

LIGHTWEIGHT AGGREGATE CONCRETE: EFFECT OF AGE AND CURING METHOD

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Summary: *For normal weight concrete we have conversion factors, when testing not at the age of 28 days or the curing of specimens is not according to the standard. Lightweight aggregate concrete may be very different from normal weight concrete from this point of view. The properties mainly depend on the properties of the lightweight aggregate like particle density, water absorption capacity. The aim is to study the impact of the time under water storage on compressive strength and fracture tests results.*

Keywords: *Lightweight aggregate concrete (LWAC), standard cube test, under water storage, age effect*

1. INTRODUCTION

According to the current standard of concrete (EN 206-1) [1] the strength for classification is at the age of 28 days, following a wet curing (kept in a space having a relative humidity of 100%). The standards also change over time and may be different from country to country. The earlier applied mixed curing (up to 7 days in water and then till age 28 days in laboratory air), in the Hungarian standard is still allowed and common in engineering practice. The real curing of a newly constructed reinforce concrete structure (which is rather close to the mixed curing) is also very different from the standardised European method. An examination of an existing structure is possible only by drilled core samples, specimens often having only 50 or 100 mm nominal diameter in case of dense reinforcement.

In the case of normal weight concrete (NWC) lots of data, experimental results were gathered over the years. Conversion factors may be found in several standards, but the lightweight aggregate concrete (LWAC) is different. Density, elasticity, hardening rate and water absorption properties of LWAC may be very different from NWC. They mainly depend on the properties of lightweight aggregate (LWA) like: particle density, water absorption capacity, surface coating, crushing resistance etc. The amount and distribution of LWA in the concrete matrix is also important. In the sign of concrete the compressive strength class is given already for two different sample shapes. (Table 1) (Table EN 206-7) Such a table is included in the lightweight concrete standard as well, but it contains different numerical values. (Table 2) (Table EN 206-8) The characteristic

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strength value, obtained from testing cylindrical or cubic sample is closer to one another. The stiffness of the LWAC is less than of the NWC. The modulus of elasticity of LWAC is defined not only by the compressive strength, but also by the density. This density effect is smaller in case of slimmer specimens, as shown in LWAC grades (*Table 2*). The ratio of compressive strength and splitting strength is different, too [2]. The LWAs are porous, so have better thermal insulation capacity, and therefore the hardening rate of concrete is faster [3]. The fast hardening helps the internal curing effect due to the typically open pore structure of LWA. These effects are generally favourable in practice, thus neglecting them influences safety in a positive way. The high porosity of LWAC due to the LWA having open pores (and this is usually the case) means an increased water absorbing capability compared to NWA. The effect of this however is that the wet curing method will influence more the measurable compressive strength result but in a negative direction. Although a good hydration causes higher strength, but less strength can be measured in wet conditions. Therefore, the standard ratio for under water and mixed storage does not give realistic result for LWAC. An even more specific situation is, if the compressive test is carried out not exactly at the age of 28 days.

Table 1 Compressive strength class for NWC (EN206-1 Table 7)

Comp. strength class	Min. characteristic cylinder strength $f_{ck,cyl}$ [MPa]	Min. characteristic cube strength $f_{ck,cube}$ [MPa]
C8/10	8	10
C12/15	12	15
C16/20	16	20
C20/25	20	25
C25/30	25	30
C30/37	30	37
C35/45	35	45
C40/50	40	50
C45/55	45	55
C50/60	50	60
C55/67	55	67
C60/75	60	75
C70/85	70	85
C80/95	80	95
C90/105	90	105
C100/115	100	115

Table 2 Compressive strength class for LWAC (EN206-1 Table 8)

Comp. strength class	Min. characteristic cylinder strength $f_{ck,cyl}$ [MPa]	Min. characteristic cube strength $f_{ck,cube}$ [MPa]
LC8/9	8	9
LC12/13	12	13
LC16/18	16	18
LC20/22	20	22
LC25/28	25	28
LC30/33	30	33
LC35/38	35	38
LC40/44	40	44
LC45/50	45	50
LC50/55	50	55
LC55/60	55	60
LC60/66	60	66
LC70/77	70	77
LC80/88	80	88

The aim is studying the impact on the compressive strength and fracture tests results of time and under water storage.

