DURABILITY PERFORMANCE OF LIGHTWEIGHT AGGREGATE CONCRETE FOR HOUSING CONSTRUCTION

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ABSTRACT: Durability can be defined as the ability of material to withstand the effects of its environment. In the building material its may be interpreted as chemical attack, water absorption and carbonation. Chemical attack usually encountered as aggressive ground-water, particularly sulphate, polluted air and spillage of reactive liquids. A chemical aspect of durability is the stability of the material itself, particularly in the presence of moisture. Concrete made with lightweight aggregate exhibit a higher moisture movement than is the case with normal weight concrete. Based on the a 24 hr absorption test, lightweight aggregate generally absorbs from 5 to 20 percent by weight of dry aggregate, depending on the pore structure of the aggregate. The important difference is that the moisture content in lightweight aggregates is largely absorbed into the interior of the particles whereas in normal weight aggregates it is largely surface moisture.

Rate of absorption in lightweight aggregates is a factor which also has a bearing on mix proportioning, handling, and control of concrete, and depends on the aggregate particle surface pore characteristics plus other factors.

Keywords: Durability, lightweight aggregate concrete, natural material, mechanical properties, lightweight aggregate.

1. INTRODUCTION

In concrete construction, structural lightweight concrete is an important and give solves weight and durability problems in building. It many item around the characteristic of lightweight aggregate for housing and the effect of material regarding the durability. The compressive strength, water absorption and workability are significant for the structural lightweight aggregate concrete. One of the ways to reduce the weight of structure is the use of lightweight aggregate concrete (LWAC). The benefit of LWAC as structural material was recognized as far back as Roman days.

Lightweight aggregate concrete is usually defined as a concrete having an air-dry density of below 1850 kg/m³ (115 kg/m³) as opposed to a normal concrete having a density of about 2300 kg/m³ (145 lb/ft³) but a finite limit is undesirable.

The lightweight concrete has its obvious advantages of high strength/weight ratio, good tensile strength, low coefficient of thermal expansion, and superior heat and sound insulation characteristic due to air voids in lightweight aggregates [Mouli, et al., 2008].

Lightweight concrete has strength comparable to normal weight concrete, yet is typically 25% to 35% lighter. Structural lightweight concrete offers design flexibility and substantial cost savings by providing: less dead load, improved seismic structural response, longer spans, and ext. [http://www.escsi.org/].

Structural lightweight concrete has its obvious advantages of higher strength/weight ratio, lower co-efficient of thermal expansion and superior heat and sound insulation characteristic due to air voids in the lightweight aggregate. Furthermore, the reduction in dead weight of a construction could result in a decrease in cross-section of structural members and steel reinforcement [Hossain, 2006].

Concrete is composed essentially of cement, aggregates and water. In some cases an admixture is added, generally for the purpose of entraining air, but occasionally for special reasons such as modifying setting time or reducing water content.

The maximum size grading designations of lightweight aggregates generally available are ¾ in. (19 mm), ½ in. (13 mm), or 3/8 in. (10 mm). Maximum size of aggregate influences such factors as workability, ratio of fine to coarse aggregate, cement content, optimum air content, potential strength ceiling, and drying shrinkage [213R-87, A.C.I. 1987].

2. CHARACTERISTIC LIGHTWEIGHT AGGREGATE CONCRETE

An important feature of lightweight aggregate concrete is the good bond between the aggregate and the surrounding hydrated cement paste. This is the consequence of several factors. First, the rough surface texture of many lightweight aggregates is conducive to a good mechanical interlocking between the two materials. In fact, there is often some penetration of cement paste into the open surface pores in the coarse aggregate particles. Second, the moduli of elasticity of the lightweight aggregate particles and of the hardened cement paste do not differ much from one another [Neville, 1995].

Lightweight aggregates are light due to the inclusion of air voids and it follows that they are absorbent, expect for the very few with sealed cells. This absorbency plays an important part in the way the concrete performs in its wet state. Most lightweight aggregates are manufactured and hence are, by careful production control, uniform and consistent, which is important to mixing, placing and compaction [Clarke, 1993].

A variety of porous solids, both natural and man-made, are available for use as lightweight aggregates. As a general rule, the higher the porosity of the aggregate, the lower the thermal conductivity, density and strength of the lightweight concrete made with it. Aggregates having high porosity, such as vermiculite, make low-weight concretes of excellent thermal insulating value but little resistance to stress. The less porous lightweight aggregates can produce concretes which are strong enough to resist structural stresses, but which are denser and less efficient thermal insulators than those made with the high-porosity aggregates [Shirley, 1975].

