[1], Daniela A. M. Barcelos [2], Hélvio J. Barcelos[3], Adeilton S. Umbelino[4], Petrus A. Neto[5], Raimundo C. S. Júnior[6]

[1, 4, 6] *UNA University Center, Brazil,* [2] *Federel University of Minas Gerais, Brazil*

Abstract *– The manufacture of lightweight concrete is economically viable because it presents low values of specific mass, which significantly reduces the proper weight of the cementitious elements, influencing the active loading in the foundation structures. In addition, the use of lightweight structural concrete contributes to increased productivity since transport and launch operations are facilitated due to their lower self-weight. However, despite being an alternative material to conventional concrete already used in several countries, the technology in Brazil is still little spread. This article shows the worldwide use of lightweight concrete over the years and describes some of the works that employed it in its construction. Also presented is the characterization of lightweight concrete in the fresh and hardened states. The main physical properties, such as specific mass, index of consistency and water absorption, mechanical properties of compressive strength, tensile and modulus of elasticity, thermal properties of thermal conductivity and thermal diffusivity of light concrete are exposed and analyzed. The work also describes the causes of lightweight concrete having less resistance to aggressive agents and presents pore connectivity as a fundamental prerequisite for the deterioration of structures. Aspects related to production, dosage, transport, launch and densification are also addressed, highlighting the phenomenon of segregation, which constitutes a point of attention that demands care to avoid its occurrence.*

Keywords *— Lightweight concrete, employment, characterization, properties*

I. INTRODUCTION

Portland cement is the most widely used construction material in the world, largely due to the ease of extraction and production of its components, as well as the ease of execution of these structures and its widespread use worldwide.

The conventional concrete has high specific mass, with consequent increase in its own weight of the elements executed in concrete.

Due to the fact that it presents reduced values of specific mass, with consequent reduction of its own weight of the cementitious elements, combined with a greater productivity and reduction of the costs in relation to the conventional concrete, the light concrete is being widely used in the constructions in Brazil and around world.

This work aims to characterize lightweight concrete by analyzing its specific mass, strength, durability, thermal conductivity, dosage, production, release and densification, as well as to analyze the performance of lightweight concrete compared to conventional concrete.

II. CONCEPT AND CLASSIFICATION OF LIGHTWEIGHT CONCRETE

Lightweight concretes are named this way just because they have low specific mass. According to NBR 6118, the specific mass of conventional concretes varies between 2000 kg / m³ and 2800 kg / m³. So, we can classify lightweight concretes as those which have a specific mass of less than 2000 kg / m³ [1].

Lightweight concrete is construction material with a porous structure that presents refractory and thermal insulation properties, specific masses between 300 kg / m³ and 2000 kg / m³, which can be obtained by replacing part of the solid materials of conventional concrete with air [1].

The property that most differentiates light concrete from conventional is the reduction of specific mass. However, changes in workability, mechanical strength, modulus of deformation, thickness of the transition zone between the aggregate and the cement matrix are also observed [2].

There are three possibilities of localization of the air in the concrete: in the aggregate particles, in the cement paste and between the particles of the large aggregate, without using the small aggregate [3].

Based on the positioning of the air, the lightweight concretes are classified as:

a) Concrete with light aggregate: with total or partial replacement of conventional aggregates for light aggregates. They are the only concretes produced that can achieve acceptable resistances for structural purposes [1].

b) Cellular or aerated concrete: it results from the action of products added to the slurry of the concrete that react producing air bubbles. Although accepted and usual, this technique is questioned by many authors since the resulting material is in the paste and not in the concrete [1].

c) Concrete without fines: produced only with binder and large aggregate, and its resistance is directly related to the resistance of the aggregate and to the consumption of cement. This concrete can produce materials such as partition panels, drainage structure and sub-base of sports courts [1].

Figure 01 schematically illustrates the three types of lightweight concrete.

This work will be restricted to the study of concretes with light aggregates, that is, those used for structural purposes.

A. Applications of Lightweight Concrete

Structural lightweight concrete is applied in many construction sectors, but its technical and economic viability is more evident in structures in which most of the requests are related to its own weight, such as bridges and multi-storey buildings, component transports, prefabricated building systems, floating structures and tanks [5].

The wide use of lightweight concrete in the world is mainly due to the lower specific mass, which results in the reduction of efforts in the structure of buildings, economy with shapes and structures and the reduction of costs with transport and assembly of prefabricated constructions [6].

