The properties of high strength lightweight concrete

by P B Bamforth, Taywood Engineering Ltd

The properties of lightweight concrete, manufactured using Lytag, differ significantly from those of concretes using gravel or crushed rock aggregate. This article contains a summary of the results of tests carried out by Taywood Engineering to compare the behaviour of two Grade 40N concretes, one containing Lytag 12mm aggregate and the other containing 20mm gravel. Properties which have been measured include:

- Water permeability
- Air permeability
- Direct tensile strength and strain capacity
- Flexural strength (modulus of rupture) and strain capacity
- Bond strength
- Elastic modulus and creep
- Thermal expansion coefficient.

Both the normal weight and lightweight concretes were designed to achieve a characteristic strength of 40N/mm^2 and a slump of 75mm. Mix details are given in Table 1. To achieve comparable strengths, a cement content for the Lytag concrete of 505kg/m^3 was required, compared with 425kg/m^3 for the control mix.

All specimens, with the exception of the control cubes, were subjected to sealed curing. This involved removal from the moulds after 24 hours and storage in sealed plastic bags at 20°C. This curing regime was designed to simulate that which normally occurs in situ, where the only water available for curing is that which is added at mixing.

Test results

A summary of the results obtained is given in Table 2 together with details of the specimen geometry and the age at test. Further details of the test methods and individual test results are given in Reference 1. Overall, the properties of the lightweight concrete were better than those of the equivalent Grade 40N gravel concrete. The following differences were recorded:

- Permeability was reduced by about two orders of magnitude
- Tensile strength and flexural strength was increased by 20 to 30 per cent
- Strain capacity was increased by about 50 per cent
- Elastic modulus was reduced by 35 to 40 per cent
- Creep was unaffected
- Bond strength was increased by about 20 per cent
- Thermal expansion coefficient was reduced by about 20 per cent.

These changes in concrete properties are the result of not only the significantly different physical properties of the lightweight aggregate, but also the changes in mix proportions arising from its use. Consider, for example, water permeability; this property was most significantly affected by the use of the lightweight aggregate, being reduced by about 100 times.

This has been attributed to the following features of the lightweight concrete:

- To achieve a particular strength grade more cement is required, resulting in a lower water/cement ratio paste
- The aggregate is porous, providing a reservoir of moisture within the body of the concrete. The internal humidity is, therefore, maintained at a higher level for a longer period, resulting in a more fully hydrated cement paste. For the same reason it would be expected that under less favourable curing conditions, the performance of lightweight concrete would be at least as good as, and probably better than, that of a similar grade concrete using gravel aggregate
- The aggregate tested is a sintered pfa and may, therefore, chemically react with the Portland cement resulting in enhanced bond between the aggregate and cement paste. This will have reduced leakage paths along the aggregate/cement paste boundary
- The porous texture of the Lytag particles enables the cement gel to grow into the aggregate surface, also enhancing the physical bond
- Compared with a gravel or crushed rock the elastic modulus of lightweight aggregate is much more compatible with that of cement paste. In addition its shape is roughly spherical, hence the tendency for microcracking is reduced.

Implications in design and construction

Resistance to cracking

The modified properties of high strength lightweight concrete can be utilised in a number of ways. For example, the combination of low thermal expansion coefficient and high strain capacity means that lightweight concrete is much less likely to crack under conditions of thermal loading. This may lead to benefits in terms of increasing acceptable pour sizes, particularly in water retaining structures where cracking has the most obvious implications. Based on results obtained, acceptable temperature changes using lightweight aggregate concrete are about double those for gravel aggregate concrete, resulting in similar performance to a concrete using low thermal expansion limestone[2]. On this basis, therefore, it would be reasonable to assume that bay lengths for thick walls and slabs could be increased by a similar amount.

Bond to reinforcement is also of importance in minimising crack widths. The increased bond recorded for the high strength concrete using lightweight aggregate indicated better crack control than would occur in the comparable gravel concrete. This is in contradiction to the recommendations in BS 8110, which limit bond stresses in lightweight concrete to 80 per cent of those for conventional dense aggregate concrete.

Permeability and durability

Low permeability is of considerable importance, not least for containment structures[3]. It is surprising, therefore, that lightweight aggregate is not permitted, by BS 5337, for use in water retaining structures. Not only is lightweight concrete likely to be less permeable than a dense aggregate concrete of the same strength grade, but it is also less likely to crack.

