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PROPERTIES OF CONCRETE USING SCORIA LIGHTWEIGHT AGGREGATE CONCRETE

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ABSTRACT

Lightweight Aggregate concrete has been proven to be able to reduce the self-weight of a structure. An experimental study was undertaken using lightweight scoria aggregate concrete (LWSAC) aiming to determine the viability of scoria being used in structural concrete. Bulk density, water absorption and a sieve analysis was conducted on the scoria aggregate prior to mix design for concrete. LWSAC has produced a compressive strength of 30.50MPa at 28 days compared to the control concrete had 38.93MPa. Replacing 15% of Portland cement using fly ash has increased the compressive strength to 41.14MPa at 28 days. Nevertheless, replacing 10% of Portland cement by silica fume, the compressive strength of LWSAC has decreased with the time. Although, high water absorption property of aggregate may have contributed for a relatively high drying shrinkage, it is still within an acceptable limit for general purpose concrete. Therefore it can be concluded that scoria can be used to produce structural concrete with a relatively low density.

KEYWORDS

Lightweight aggregate, scoria aggregate, lightweight concrete, scoria concrete, lightweight compression test.

INTRODUCTION AND BACKGROUND

Concrete is a composite material that is typically made by combining cement, aggregates, water and often, mineral admixtures in appropriate proportions (Edward & Nawy 2008). Concrete is also considered in a biphasic model, which has two phases composing of coarse aggregates surrounded by a mortar mix that includes fines, adjuvants, binders and water voids (Bogam & Gomes 2013). Nevertheless, 60-80% of concrete, by volume, contains aggregates, which voluntarily affect the properties of concrete. Therefore properties of aggregate including shape, texture, size, moisture content, specific gravity, any intact chemicals, are significant for the properties of concrete. Lightweight concrete (LWC) is favorable over normal weight concrete (NWC) for earthquake prone areas as LWC reduces the dead load of a structure, thus, to reduce the risk of earthquake damages, because the earthquake forces are proportional to the mass of those structures (Yasar et al., 2003). Additionally, the reduction in self-weight will reduce reinforcements (Topcu 1997) transportation and handling cost. Khandaker and Hossain (2006) discovered using Lee's apparatus that lightweight aggregate had good thermal insulating properties satisfying ASTM C332 requirements. The lightness of scoria is due to porousness of the material that is highly sensitive to water content and high water absorption compared to granite crush rock aggregate (Kamsiah et. Al 2013). Hence the water-binder ratio in a typical normal concrete mix design is required some adjustments to accommodate this increase in water absorption. However, the porous nature of the aggregate enhances interlocking sites for the cement paste to infiltrate and to form dense uniform interfacial zones between aggregate (Lo 2004). This strong interfacial bond compensates for the strength loss in lightweight aggregate due to its porosity relative to normal gravel aggregate. Bogam and Gomes (2013) supported this discovery, where they observed fractures travel through the aggregate due to the strong bonds.

This paper investigates the structural properties of lightweight scoria aggregate concrete (LWSAC) produced using scoria which is used for gardens and landscape purposes. Combining various cementations martial as partial replacement to Portland cement and subsequent effects on strength were evaluated. Fly Ash and silica fumes are commonly used as mineral admixtures to increase the workability as well as the strength of concrete. After working on pumice aggregate which is similar to scoria, Cengiz et al (2003) reported that by replacing 10% of Normal Portland Cement (NPC) with silica fumes, a compressive strength of 38.9MPa was achieved at 28 days whilst without silica fumes reached 28MPa. The increase in strength was described due to the filler effect of the binder in the mixture and the pozzolanic reaction between silica fume and the mixture (Yasar & Duran 2003).

EXPERIMENTAL PROGRAM

The experimental program focused on investigating the properties of fresh and hardened concrete containing scoria aggregate and mineral admixtures, specifically fly ash and silica fumes. A total of 36 cylinders, 3 prisms and 2 beams were prepared to measure the compressive strength, modulus of elasticity, flexural strength and shrinkage of concrete specimens. Samples were prepared in compliance with the Standards Australia. Scoria lightweight aggregate, crush rock aggregate, Geelong GP cement, silica fume, fly ash and sand were used with the properties shown in table 1.

Table 1. Physical Properties of Cement, Sand, Silica Fume and Fly ash

Type of Material	Density (kg/m^3)	Type of Material	Density (kg/m^3)
Geelong General Purpose Cement	3150	Scoria aggregate	1500
Fly Ash	2400	Crush rock	2600
Silica Fume	2200	Sand	2600

The concrete mix designs were prepared in order to compare between lightweight concrete versus normal concrete and the effects of mineral admixtures. The initial mix design was found to be dry and therefore it was adjusted aiming to improve the walkability of the scoria concrete mix. Hence the water in the mixing process was increased by 10.5% that is equivalent to an increase in water- cement (w/c) ratio from 0.33 to 0.34. In order to draw a comparison, the w/c was kept constant throughout all the mix designs. Super-plasticiser, 5 litres per m^3 of concrete, was added to maintain the workability required in the mix. Three lightweight mix designs and one control normal weight mix design were:

- Mix 1: lightweight scoria aggregate only;
- Mix 2: 15% of cement is replaced by fly ash;
- Mix 3: 10% of cement is replaced by silica fume; and
- Mix 4: Control Mix 1 (CM1) - Normal gravel aggregate mix design

Only the mix 1 was explored for full testing i.e. compressive, flexure and drying shrinkage whilst mix 2, 3 and the control mix 1 were just tested for the compressive strength (table 2). Initially, coarse and fine aggregate were mixed followed by cement, mineral admixtures and water was poured slowly into the mixing drum. A slump test was used to measure the workability of the concrete mixes with a constant water-cement ratio of 0.34 (table 2). A standard vibration table was used to vibrate samples to ensure sufficient compaction.