Another characteristic of lightweight concrete is low thermal conductivity, property that improves with decreasing unit mass.

According to [4], the thermal insulation of a 15cm thick aerated concrete wall is about four times greater than that of a 23 cm thick massive brick wall.

Thus, it can be concluded that elements manufactured with light concrete help in the natural thermal conditioning of buildings, reducing the financial resources applied in artificial conditioning systems.

Besides these technical properties, some lightweight concretes have the additional merit of allowing the use of industrial waste, which is an alternative for regions where deposits of large and mainly small aggregates are scarce [7].

Although the use of lightweight concrete is being expanded in this century, the Romans had already used it to construct the 44m diameter dome of Pantheon, Couliseu and other structures approximately 2000 years ago [8].

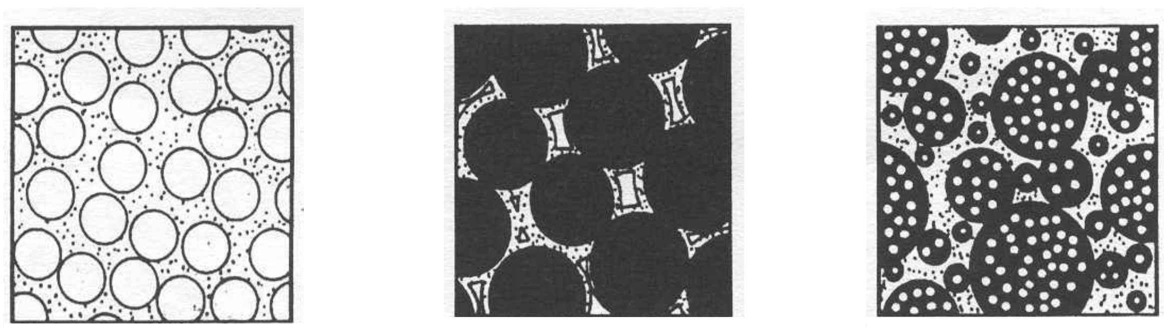
During World War I, expanded clay was used as a lightweight aggregate for reinforced concrete construction of barges and ships in the United States. From the twenties, concrete blocks have been produced with lightweight concrete [7].

After World War II, the National Bureau of Standards (NBS) and the U.S. Bureau of Reclamation studied the properties of concrete made with a wide variety of lightweight aggregates.

These studies and others, carried out later, increased interest in the use of lighter concrete in building structures, bridge slabs and in the precast industry [9].

In the last 40 years, lightweight concrete has been applied in marine environments, such as on oil platforms [2].

Figures 02 (a) and (b) present the Rochaverá Corporate Towers business complex, located on the Marginal Pinheiros River in São Paulo - SP. This work used facade panels in light structural concrete in the two towers (A and B) inaugurated in 2008, with the purpose of alleviating structural requests [5].



Aerated Concrete | Concrete without fine | Concrete with light aggregate

Figure 01: The three types of lightweight concrete
Source: [4]

Figure 2: (a) Assembly of facade panels during the construction of Rochaverá Corporate Towers (b) Towers A and B of the building, completed in 2008
Source: [5]

Figure 3 shows the Benicia-Martinez bridge, located in California, United States. Lightweight concrete was used to overcome spans around 200 m and reduce costs with the foundation structure [10].

Figure 03: Benicia-Martinez Bridge, United States
Source:[10]

B. Properties of Lightweight Structural Concrete

a). Specific Mass and Compressive Strength: Together with the workability, specific mass and compressive strength are the two properties usually required for lightweight structural concrete [11] and are directly related to the type and grain size of the lightweight aggregate used [5].

The American standard Society for testing and materials - ASTM C 330-77 states that the specific mass of structural light concrete in the dry state must not be greater than 1850 kg / m 3 and must have values between 1400 kg / m3 and 1800 kg / m3. However, it is known that the use of a highly porous aggregate with a maximum dimension greater than 19mm allows the reduction of the specific concrete mass to values below 1440 kg / m³, with a compromise of the minimum compressive strength of 17MPa at 28 days, required for lightweight structural concrete [11].

In lightweight structural concretes, the size and granulometry of the aggregates have a greater influence on the specific mass and compressive strength than, comparatively, on conventional concretes. In fact, the values of the specific mass and the compressive strength of the lightweight aggregates are inversely proportional to their size. Furthermore, it is observed that the lightweight concretes achieve the stability of the final values of compressive strength more quickly, and, low elevation after 28 days of age when compared to the conventional ones [5].

