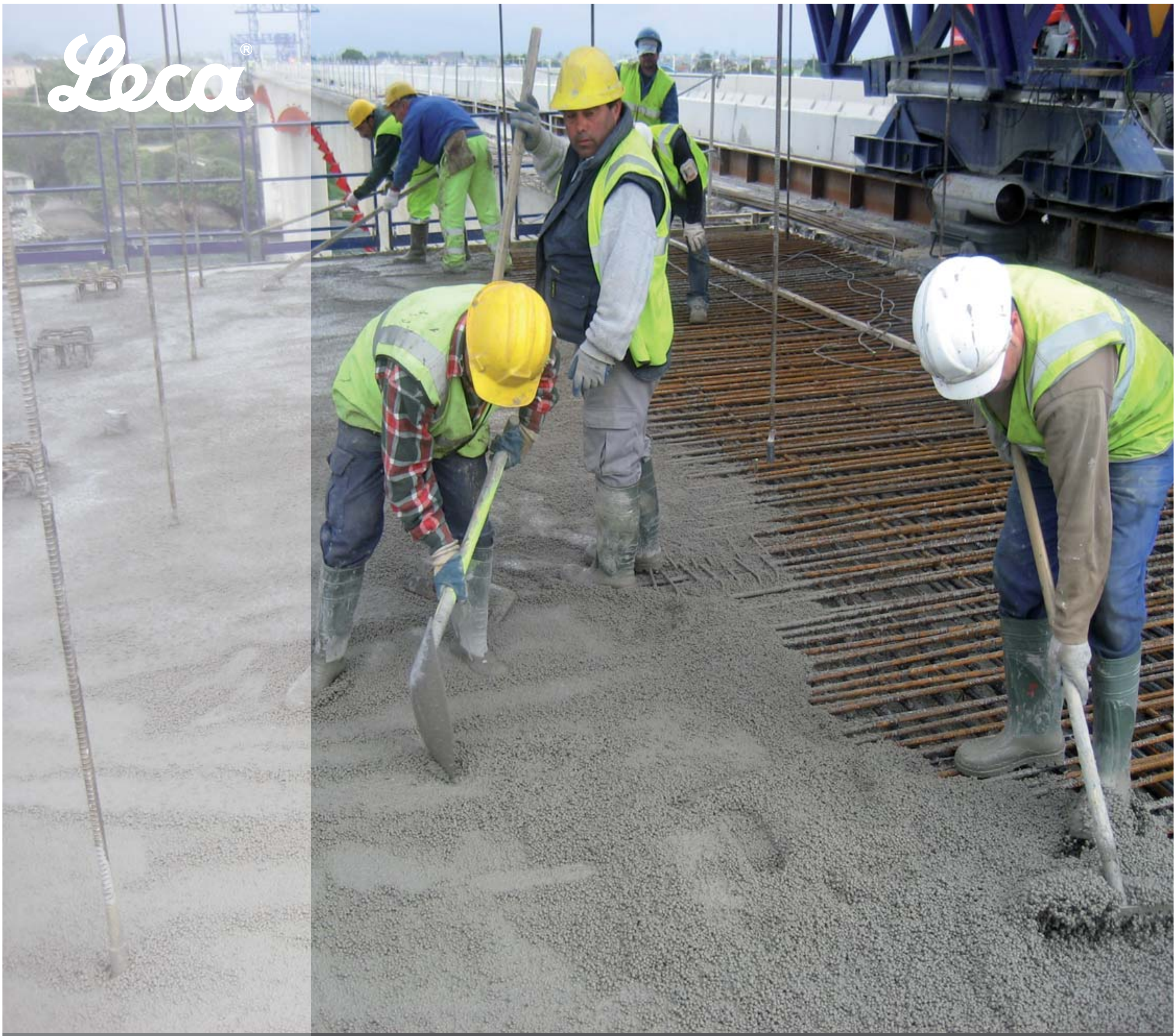
