Transport and Mechanical Properties of Silica Fume Lightweight Aggregate Concrete

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Abstract: This paper describes the use of scoria, a natural lightweight aggregate in concrete. The purpose of this paper is to study the performance of a structural Light weight aggregate concrete up to 28 days in terms of permeability and compressive strength concrete. The concrete mixes contained silica fume at 10% replaced by weight of cementitious materials. Variables, which were taken into consideration, were the percentage of sand as a partial replacement for lightweight fine aggregate (0, 25, 50 and 75% by weight). The effect of sand replacement is considerable in terms of densities, strength-to-density ratio and chloride ion permeability. It was found that when the sand content in increased in the mixes, both the density and compressive strength were increased in value up to 30% and 27%, respectively. The resistance of scoria lightweight aggregate concrete to chloride ion penetration was increased when the silica fume was utilized in the mix. As per the assessment parameters, all the lightweight concrete containing silica fume exhibited much lower corrosion rates when compared to normal weight aggregate concrete.

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1. Introduction:

Permeability is defined as the ease with which a particular substance (liquids, gases, ions, etc.) can flow through a solid. Defects such as those caused by settlement in fresh concrete, plastic and drying shrinkage cracks, thermal cracks, structural cracking, segregation or honeycombing of the concrete will increase the permeability rates, which in turn leads to less durable concrete. Comparative studies on the water permeability and chloride penetration of lightweight aggregate concrete (LWAC) and normal weight aggregate concrete (NWAC) were conducted [1- 3]. In these studies, W/C ratios of 0.35 and 0.55, and silica fume content of 0% and 10% were used as a partial replacement of cement by weight to obtain concrete with different compressive strength. The results indicate that the water permeability for the LWAC with a W/C ratio of 0.55 was lower than that of the NWAC. However, at a W/C ratio of 0.35 the water permeability of LWAC and NWAC was similar. The resistance of the LWAC to chloride ion penetration was similar to that of the corresponding NWAC with the same W/C ratio. Finally, the results indicated that the LWAC could have lower water permeability and better resistance to chloride ion penetration than NWAC with an equivalent 28 day compressive strength. Data on the resistance of LWAC, NWAC and high strength lightweight concrete (50-100 MPa) to water permeability and chloride penetration is presented in references [4] and [5]. Test results show that the permeability appears to be very low, but it may be higher than that of normal strength concrete having a similar strength. A direct relationship between water permeability and accelerated rate of chloride penetration was observed. Other theoretical investigations have reported a more rapid increase in permeability occurring at lower levels of applied stress-to-strength ratio with NWAC than with LWAC [6,7].

Two LWAC specimens, with 28-day cube compressive strength of 35 and 50 MPa were cast. The concrete samples made with lightweight coarse aggregates and dune sand were continuously cured in water for 1 or 7 days, and then exposed to predominantly hot and humid coastal ambient conditions containing air-borne salts. After 7 days of initial curing, and on subsequent exposure to hot and humid air, both attained a similar strength to those continuously water cured cubes at 12 months. In contrast, the water penetrability of 35 and 50MPa after 7 days of initial curing and subsequent exposure to coastal conditions was about 2 and 1.8 times the water penetration of those slabs, which were water cured for the entire duration of 12 months.

The results suggest that compressive strength is comparatively less sensitive to the curing regimes investigated. Both the chloride and sulphate penetration after 12 months exposure were found to be within tolerable limits. Also the replacement of light weight fine aggregate with normal weight sand produces a concrete that is somewhat more durable as indicated by their water penetrability and the depth of carbonation when concretes are of equal strength [8].Using natural lightweight aggregates instead of processed artificial aggregates can significantly reduce the cost of such concretes. In this research, selected samples of these lightweight rocks were used to produce high strength LWAC. The binding medium was made of Portland cement, silica fume and super plasticizing admixture. For each concrete mixture properties at various ages, as well as splitting tensile strength, modulus of elasticity and thermal conductivity values were determined to find the optimum quantities of materials to be used. Tests showed that it is possible to produce a natural LWAC with a 28-day compressive strength of 55 MPa, a dry unit weight in the range of 1700-2100 kg/m^3 and a thermal conductivity coefficient value of about 0.55 W/(m-K)[9].