In Brazil, the highest compressive strength of concrete with expanded clay is 73 MPa, obtained by [12] in concretes with specific mass of 1720 kg / m3. To obtain this resistance, a mix with cement consumption of 1200 kg / m3 and aggregate with a maximum characteristic dimension of 6.3 mm was performed.

It is observed that concretes with compressive strength below 50 MPa, specific mass between 1400 kg / m3 and 1800 kg / m3 have been obtained with the use of Brazilian expanded clay [5]. Figure 4 shows the relationship between compressive strength and the specific mass of light concrete produced with Brazilian expanded clay.

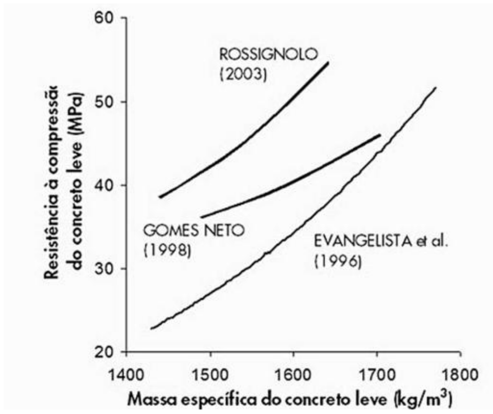


Figure 4: Relation between compressive strength and specific mass value of light concrete with Brazilian expanded clay.
Source: [5]

b). Tensile strength: The tensile strength in lightweight concrete is lower than the strength of concrete with normal specific mass, considering the same degree of compressive strength. This characteristic can be explained due to voids in light aggregates, which may occupy, in the case of expanded clays, 50% of the total volume of the concrete. [13] observed that the diametral compression tensile strength in concretes produced with Brazilian expanded clay ranges from 6% to 9% of the compressive strength.

c). Modulus of elasticity: The modulus of elasticity of the concrete is obtained from the slope of the strain-strain curve under uniaxial tensile or compression loading. In lightweight concretes, the deformation modulus is directly related to the type and amount of light aggregate used. The closer the values of the deformation modulus of the aggregate and the cement paste, the better the behavior of the concrete in the elastic regime [5].

According to [7], considering the same compressive strength, the modulus of elasticity of lightweight concrete is generally lower than that of conventional concrete.

The value of the modulus of elasticity of light concrete ranges from one-third to two-thirds of the modulus of elasticity of conventional concrete [4].

When compared to conventional concrete, lightweight aggregate concrete has slightly higher shrinkage (shrinkage during drying) slightly higher and creep (increase of deformation over time for a same tension) considerably higher. Thus, it is believed that low compressive strength and low modulus of elasticity affect flow significantly more than drying retraction [11].

According to [14], the modulus of elasticity is of considerable importance for lightweight structural concrete due to its influence on the arrows of the parts subjected to bending, on the internal forces of the cross section of parts subject to compression and on the critical load in the case of parts prone to failure due to elastic instability.

In these cases, the low value of the modulus of elasticity influences negatively. However, there is a positive influence on the mechanical strength of the parts subjected to the impact (ductility), which improves with the lower values of the modulus of elasticity.

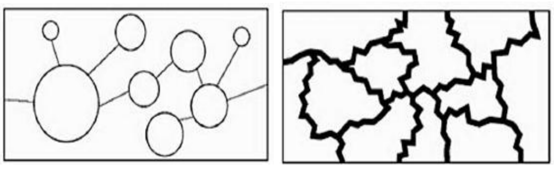


Figure 5: (a) High Porosity / Low Permeability - (b) Porous / High Permeability
Source: [5]

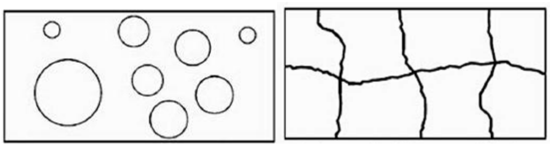


Figure 5: (c) Porous / Non-Permeable - (d) Low Porosity / High Permeability
Source: [5]

d). Durability of lightweight concrete: Due to the high porosity of lightweight concrete, the composite tends to decrease its resistance to aggressive agents. The evaluation of the concrete's durability is due to its own porous structure the constitution of the pores and the interconnections between them, not necessarily porous structures are more permeable [5]. The permeability has a direct influence on the durability of the concrete.

Figures 5 (a), (b), (c) and (d) illustrate the difference between porosity and permeability, rectifying pore connectivity as an important prerequisite for the transport of aggressive agents in concrete.