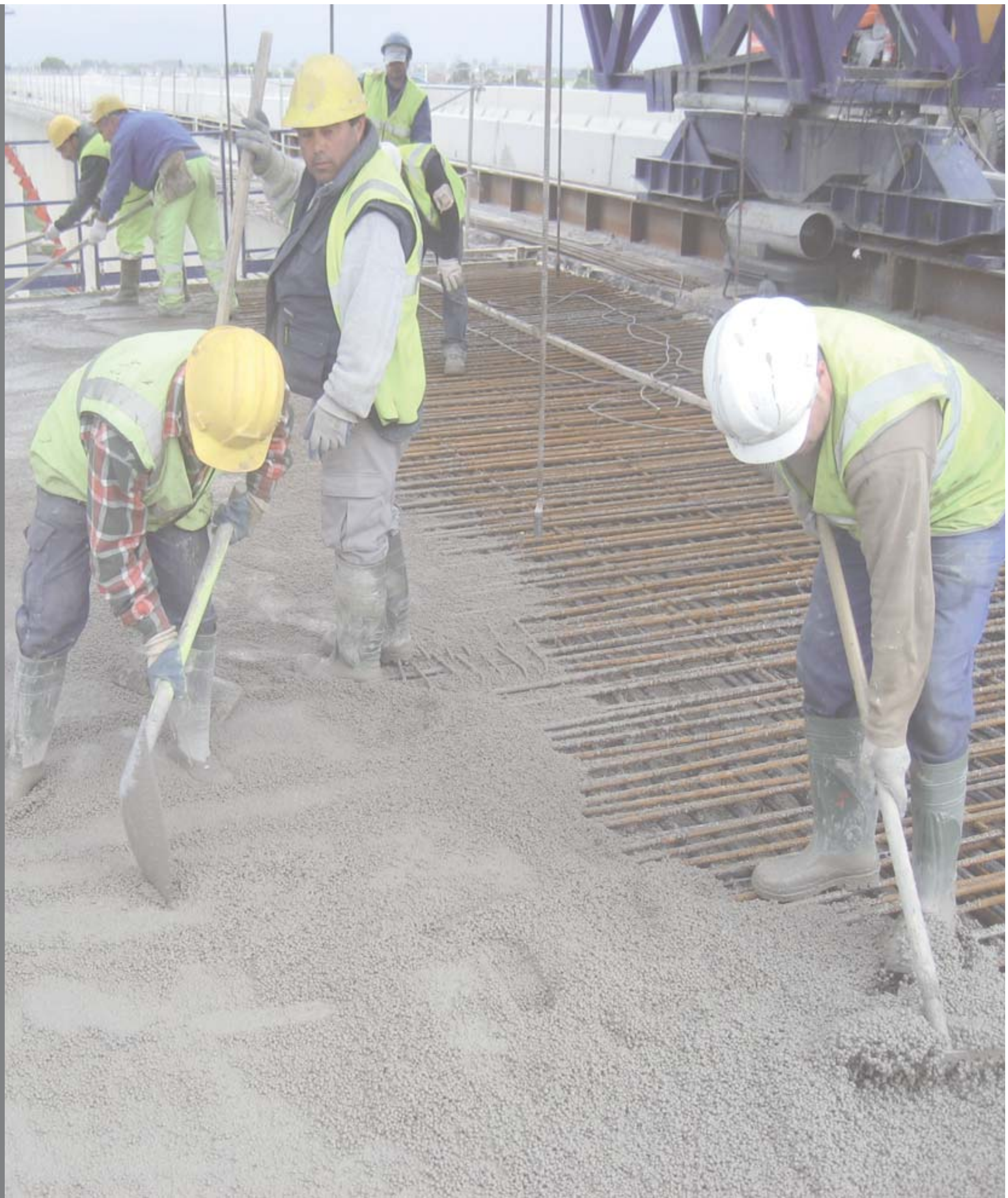