Experimental results over one year showed the benefits of incorporating LWA in the concrete, with permeability and diffusion coefficients being reduced significantly. Concrete samples were fabricated with a blended silica fume cement at a W/C ratio of W/C = 0.40 or 0.30 and with combinations of aggregate as follows: (i) limestone coarse aggregate and river sand, (ii) expanded slate coarse aggregate and river sand, or (iii) expanded slate coarse and fine aggregate. There appeared to be improvement with the maturity of the concrete and, after three years continuous curing, the reduction in the apparent chloride diffusion coefficient was observed to be as much as 70%. Also, as expected, the addition of fly ash produced further reductions in permeability and diffusion [10,11].The results of experimental study to evaluate the influence of coarse and fine LWA, the quality of the paste matrix on water absorption, permeability, and resistance to chloride ion penetration in concrete, indicate that incorporation of pre-soaked coarse LWA in concrete increases water sorptivity and permeability slightly compared to normal weight concrete of a similar W/C ratio. Furthermore, the resistance of lightweight sand concrete (LWSC) to water permeability and chloride ion penetration is inversely proportionate to the porosity of coarse LWA. With a low W/C ratio and silica fume, low unit weight LWAC (1300 kg/m^3) was produced with a higher resistance to water and chloride ion penetration compared with NWC and LWC of higher unit weights [12]. The influence of different lightweight fly ash aggregates on the behavior of concrete mixtures was investigated. In order to investigate the aggregate–cement paste interfacial transition zone (ITZ), SEM observations were performed. Regression and graphical analysis of the experimental data obtained were also performed. An increase in compressive strength was observed with the increase in oven-dry density. The ratios of splitting tensile strength to compressive strength of LWAC were found to be similar to that of NWAC. All the 28 and 56 day concrete specimens had a durability factor of 85 and 90, respectively, which met the requirement for freezing and thawing durability [13].This paper studies permeability, the effect of sand replacing and silica fume on concrete permeability. The strength development and strength-to-density ratio were also studied up to 28 days. Pozzolanic natural lightweight aggregate (scoria) occurring in the western province of Saudi Arabia was utilized**.**

2. Research Significance

There is a growing awareness of the importance of permeability with regard to the long-term durability of concrete structures. If an aggressive substance (water, sulfates, chloride ions, etc) can be kept out of concrete by virtue of low permeability, then the associated problems, such as freeze-thaw deterioration, corrosion of steel reinforcement and formation of expansive components may be mitigated. Therefore, there has been interest both in determining the permeability of lightweight concrete made from locally produced LWA compared with conventional concrete and in the development of improved concretes with lower permeability.

3. Experimental Work

The effect of sand content at 0,25,50 and 75% as a partial replacement of fine LWA and an addition of silica fume of 10% by weight of cement content on chloride ion permeability and compressive strength of lightweight aggregate concrete were studied.

4.Material properties

A pozzolanic natural LWA (scoria), occurring in the western province of Saudi Arabia, was used in this investigation. Scoria is volcanic in origin and is geologically categorized as pozzolanic scoria and tuff material. This type of LWA is available in different sizes and was used as a coarse aggregate with size varying between 5-20mm. LWA has been tested extensively at the quality control laboratories of the Saudi Arabian Standards Organization (SASO). The results show that values for coarse and combined aggregate fall within the limit specified by ASTM C-332, both for grading and unit weight tests conducted by SASO on light weight concrete panels made from LWA. It yielded a thermal conductivity value of 0.140 w/m-k (<0.43 as required by ASTM C-332). The physical properties of LWA used in this research are given in Table 1.A locally produced ordinary Portland cement (Type I) was used in this investigation. The density of cement was 3.15 and its fineness was 3315cm^2/gm. The cement content was kept constant at 400 kg/m^3. Normal weight fine, clean sand, free from any impurities such as silt, clay organic compound aggregate was used. The fine aggregate met the ASTM C-33 requirements: The specific gravity of the sand was 2.62åand fineness modulus was 2.84. Clean, fresh water, free from impurities was used for mixing and curing the samples. Silica fume as a fine powder consisting of over 90% silicon dioxide was used. The bulk density and surface area of the used silica fume were 600 kg/m^3 and 18000-22000m^2/kg. For the concrete mixtures, a suffocated naphthalene formaldehyde condensate high-range water reducer was used (super plasticizer). The super plasticizer is available as a dark-brown aqueous solution containing 40–42% solids, with a density of 1,210 kg/m^3 and was used to control the slump at 120 mm±25 mm.