Due to the similarity between the modulus of elasticity of the light aggregate and the ciment, the absence of microcracks occurs in the transition zone between the aggregate and the cement matrix [15].

The pozzolanic reaction between the aluminum silicates of the powder of the light aggregate grains and the calcium hydroxide of the cement matrix is responsible for the increase of the resistance and densification of the transition zone [16].

This densification in the transition zone tends to reduce the permeability of lightweight concrete, consequently reducing the transport of aggressive agents through pores and pore interconnections, with a consequent direct influence on the durability of lightweight concrete.

e). Thermal Properties: The Thermal conductivity is related to the ability of a material to conduct heat and is defined by the ratio between the transmitted heat flux of a given unit area and the temperature gradient [16]. The amount of internal water in the pores of the concrete directly influences the thermal conductivity of the concrete. In conventional concretes the higher the saturation, the lower the thermal conductivity in the hardened state, and in the hardened concrete with the increased moisture content, the thermal conductivity is increased. This phenomenon is easily explained by the thermal conductivity of the air between the pores being smaller than that of the water, being less than half the thermal conductivity of the cement paste [17].

The Thermal diffusivity represents the rate of occurrence of temperature variations within a mass. Thus, it is an indicator of the ease with which concrete can undergo these variations [17]. The thermal diffusivity is directly related to the conductivity and inversely related to the specific heat and the product of the specific mass.

In the conventional concrete, the specific mass and the specific heat do not vary much and thermal diffusivity depends directly on the thermal conductivity, whereas in the light concrete the specific mass and the thermal conductivity decrease, resulting in a higher value of thermal diffusivity [16].

NBR 12815 states that the diffusivity measure is to determine the time and temperature difference between the interior and the surface of a sample [18].

C. Structural Lightweight Concrete Production

a). Dosage and Water Cement Relationship: The dosage of lightweight concrete is similar to the dosage of conventional concretes, however, it is necessary to consider some factors, such as concrete specific mass, absorption and permeability of light aggregates, variation of the mass of the aggregate as a function of its size, in addition to characteristics of the aggregates to be used [16].

The two methods for the dosing of concrete are the Mass Method and the Volumetric Method according to ACI 211.2-98 [19], which are:

- Mass method: for concrete with small aggregates with normal specific mass and small light aggregates;
- Volumetric Method: for concrete with light small and large aggregates.

The granulometric adjustment using the aggregate with a maximum dimension equal to the large aggregate tends to increase cohesion, reducing segregation and increasing the compressive strength of the mass, tends to optimize the dosage of the lightweight concrete. Mineral additives may be used in the blending in the manufacture of lightweight concrete, but care must be taken in the application of the additive and it must be mixed with the concrete before application.

In light concretes the water absorption of the aggregates should be considered, indicating the pre-saturation of the aggregates. It is also indicated the addition of water to the mixture, proportionally to the water to be absorbed by the light aggregate, maintaining constant the relationship between water and cement [5].

b). Workability: The range of change in the abatement of lightweight concrete is usually less than that recorded in conventional concrete. [5]

In light concrete, the water absorption of the aggregates that directly influence the workability of the concrete after mixing must be considered. In the case of cone trunk abatement standardized by NBR NM 67 [20], the lightweight concretes present lower abatement values than conventional concrete as shown in Figure 6.

By gravity, light concrete deforms less than conventional concrete. However, lightweight concretes with 80mm abatement can have the same workability as conventional concrete with 100mm abatement for example.

Cone trunk spreading is considered an adequate way to evaluate the workability of lightweight concretes. This method consists of evaluating the deformation of the concrete through repetitive lifting and falling movements. In this test the values obtained by the lightweight concretes are similar to the results obtained in conventional concretes [5].

c). Transport, Launch and Density: During the transport process the segregation phenomenon can occur due to the low values of specific mass. Such phenomenon can be minimized by controlling the water / cement relationship, the content of the small aggregates, the mineral additions and the dosage with the appropriate cohesion and consistency.

The hydrostatic pressure due to the humidity and granulometry of the aggregates directly influence the water intake during the pumping process, it is necessary to control this water intake with the pre-saturation of the light aggregates.

The specific mass also influences the launch process. As a result of the lower values of specific mass, the efforts transmitted to the forms are inferior to the conventional concretes [5].

Low-frequency vibrators and vibration rays with half the values used in conventional concrete tend to minimize voids during the densification process [15].