Lightweight aggregate concrete – Production and fresh concrete properties

Guideline 1
Production and
fresh concrete properties

Guideline 2
Lightweight aggregate concrete –
characteristics of hardened
concrete



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Introduction

Lightweight Aggregate Concrete (LWAC) has been utilized over a long period of time. The first known construction to use LWAC is more than 2000 years old using natural volcanic materials. Among several structures to utilize LWAC at that time is the Coliseum in Rome the most well-known.

Industrialized and commercial production of Lightweight Aggregate (LWA) started early in the nineteenth century and the rotary kiln was invented. One of the earliest uses of reinforced LWAC was in the hulls of ships and barges from around 1918 in the USA. Today LWAC is used widely across the world as a lightweight and durable alternative to structural, normal density concrete. Typical applications are bridges, slabs, floaters, extensions, balconies, high rise buildings and constructions where lightweight are important.

The Colosseum
in Rome, Italy

Light weigh
aggregate

Leca LWA
production plant

2 Lightweight aggregate - LECA

Leca is produced of clay with poor lime content, which is dried and fired in rotary kilns. The kilns shape the clay into pellets and at a temperature of 1.150 °C gas is formed.
The gas expands the pellets resulting in high porosity and low-weight properties. The porosity is caved in by a matrix of solid brick-like ceramic material with high compressive strength. The porosity is partly open and allows water to penetrate into the LWA. The LWA particles absorbs about 5-10% water after one hour and the long time absorption is 50-100% water by weight measured as increase of bulk density when immerged in water.

When absorbing water contained air is evacuated from the porosity of the LWA. The water absorption for LWA in LWAC is somewhat lower than the values presented above. As a general guide 90% of one hour LWA absorption in water may be used as the total absorption in fresh state LWAC. Exact water absorption characteristics are declared by the manufacturer for each product.

The advantages by using clay as a source material instead of shale and other raw materials are the ability for the manufacturer to decide the density of the LWA. maxit Group is today manufacturing LWA at 10 plants in Europe. The standard LWA has a bulk density at 250-350 kg/m^3 and a corresponding particle density at 450-550 kg/m^3.

Some factories can produce higher density material with considerably higher particle strength with bulk density up to 800 kg/m^3. In general, the particle strength is dependent by the particle density. A high density Leca has a considerably higher strength than a low density material when manufactured at the same site and with the same raw materials. The LWA surface is rough and porous and fresh cement paste bonds very well to the surface resulting in excellent surface interaction properties.

Construction of
Eidsvoll bridge,
Norway

Leca®

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Applications

Leca is well suited for use as aggregate in concrete products. As the weight is low it is possible to produce light masonry construction blocks with good insulation characteristics. Ready mix and precast LWAC may be produced with a large number of densities and with compressive strength up to 70 MPa or even more. LWAC is today used in large number of constructions all over the world. Some examples of utilizing the benefits by LWAC are mentioned below:

SLABS: Lighter concrete can result in longer span for slabs in buildings. Easier handling and lifting of precast slabs.

FOUNDATIONS: Lighter concrete can result in simpler foundations and consequently lower costs.

BRIDGES: Longer spans, wider profiles and more cost efficient foundations.

MARINE STRUCTURES: Low density material results in lower dead load and better floating properties for all types of submerged and partly submerged structures including floating foundations, platforms, ships, piers etc.

EXTENSIONS: All types of extensions can be made lighter which simplify the construction process.

REHABILITATION: Old bridges, building slabs and other structures. Reduce of loads to the support structure.

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Norms

LWAC can be manufactured with a large variation of densities and strength classes. EN 206-1 defines LWAC as concrete with oven dry density between 800 and 2000 kg/m^3. The norm define classes for density D 1,0 – D 2,0 and compressive strength LC 8/10 - 80/88.
The classes for LWAC compressive strength are different from normal density concrete (NDC). This is caused by the difference in the relation between cube and cylinder strength for the two types of concrete. EN 206-1 considers NDC and LWAC similar for all other properties and classifications.

Compressive strength

Compressive strength	LC 8/9	LC 12/13	LC 16/18	LC 20/22	LC 25/28	LC 30/33	LC 35/38	LC 40/44	LC 45/50	LC 50/55	LC 55/60	LC 60/66	LC 70/77	LC 80/88
Characteristically strength in cubes ($f_{ck,\ cube}$ in MPa)	9	13	18	22	28	33	38	44	50	55	60	66	77	88
Characteristically strength in cylinder ($f_{ck,\ cylinder}$ in MPa)	8	12	16	20	25	30	35	40	45	50	55	60	70	80

density

density classes	D 1,0	D 1,0	D 1,0	D 1,0	D 1,0	D 1,0
density (kg/m^3)	≥ 800, ≤ 1000	> 1000, ≤ 1200	> 1200, ≤ 1400	> 1400, ≤ 1600	> 1600, ≤ 1800	> 1800, ≤ 2000

Proportioning mixing and handling

Proportioning of LWAC should be done in the most economical way by choosing Leca from a local supplier and appropriate ingredients to meet the required physical properties. A recommended method of proportioning is the volume method. The principles is that the mortar volume defined as cement, sand, water, admixtures, entrained air etc. should be sufficient to fill the voids between the coarse aggregate particles plus sufficient additional volume to provide satisfactory workability. A proposal of how to proceed is explained below.