Table 2. Mix Design

Mix no.	Cement (kg/m^3)	Water (kg/m^3)	W/C ratio	Scoria (kg/m^3)	Gravel (k/m^3)	Fly Ash (kg/m^3)	Silica Fume (kg/m^3)	Sand (kg/m^3)
1	490	163	0.34	559.1		-	-	623
2	416.5	163	0.34	432		73.5	-	481
3	441	163	0.34	466		-	49	520
4-CM 1	490	163	0.34	-	1136	-	-	623

RESULT AND DISCUSSION

Particle Size of Scoria Aggregate

The Figure 1 compares particle size distribution of scoria and normal crush rock aggregate. The particle size distribution for scoria aggregate is similar to the recommended distribution by AS 2758 (1998) and the Cement and Concrete Association of Australia (Cement & Concrete Association 2002) for concrete production. The aggregates size grading is considered acceptable although 45% aggregates are bigger than 19mm. The bigger and porous particles may have contributed for reduced strength. Previous work has observed a better compressive strength for pumice aggregate concrete when aggregate size changes between 8-16mm and with a mix of 25% fine pumice (0-4mm), 25% medium pumice (4-8mm), and 50% coarse aggregate is used (Shannag 2011, Topcu 1997).

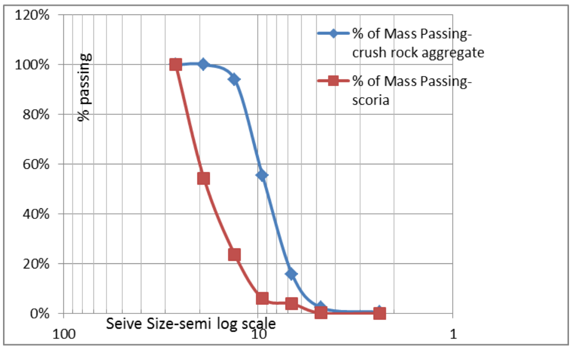

Figure 1. Sieve analysis data for scoria

Table 3. Fresh and 28 day properties of LWSAC

Mix no.	Slump (mm)	Fresh Density (kg/m^3)	28 day Compressive Strength	Modulus of Elasticity, E_c (MPa)
1	17	1819	30.50	28164
2	18	1550	41.14	17030
3	14	1623	31.50	15779
4 - CM1	40	2396	38.93	31545

Workability

The results demonstrates that lightweight scoria concrete had a much lower workability compared to a normal mix (table 4). However it was observed that the mix 3 with silica fume had the lowest workability, and the mix was more cohesive that made it difficult to work with.

Compressive Strength

Compressive strength of concrete samples was tested after 7, 14 and 28 days (table 5). Based on the results, mix 2, which is LWSAC with fly ash, produced the highest compressive strength at 28 days of 41.14MPa. The increase in strength of LWSAC with addition of fly ash could be due to the increase in pozzolanic reaction between fly ash and the mixture as well as better adherence being provided by the porous surfaces of scoria aggregate (Yasar et al 2003). This filler effect led to an increase in compression strength of LWSAC.

Table 4. Compressive & Flexure Strength Result

Mix no.	Age (days)	Compressive Strength (MPa)	Flexure Strength (MPa)	Mix no.	Age (days)	Compressive Strength (MPa)	Flexure Strength (MPa)
1	7	26.20	n/a	3	7	38.6	n/a
	14	27.20	n/a		14	34.68	n/a
	28	30.50	2.24 (average)		28	31.50	n/a
2	7	30.74	n/a	CM	7	35.23	n/a
	14	34.82	n/a		14	36.74	n/a
	28	41.14	n/a		28	38.93	n/a

Although silica fume contributes for a higher early strength, it has a negative effect with the time for LWSAC. Although the seven day strength noticed was 38.6MPa, equivalent to normal weight concrete, 14 and 28 day strength has decreased to 34.68MPa and 31.50MPa respectively. This trend contradicts with the claim that 10% silica fume replacing normal Portland cement produces a higher compressive strength at the expense of workability (Yasar et al 2003a, b). However, it still produced a slightly higher compressive strength than that of mix 1 at 28 days. In general LWSAC has a relatively high compressive strength of 30.50MPa at 28 days with w/c ratio of 0.34. However, this value is lower than the experiments conducted by Alaettin Klic et al (2003) that are 35MPa with w/c equals to 0.55. However, LWSAC without mineral admixture has still produced an acceptable compressive strength at 28 days. The flexural strength of LWSAC was 2.24 MPa which is 7% of the cylinder compressive strength of mix 1 and this value is significantly lower than normal aggregate concrete where the flexure strength is usually 10% of the cylinder compressive strength. According to Standards Australia, the expected flexure stress for CM1 and Mix 1 would be 3.74MPa and 3.3MPa respectively. Since this estimation is for normal concrete it may not be applicable for LWSAC which exhibits a lower flexural stress that depends on many factors including concrete composition, and degree of compaction, aggregate strength and quality. The high porosity and voids in aggregate may have eased for crack propagation and reduction in flexural strength.

