Mechanical Properties of Light Weight Aggregate Concrete Using Pumice as a Coarse Aggregate

Hayder Kadhem Adai Al-Farttoosi1,*, Oday A. Abdulrazzaq2, and Haleem K. Hussain2

1 Ph.D. Candidate in Civil Eng. Department, College of Engineering, University of Basrah, Basra, Iraq
2 Civil Eng. Department, College of Engineering, University of Basrah, Basra, Iraq
*Corresponding author’s e-mail address: hayder.k.alfarttoosi@gmail.com

Abstract. This study investigates the mechanical properties of hardened lightweight coarse aggregate concrete (LWAC) using Pumice as a lightweight aggregate. Eleven concrete mixes were prepared to investigate the effects of pumice ratio to total aggregate, micro-silica to binder ratio (MS/b), and the water to binder ratio ($w/b$) on equilibrium density, compressive strength ($f_{cu}$), splitting tensile strength ($f_{ct}$), and modulus of rupture ($f_r$). The main parameters were performed by reducing Pumice to total aggregate ratio, reducing micro-silica to binder ratio, and water to binder ratio by reducing binder content. Six cubic specimens (150×150×150 mm³), three cylinders (100 dia. and 200mm height), and one prism (100×100×350 mm³) were used to investigate $f_{cu}$, $f_{ct}$, and $f_r$, respectively. All specimens were tested at 28 days. The specimens had a density of 1833 – 2031 kg/m³ with a compressive strength ranged from 27 MPa to 44 MPa. The results showed that using micro-silica increases $f_{cu}$, $f_{ct}$, and $f_r$, along with an insignificant decreasing equilibrium density. Due to the low weight of Pumice compared to the other material of the mix, the result showed that decreasing the amount of Pumice increases the equilibrium density, $f_{cu}$, with decreasing in $f_{ct}$, and $f_r$ of concrete. Also, increasing the $w/b$ decreases equilibrium density, $f_{cu}$, $f_{ct}$, and $f_r$ of concrete.

Keywords: Light weight aggregate, Concrete, Pumice, Coarse aggregate

Nomenclature

- $f_{ct}$: Concrete splitting tensile strength of three cylinders
- $f_{cu}$: Concrete compressive strength of three cubic samples
- $f_r$: Modulus of rupture
- LWAC: Lightweight aggregate concrete
- MS/b: Microsilica to binder ratio
- $w/b$: Water to binder ratio

1. Introduction
The high dead weight of a building is one of the main concerns that face the designers of concrete structures. Many researchers have studied the dead-weight reduction of the concrete structures using concrete with lower density and higher compressive strength. The seismic forces, which influence the...
buildings, are related to the mass of such structures. Therefore, reducing the mass of a building leads to a reduction in earthquake risks [1]. Reducing the weight of a concrete structure can be accomplished by using lightweight concrete (LWC) in construction.

Concrete is one of the materials used as structural and non-structural elements of the building. Roofs, beams, columns, and shear walls are the main members made of reinforced concrete, while in steel structures, the concrete is mainly used in composite roofs. Even with the main advantages of concrete, there are two significant disadvantages: first is its low tensile strength, and the other is its low strength per unit weight of concrete consequences heavy members. Likewise, the low strength per unit volume of concrete leads to relatively large members; this is an essential consideration for long-span structures and very high buildings; as the building’s dead weight increases, the seismic force also increases. Generally, there are two different strategies to solve this problem. The first way is based on increasing the concrete strength to reduce the dimensions of structural elements and the volume of concrete. The second way is based on reducing the specific weight of concrete by using LWC [2].

The LWC advantages compared with normal-weight concrete (NWC) are abundant and well-identified, such as lower density, higher strength to unit weight, lesser thermal conductivity coefficient, better fire resistance, and better durability properties. Reducing the dead load gained using LWC result in a decreasing in the cross-section of concrete elements and reduce the induced seismic loads, which minimize the risks of earthquake damages to concrete structures. Lightweight aggregate concrete (LWAC) is usually produced by replacing totally or partially natural, normal-weight aggregates with natural or artificial lightweight aggregate (LWA) [3].

For many decades the structural LWC was defined as concrete with a maximum oven-dry density of 2000 kg/m³. The LWC has specific properties that differ from NWC. In addition to low density, a better reinforcing bond between steel and concrete, improved tensile capacity, enhanced durability characteristics, and better fatigue resistance. All these properties made LWC preferable to normal weight concrete [4].