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Starting up

Start by determine if the LWAC shall be pumped or not. This will influence the mix design and also influence the choice of ingredients, type of LWA and possible degree of presaturation.

Planing the compressive strength

Study the specification and plan the proportioning accordingly. Be aware of the relationship between concrete density and specified compressive strength. Please consult the local maxit organisation for information on the aggregate.

Standard low weight expanded clay (bulk density 300 kg/m^3) is usually limited to LC 30/33 or LC 25/28. If higher compressive strength is specified, use high strength LWA or LWA with higher density. If more than one aggregate is available, choose the lightest type of LWA which manage to fulfill the requirements of LWAC strength. By choosing a normal weight Leca material, better economy is achieved. Notice that LWAC strength is very dependent on aggregate strength and less dependent on paste strength compared to normal density concrete NDC. The volume of the aggregate is larger than the paste. The LWA is considerably weaker than normal aggregate and the fracture zone is likely to penetrate the Leca and not through the interface zone as for NDC. As a guideline following expression may be used:

$$\sigma_{LWAC} = (\sigma_{LWA})^{n} \cdot (\sigma_{mortar})^{1-n}$$

σ_{LWAC} is LWAC compressive strength

σ_{LWA} is LWA strength

σ_{mortar} mortar compressive strength

n is volume prosentage of LWA in the mix

Presaturation of Leca or not
decide if needed or not to presaturate the Leca. Use of dry aggregate results in lower density than presaturated aggregate. The range of water absorption in a presaturated aggregate may vary from 10% to 30% by weight. To achieve a pumpable LWAC, experience indicates a minimum presaturation level of 20% or more is necessary.

Example 1: The presaturation level of 25% for LWA with bulk density 670 kg/m^3 and 726 liters LWA per m^3 LWAC, increases the LWAC density of 122 kg/m^3. The initial dry LWA water absorption in LWAC will be about 6%. The increased density of the LWAC is therefore about 100 kg.

Increased work, winter freezing, handling and logistics must also be considered before presaturating the LWA. In example 1 the 6% water absorption is used, but the dry LWA water absorption in LWAC is usually between 5% and 10% dependent on type of LWA, LWAC flow and retention time. The absorbed water is taken from the initial mix water and this amount has to be calculated and replaced. In this example 6% water absorption results in 30 litres water which has to be added to the mix while mixing. The mix is therefore excessive flowing during mixing and short time after mixing. The water absorption is rather quickly and the LWAC can be delivered at site after 10-15 minutes.

The advantage by presaturating is reduced loss of flow during mixing and transportation resulting in a LWAC which are more similar during mixing as when supplied at site. In general, more quality control and effort must be performed if using a dry aggregate.

If pumping of the LWAC with ordinary piston pump is the only option to place the LWAC, presaturation is a necessary.
Presaturation of LWA is done best and fastest by sprinkling flat stock piles. beware of freezing problems during winter time in northern territories. Keep in mind that the water absorption should not affect the w/c-ratio. Only water remaining accessible for the cement in the paste is used for calculating the w/c-ratio. For initial dry aggregate, the absorbed water will be compensated by the added water and the w/c-ratio will not change. The presaturated water in presaturated aggregate will not affect the w/c-ratio at all.

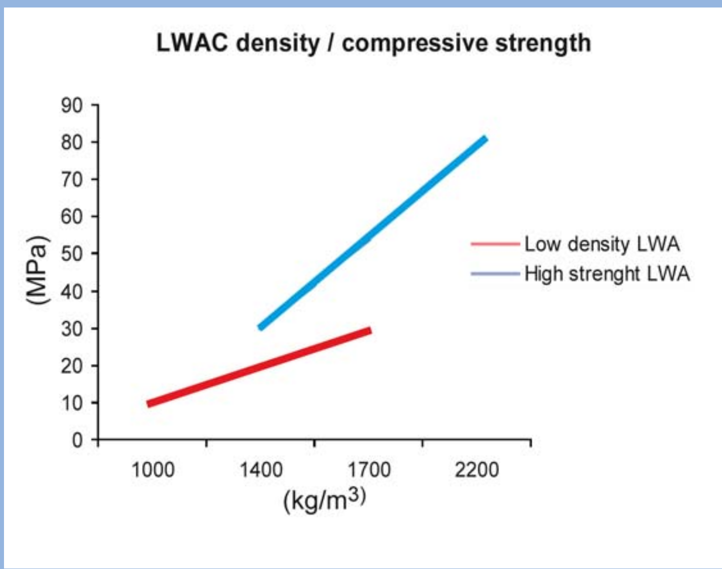
Finding the density
Decide the volume of Leca, paste and sand necessary. In general, the volume mortar necessary is the volume that fill the voids between the coarse aggregate plus some additional volume to provide satisfactory workability. The volume of the Leca necessary is determined by the specified density. Thus, the engineer must perform an interactive calculation between necessary mortar and Leca volume.