Figure 2.a) Columnar shear failure b) Cone shear failure c)Flexure failure respectively

Majority of concrete samples exhibit a cone failure mode whilst only mix 3 had a consistent columnar failure mode. Figure 2, shows a typical cone and columnar failure mode of the specimens. Cone failure is a typical failure mode for concrete however columnar failure mode occurs when the friction at the platens of the testing rig restrains lateral expansion of concrete is eliminated. Then, the vertical compressive force splits sample as the cylinder expands more laterally. This type of failure usually occurs on high-strength specimens. Therefore, the presence of this type of failure in mix 3 contradicts the low compressive strength obtained.

Modulus of Elasticity

The modulus of elasticity is important for estimating the deformation and flexure design of structural concrete elements. The modulus of elasticity of concrete from each mix were calculated according to

Australian standards and then compared with the modulus of elasticity for standard strength grade normal concrete at 28 days. Depending on the density and strength of concrete at 28 days the modulus of elasticity of concrete were different. Table 3 summarizes the modulus of elasticity calculated and the table 5 shows the standard elastic modulus of concrete recommended by the Australian Standard for a particular strength.

Table 5. A sample of Elastic Modulus standard taken from AS3600

Concrete Properties at 28 days				
f_{cmi}	28	35	43	53
E_c	26700	30100	32800	34800

Even though elasticity values in the table 5 are applicable for normal weight concrete at 28 days, it may estimate the modulus of elasticity for LWSAC. The mix 1 produced an elastic modulus of 28164 MPa with a compressive strength of 30.50MPa, which is in between fcmi of 28 and 35MPa. However, elastic modules for mix 2 and 3 with added mineral admixtures are very different compared to the standardized value. The presence of mineral admixture has reduced the density of the concrete as well as affected the elastic modulus (table 4). The presence of mineral admixture has affected the properties of concrete and the strengths in the standard (table 5) which are compatible for normal aggregate concrete without any admixtures may not be applicable for this work. The elastic modulus is directly related to the density and compressive strength of concrete.

Shrinkage

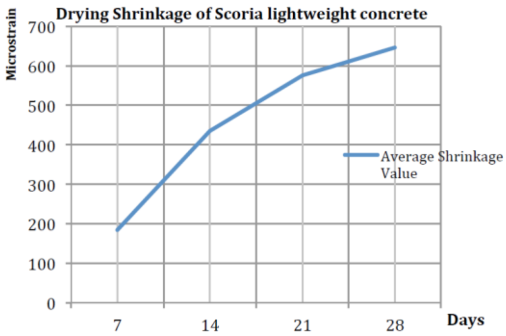

Figure 3a. Drying shrinkage test equipment 3b. Drying shrinkage results for LWSAC

Drying shrinkage for LWSAC was measured for the mix 1, which didn't contain any admixtures. The result from the experiment shows that the average drying shrinkage of LWSAC is about 650 micro-strains at 28 days. This is relatively and expected high value due to the high water absorption property of scoria aggregate (Cement & Concrete Association 2002). However other factors such as curing temperature, relative humidity, and cement composition will affects the drying shrinkage properties of concrete. Even though the value of LWSAC is considerably high it is still below the expected drying shrinkage limit of 800 micro-strains in Melbourne for normal concrete based on the Australian Standard 3600 clause 3.1.7.2 (Standards Australia, 2009).

SUMMARY AND CONCLUSIONS

This investigation proves a potential use of ungraded scoria as an aggregate to produce concrete. By replacing normal 15% of Portland cement with fly ash, the compressive strength of LWSAC has improved by about 35% compared to LWSAC with Portland cement only. 10% silica fume as normal Portland cement replacement has decreased the overall strength of concrete over time. It is hypothesis that low workability may have contributed reduced strength. Although addition of fly ash does not affect the workability and the slump, silica fume has significantly reduced the workability, slump and increased the viscosity of the fresh LWSAC.

Although LWSAC experiences a high drying shrinkage of about 650 micro strains at 28 days, it is in acceptable limit for Australian Standard 3600. The density of LWSAC ranges from 1300-1700kg/m^3 while crush rock aggregate density ranges from 2200-2800kg/m^3 and normal weight concrete (NWC) has a density about 2400kg/m^3. LWSAC will provide engineers and the construction industry with an alternative for conventional concrete with a reduced dead weight. Depending on the importance of the structure, LWSAC can be more beneficial and it can provide engineers with more design opportunities as the lighter concrete beams could potentially have greater spans or smaller footprints for a structure.

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