construction. Therefore, explosive spalling at high temperatures must be effectively dealt with in order to maximise the benefits structural LWAC brings about.

Several mechanisms have been put forward to explain spalling of concrete exposed to fire, such as induced thermal stress (between the exterior layer and the interior of concrete) and vapor pressure. High temperatures can cause the water in the pore spaces of the concrete to vaporise, increasing the vapour pressure in the pores and inducing spalling on the exterior surface.

In recent years, it has been found that concrete porosity may be the underlying factor that adversely affects lightweight concrete's resistance to elevated temperatures. Porosity of a concrete is the measure of how much open spaces or voids are present and porosity is often linked to the permeability of the concrete. Permeability is the ability of fluid to flow through these voids and if these voids are well connected, a concrete is said to be highly permeable. It is important to note that it is possible for a porous concrete to not be significantly permeable and thus have a closed pore system if the open voids are not well connected throughout (Fig. 1A to 1D).

Usually, thermal crack patterns tend to follow a concrete's weakest zone, or the interfacial transition zone (ITZ). However, for the case of very porous lightweight aggregate concrete (LWAC), cracks tend to follow a path inside specifically porous aggregates (Fig. 1E). This leads to an uneven distribution of cracks in the concrete matrix. With the higher porosity leading to a higher moisture content inside the concrete, pore vapor pressure and thermal gradient increase. Spalling is worsened in concrete with lower permeability, where vapour cannot escape quickly enough.

In order to reduce explosive spalling, a concrete mix of low moisture content and high permeability is desired. The permeability of a concrete is primarily dependent on the hardened cement paste and voids between the aggregates. Therefore, the size of the voids is crucial. Larger voids increase permeability of the concrete and allow for more cement paste to be filled .

There is therefore a need for development of a concrete composition that overcomes or at least ameliorates, one or more of the disadvantages described above. That is, there is a need for a concrete composition that maintains all of the advantageous properties of a conventional lightweight concrete having high strength suitable for structural use, while preventing it from explosive spalling during fire exposure.

## Summary

In an example, there is provided a composition comprising:

about 28 % to about 42 % by weight of a binder;

about 3 % to about 7 % by weight of cenospheres;

about 35 % to about 50 % by weight of sand;

about 8 % to about 13 % by weight of a lightweight coarse aggregate;

about 0.05 % to about 0.5 % by weight of a first fibre; and

about 1 % to about 4 % by weight of a second fibre,

wherein the total weight of the composition adds to 100 %.

In one aspect, the present disclosure refers to a composition comprising:

about 28 % to about 42 % by weight of a binder;

about 3 % to about 7 % by weight of cenospheres;

about 35 % to about 50 % by weight of sand;

about 8 % to about 13 % by weight of a lightweight coarse aggregate;

about 0.05 % to about 0.5 % by weight of a first fibre, wherein the first fibre has a length of about 6 mm to about 20 mm; and

about 1 % to about 4 % by weight of a second fibre, wherein the second fibre has a length of about 30 mm to about 40 mm,

wherein the total weight of the composition adds to 100 %.

In an example, the composition may further comprise water in an amount such that the water:binder ratio by weight is in the range of about 0.2 to about 0.3.

In another example, the composition may further comprise about 0.5 % to about 1 % by weight of a superplasticizer.

Advantageously, the composition as defined above may have the combined properties of anti-spalling, high-strength and lightweight due to a proportional mix of hybrid fibres in a high-strength lightweight concrete. Compared to other lightweight concretes, the composition as defined above may have a relatively high early strength and significantly higher modulus of elasticity even when cured in ambient air. More importantly, the composition as defined above may show better performance of flexure strength, ductility and workability. Further, the composition as defined above may resist explosive spalling while maintaining excellent mechanical properties during exposure to fire.

Advantageously, the composition as defined above may reach a 1-day strength of more than 26.7 MPa even at ambient air curing. This may facilitate the use of the composition in pre-fabricated or pre-cast construction materials, which are required to have sufficient strength to be transported out of the precast plants as early as 1 to 3 days after production.

Further advantageously, the composition as defined above may meet structural requirements of having a 28-day compressive strength of at least 40 MPa with air-dried density not exceeding 1850kg/$m^3$ by varying water to binder ratio and cenosphere to sand ratio.

Further advantageously, the Young's modulus of the composition as defined above may be much higher than that of commonly used lightweight concrete. The Young's modulus of the composition as defined above may be close to that of normal concrete, which is about 25-30 GPa. The high modulus of elasticity of the composition as defined above may be attributed to the strength of the matrix and its strong bond to the aggregates.

Advantageously, the two main reasons for spalling, that is pore pressure and thermal stress, may be effectively dealt with by lowering water content of the concrete mix and increasing the permeability of the concrete. The composition as defined above comprises a first fibre such as polypropylene (PP) which may melt in high temperature conditions to create channels or pore systems to allow for vapour pressure to escape, thereby preventing explosive spalling.