To start with, following typical values may be used: paste: 300-320 litres, sand: 220-280 litres (600-800 kg) and LWA 400-500 litres. Remember to use the particle density and not the bulk density and

not the bulk density when calculating volumes.
450 litres of LWA with bulk / particle density of 670 /1150 kg/m^3 in the mix means 450 litres x 1,15 kg/l = 517 kg LWA.
517 kg LWA divided on 670 kg/m^3 = 0,77 m^3 LWA which is the bulk volume LWA necessary for make one m^3 LWAC in this specific example.

This calculation proves there are limitations of how low density the LWAC may have and that the weight is limited by the LWA density. Do not push the limit since it only results in poor workable concrete. In addition, for initial dry aggregate, the water absorption must also be calculated and an equal amount of water must be added as compensation to maintain the total volume of 1 m^3. Note, if particle density is unknown, an approximate value may be obtained by dividing the bulk density by 0,57. Note that some national construction codes may have strength/density limitations.

Achievable strength density ratio for LWAC for high density and low density Leca based on experience under optimised conditions.



Typical mix design for LWAC

	Cement	Water	Sand	Leca	Micro air	Total
Volume [litres]	300-320	300-320	220-280	350-450	50	1000
Weight [kg]	350-450	150-200	600-800	300-600	0	1600-1800

Designing the mortar

Design of the mortar phase in a LWAC is based on same principles as for NDC. The requirements in the specification for strength, workability and density have to be considered. Keep in mind the difference of densities between LWA (particle density 500-1400 kg/m^3) and paste density (typically 1800 kg/m^3) and mortar density (typically 2200 kg/m^3). The difference in densities works towards segregation of the LWA from the mortar. The light weight particles will simply try to float to the surface, opposite to the heavy coarse aggregate in NDC which will try to sink. This may be prevented by using sand with particle size distribution typically as 0-4 mm or 0-5 mm instead of standard 0-8 mm. Keep in mind that the LWA particle size distribution is usually 4-10 mm or 4-12 mm allowing the use of sand with limited maximum size. Another approach is to use some crushed sand with sharp edgy none spherical shape resulting in a higher viscosity mixture.

Due to the weak LWA aggregate, the w/c-ratio must be lower compared to a similar class NDC. w/c-ratio is seldom over 0,45 and less than 0,35. Additives like pozzolanic materials or/and fillers are recommended to increase strength and increase viscosity. Consequently, superplastizisers is necessary to maintain flow. The latest generation of co-polymers is recommended. Increasing micro air content by air entrainers is also recommended. Micro air results in both a lighter mortar and a more stable mixture. A typical LWAC with density 1800 kg/m$_3$ and 2% initial air content will by increase of 3% air to 5% reduce the density to 1750 kg/m^3, which is considerably. The disadvantage by use of air entrainers is reduced mortar strength. In general, the most important difference between a NDC and LWAC mortar is the need for higher viscosity for the latter one.