2.1 Bulk Density and Moisture Content

Most lightweight aggregate manufacturers publish the average dry bulk density for their materials and this provides a satisfactory value for initial examination of mix design and cost. However, both the dry bulk density and the moisture content cal alter, and unless these changes are measured and allowed for the consequences can affect both the costs and performance of the concrete [Clarke, 1993].

The bulk specific gravity of lightweight aggregate also varies with particle size, being highest for the fine particles and lowest for the coarse particles, with the magnitude of the differences depending on the processing methods. The practical range of bulk specific gravities of coarse lightweight aggregates, corrected to the dry condition, is about 1/3 to 2/3 of that for normal weight aggregates [213R-87, A.C.I. 1987].

The dry, loose bulk density ranges from about 380 kg/m³ to 870 kg/m³ for coarse aggregates and 700 kg/m³ to 1200 kg/m³ for fine aggregates. For typical normal aggregates the corresponding figures are about 1400 kg/m³ and 1600 kg/m³ [Lydon, 1972].

2.2 Water Absorption

Generally, lightweight concretes have considerably higher water absorption values than do normal weight concretes. High absorption, however, does not necessarily indicate that concretes will have poor durability or high permeability [213R-87, A.C.I. 1987].

Most lightweight aggregates exhibit significantly higher water absorption than normal weight aggregates. This results in lightweight aggregate concrete having higher absorptions than typical normal weight concretes on a mass basis although the difference is not as large as expected since the aggregate particles in lightweight aggregate concrete are surrounded by a high-quality matrix [Clarke, 1993].

The water absorption is, of course, time-dependent and very much depend upon the aggregate type and to some extent upon particle size. It varies from being fairly slow, continuing at a more or less constant rate for a long time, to being extremely rapid initially followed by a much slower constant rate for along time. For many purposes the early absorption is the important one and this ranges from about 5 to 15% of the dry weight after 24 h, perhaps 3% to 12% after 30 min. typical data normal aggregates are 0.5% to 2% for 24 h absorption [Lydon, 1972].

The 24 hour absorption of lightweight aggregate range from 5 to 20 per cent by mass of dry aggregates but, for good quality aggregate for use in structural concrete, it is usually not more than 15 per cent.

By comparison, the absorption of normal weight aggregate is usually less than 2 per cent. On the other hand, fine normal weight aggregate may have a moisture content of 5 to 10 per cent, sometime even more, but this water is on the surface of the aggregate particles.

There is another important consequence of the absorption of water by lightweight aggregate: when hydration of cement lowers the relative humidity of the capillary pores in the hardened cement paste, the water in the aggregate migrates outwards into these capillaries. Enhanced hydration is thus possible. The situation could be termed ‘internal moist curing’. This makes lightweight aggregate concrete less sensitive to inadequate moist curing [Neville, 1995].

2.3 Specific Gravity

Because of difficulties in determining the saturated surface-dry condition of many lightweight aggregates (a factor which obviously also affects the precision of water absorption data), data on specific gravity are not easily determined but, some guidance is possible.

The lightest coarse aggregates has a specific gravity, on a dry basis, of about 0.50 to 0.60, the other ranging from about 1.20 to 1.50. The fines are about 1.30 to 1.70, but depend very much very much upon grading, the density increasing with decrease in particle size, with the material passing a 150 μ sieve being about 2.20 to 2.50. Comparable data for normal aggregates are in the range of about 2.50 to 2.70 [Lydon, 1972].

Specific gravity of the aggregate particles in a saturated and surface-dry state is also difficult to determine because the presence of open pores on the surface does not make it possible to establish when this state has been achieved [Neville, 1995].

2.4 Slump

Based on British Standard, BS 1881, Part 102, 1983, Method for determination of slump, describes a method for determination of slump of cohesive concrete of medium to high workability. Slump is a most important factor in achieving a good floor surface with lightweight concrete and generally should be limited to a maximum of 4 in. (100 mm). A lower slump, of about 3 in. (75 mm), imparts sufficient workability and also maintains cohesiveness and "body", thereby preventing the lighter coarse particles from working up through the mortar to the surface. (This is the reverse of normal weight concretes where segregation results in an excess of mortar at the surface). In addition to "surface" segregation, a slump in excess of 4 in. (100 mm) will cause unnecessary finishing delays.