2. EXPERIMENTAL STUDIES

2.1 CONCRETE MIXTURES

We studied four different LWAC mixtures (with different aggregates, and different strength grades) compared to a reference, normal concrete (*Table 3*). The cement type and content (CEM I 42.5 N, 350 kg/m³) and the water-cement ratio (w/c=0.43) was kept constant, so the cement stone was uniform in all cases. The concrete mixes differ only in the added aggregate. We used different LWA types, and quantities. The grading curve and the rate of normal weight aggregate (NWA) was different to give good workability and enough strength.

Table 3 Measured mixes (aggregate type, strength grade and density of concrete)

Marking of mix	Aggregate name	Planned strength grade	Planned density of concrete [kg/m ³]
R	sandy gravel aggregate (reference)	C35/45	2360
L	Liapor	LC30/33	1900
G	Geofil-N	LC25/28	1930
LL	Liapor + Liasand	LC20/22	1430
P	Poraver	LC8/9	1660

The material of the LWAs were expanded clay and expanded glass (*Table 4*). Aggregate for LWAC is most commonly expanded clay. Typically, in load-bearing LWACs only for the bigger fractions is LWA used instead of gravel (>4mm) like the Liapor products, but in case of lower load bearing capacity requirement it is possible to use LWA in the sand fraction (Liasand) too. The most readily available LWAs in Europe are the Liapor products. Most of the literature data for LWAC is available for expanded clay aggregate. An other choice for artificial expanded LWA is expanded glass. Most expanded glass aggregates have low density and high water absorption capacity (e.g. Poraver products), but there exist expanded glass LWA with low water absorption (<10% by mass) (e.g. Geofil products). The aggregate particles are very porous, but the surface is closed, this causes the low water absorption. Both expanded glass products have the great advantage of producing them from waste, the energy demand out of the production is smaller, than in case of expanded clay pellets.

The LWAs are mixed only with water before concrete mixing. Due to the high water absorption is necessary a premixing with 50% of the one-hour-water absorption quantity of water. The other 50% was added to the mixing water. Thus, the LWAs were saturated and the water-cement ratio of cement paste was kept constant.

Table 4 Characteristics of aggregates

Name	Material	Particle density [g/ml]	Water absorption [% by mass]	Water absorption [% by volume]	Fraction [mm]
gravel	natural quartz	2.64	0	0	4/8
sand	natural quartz	2.64	0	0	0/4
Liapor	expanded clay	0.83	36	30	4/16
Liasand	expanded clay	could not be measured, considered to the same to the Liapor			0/8
Geofil-N	expanded glass	1.14	1	1.1	2/10
Poraver	expanded glass	0.3	26	8	4/8

The main difference between the studied mixtures:

- R: reference mixture with natural normal weight aggregate (quartz gravel and sand)
- L: a typical load-bearing LWAC with the most common aggregate type
- G: a load-bearing LWAC with closed surface porous LWA (a special expanded glass)
- LL: LWAC with all fractions out of LWA (without NWA)
- P: LWAC with very low strength coarse LWA and natural sand

2.2 SPECIMENS, CURING METHODS AND AGES

All measured specimens were standard cubes (150x150x150 mm). The studied ages were 3, 7, 28 and 91 days. The specimens were cured under water for 3, 7 or 28 days. During the 7 days testing period three specimens were cured for 3 days and three specimens till 7 days under water. During the 28 and 91 days testing period three-three specimens were for 3, 7 and 28 days cured under water. For all cases we prepared three-three specimens (*Table 5*).