Many studies have been done on LWC. For instance, M. Aslam et al. have used Oil-palm-boiler clinker (OPBC) and oil palm shell (OPS) to produce a LWC with 42.5 MPa compressive strength and a dry density of 1856 kg/m³ [5]. D. Rumšys et al. investigated various shapes of high-density polyethylene (HDPE) and low-density polyethylene (LDPE) plastic waste impact on the mechanical properties of lightweight concrete. At 28 days, they acquired a LWC with a dry density of 1950 to 2050 kg/m³ and compressive strength above 40 MPa [6]. Demirboga et al. published results from a comprehensive laboratory test investigating the effects of expanded perlite aggregate and mineral admixtures on the compressive strength of LWC. They concluded that adding mineral admixtures improved the concrete compressive strength made with an expanded perlite aggregate [7].

Norokshchenov and WhitComb have revealed the possibility of making LWC with 70.5 MPa compressive strength and 1,860 kg/m³ density using LECA, with a cement content of 520 kg/m³, and 20% silica fume as a percentage of cement weight [8]. Kiliç et al. produced a LWC with 44 MPa compressive strength and 1,860 kg/m³ dry density in 90 days using basalt-pumice aggregate, 450 kg/m³ cement, and 10% silica fume as a percentage of cement weight [9]. Rossignolo et al. revealed that a lightweight concrete with a 53.6 MPa compressive strength and about 1,605 kg/m³ dry density in 28 days using Brazilian's LWC could be produced [10].

Pumice is a natural lightweight aggregate with a highly porous structure, and it is realized that the granulated shape is created by the rapid cooling of the molten lava. It is used as an aggregate in many countries for LWC production. Specifically, in Italy, Turkey, Greece, Spain, the United States, and Iran [11–14]. Researchers showed that Pumice lightweight aggregate concrete complies with the requirements of semi-lightweight structural concrete. Compressive strength of up to 55 MPa (in 28 days) was achieved by incorporating the Turkish pumice aggregate [15]. Top S. and Vapur H used a mixture of basaltic Pumice aggregates and fly ash to produce lightweight concrete with compressive strength ranged from 20 MPa to 55 MPa and concrete density between 1700 kg/m³ and 1792 kg/m³ [16].

In this study, Pumice, which can be found easily in Iran, proposed to be applied as the coarse aggregate to develop LWAC. The main objective of this research is to investigate the effect of using Pumice as a....
coarse aggregate to develop LWAC mixes that meet the technical specifications for structural applications. Furthermore, this study examines the effect of micro-silica and water to binder ratio ($w/b$) on the hardened properties of LWAC containing Pumice as coarse aggregate. The rest of this paper is organized as follows. Section 2 showed the properties of the materials used, mix proportions, molding, curing, and testing techniques. Section 3 presented the experimental results and discussions. Section 4 includes conclusions while the recommendations and references will be in sections 5 and 6 respectively.

2. Experimental Work

2.1. Materials

2.1.1. Cement

Ordinary Portland cement (OPC) type (I) was used for all mixes. The initial and final setting times were 152 minutes and 264 minutes, respectively. Its Fineness is using Blaine air permeability apparatus 390.7 (m$^2$/kg). The compressive strength was 20.5 and 30.1 MPa for 2 and 28 days, respectively. Table 1 shows the chemical properties of this cement.

| Chemical composition % | Cement type I |
|------------------------|---------------|
| CaO                    | 62.00         |
| SiO$_2$                | 21.00         |
| Al$_2$O$_3$            | 5.26          |
| Cl                     | 0.07          |
| Fe$_2$O$_3$            | 3.00          |
| MgO                    | 1.35          |
| SO$_3$                 | 2.14          |
| LOI                    | 2.20          |
| I.R                    | 0.38          |
| LS F                   | 0.92          |

2.1.2. Micro-silica

A very fine pozzolanic prepared as a high-performance mineral additive to be used in concrete. Physically, it acts to optimize the particle packing of a concrete mixture or mortar, and chemically, as a high reactive pozzolan. The bulk density, specific gravity, and specific area of micro-silica are 700 kg/m$^3$, 2.40, and 15 m$^2$/g, respectively. In past research studies, the content of the micro-silica has been used in a wide range as a percentage of cement weight. Micro-silica was applied to the mixtures in powder form.