This is the oldest and most widely used test on site. The standard form suffers from the disadvantages that it is virtually impossible to lift the cone vertically at the end of the test and thus it is easy to tilt the concrete cone, thereby affecting the result. The cone can be lifted vertically only and there is no danger of tilting [Lydon, 1972].

2.5 Compressive Strength

British Standard 1881, Part 116, 1983, Method for determination of compressive strength of concrete cubes.

Compressive strength of structural concrete is specified according to engineering requirements of a structure. Normally, strengths specified will range from 3000 psi to 4000 psi (20.68 to 27.58 MPa) and less frequently up to 6000 psi (41.36 MPa) or higher. It should not be expected that the higher strength values can be attained consistently by concretes made with every lightweight aggregate classified as "structural" although some are capable of producing very high strengths consistently [213R-87, A.C.I. 1987].

The compressive strength of lightweight aggregate is usually related to cement content at a given slump rather than water-cement ratio. Water-reducing or plasticizing admixtures are frequently used with lightweight concrete mixtures to increase workability and facilitate placing and finishing. In most cases, compressive strength can be increased with the replacement of lightweight fine aggregate with a good quality of normal weight sand.

Compressive strength is the primary physical property of concrete (others are generally defined from it), and is the one most used in design. It is one of the fundamental properties used for quality control for lightweight concrete. Compressive strength may be defined as the measured maximum resistance of a concrete specimen to axial loading.

2.6 Flexural Strength

British Standard 1881, Part 118, 1983, describes a method for the determination of the flexural strength of test specimens of hardened concrete by means of a constant moment in the centre zone using a two-point (or third-point) loading.

All rollers shall be manufactured from steel and shall have a circular cross-section with a diameter of 20 mm to 40 mm; they shall be at least 10 mm longer than the width of the test specimen.

All rollers except one shall be capable of rotating around their axes and of being inclined in a plane normal to the longitudinal axis of the test specimen. The distance/between the outer rollers (i.e. the span) shall be equal to 3*d*. The distance between the inner rollers shall be equal to *d*.

2.7 Cement Content

The cement and water contents required for a particular strength and slump have significant effects on the hardened concrete properties.

With lightweight concrete, mix proportions are generally expressed in terms of cement content at a particular slump rather than by the water-cement ratio. Increasing the mixing water without increasing the cement content will increase slump and also increase the effective water-cement ratio. The usual range of compressive strengths may be obtained with reasonable cement contents with the lightweight aggregates being used for structural applications today. Generally air-entraining admixtures are found advantageous. The following table, which is based on a number of tests of job concretes, suggests the range of cement contents for 28 day compressive strengths for concretes with 3 to 4 inch (75 to 100 mm) of slump and 5 to 7 percent air contents [213R-87, A.C.I. 1987].

Table 1. Approximate relationship between average compressive strength and cement content.

Approximate Relationship Between Average Compressive Strength and Cement Content			
Compressive Strength		**Cement Content lb/ky³ (kg/m³)**	
psi	**(Mpa)**	**All-Lightweight**	**Sand-Lightweight**
2500	(17,24)	400-510 (237-303)	400-510 (237-303)
3000	(20,68)	440-560 (261-332)	420-560 (249-332)
4000	(27,58)	530-660 (314-392)	490-660 (291-392)
5000	(34,47)	630-750 (374-445)	600-750 (356-445)
6000	(41,37)	740-840 (439-498)	700-840 (415-498)

2.8 Unit Weight

Weight reduction for concrete of structural quality is the primary advantage of lightweight concrete. Depending upon the source of material, structural grade lightweight concrete can be obtained in a dry weight range of 90 lb/ft^3 to 115 lb/ft^3 (1440 kg/m^3 to 1840 kg/m^3). ASTM limits the weight of the coarse fractions-the first two-to 55 lb/ft^3 (880 kg/m^3) and the sand or fine fraction to 70 lb/ft^3 (1120 kg/m^3) dry loose basis. Generally the coarse fractions weigh from 38 lb/ft^3 to 53 lb/ft^3 (608 kg/m^3 to 848 kg/m^3) with the larger top size being the lighter for a particular source of material. The sand size will generally range from 50 t lb/ft^3 to 68 lb/ft^3 (800 kg/m^3 to 1088 kg/m^3) [213R-87, A.C.I. 1987].