Table 5 Test matrix: specimen storage and test age (and the status in time of the test)

Test age [day] / Under water storage [day]	3	7	28
3	3 cubes (wet)		
7	3 cubes (dry)	3 cubes (wet)	
28	3 cubes (dry)	3 cubes (dry)	3 cubes (wet)
91	3 cubes (dry)	3 cubes (dry)	3 cubes (dry)

3. TEST RESULTS

3.1.EFFECT OF CURING ON THE HARDENING RATE

In each tests case, it was found that the hardening rate of LWAC was faster than that of the reference concrete. However depending on the type of the aggregate, the hardening rate was different.

In case the specimens are stored under water (i. e. under the same conditions of hydration and crushing state) and the reference concrete strength (*Figure 1*) is taken to 100% we see in each case that the LWAC strength ratio at three days age is the maximum and continuously decreased (*Table 6*). So the hardening rate of all LWAC was faster than the reference concretes (*Table 7*).

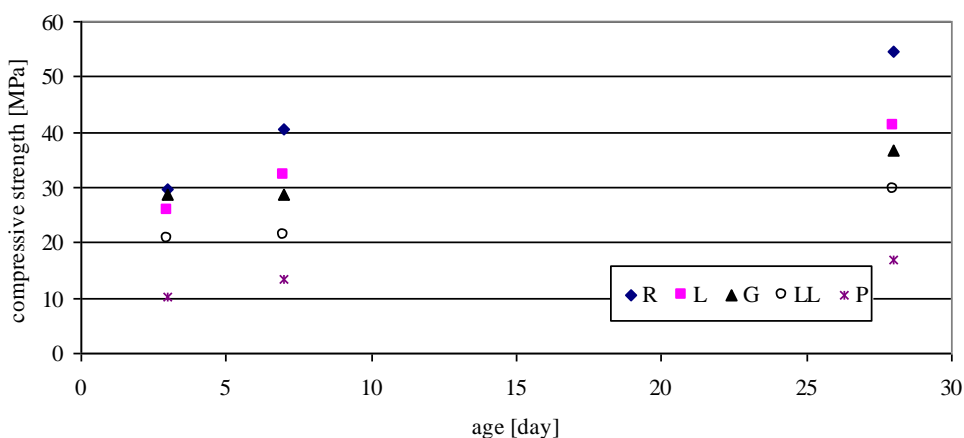


Figure 1 Compressive strength of LWAC and reference concrete in case of under water curing till crushing

Table 6 Strength ratio of the different LWAC to reference concrete (under water stored, “wet cured” specimens)

Mixture / Age	3 day	7 day	28 day
R	100%	100%	100%
L	87%	80%	80%
G	97%	70%	67%
LL	70%	53%	54%
P	34%	33%	31%

Table 7 Hardening rate of the different LWAC (under water stored, “wet cured” specimens)

Mixture / Age	3 day	7 day	28 day
R	54%	74%	100%
L	62%	78%	100%
G	78%	78%	100%
LL	70%	72%	100%
P	60%	79%	100%

All specimens were already air-dry at the age of 91 days, so the crushing conditions in this case are the same. Thus, the effect of curing (under water storage time) can be observed here.

When using very low particle density and high water absorption LWA (P) or very much LWA (LL) the storage method has no effect. Of course, there should not be a large surface of a structure to dry, early cracks should be avoided, then the curing method has little effect on strength and thus on the classification if it is not the same as the standard method (28 days, wet cured specimen) [4,5]. The reason of this small difference in strength is the large amount of water inside the aggregates, which promotes the hydration of the critical area at the border of the aggregate pellet and mortar matrix. There is other supplementary material in the LWAC, this effect will be stronger [6].