Mixing

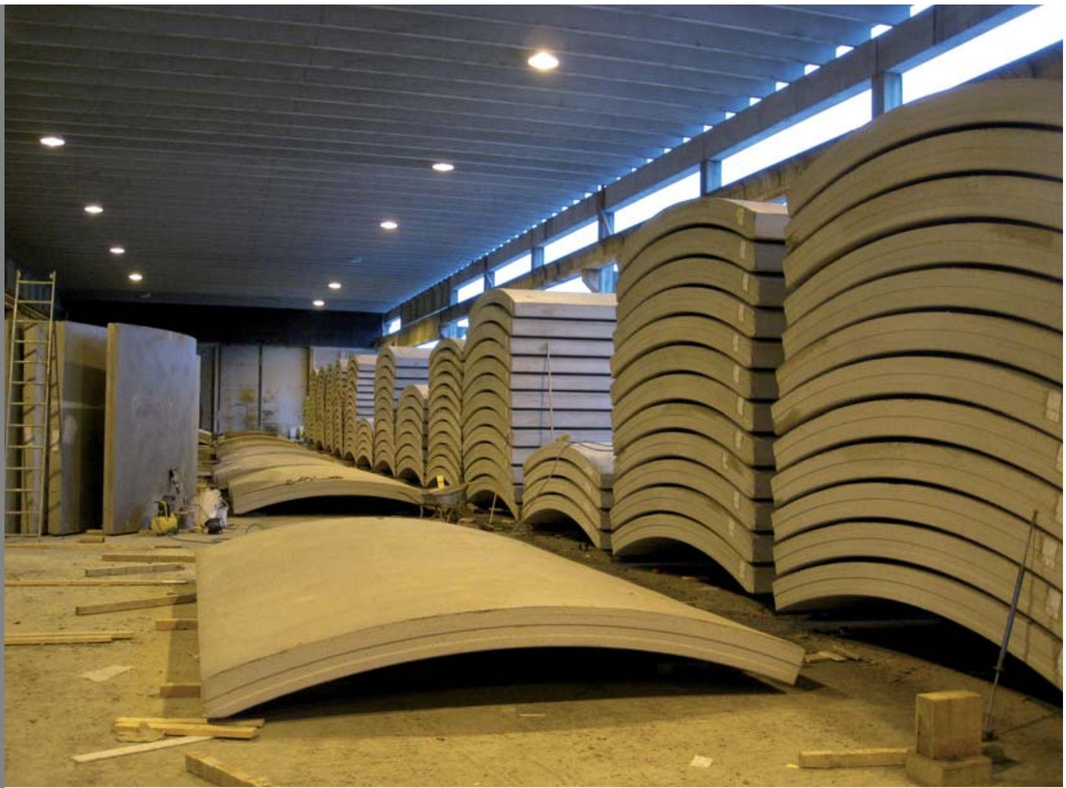
The fundamental principle for mixing NDC also applies for LWAC. Keep in mind the absorbing nature of the LWA. Some suppliers recommend a 3 minute soaking time in the batch mixer before adding the remaining ingredients. The advantage by presoaking is less loss of workability later. The disadvantage is increased production time which for many projects is not possible. Others prefer to mix the LWAC as it was NDC.

Transport and pumping

Transporting and placing LWAC may be done by traditional equipment. When using initial dry LWA keep in mind the high flowability due to the compensated water. The high flow will gradually be reduced during the first 30 – 60 minutes.

Before supplying the concrete at site, the LWAC should be remixed by automixer to remove the evacuated air from the surface of the LWA. Pumping LWAC with initially dry Leca and piston pumps is not recommendable. The high pumping pressure will force water from the LWAC mix into the porous LWA resulting in considerably reduced flow and loss of pumping pressure in the pipeline. Consequently, the pipeline will be clogged and the pump operation will stop.

LWAC panels for the Asurtjerne tunnell in norway



To achieve pumpable LWAC, the LWA must be presaturated to a level of at least 20-25%. The presaturation level is dependent on the type of LWA but the degree of success in a pump operation is also dependent on type of pump, pump height, pipe dimensions, bends, rapid size reductions and mix design. Traditional piston pumps are more difficult to use than pumps with continuous pressure.
Even with presaturated LWA, water will be forced into remaining air pores and some loss of workability may be the result. In some setups, the compressed air in the LWA will push water out and into the mix during the early hardening phase of the concrete. The water may interrupt the aggregate -paste interface phase and reduce the strength and durability. It is therefore strongly recommended to perform workability and compressive strength test of concrete taken before and after pumping and compare them. If the compressive strength is reduced for samples which are pumped compared to samples which are not pumped, it is recommended to increase the presaturation level. This should be done in a trial with the same equipment before start of construction

