Mechanical properties of lightweight foamed concrete using polycarboxylate ether superplasticizer

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Abstract. A study was conducted on the effect of polycarboxylate ether superplasticizer on the mechanical properties of lightweight foamed concrete. This research focuses on the compressive strength, splitting tensile strength and flexural strength of lightweight foamed concrete using 0.5% and 1.0% polycarboxylate ether superplasticizer with targeted density of 1500 kg/m³. Trial mix is carried out to determine the optimum water content for the 1:1 cement to sand ratio concrete mix. With optimum water content obtained, 7 days and 28 days samples are prepared and tested for both with and without polycarboxylate ether superplasticizer in compliance to ASTM standard. From the experiment, the optimum water content for 0.5% superplasticizer is 0.33 whereas the ratio for 1.0% superplasticizer is 0.30. The addition of superplasticizer yields best performance in all 28-days strength of lightweight foamed concrete. 1.0% addition of superplasticizer produces best result with 24.5 MPa of compressive strength, 2.13 MPa of splitting tensile strength and 9.49 MPa of flexural strength. The addition of 1.0% superplasticizer makes the concrete mix fulfil the requirement of ACI 318 of structural concrete, which indicate the potential of mix in structural work.

1. Introduction
Lightweight concrete had been widely used in the construction industry. Its lower density helps to reduce the self-weight of structure, thus reduce members size and lower material cost [1]. Reduction of overall concrete used also contributes towards greener construction. Three major types of lightweight concrete are lightweight aggregates concrete, no-fines concrete and foamed concrete. Foamed concrete, or sometimes called aerated, cellular, or gas concrete, is type of concrete with entrapped air either by injecting or mixing air into the mixture during the production. Lightweight foamed concrete is known by its low density, high flowability, self-compacting, and good thermal and acoustic insulation. It can be used in a wide range of construction applications including void filling, trench reinstatement, soil stabilization, thermal and acoustic insulation, floor and roof screeds [2]. However, since the compressive strength for foamed concrete is merely around 10 MPa, which is not suitable for structural use [3].

Researches had been conducted on lightweight foamed concrete, including the utilisation of recycled waste into foamed concrete [4-6], sand grading behaviour [7,8] and enhancement for structural usage [9-10]. Several attempts had been done to increase the strength of foamed concrete by incorporating various additive and admixture into the concrete such as fly ash, silica fume and superplasticizer [11]. The inclusion of superplasticizer helps to increase the flowability of foamed concrete with lower water
content. Reduced water content in turn can yield better early age strength, long-term mechanical properties, durability, permeability etc [2,12]. Polycarboxylate ether superplasticizer is high-range water reducer which can perform up to 30% water reduction. When it is adsorbed at the solid–liquid interface in a molecule suspension, it incites an appalling interparticle constrain that keeps away from the development of agglomerates, thus increases the workability of concrete [2,13]. The uses of polycarboxylate ether superplasticizer inside foamed concrete is beneficial as it entrains more air inside the concrete and keep the foam stable as compared to conventional naphthalene or melamine superplasticizer [2,14,15]. Although the use of superplasticizer is successful in producing high performance concrete, the extent of how much superplasticizer helps in the improvement of lightweight foamed concrete performance is unknown as the performance of different superplasticizer on different concrete mix varies with dosage.

This research aims to investigate suitability of lightweight foamed concrete with addition of polycarboxylate ether superplasticizer for structural use. A high strength lightweight foamed concrete will become more acceptable in construction industry and been used in wider range of application.

2. Methodology
2.1. Material
The cement used was with compliance to Type 1 Portland Cement. Only river sand was used since there is no coarse aggregate needed for foamed concrete. The river sand was sieved through 0.60mm sieve and only the fine sand passed through the sieve was chosen. The fine sand was oven-dried at 105°C for 24 hours to completely remove any moisture content in aggregate for better control of water content in concrete mix. Local synthetic ether-based foaming agent was used to produce foam. Polycarboxylate ether superplasticizer was added as admixture in this study.

2.2. Experiment Design for Trial Mix Mortar
Cement content used is around 650kg/m³ and the content is adjusted based on density of fresh mix (1500kg/m³) and water-cement ratio. Cement-sand ratio of 1:1 was chosen in concrete mix throughout this study for constant comparison. Three groups of concrete mix were yielded with 0%, 0.5% and 1% of superplasticizer content with respective of water added. Different water-cement ratio was adopted to find the optimum water content which gave highest strength and still workable. For control set (0% superplasticizer), water content ranged from 0.42 to 0.50 with increment of 0.02. For concrete mix with 0.5% superplasticizer, 0.32 to 0.36 with increment of 0.01 water-cement ratio was used. For 1% superplasticizer, 0.30 to 0.34 with increment of 0.01 water-cement ratio was used.