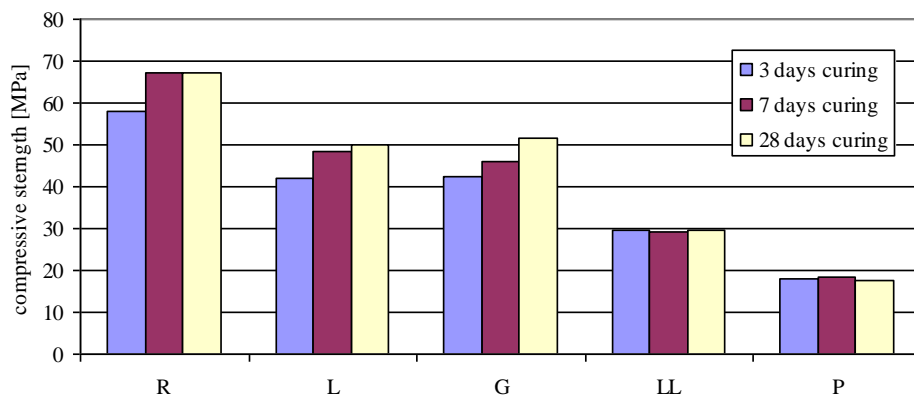


Figure 2 Compressive strength at the age of 91 days following different curing under water

However in contrast, if the LWA has relative high strength (Liapor, Geofil-N), the longer curing has a well detectable positive effect. The strength of reference concrete is decreased by 13% if the curing is only 3 days, this decreasing in case of mixture L or G is 16-18%. After 7 days of wet curing 3-10% decrease could be observed. So despite the fact that according to the general perception of the curing is less important, but for the structural strength it is even more important. Significant effect of curing explained the faster hardening rate.

3.2.EFFECT OF THE PHYSICAL STATE OF THE SPECIMENS WHEN CRUSHING

In 7 days age, two cases were studied: 3 days under water curing followed by laboratory air conditioning, and 7 days under water storage in each cases (the reference and all the lightweight concrete). It was found that the specimens stored in water for 7 days smaller strength was measured then of those, which were stored under water for only 3 days. At this age, the saturation effect of the test sample is greater than the positive difference from the better hydration. At higher strengths range (R, L, G) the effect is 6-8% lower than in the case of the strength of wet curing. It is in the saturated state at high water

absorption and crushing the additive difference between 11-16% respectively. This can be explained by the higher water absorption capacity of the specimen.

In case of NWC was measured at 28 days of age a greater strength value. The longer the specimen is stored under water, thus enhancing a good curing (good hydration) the influence on strength is greater than the effect in case of wet specimens. We had identical values in the case of three LWAC storage mode. The effect of increasing strength due to right hydration neutralises the decrease in strength due to the wet state.

4. CONCLUSION

The four LWAC were very different (low and high strength, low and high water absorption capability, low and high LWA content) however the 28-day strength was independent on the type of curing (time of under water storage) in all cases. This effect is given in the difference from the strength of the reference concrete (NWC). Thus different curing methods of the LWAC does not make any difference in compressive strength classification of the 28 days old samples. The opposing effects neutralize each other.

This does not mean that there is no positive effect of the good treatment (curing). Compressive strength of reference concrete after only 3-days curing is 10 % lower, than after 28-days curing. The difference of 91-days strength after 7 and 28 days curing is minimal. For NWC 7 days curing can be enough.

By the literature in case of LWAC is an internal curing effect. If the aggregate has low density, and high water absorption capacity (LL, P), there is no measurable difference in the 91 day compressive strength depending on the time period of curing (3, 7 or 28 days). So here prevails the internal curing effect. This of course, under the condition of high water absorption capability of the aggregate is true, and that these aggregates are really saturated with water, before mixing.

In case of LWAC with high strength and closed aggregate surface (low water absorption capacity) the curing has even greater effect on compressive strength than in the case of NWC. The strength reduction of LWACs was between 15 and 20 % after only 3 days curing, and between 3 and 10 % after only 7 days curing instead of 28 days under water storage.

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