By combining two or more of these size fractions or by replacing some or all of the fine fraction with a good local normal weight sand weighing from 95 lb/ft^3 to 110 lb/ft^3, (1520 kg/m^3 to 1760 kg/m^3) a weight range of concrete of 100 lb/ft^3 to 115 lb/ft^3 (1600 kg/m^3 to 1840 kg/m^3) can be obtained. The aggregate producer is the best source of information for the proper combinations to achieve a specific unit weight for a satisfactory structural lightweight concrete.

With a particular lightweight aggregate, normal weight sand replacement will increase the unit weight at the same compressive strength by about 5 lb/ft^3 to 10 lb/ft^3 (80 kg/m^3 to 160 kg/m^3). With the same source of material the additional cement required will increase the weight of 5000 psi (34.47 MPa) concrete over 3000 psi (20.68 MPa) concrete approximately 3 lb/ft^3 to 6 lb/ft^3 (48 kg/m^3 to 96 kg/m^3).

Unit weight is therefore a most important consideration in the proportioning of lightweight concrete mixtures. While this property depends primarily on the unit weight or density of the lightweight or normal weight aggregates, it is also influenced by the cement, water and air contents, and to a small extent, by the proportions of coarse to fine aggregate. Within somewhat greater limits the unit weight can be tied by adjusting proportions of lightweight and normal weight aggregates. For instance, if the cement content is increased to provide additional compressive strength, the unit weight of the concrete will be increased.

On the other hand, complete replacement of the lightweight fines with normal weight sand could increase the unit weight by approximately 10 lb/ft³ (160 kg/m³) or more at the same strength level. This should also be considered in the overall economy of structural lightweight concrete [213R-87, A.C.I. 1987].

2.9 Water – Cement – Ratio

With lightweight concrete, the water-cement ratio is not generally used, primarily due to uncertainty of calculating that portion of the total water in the mix which is applicable. The water absorbed in the aggregate prior to mixing is not part of the cement paste, and complication is introduced by absorption of some indeterminate part of the water added at the mixer.

However, it is quite probable that this absorbed water is available for continued hydration of the cement after normal curing has ceased. The general practice with lightweight aggregates is to proportion the mix, and to assess probable physical characteristics of the concrete, on the basis of given cement content at a given slump for particular aggregates [213R-87, A.C.I. 1987].

3. DURABILITY OF LIGHTWEIGHT CONCRETE

Chemical attack is usually encountered as aggressive ground-water, particularly sulphate, polluted air and spillage of reactive liquids. Lightweight concrete has no special resistance to these agencies: indeed, as it is generally more porous than the more conventional concrete, it is, if anything, more vulnerable [Short, et al., 1968].

Laboratory tests have shown that for the majority of aggregate types both in the presoaked and air-dry condition non-air-entrained lightweight aggregate concrete is potentially more durable under freeze/thaw conditions than equivalent strength non-air-entrained normal weight concrete, particularly when natural fines are used [Clarke, 1993].

Freezing and thawing durability and salt-scaling resistance of lightweight concrete are important factors, particularly in horizontally exposed concrete construction such as access ramps, exposed parking floors, or bridge decks. Generally, deterioration is not likely to occur in vertically exposed members such as exterior walls or exposed columns, except in areas where these structures are continually exposed to water. As in normal weight concretes, it has been demonstrated that air entrainment provides a high degree of protection to lightweight concretes exposed to freezing and thawing and salt environments [213R-87, A.C.I. 1987].

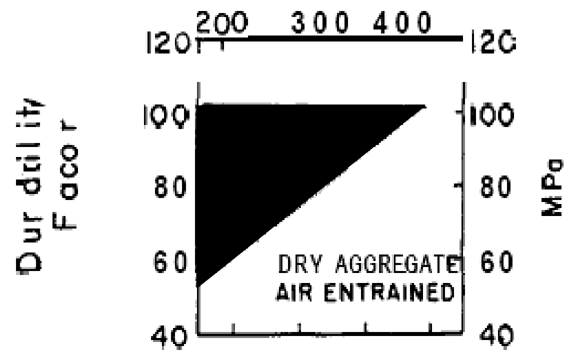

Figure 1. Durability factors-freezing and thawing.

