Feature

Lightweight aggregates

The benefits of using lightweight aggregates in concrete and some of the practicalities of its use are revealed by Alan Beattie of Lytag Ltd

Concrete is one of the most versatile and commonly used materials in construction, and has been so since Roman times. However, normal weight concrete can cause issues during the design process and can limit creativity and practicality. Addressing the weight issue of the concrete allows the designer and engineer greater scope in the design and there is potential for both cost and time savings. This article not only looks at the benefits of using lightweight aggregate (LWA), but also some of the practicalities of its use.

A cubic metre of 'normal' concrete, *in situ*, weighs around 2300kg/m^3. Reducing this weight by 25% or more, would give positive advantages to the architect, engineer and client. Designing with this reduced weight in mind can give benefits such as reduced foundation size, increase the number of floors, reduce column size and increase spacing, reduce steel reinforcing etc.

Reducing the weight of concrete is not new, both the Colosseum and Pantheon, built during the days of the Roman Empire, were partly constructed with materials that can be characterised as lightweight aggregate concrete (aggregates of crushed lava, crushed brick and pumice). During the Second World War in the US many ships were constructed with lightweight aggregate concrete. Their success led on to its use in structural lightweight aggregate concrete (LWAC) in buildings and bridges.

Since the 1960s lightweight aggregates have been used in many construction applications including structural LWAC which has been readily available in the UK in the form of Lytag®.

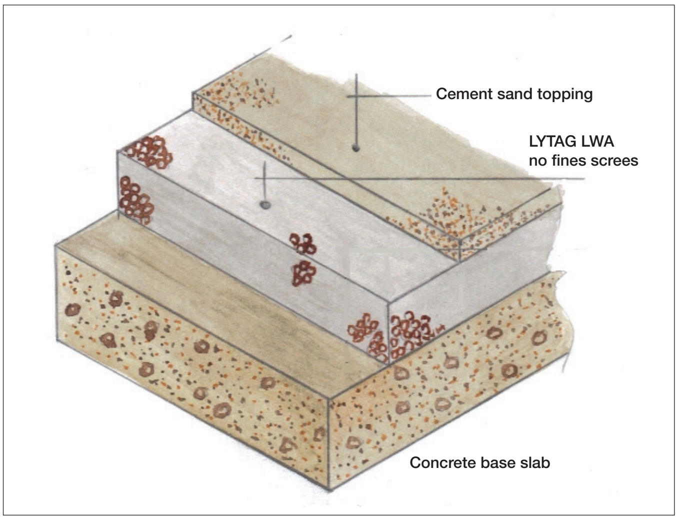
There are a number of lightweight aggregates available in the UK, ranging from the ultra light perlite and vermiculite through expanded clay and pumice to the fly ash-based Lytag®. Whilst each of these aggregates comply with the requirements of EN 13055, the European standard for lightweight aggregates, care needs to be taken in the specific application to which they are applied. The ultra light aggregates are extremely good in insulation and fire resistance applications, however, in concrete the strength capacity is very low. As the density of the aggregates increase, generally their structural capacity also increases. Therefore care needs to be taken in identifying the correct lightweight aggregate for the specific application.

Sintered pulverised fuel ash (spfa) lightweight aggregate

Fly ash based LWA has been used for nearly 50 years in the UK, and abroad, for many applications, where it replaced normal weight natural aggregates in structural and civil engineering applications as well as finding uses in other sectors.

The raw material, fly ash, is the waste material produced from electricity production in coal-fired power stations and the finished aggregate is called 'sintered pulverised fuel ash lightweight aggregate' (Lytag® LWA).

It is made by pelletising the fly ash. By adding a controlled quantity of water in specially designed dish pelletising pans, rounded pellets are formed. The pellets are then heated on a sinter strand to a temperature of around 1100°C. The result is a hard, honeycombed structure of interconnecting voids within the aggregate. The particles formed are rounded in shape and range in size from 14mm down to fines; these are processed to the required grading, depending on the final use.



LWA screed – basic build up (Lytag®)

The oven dry loose bulk density of the lightweight coarse aggregates is typically in the range of 700 to 800kg/m^3. Particle densities range from 1300 to 1650kg/m^3. Normal weight aggregates have typical loose bulk densities of 1550kg/m^3 and particle densities of 2600kg/m^3. Therefore, the weight of the lightweight aggregate is approximately 50% that of normal weight aggregate.