The fresh mortar will then be tested with flow table test for its workability in accordance to ASTM C1437 [16]. Three 100mm×100mm×100mm cube specimens were also prepared for the 28-days compressive strength in accordance to ASTM C39 [17]. The cube specimen was prepared by filling the mould with three layers of concrete. The specimens were then left air-dried for 24 hours before been removed from mould and water-cured until 28 days.

2.3. Experimental Design for Lightweight Foamed Concrete
After the concrete mix with optimum water content was obtained, the selected mix design will be used to cast the lightweight foamed concrete specimens for 7-days and 28-days compressive strength, flexural strength and splitting tensile strength. Foam was prepared by adding foaming agent and water with ratio of 1:30 into the foam generator. Constant air pressure was maintained inside the generator. Stable foam was then produced from the nozzle of foam generator by opening the air and liquid valve. After that, foam was mixed with mortar carefully to produce fresh lightweight foamed concrete. When the mortar mixed with foam became homogenous, the fresh foamed concrete was weighed to ensure the density is within 1500 kg/m³. Additional foam will be added until target density is achieved.

Six 100mm×100mm×100mm cube specimens, three 100mm diameter times 200mm height cylinder specimens and three 160mm×40mm×40mm prism specimens were prepared for each 0%, 0.5% and 1% superplasticizer batch. The foamed concrete was poured into the mould in three layers separately.
During the process of casting of specimens, for each layer of foamed concrete the mould was slightly shaken and no tamping or vibration was done to prevent the collapse of foam inside concrete. All specimens were then left air-dried for 24 hours before been removed from mould and water-cured until 28 days. All the testing done were in accordance to ASTM standard, with splitting tensile test comply to ASTM C496 [18] and flexural test in comply to ASTM C293 [19].

3. Results and Discussion

3.1. Result from trial mix mortar

The results of flow table test, 28-days compressive strength and density of trial mix mortar for 0%, 0.5% and 1% superplasticizer were shown as Table 1.

| Percentage of superplasticizer | w/c ratio | Flow table measurement (cm) | Compressive Strength (MPa) | Mortar density (kg/m³) |
|-------------------------------|-----------|----------------------------|---------------------------|----------------------|
| 0%                            | 0.42      | 18.8                       | 51.63                     | 2140                 |
|                               | 0.44      | 19.3                       | 50.61                     | 2160                 |
|                               | 0.46      | 20.9                       | 52.35                     | 2160                 |
|                               | 0.48      | 21.6                       | 47.70                     | 2100                 |
|                               | 0.50      | 23.3                       | 40.48                     | 2160                 |
| 0.5%                          | 0.32      | 16.8                       | 73.70                     | 2240                 |
|                               | 0.33      | 23.4                       | 75.18                     | 2235                 |
|                               | 0.34      | 24.3                       | 71.00                     | 2230                 |
|                               | 0.35      | >25                        | 74.41                     | 2235                 |
|                               | 0.36      | >25                        | 73.38                     | 2240                 |
| 1%                            | 0.30      | 20.1                       | 75.44                     | 2227                 |
|                               | 0.31      | 20.3                       | 75.89                     | 2243                 |
|                               | 0.32      | 21.3                       | 82.07                     | 2277                 |
|                               | 0.33      | 23.8                       | 70.57                     | 2260                 |
|                               | 0.34      | >25                        | 64.49                     | 2253                 |

From the results obtained, the water-cement ratio required for workable trial mix mortar (flow table result more than 20cm but less than 25cm) had been reduced from 0.46 to 0.33 for 0.5% superplasticizer and 0.30 for 1% superplasticizer. The reduction of water content also increased the compressive strength of mortar from 52.35MPa to 75.18MPa for 0.5% superplasticizer and 82.07MPa for 1% superplasticizer. The addition of superplasticizer also increased the density of mortar, but the increment of water-cement ratio produced mortar with similar density. For next stage of testing, water-cement ratio of 0.46, 0.33 and 0.30 were chosen for 0%, 0.5% and 1% superplasticizer addition. Water-cement ratio of 0.30 was chosen for 1% superplasticizer instead of 0.33 which gave highest compressive strength is due to the severe segregation issue when w/c ratio of more than 0.30 was used. The issue was believed to be caused by prolonged period for polycarboxylate ether superplasticizer to react with mortar. From observation it took 30 minutes for complete reaction for superplasticizer while the preparation of trial mix specimen only took 10 minutes.