2.1.3. Fine Aggregate

The fine aggregates used as natural sand from Basra city with fineness modulus, specific gravity, and loose bulk density of 2.64, 2.65, and 1645 kg/m$^3$, respectively. The absorption of fine aggregate was 1.1% in 24 hours. Figure 1a shows the grading of fine aggregate.

2.1.4. Lightweight Coarse Aggregate (Pumice)

Lightweight aggregate (Pumice) was used as a coarse aggregate in this study. Pumice is a high porosity material with dark brown color; it was imported from the north of Iran. Table 2 summarized the physical and chemical properties of Pumice. The grading of pumice particle size is presented in figure 1b.

2.1.5. Superplasticizer

Sika ViscoCrete F180G admixture for concrete with a density of 1061 kg/m$^3$ was used as a high range water reducer that provides long workability times.
Table 2. Physical and chemical properties of Pumice.

| Property                     | Pumice |
|------------------------------|--------|
| Loose Bulk Density (kg/m³)   | 826    |
| Oven dry Density (kg/m³)     | 802    |
| Dry specific gravity         | 1.75   |
| Water Absorption (%)         | 10     |
| Crushing Resistance          | 3.6    |
| Chloride %                   | 0.02   |
| Acid-Soluble Sulphate %      | 0.5    |
| Total Sulphur %              | 0.32   |

2.2. Mix Proportions
Mix proportions of eleven mixes are given in table 3. The mixes are divided into four groups. The first and second groups are made to examine the ratio of lightweight aggregate to the total aggregate with two different water to binder content (cement + micro-silica). The third group is designed to investigate the content of micro-silica. The fourth group investigates the effect of water to binder ratio (w/b) by changing the cement and micro-silica contents.

Table 3. Mix proportions

| Mix No. | w/b | Water (kg/m³) | Cement (kg/m³) | Sand (kg/m³) | Pumice (kg/m³) | Microsilica (kg/m³) | Superplasticizer (kg/m³) |
|---------|-----|---------------|----------------|--------------|----------------|---------------------|--------------------------|
| T1      | 0.42| 226           | 500            | 218          | 815            | 40                  | 3.95                     |
| T2      | 0.42| 226           | 500            | 301          | 732            | 40                  | 3.95                     |
| T3      | 0.42| 226           | 500            | 383          | 650            | 40                  | 3.95                     |
| T4      | 0.40| 226           | 510            | 636          | 534            | 55                  | 4.46                     |
| T5      | 0.40| 226           | 510            | 754          | 456            | 55                  | 4.46                     |
| T6      | 0.40| 226           | 510            | 880          | 371            | 55                  | 4.46                     |
| T7      | 0.43| 226           | 500            | 383          | 650            | 20                  | 3.95                     |
| T8      | 0.45| 226           | 500            | 383          | 650            | 0                   | 3.95                     |
| T9      | 0.42| 226           | 500            | 520          | 633            | 40                  | 3.95                     |
| T10     | 0.52| 226           | 400            | 520          | 633            | 32                  | 3.95                     |
| T11     | 0.60| 226           | 350            | 520          | 633            | 28                  | 3.95                     |
2.3. Molding, Curing, and Testing of samples

For each of the proposed mixes, six standard cubes with (150×150×150) mm³, three cylinders with 100 mm diameter and 200 mm height, and a prism with (100×100×350) mm³ were prepared. The six cubes were divided into two groups of three cubes for compressive strength and equilibrium density test while the cylinder and prism for splitting tensile strength and modulus of rupture, respectively. All specimens have been tested after 28 days. After making and molding concrete specimens, the specimens were taken out of the mold after 24 hours and kept in a water pool by immersion. Compressive, flexural, splitting tensile strength, and density tests were performed according to BS. EN 12390-1:2012, ASTM C78 (2016), ASTM C 496 (2011), and ASTM C567 respectively. Figure 2 shows the molding and testing techniques for the specimens [17–20].