# Claims

1. A composition comprising:

   about 28 % to about 42 % by weight of a binder;

   about 3 % to about 7 % by weight of cenospheres;

   about 35 % to about 50 % by weight of sand;

   about 8 % to about 13 % by weight of a lightweight coarse aggregate;

   about 0.05 % to about 0.5 % by weight of a first fibre, wherein the first fibre has a length of about 6 mm to about 20 mm; and

   about 1 % to about 4 % by weight of a second fibre, wherein the second fibre has a length of about 30 mm to about 40 mm,

   wherein the total weight of the composition adds to 100 %.

2. The composition according to claim 1, further comprising water in an amount such that the water:binder ratio by weight is in the range of about 0.2 to about 0.3.

3. The composition according to claim 1 or 2, further comprising about 0.5 % to about 1 % by weight of a superplasticizer.

4. The composition according to any one of claims 1 to 3, wherein the binder comprises about 25 % to about 36 % by weight of cement and about 3 % to about 6 % by weight of a pozzolanic filler.

5. The composition according to claim 4, wherein the cement is Portland cement CEM 52.5 (ASTM Type I), Portland cement CEM 42.5 (ASTM Type I), Portland Pozzolana Cement (PPC), Rapid Hardening Cement, Extra Rapid Hardening Cement, Low Heat Cement, Sulfates Resisting Cement, Quick Setting Cement, Blast Furnace Slag Cement and any mixture thereof.

6. The composition according to claim 4 or 5, wherein the pozzolanic filler is selected from the group consisting of silica fume, microsilica, nanosilica, furnace slag, fly ash, glass powder, rice husk ash and any mixture thereof.

7. The composition according to any one of the preceding claims, wherein the lightweight coarse aggregate is selected from the group consisting of lightweight expanded clay aggregate (LECA), lightweight expanded shale aggregate, lightweight expanded slate aggregate, foamed slag, sintered pulverised fuel ash aggregate, and any mixture thereof.

8.The composition according to any one of the preceding claims, wherein the lightweight coarse aggregate has a diameter in the range of about 4 mm to about 20 mm.

9.The composition according to any one of the preceding claims, wherein the sand is silica sand, natural sand or river sand.

10. The composition according to any one of the preceding claims, wherein the sand has a particle size of less than 2 mm.

11. The composition according to any one of claims 3 to 10, wherein the superplasticizer is selected from the group consisting of sulfonated naphthalene formaldehyde condensate, sulfonated melamine formaldehyde condensate, acetone formaldehyde condensate, polycarboxylate ethers and any mixture thereof.

12. The composition according to any one of the preceding claims, wherein the first fibre is selected from the group consisting of polypropylene fibre, nylon fibre, rubberized fibre and any mixture thereof.

13. The composition according to any one of the preceding claims, wherein the first fibre is a monofilament cylindrical fibre having a diameter in the range of about 10 μm to about 40 μm.

14. The composition according to any one of the preceding claims, wherein the second fibre is selected from the group consisting of steel fibre, glass fibre, carbon fibre, polyethylene fibre and any mixture thereof.

15. The composition according to any one of the preceding claims, wherein the second fibre has a width in the range of about 0.5 mm to about 0.75 mm.

16. A method of preparing a composition according to any one of claims 3 to 15, comprising the steps of:

a) mixing about 28 % to about 42 % by weight of a binder, about 3 % to about 7 % by weight of cenospheres and about 35 % to about 50 % by weight of sand to form a dry mix;

b) mixing a first volume of water with the dry mix to form a first wet mix;

c) mixing about 0.5 % to about 1 % by weight of a superplasticizer with a second volume of water to form a second wet mix;

d) mixing the first wet mix with the second wet mix to form a third wet mix;

e) mixing about 0.05 % to about 0.5 % by weight of a first fibre, about 1 % to about 4 % by weight of a second fibre, and about 8 % to about 13 % by weight of a lightweight coarse aggregate with the third wet mix to form the composition,

wherein step e) further comprises a step of soaking the lightweight coarse aggregate in soaking water before mixing with the third wet mix;

wherein the first volume of water in step b) and the second volume of water in step c) are mixed such that in combination, the water:binder ratio by weight of the composition is in the range of about 0.2 to about 0.3, and

wherein the total weight of the composition adds to 100 %.

17. The method according to claim 16, wherein after the soaking step, the lightweight coarse aggregate has a water content in the range of about 10 % to about 22 % by weight.

18. The method according to claim 16 or 17, wherein the first volume of water in step b) and the second volume of water in step c) are substantially the same volume.

19. The method according to any one of claims 16 to 18, wherein the mixing steps a) to e) are each independently performed in air at atmospheric pressure and at a temperature in the range of about 20 °C to about 35 °C.

20. The method according to any one of claims 16 to 19, wherein the composition is further cured in air or water at atmospheric pressure and at a temperature in the range of about 20 °C to about 90 °C.

21. A concrete structure comprising the composition according to any one of claims 1 to 15.

22. The concrete structure according to claim 21, wherein the concrete structure is a pre-fabricated structure.

23. The concrete structure according to claim 22, wherein the pre-fabricated structure is selected from the group consisting of a beam, a slab, a brick, a pipe, a pole, a vault, a tank, a well, a barrier, a wall, a column, a panel, stairs, a bridge, a containment vessel, a foundation, a floating structure and any combination thereof.