As well as having a lower density than natural aggregates the spfa lightweight aggregate has other improved physical properties such as a Class 1 fire resistance. As the aggregate has been produced by a refractory process, the cellular structure of the aggregate particles relieves any pressures from expanding gases. The result is a material that is highly stable at elevated temperatures. The high void ratio, typically 40%, gives excellent freeze/thaw properties. The internal voids in the pellets provide space for the freezing water to expand into which minimises the disruption to the aggregate particle. The spherical shape of the pelletised aggregate also helps in placing concrete or screeds and, when placed loose, leads to minimal settlement after depositing.

It has a wide number of applications, some of which will be discussed in this feature. It has been used in lightweight concretes since the early 1960s and the reduction in concrete density has a significant effect on the dead load of the structure. Consequently foundation sizes can be reduced, additional floors can be constructed, thinner section beams and columns can be used, etc. As well as weight reductions, it also imparts improved durability benefits to concrete. In addition to the benefits when used for *in situ* concrete there are extra benefits associated with handling and logistical costs when used for precast units.

Spfa lightweight aggregate is widely used throughout the UK in floor and roof screeds providing cost effective ways of reducing

T5 – lightweight aggregate no fines screed used on the main floor areas to reduce loading

Samual Becket bridge and DCC – lightweight aggregate concrete used on the bridge deck to reduce loading and in the Dublin Convention Centre to reduce loading in the foyer main slab

weight, improving thermal and acoustic insulation and reducing the quantity of cement required in the construction.

The particle size and shape of the aggregate allows up to six times more water to pass through it than through standard gravel aggregates, thereby reducing the risk of silt blockages in trench systems. Finely graded lightweight aggregate can be used allowing grass to grow and 'knit' over the trench in a few days. It is also an ideal material for SUDs systems.

In addition the spfa aggregate is an excellent medium for biological filtration, it can be used in arrestor beds to bring run-away vehicles to a halt in a controlled manner and as Geo fill® civil engineering bulk fill, either bonded with cement or unbonded.

Environmental considerations

Being a secondary aggregate manufactured from the by-products of an industrial process, it not only diverts waste from landfill, but also reduces demand for natural quarried material.

With more and more emphasis being put on sustainable construction, and clients looking to gain recognition of their environmental credibility, for example getting BREEAM ratings, then using secondary aggregates which are by-products of industrial processes, processed to produce high grade aggregates, can gain additional valuable points.

From the sustainability point of view, spfa aggregate has distinct advantages over natural, virgin, materials.

Lightweight aggregate concrete

When lightweight aggregates are used in structural concrete design, codes generally make provision for its use. Structural design using spfa lightweight aggregate concrete should be in accordance with BS EN 1992-1-1, *Eurocode 2: Design of concrete structures, General rules and rules for buildings* and the UK National Annex. Section 11 of the BS EN 1992-1-1 covers lightweight aggregate concrete structures. It should be noted that some of the design approaches adopted differ from those in earlier design standards, such as BS 8110, *Structural use of concrete*.

In line with EN 206, the European concrete standard, and BS 8500, the complementary British Standard to BS EN 206-1, lightweight concrete is defined in terms of its strength class, e.g. LC30/33, indicating a characteristic cylinder strength of 30MPa and a characteristic cube strength of 33MPa. (Note that the assumed difference between the cylinder and cube strengths for lightweight concrete is less than for a normal weight concrete, which would be C30/37 in this case.)

An important point to note is that in BS 8110, design was based on concrete cube compressive strengths and so the equivalent lightweight concrete strength would reflect the cube strength, i.e. C30 normal weight concrete would equate to a C30 lightweight concrete. In the Eurocodes, design is based on cylinder strength, hence the equivalent strength class would be based on the cylinder strength, i.e. C30/37 would become an LC30/33.

Additionally, lightweight concrete is defined by its density. Concrete using coarse spfa lightweight aggregate and natural fine aggregate should be assumed to be Density Class D1.8 and concrete using both coarse and fine spfa lightweight aggregate should be assumed to be Density Class D1.6.

Extracted from table 8 in EN 206 – Compressive strength classes for lightweight concrete

Compressive strength class	Minimum characteristic cylinder strength – N/mm²	Minimum characteristic cube strengths – N/mm²
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
another values may be used if the relationship between these and the and the reference cylinder strength is established with sufficient accuracy and is documented.		