3. Results and Discussion

3.1. Fresh concrete

Fresh unit weights and slump workability values of the concrete produced are measured as presented in table 4.

| Mix No. | Fresh density (kg/m³) | slump (mm) | Mix No. | Fresh density (kg/m³) | slump (mm) |
|---------|-----------------------|------------|---------|-----------------------|------------|
| T1      | 1889 ± 27             | 155        | T7      | 1942 ± 30             | 150        |
| T2      | 1910 ± 25             | 150        | T8      | 1935 ± 26             | 161        |
| T3      | 1949 ± 22             | 150        | T9      | 1987 ± 24             | 150        |
| T4      | 2049 ± 23             | 110        | T10     | 1938 ± 21             | 154        |
| T5      | 2098 ± 21             | 115        | T11     | 1925 ± 20             | 165        |
| T6      | 2137 ± 25             | 130        | -       | -                     | -          |

3.2. Hardened concrete

3.2.1. Effect of Pumice to Total Aggregate ratio with w/b=0.42

The sponge-like structure of pumice aggregate made it a low density compared to other mixture materials; because of this, the equilibrium density of concrete increases promotionally with decreasing the amount of Pumice. For the same reason, the compressive strength increased. Results of specimens with variable Pumice to total aggregate ratio with w/b equal to 0.42 are summarized in table 5. The
Experimental results show that decreasing the amount of Pumice from 79% to 71% and 63% increases the compressive strength by 13.1% and 27.8%, respectively, as shown in figure 3a. Similarly, the equilibrium density increased by 1.2% and 1.7%, respectively, as shown in figure 3b. While the tensile strength decreased by 3.8% and 18.5%, respectively, as shown in figure 3c. The modulus of rupture also decreased by -18.5% and 18.9%, respectively, as shown in figure 3d.

Table 5. Results of specimens with variable Pumice to total aggregate ratio with \( w/b = 0.42 \).

| Mix No. | Pumice Ratio | Equilibrium Density (kg/m³) | \( f_{cu} \) (MPa) | \( f_{ct} \) (MPa) | \( f_r \) (MPa) |
|---------|--------------|-----------------------------|-------------------|-----------------|---------------|
| T1      | 79%          | 1833                        | 28.50             | 2.60            | 5.30          |
| T2      | 71%          | 1855                        | 32.23             | 2.50            | 4.32          |
| T3      | 63%          | 1864                        | 36.43             | 2.12            | 4.30          |

Figure 3. Test results of specimens with variable Pumice to Total Aggregate ratio with \( w/b = 0.42 \).

3.2.2. Effect of Pumice to total aggregate ratio with \( w/b = 0.40 \)
Decreasing the Pumice increases the free water since the Pumice absorbs 10% of its weight from the water of the mix, the content of cement and micro-silica increases to stabilize the mixed water and increased the compressive strength at the same time, and that decreased the \( w/b \) to 0.40. The results for LWAC specimens are listed in table 6. As mentioned before, the compressive strength and equilibrium density tend to increase, inversely proportional to the reduction of the volume fraction of pumice.
aggregate into the mixes, as shown in figure 4 (a and b). Decreasing the pumice ratio from 46% to 38% and 30% increases the compressive strength by 9% and 14.2%, respectively, as shown in figure 4a. The equilibrium density increased by 2% and 4.5%, respectively, as shown in figure 4b. While the tensile strength decreased by 6.8% and 13.5%, respectively, as shown in figure 4c. The modulus of rupture decreased by 10.9% and 15.7%, respectively, as shown in figure 4d. It is noted that the increase of pumice aggregates resulted in significant improvement in the splitting tensile strength and flexural strength for LWAC. The angular shape and the surface roughness of the pumice material improve the bond between the paste and the aggregates leading to an increase in the splitting tensile strength [12].

Table 6. Results of specimens with variable Pumice to total aggregate ratio with w/b=0.40

| Mix No. | Pumice Ratio | Equilibrium Density (kg/m³) | f_{cu} (Mpa) | f_{ct} (Mpa) | f_{tr} (Mpa) |
|---------|--------------|----------------------------|-------------|-------------|-------------|
| T4      | 46%          | 1943                       | 38.25       | 2.37        | 6.62        |
| T5      | 38%          | 1982                       | 41.70       | 2.21        | 5.90        |
| T6      | 30%          | 2031                       | 43.67       | 2.05        | 5.58        |

Figure 4. Test results of specimens with variable Pumice to Total Aggregate ratio with w/b=0.40.