Permeability is also considered to be an indicator of durability. Lower permeability will result in less likelihood of deterioration and hence, lower maintenance costs. The lower permeability of lightweight concrete is not reflected, however, in the

Table 1: Concrete mix details

	Lytag concrete (kg/m^3)	Gravel concrete (kg/m^3)
Mix proportions		
Ordinary Portland cement	505	425
Lytag (12mm)	720	—
Thames Valley gravel (20mm graded)	—	1115
Sand (Zone 2)	495	630
Sika AEA	0.18	0.31
Density	1940	2365
Properties		
W/C	0.44*	0.46
Air content (%)**	6.4	4.8
Slump (mm)	70	75
Strength (N/mm^2)		
— 7 days	40.8	42.4
— 28 days	50.4	52.8

***Free w/c at time of mixing. This may have been reduced by absorption of water into the lightweight aggregate**

****The air content measured for the Lytag concrete represents all the air in the system. This includes both the air entrained in the paste and the voids in the aggregate not filled with water**

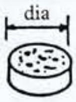
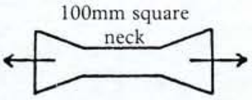
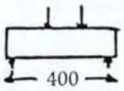
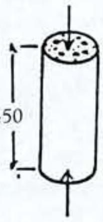
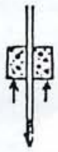
Test	Specimen geometry	Age	Lytag concrete	Gravel concrete	Units
Water permeability	 cast spec	56 days	0.0071	7.04	($m^2 \times 10^{-18}$)
	 cut from block	56 days	0.0022	1.54	($m^2 \times 10^{-18}$)
	 50mm cut from 200mm long cylinder	2 years	0.0040	5.36	($m^2 \times 10^{-18}$)
Air permeability	100mm dia  cut from 200mm long cylinder	2 years	0.56	16.4	($m^2 \times 10^{-18}$)
Direct tensile strength and strain capacity	100mm square neck 	56 days	1.82 86	1.39 36	Strength (N/mm^2) Strain (1×10^{-6})
Flexural strength and strain capacity	 400 100mm sq	56 days	3.89 193	3.27 134	Strength (N/mm^2) Strain (1×10^{-6})
Elastic modulus and creep	 150mm dia 450 $14N/mm^2$ Stress	56 days 180 days	19.5 24.5 14.0	31.6 38.8 19.5	kN/mm^2 — elastic kN/mm^2 — elastic kN/mm^2 — effective modulus after 180 days under load
Bond strength	20mm deformed bar  150mm cube helically reinforced	56 days	4.25	3.58	N/mm^2
Thermal expansion coefficient	 150mm dia 450 +20 to −20°C	56 days	9.52	12.11	1×10^{-6} per °C

Table 2: Summary of concrete properties

recommendations of BS 8110, which require increased cover for lightweight concrete in severe to extreme environments.

Deflections

The low modulus will result in greater deflections in elements containing lightweight concrete, but this can be accommodated at the design stage. Similarly, prestress loss will be higher compared with conventional concrete. The contribution to the increased deflection is, however, largely elastic. In the long term deflections due to creep will be similar for lightweight and gravel concretes.

Conclusions

A comparison of two Grade 40N concretes, one containing 20mm gravel aggregate and the other containing Lytag, has demonstrated the benefits which can be achieved by the use of high strength lightweight concrete. Permeability to water and air is reduced and the tensile properties are enhanced. It is unfortunate that these properties are not recognised by existing UK standards and codes of practice, in some cases prohibiting the use of lightweight concrete when it could provide substantial benefits.

References

1. Bamforth, P B. The performance of high strength lightweight concrete using Lytag aggregate. Taywood Engineering Research Report No 014H/85/2820 (on behalf of Pozzolanic/Lytag).
2. Bamforth, P B. Early age thermal cracking in concrete. Institute of Concrete Technology, Tech Note No TN/2, 1982.
3. Bamforth, P B, Murray, W T and Browne, R D. The application of concrete property data at cryogenic temperature to LNG tank design. Second Int Conf on Cryogenic Concrete, Amsterdam, October 1983. □