At site

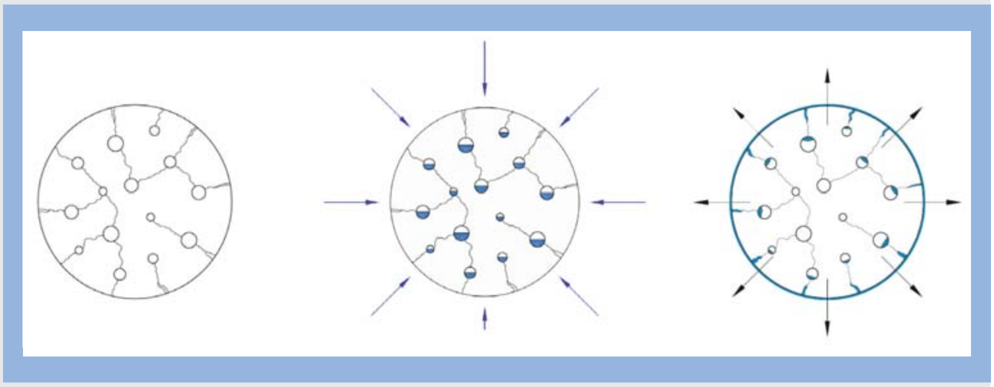
At site, in order to adjust the slump consistency, as it is for NDC, no water should be added to the LWAC mix. Minor and careful addition of an appropriate super plasticizer is recommended. Remember to remix the concrete after the addition.
A well designed LWAC may be easier to handle, moved and cast into the formwork than a comparable NDC. A difference is the use of vibrators. LWAC may absorb some of the vibrating energy and the vibration is therefore less ef- fective. In addition, over- vibration easily leads to segregation. Consequently, vibration has to be applied with shorter distance between each dipping, shorter vibration time and should result in less transport distances of the concrete. According to experiences it is recommended to reduce the frequency of the vibration energy.

As soon as possible an appropriate curing should be applied. Experience from curing of NDC may be used in a similar way. A LWAC is not more exposed for environmental drying compared to a similar NDC, in fact opposite due to the internal reservoirs in the LWA, but the Modulus of Elasticity is less and the total long time shrinkage is therefore slightly larger.

Laboratory work

Laboratory tests should be conducted with all the ingredients and trial batches should be performed with actual material composition latest 2-3 weeks before start of construction. Measure 7 days compressive strength as an indication of 28 days strength and it is still time for another trial batch.

Schematic figure



Initial dry LWA to the left. In the middle; the same LWA under water pressure. Water is pressed into the LWA and air is evacuated. To the right; when the pumping pressure is released, captured water may be evacuated to the surface of the LWA during and after hardening of LWAC.

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How to mix LWAC with dry LWA

1 Measure 1 hour water absorption of LWA
2 Multiply with 0,9 and the total weight of LWA in the mix. This is the expected total absorbed water.
3 Add the absorbed water to the total mix water
4 Use the concrete at earliest 10-15 minutes after start of mixing
5 Trial mixing is recommended.

How to mix LWAC with presaturated LWA

1 Place LWA on a flat stock pile
2 Irrigate the LWA until the water saturation has stabilized at a decided level
3 Take several samples to confirm that the saturation level is uniform
4 Mix and supply the LWAC as a normal concrete.
5 Trial mixing is recommended.

How to pump LWAC

1 Determine with the supplier the experiences by pumping the actual aggregate
2 Follow the same water saturation procedure as above.
3 Choose the type of pumping equipment.
4 Perform a trial with exact mix design, pumping equipments and hose configuration as the full scale operation.
5 Take tests of workability and compressive strength BEFORE AND AFTER pumping.
6 Monitor the pump operation closely.

7

Examples of Mix designs

Specification	LC 25/1700	LC 60/1950	LC40/1600	LC50/1750
Country where used	norway	norway	Portugal	Portugal
Cement	380	422	440	430
Silica fume (k=2)				
Fly ash	11	34		
Slag			140	100
Free water	175	160	167	142
Absorbed water in LWA	25	47	–	–
Sand 0-8 mm	940			
Sand 0-5 mm		680	405	390
Leca Sand 0.5-3 mm			68	
Leca 650, 2- 4 mm				203
Leca 300, 4-10 mm	180			
Leca 800, 4-12 mm		600		
Leca 600, 4-12 mm			405	
Leca 600, 4- 8 mm				504
Super plasticiser	2	5	9,9	8,6
$v/(c + \Sigma kp)$	0,44	0,33	0,28	0,27

Note: the above presented figures are only indications and should always be confirmed with a local supplier of Leca.

Leca®

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