3.2.3. Effect of Micro-silica

Besides the contribution of micro-silica in the concrete hydration process, it has a unit weight of approximately half of cement, which decreases the density slightly with increasing the compressive strength. The experimental results in table 7 showed that by reducing the micro-silica content from 7.4%...
to 3.8%, and 0% as a percent of binder content, the compressive strength decreased by 7.8% and 14%, respectively, as shown in figure 5a. However, the equilibrium density increased by 1.1% and 1.7%, respectively, as shown in figure 5b. Observation of figure 5c illustrates that very high micro-silica ratios do not remarkably increase the splitting tensile strength; the increase is almost insignificant above 3.8%. The initial filling of the aggregate voids by micro-silica improves the split tensile strength, but no significant improvement was observed at higher micro-silica levels. Figure 5d shows the variation of modulus of rupture with micro-silica percentages. The flexural strength decreased to 7% and 22.1%, by reducing MS/b to 3.8% and 0%, respectively. Micro-silica tends to have an additional noticeable effect on flexural strength more than split tensile strength does. For flexural strength, even at very high micro-silica ratios significantly enhance their strength.

Table 7. Results of specimens with different content of micro-silica.

| Mix No. | MS/b Ratio | Equilibrium Density (kg/m³) | f_{cu} (Mpa) | f_{ct} (Mpa) | f_{fr} (Mpa) |
|---------|------------|-----------------------------|--------------|--------------|--------------|
| T3      | 7.4%       | 1864                        | 36.43        | 2.12         | 4.30         |
| T7      | 3.8%       | 1885                        | 33.60        | 2.10         | 4.00         |
| T8      | 0.0%       | 1895                        | 31.34        | 2.00         | 3.35         |

Figure 5. Test results of specimens with different content of micro-silica.

3.2.4. Effect of water to binder ratio

Table 8 presents the results of specimens with different water to binder ratios. The results showed that decreasing the binder content leads to an increase in the w/b ratio in the concrete mix, which leads to a
reduction in compressive strength, equilibrium density, tensile strength, and modulus of rupture. Compressive strength decreased by 14.9% and 28.1% when the w/b ratio increased from 42% to 52% and 60%, respectively, as shown in figure 6a, while the equilibrium density decreased by 2.1% and 4%, respectively, as shown in figure 6b. As presented in figure 6c, the tensile strength decreased by 29.7% and 35.4% by increasing the w/b from 42% to 52% and 60%, respectively. The modulus of rupture decreased by 9% and 10.9% by increasing the w/b from 42% to 52% and 60%, respectively, as depicted in figure 6d.

Table 8. Results of specimens with different water to binder ratio.

| Mix No. | w/b | Equilibrium Density (kg/m³) | f_{cu} (MPa) | f_{ct} (MPa) | f_{r} (MPa) |
|---------|-----|-----------------------------|-------------|-------------|-------------|
| T9 42%  | 1931| 37.78                       | 3.87        | 5.88        |             |
| T10 52% | 1891| 32.16                       | 2.72        | 5.35        |             |
| T11 60% | 1854| 27.16                       | 2.50        | 5.24        |             |

Finally, the more effective parameter that affects the compressive and splitting tensile strength is the aggregate ratio with suitable water to binder ratio, which is very clear in the second group, as shown in figure 7. All the tested specimens have a density between 1833 kg/m³ and 2031 kg/m³ with compressive strength ranged from 27 MPa to 44 MPa.
4. Conclusions

Based on the results of this experimental study, the following conclusions can be drawn:

1. Experimental results indicate that the micro-silica content increases the compressive strength with no significant tensile strength variation with a micro-silica ratio beyond the 3.8% of cement content. However, the modulus of rupture increases when the ratio of micro-silica exceeded 3.8%.

2. The results showed that the equilibrium density decreased with increasing micro-silica ratio due to the low bulk density of micro-silica compared to the cement density.

3. The results showed that decreasing the volume of Pumice in lightweight concrete increases the compressive strength due to the decrease in aggregate cavities. Also, the high content of Pumice increases the amount of water used in concrete mixing due to its high-water absorption in concrete mortar.

4. It was shown that by increasing the water to cement ratio of the lightweight concrete mixing design, the concrete strength decreases. This is because the high amount of water entering the cement paste causes its fluidity and reduces its adhesion. As a result, the necessary bond is not established between the paste and the aggregate. Reducing the water-binder ratio and keeping it at about 40% improves concrete efficiency and compressive strength.