Figure 1. Indicates the range of durability factors, for all lightweight concrete and for sand-lightweight concrete. The durability factor is the percent of the dynamic modulus of elasticity retained after 300 cycles of freezing and thawing. Some of the concrete shown in the fig.1 had relatively poor freeze-thaw resistance in the lower strength ranges. Generally, these concrete have high water-cement ratios, thus the quality of the cement paste is poor. The same concretes had a much improved rating at higher strength (lower water-cement ratio). Many lightweight concretes, as shown, can perform equivalent to or better than normal weight concretes. Limited salt-scaling tests have indicated similar satisfactory performance. Natural sand provides for additional resistance at all strength levels. However, the difference in the resistance of air-entrained all-lightweight and sand-lightweight concretes having compressive strengths higher than 5000 psi (34.47 MPa) is small.

The use of water-saturated aggregates (approaching the 24 hr water absorption) at the time of mixing generally reduces freezing and thawing resistance of lightweight concrete. Under some conditions air entrainment will improve the durability of concrete made with these saturated aggregates. However, experience has shown that as such concretes are allowed to dry, durability improves considerably. If freezing and thawing resistance is required in lightweight concretes, and if it cannot undergo drying prior to freezing exposure, the moisture content of the aggregate should be minimized [213R-87, A.C.I. 1987].

Because the pore system in lightweight aggregate is generally discontinuous, the porosity of the aggregates particles themselves does not influence the permeability of concrete, which is controlled by the permeability of the hardened cement paste. Nevertheless, the permeability of the concrete is reduced when normal weight fine aggregate is used to replace a part of the lightweight fine aggregate; the probable reason for this is that, in former case, the water/cement ratio is lower. The low permeability of lightweight aggregate concrete is the result of several factors: the water/cement ratio of the cement paste is low; the quality of the interface zone around the aggregate is high, so that easier flow paths around the aggregate are absent; and the compatibility of the moduli of elasticity of the aggregate particles and of the matrix means that little micro cracking develops under load or in consequence of temperature variation. Moreover, the supply of water from the aggregate enables continuing hydration of cement to take place with a consequent reduction in permeability [Neville, 1995].

4. APPLICATION LIGHTWEIGHT AGGREGATE IN HOUSING

The structural benefits of lightweight aggregate concrete are probably most significant for medium to long-span structures; where self-weight are dominant and where the ground condition makes it particularly important to keep the weight of the building down. For high-rise buildings these factors are especially applicable; the form and construction of the floor slabs is possibly the most critical aspect of the construction in relation to programmed and there several instances where lightweight aggregate concrete is used only for all or part of the horizontal structure.

The use of lightweight aggregate concrete was specified here to take advantage of three particular of the material:

1. The reduction in dead load due to the floor slabs enabled very slender supporting mullions to be used.
2. The improved fire resistance again allowed the mullions to be particularly slender while complying with the requirements of the Building Regulations, as a lower cover could be used than that required for normal weight concrete.
3. The improved thermal insulation of the spandrel beams and cladding panels permitted the required exposed concrete finish to be adopted both internally and externally, and the absence of applied finishes also enabled a short construction period to be achieved [Clarke, 1993].

When using lightweight aggregate concrete, designers expect two main advantages, namely, reduced weight and high thermal insulation; these may be combined with high strength where the concrete is used for structural purposes.

A difference of temperature between the inside and the outside of a building must result in a transfer of heat from the warmer to the cooler zone, so there is a progressive difference of temperature across the thickness of the wall; the steepness of the temperature drop is termed the temperature gradient [Short, et al., 1978].

5. CONCLUSIONS

1. The durability of lightweight aggregate concrete depends of some factors. Like a freeze/thaw behavior, chemical resistance, abrasion resistance, water absorption, permeability, and carbonation. And for the thermal behavior for lightweight aggregate concrete are less than normal weight concrete made with the majority of aggregate types.
2. Whatever design method is used, it is necessary to ensure that the structure evolved is not only safe against collapse under vertical loading and stable against overturning forces but that its deformations under load are not excessive.
3. Durability is another complex structural property which may be regarded as an ultimate limit state in certain conditions. It requires careful consideration of the conditions of uses, of the materials and workmanship employed and of the regime of inspection, maintenance and repairs which it is practicable to enforce in particular cases.

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