3.2. Results for lightweight foamed concrete

3.2.1. Density of lightweight foamed concrete
Table 2 shows the average density of the cube specimen for compressive test at 7 days and 28 days. The introduction of superplasticizer into foamed concrete will increase the density of foamed concrete after curing and the more superplasticizer added, the higher the density. With 0.5% or no superplasticizer added, the increment of density from 7 days to 28 days was small compared to 1% addition. As compared to density of mortar in Table 1, the reduction of density indicated that the foam inside the concrete was stable and not affected by the addition of polycarboxylate ether superplasticizer. Overall the hardened foamed concrete is considered lightweight.

| Percentage of superplasticizer | Density (kg/m³) | Percentage of reduction to trial mix mortar (%) |
|-------------------------------|-----------------|-----------------------------------------------|
|                               | 7 Days | 28 Days |                                      |
| 0%                            | 1498   | 1505    | 30.3                                             |
| 0.5%                          | 1550   | 1558    | 30.3                                             |
| 1%                            | 1587   | 1613    | 27.6                                             |

3.2.2. Compressive strength of lightweight foamed concrete

The compressive strength of lightweight foamed concrete is shown in Figure 1. The usage of superplasticizer did increase the compressive strength of foamed concrete. With 0.5% superplasticizer, the 28 days strength increased by 118% whereas with 1% superplasticizer, 236% increment was obtained compared to control specimen with no superplasticizer added. This is impressive as the characteristic strength of 24.5MPa for foamed concrete with 1% superplasticizer can be potential for structural purpose. The compressive strength of this mix fulfils the minimum requirement of ACI for structural concrete, which is 17MPa [20].

From the perspective of strength development, foamed concrete exhibits different trend compared to conventional concrete. With control specimen, 7-days compressive strength is 82% of characteristic strength. For 0.5% superplasticizer, the concrete had developed 92% of characteristic strength at 7 days while with 1% superplasticizer, 57% of characteristic strength was developed in 7 days. As for normal concrete, the 7 days strength will be 66% of 28 days characteristic strength.
Table 3: 28 Days Flexural Strength and Splitting Tensile Strength of Foamed Concrete

| Percentage of superplasticizer | Compressive Strength (MPa) | Flexural Strength(MPa) | Splitting Tensile Strength(MPa) |
|--------------------------------|---------------------------|------------------------|-------------------------------|
| 0%                            | 7.29                      | 3.55                   | 1.21                          |
| 0.5%                          | 15.88                     | 4.98                   | 1.76                          |
| 1%                            | 24.50                     | 9.49                   | 2.13                          |

3.2.3. Flexural strength of lightweight foamed concrete
The 28 days flexural strength of lightweight foamed concrete is shown in Table 3. The flexural strength of foamed concrete increased with the addition of superplasticizer by 40% with 0.5% superplasticizer and 167% with 1% superplasticizer. The flexural strength of foamed concrete ranged from 31% to 48% of characteristic strength. Foamed concrete can benefit from higher flexural strength when subjected to bending stress, especially in the case where plain concrete is used.

3.2.4. Splitting tensile strength of lightweight foamed concrete
The 28 days splitting tensile strength of lightweight foamed concrete is shown in Table 3. The splitting tensile strength of lightweight foamed concrete increased with the addition of superplasticizer, from 1.21MPa to 1.76MPa for 0.5% superplasticizer (45% increment) and 2.13MPa for 1% superplasticizer (76% increment with respective of control). The ratio of splitting tensile strength to compressive strength is 17%, 11% and 9% respectively. Foamed concrete with higher tensile strength is more resistant to crack formation, which is advantageous in aesthetic work. It also reduces the chance of water leakage into concrete, which is crucial as void in foamed concrete can easily conduct water to reinforcement, causing corrosion issue from the inside of concrete.

4. Conclusion
Lightweight foamed concrete had huge advantages over the conventional concrete. From the study done, lightweight foamed concrete with density ranged from 1505kg/m³ to 1613kg/m³ were produced. The addition of polycarboxylate ether superplasticizer can enhance the mechanical properties of foamed concrete. The inclusion of 1% superplasticizer had yielded best result, with compressive strength of 24.5MPa, 9.49MPa of flexural strength and 2.13MPa of splitting tensile strength. The compressive strength of this mix fulfils the requirement of ACI for structural concrete. Future research is encouraged to investigate on long term properties of foamed concrete. Besides, addition of other admixture or changing of cement-sand ratio is proposed to further increase the strength of foamed concrete for better structural performance.

5. Reference
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