Density class	D1.0	D1.2	D1.4	D1.6	D1.8	D2.0
Range of density kg/m³	≥800 and ≤1000	>1000 and ≤1200	>1200 and ≤1400	>1400 and ≤1600	>1600 and ≤1800	>1800 ≤2000

Extracted from table 9 in EN 206 – Classification of lightweight concrete by density

St Pancras Platform – lightweight no fines screed used to build up levels of the platform

St Pancras Station – lightweight aggregate concrete used in the structure to reduce overall loadings in the structure

As well as improving the physical characteristics of concretes using lightweight aggregates they can also improve the durability of concrete. In spfa LWAC there are a number of factors that combine to reduce the chance of moisture or vapour ingress:

- Lightweight aggregate concrete tends to have lower free water / cement ratios, considerably reducing capillary action.
- The lower coefficient of expansion reduces thermal movement due to heat of hydration.
- The high tensile strain capacity together with the low elastic modulus and reduced early drying shrinkage combine to minimise the risk of cracking.
- The pelletised surface is rough, giving an excellent bond with the matrix in the contact zone.

The high water absorption of the aggregate allows moisture to be available for longer within the matrix, thus leading to a better, more complete, hydration of the cement. This leads to a higher quality of concrete hence permeability is reduced and durability improved.

Lightweight aggregate concrete (LWAC) skip mixes are generally designed around a BS 8500-1:2006 S2 consistence class (50mm – 90mm) or a target slump of 70mm and to pump it requires the use of admixtures and an appropriate mix design to produce a semi-flowing concrete equivalent to BS 8500-1:2006 flow class F5 or target flow of 560–620mm. It is important that monitoring is carried out to ensure the correct workability of the concrete discharge into the pump. However when pump pressures are high, it may be necessary to increase the target flow to compensate for loss of consistence. It is essential that if this approach is taken the mix design is sufficiently robust to compensate for this increase.

If the workability is low prior to discharge, this is either due to insufficient water at the time of batching or absorption of water by the lightweight aggregate (LWA). It is important that if water is added, normally on site, to achieve the specified workability, it is done in a controlled manner and within the time allowed for placing the concrete and should not affect the hardened properties of the lightweight concrete, i.e. strength and durability.

There are no significant differences in concreting techniques for placing normal weight concrete and LWAC. It should be vibrated as for normal weight concrete. Where a vertical surface requires a high quality finish and minimal blowholes, the LWAC may require slightly more vibration as it releases entrapped air more slowly due to the reduced hydrostatic head. However, care should be taken not to over-vibrate the concrete. Lightweight concrete with coarse and fine LWA may have a tendency to bleed more than normal weight concrete resulting in clear bleed water appearing on the surface of slabs subsequent to vibrating and tamping. This bleed water should be allowed to evaporate prior to any further finishing operations taking place. LWAC is readily placed by concrete pumps providing the concrete has the necessary pumpability and consistence characteristics.

Whilst LWAC can be produced in the same manner as normal weight concrete there are some areas where additional care is required. As Lytag® aggregate has a relatively high absorption, where required, the aggregate should be pre-wetted prior to use. This is to reduce the quantity of free water in the concrete that can potentially be squeezed into the aggregate during pumping. This should be done 24h before use and can be as simple as hosing the material with clean water and allowing to drain. This operation is generally carried out by the concrete producer. If the concrete is being pumped long distances, either horizontally or vertically, a greater degree of pre-wetting should be applied. This could be using spraying techniques round the stockpile or submerging in lagoons. Discussion with the concrete producer prior to commencing operations will ensure that things go smoothly. Although the above is the ideal, there are instances where storage and pre-wetting are impractical. In these situations other precautions may be appropriate such as:

- extending mixing times to allow for absorption to take place.
- specifying higher consistence class to allow for absorption during pumping.
- modifying the mix design and choosing an appropriate combination of admixtures.

It is fair to say that each site's situation and requirements will differ and communication between all parties is essential.

When the LWAC is placed by pump it is normal to observe the pellets 'pimpling' on the surface of the concrete after tamping and ruling off. This effect can be significantly reduced by floating the surface when the concrete has stiffened but whilst it is still semi-plastic. Henceforth the LWAC can be finished by all recognised techniques from tamping through to powerfloating. As long as the operatives are aware of the timing differences from normal weight pumped concrete, any finish can be achieved.