5. The splitting tensile strength of Pumice approximately ranged from 5% to 10% of its compressive strength.

6. The modulus of rupture of Pumice approximately ranged from 11% to 24% of its compressive strength.

5. Recommendations for future works

The authors recommended further studies to investigate modulus of elasticity for lightweight aggregate (pumice) concrete and evaluate the stress-strain curves for pumice concrete with and/or without spiral steel confinement.

6. References

[1] Yaşar E, Atış C D and Kiliç A 2004 High strength lightweight concrete made with ternary mixtures of cement-fly ash-silica fume and scoria as aggregate Turkish J. Eng. Environ. Sci. 28 95–100
[2] McCormac J C and Brown R H 2015 *Design of reinforced concrete* (John Wiley & Sons)

[3] Sarıdemir M and Çelikten S 2020 Investigation of fire and chemical effects on the properties of alkali-activated lightweight concretes produced with basaltic pumice aggregate *Constr. Build. Mater.* 260

[4] Sivalingarao N and Manju N 2016 A Brief Study on Mechanical Properties of Silica Fume Light Weight Aggregate (Pumice) Concrete *IOSR J. Mech. Civ. Eng.* 16 66–71

[5] Aslam M, Shafiq P, Alizadeh Nomeli M and Zamin Jumaat M 2017 Manufacturing of high-strength lightweight aggregate concrete using blended coarse lightweight aggregates *J. Build. Eng.* 13 53–62

[6] Rumšys D, Bačinskas D, Spudulis E and Meškenas A 2017 Comparison of Material Properties of Lightweight Concrete with Recycled Polyethylene and Expanded Clay Aggregates *Procedia Engineering* vol 172 (The Author(s)) pp 937–44

[7] Demirboğa R, Örüng I and Göl R 2001 Effects of expanded perlite aggregate and mineral admixtures on the compressive strength of low-density concretes *Cem. Concr. Res.* 31 1627–32

[8] Novokshchennov V and Whitcomb W 1990 How to Obtain High-Strength Concrete Using Low-Density Aggregate *ACI Symp. Publ.* 121 121

[9] Kiliç A, Afiş C D, Yaşar E and Özcan F 2003 High-strength lightweight concrete made with scoria aggregate containing mineral admixtures *Cem. Concr. Res.* 33 1595–9

[10] Rossignolo J A, Agnesini M V C and Morais J A 2003 Properties of high-performance LWAC for precast structures with Brazilian lightweight aggregates *Cem. Concr. Compos.* 25 77–82

[11] Zhou S, Lu C, Zhu X and Li F 2020 Upcycling of natural volcanic resources for geopolymer: Comparative study on synthesis, reaction mechanism and rheological behavior *Constr. Build. Mater.* 121184

[12] Wongsa A, Sata V, Nuaklong P and Chindaprasirt P 2018 Use of crushed clay brick and pumice aggregates in lightweight geopolymer concrete *Constr. Build. Mater.* 188 1025–34

[13] Libre N A, Shekarchi M, Mahoutian M and Soroushian P 2011 Mechanical properties of hybrid fiber reinforced lightweight aggregate concrete made with natural pumice *Constr. Build. Mater.* 25 2458–64

[14] Robayo-Salazar R, Mejía De Gutiérrez R and Puertas F 2019 Alkali-activated binary concrete based on a natural pozzolan: Physical, mechanical and microstructural characterization *Mater. Constr. 69*

[15] Parhizkar T, Najimi M and Pourkhorshidi A R 2012 Application of pumice aggregate in structural lightweight concrete *Asian J. Civ. Eng.* 13 43–54

[16] Top S and Vapur H 2018 Effect of basaltic pumice aggregate addition on the material properties of fly ash based lightweight geopolymer concrete *J. Mol. Struct.* 1163 10–7

[17] British Standard 2000 Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds *Bs En 12390-12000* 3 1–14

[18] ASTM C78 2016 Standard Test Method for Flexural Strength of Concrete *Annu. B. ASTM Stand.* 0 1–4

[19] ASTM C496 2011 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens *ASTM Int.* i 5

[20] ASTM C 567 2004 Standard Test Method for Determining Density of Structural Lightweight Concrete *ASTM Int.* 16–9