III. CONCLUSION

With the this work it was possible to present, characterize and present a study on light concrete, its applications, characteristics regarding workability, specific mass, durability, production, transport, launch and densification.

Porosity and permeability have a direct influence on the durability and strength of the concrete. And it can be used for structural elements or any other application similar to conventional concrete, but it must have a quality control since its production, through the transport and the launch.

We can then apply lightweight concrete in structural and sealing elements, with a high reduction of the specific mass compared to conventional concrete, but with an excellent performance in the mechanical properties and workability, providing lighter parts without compromising its structural function.

ACKNOWLEDGMENT

The authors thank the Brazilian agencies: National Counsel of Technological and Scientific Development (CNPq), Coordination for the Improvement of Higher Education Personnel (CAPES), Research Support Foundation of Minas Gerais (FAPEMIG) for the support provided to this study.

REFERENCES

[1] J. Maycá, R. A. Cremonini, and F. Recena, “Contribuição ao estudo da argila expandida nacional como alternativa de agregado graúdo para concretos leves estruturais.,” Universidade Federal do Rio Grande do Sul, 2008.

[2] A. F. Angelin, “Concreto leve estrutural - Desempenhos físicos, térmicos, mecânicos e microestruturais,” Universidade Estadual de Campinas, 2014.

[3] M. Neville, Propriedades do Concreto, 2o Edição. São Paulo: Pini, 1997.

[4] Short and W. Kinniburgh, Ligthweight Concrete, 1o Edição. London: C.R, 1963.

[5] J. A. Rossignolo, Concreto leve estrutural: produção, propriedades, microestrutura e aplicações. São Paulo: Pini, 2009.

[6] C. Santis, E. P. Sichieri, J. A. Rossignolo, G. Ferreira, and J. Fiorelli, “Caracterização de massas cerâmicas do estado de S. Paulo para produção de agregados leves para concreto,” Cerâmica, vol. 59, no. 350, pp. 198–205, Jun. 2013.

[7] H. S. Sobral, Concretos Leves, tipos e comportamento estrutural, 3o Edição. São Paulo: Associação Brasileira de Cimento Portland, 1996.

[8] H. Spratt, Ao Introduction to Lightweight Concrete.

London: Cement & Concrete Association, 1960.

[9] G. Garlet, “Aproveitamento de resíduos de E.V.A. (Ethylene Vinyl Acetate) como agregado para concreto leve na construção civil,” Universidade Federal do Rio Grande do Sul, 1998.

[10] ASPIRE, “When lighter is better,” ASPIRE - Concr. Bridg. Mag., no. Summer 2007, pp. 20–24, 2007

[11] P. J. M. Metha and P. K. Monteiro, Concreto: estrutura, propriedades e materiais. São Paulo: Ed. Pini, 1994.

[12] de P. Gomes Neto, “Dosagem de microconcretos leves de alto desempenho para produção de pré-fabricados de pequena espessura - Estudo de caso.,” Universidade de São Paulo, 1998.

[13] A. F. Angelin, L. C. L. J. Ribeiro, M. S. G. Pires, A. E. P. G. A. Jacintho, R. C. C. Lintz, and L. A. Gachet-Barbosa, “Effects of Consumption of Cement in Mechanical Properties of Lightweight Concrete Containing Brazilian Expanded Clay,” Appl. Mech. Mater., vol. 368–370, pp. 925–928, Aug. 2013

[14] Short and W. Kinniburgh, Ligthweight Concrete, 1o Edição. London: Applied Science Publishers, 1963.

[15] T. A. Holm and T. W. Bremner, “High Strength Lightweight Aggregate Concrete,” in High Performance Concrete: Properties and Applications, Inglaterra: McGraw-Hill, 1994, p. 388.

[16] W. G. Moravia, “Comportamento térmico e avaliação microestrutural de concretos leves produzidos com argila expandida,” Universidade Federal de Minas Gerais, 2004.

[17] A. M. Neville, Propriedades do Concreto. São Paulo: PINI, 1982.

[18] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, NBR 12815: Concreto endurecido — Determinação do coeficiente de dilatação térmica linear — Método de ensaio. Rio de Janeiro, 2012, p. 3.

[19] American Concrete Institute - ACI, ACI 211 . 2-98: Standard Practice for Selecting Proportions for Structural Lightweight Concrete. 2004, pp. 1–18.

[20] ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, NBR NM 67: Concreto - Determinação da consistência pelo abatimento do tronco de cone. Rio de Janeiro, 1998, p. 8.