Lightweight aggregate screed

In many construction applications, whether new or refurbishment, the need for a screed is often called for. Depending on the thicknesses required this could impose significant loadings on the floor. By opting for a lightweight aggregate screed this weight could be significantly reduced. The density of traditional cement: sand screed is around 2100kg/m^3 as opposed to a lightweight aggregate screed with a density of around 1100kg/m^3. The LWA screed is placed as a no fines mix, i.e. it contains only coarse aggregate, usually 4/8mm, and cement. Mixing this with water the aggregate particles are cemented together to give a lightweight, open textured material. If the floor finish requires a smooth surface, such as carpet or vinyl, a thin topping of cement: sand, 15mm thick, is laid on top of the LWA screed. If the finished surface is paving slabs the mortar bedding can be applied directly to the no

10 Old Bailey – lightweight aggregate concrete used with Strux® synthetic fibres to reduce overall loading on the structure

Cardinal Place, Victoria London – post tensioned lightweight aggregate concrete used to reduce overall loading within the structure

fines screed.

Examples of the expected loading are shown in the table below.

Material	Buildup	Weight per m²	Weight saving
Cement: sand screed	50mm depth	105kg/m²	
Cement: sand screed	65mm depth	136kg/m²	
Lytag® LWA screed @ 50mm depth	35mm depth LWA screed plus 15mm topping	70kg/m²	33%
Lytag® LWA screed @ 65mm depth	50mm depth LWA screed plus 15mm topping	87kg/m²	36%

As well as reducing the weight of the screed, a no fines screed uses around half of the cement content of traditional cement: sand screed. It also has the added benefit of improving the thermal efficiency of the overall buildup, especially useful when used as a screed on roofing.

No fines screeds are also easy to place and lay to falls. Due to the rounded nature of the aggregate it is easily moved and compacted, using a screed bar, to the required level and falls. It can also be mixed/pumped with a pneumatic screed pump.

In conclusion

Using lightweight aggregates in construction projects can provide many benefits. From improving physical and durability properties of the actual concrete, to using LWAs to improve the environmental credentials of the building, if designed from initial concept with LWA's in mind there is the potential additional benefit of reducing project costs.

Case histories

St Pancras Station

In 1996 St Pancras was nominated to become the new UK terminal for Eurostar and a 5 year redevelopment was undertaken to upgrade the station. This would add substantial weight to the existing structure and as much of the building is over tunneled, void and unstable ground, the choice of materials was key to delivering the architect's design without needing to compromise because of the additional loading on the structure.

This was the challenge for Joint Venture group, CORBER. The ideal solution to minimise the impact of construction was to use lightweight materials and with concrete a major component of the build, this was an important area of focus. Concrete supplier, Hanson, used LWA in the concrete and screed it supplied for the construction project. CORBER used lightweight aggregate concrete in part of the refurbishment and in the underground station. For the platforms, CORBER chose a lightweight aggregate no-fines screed, topped with paving, to bring up levels on the existing platforms to accommodate the new Eurostar trains.

Using LWA significantly reduced the weight of the concrete and screed, enabling CORBER to achieve the redevelopment of St Pancras station without having to undertake extensive and costly strengthening work to the existing structure.

7-10 Old Bailey, London

Last year, a £22M, seven-storey office development was built adjacent to the Old Bailey High Court in the City of London. Constructed within the existing structure's footprint, the new building has been designed to remain sympathetic to the site's historic surroundings while also exemplifying the best of modern design.

On a site of such historic value, reducing the impact on the remaining archaeology was a key consideration. This, combined with ground composed of soft clay containing glacio-sedimentary structures derived from the last ice age, creating anomalies in the soil affecting ground stability, posed a challenge for the design team. By choosing lightweight aggregate for the concrete to be used in the floors of the 7904m² building, engineering consultancy Pell Frischmann was able to greatly reduce the structure's weight.

In addition, the lightweight aggregate concrete contained Strux® synthetic fibre reinforcement (added to the lightweight aggregate concrete as a replacement for steel reinforcing on the metal decking) which further reduced the weight, and off-set the time otherwise needed for fixing steel reinforcing.

References

BS EN 13055-1 *Lightweight Aggregates – Lightweight aggregates for concrete, mortar and grout,* BSI, London

BREEAM (BRE Environmental Assessment Method)

BS 8500-1 *Concrete – Complimentary British Standard to BS EN 206-1. Method of specifying and guidance for the specifier,* BSI, London

BS EN 1992-1-1 *Eurocode 2: Design of concrete structures. General rules and rules for buildings,* BSI, London

BS 8110-1:1997 *Structural use of concrete. Code of practice for design and construction,* BSI, London

BS EN 206-1 *Concrete – Specification, performance, production and conformity,* BSI, London