Table 1 : Physical properties of LWA.

Color	Grayish/Black
Bulk density (kg/m^3) for coarse aggregate	615-800
Bulk density (kg/m^3) for fine aggregate	850-1075
Bulk specific gravity (SSD)	1.85
Oven dry specific gravity	1.66
L-A abrasion value	28-33
Thermal conductivity of insolating concrete from cicolite	0.140 W/mk
Fire rating	3 hours
Noise attenuation	3-6 dB

5. Mix proportions

The procedures adopted for mix proportioning are still experimental in spite of considerable work done on the theoretical aspects of mix proportioning of normal weight and lightweight concretes. This is partly because LWA has a high absorption capacity and thus the W/C ratio of LWA concrete cannot be fixed. Hence, mix proportioning of lightweight concrete is generally accomplished by an experimental method. For the experiments, 24 light weight concrete mixes representing the main variables were prepared. The water binder ratio (W/B) was kept constant at approximately 0.5for all mixes, as reported in Table 2.

A concrete mixer with a maximum capacity of 0.1m^3 was used to prepare the specimens. The aggregates were used after 24hour of immersion in water in order to avoid any change of water-to-cement ratio following water absorption of aggregate during mixing. The aggregates were then dried under sun light for 120 minutes until their surface moisture became constant. The mixing sequence was as follows: firstly, coarse and fine lightweight aggregate (scoria) and 1/3 of the water were loaded into the mixer for 1 minute. Then the cement (or cement and silica fume), remaining water, and super plasticizer were added. Finally, the ingredients were mixed for 3 minutes. The mixture was rested for 3 minutes then mixed again for a further 2 minutes.

Table 2 : Mix proportions by weight for mix A.*

Sand replacement (%)	Cement (Kg)	Water (Kg)	Light weight coarse aggregate (Kg)	Light weight fine aggregate (Kg)	Normal weight fine aggregate (Kg)
0%	6	2.9	6.142	12.272	0
25%	6	2.9	6.142	9.204	4.72
50%	6	2.9	6.142	6.136	9.44
75%	6	2.9	6.142	3.068	14.16

* Mix B: silica fume were added at 10 % by weight of cement (0.6 kg).

6. Sample preparation and test method

The compressive strength of lightweight concrete samples was determined in accordance to ASTM C-39 specifications. Concrete sample cubes measuring 150-x150x150 mm were used for the compressive strength test and cylindrical samples with a diameter of 100 mm and a height of 51mm were prepared to determine chloride ion permeability of LWAC. The test method consisted of monitoring the amount of electrical current passed through 50 mm slices of 100 mm nominal diameter cores or cylinders during a 6-hour period. A potential difference of 60 V DC was maintained across the ends of the samples, one of which was immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, was found to be related to the resistance of the sample in terms of chloride ion penetration. Figure 1 shows a schematic of rapid chloride permeability test apparatus.

7. Results and Discussions

The behavior of LWAC at 28 days was investigated in terms of compressive strength and chloride ion permeability. The effect of sand content (0, 25, 50, 75%) and silica fume as an addition (10% by weight of cement content) was considered. The results were shown in Table 3 and plotted in Figures 1 to 4.

Table 3: Test results

Mix Type	Sand Replacement%	Density kg/m³	Compressive Strength MPa	Percentage Increase of compressive strength (%)	Chloride Ion Penetration, Charged Passed (Coulombs)	Strength/density
A	0	1700	16.5	0	11,567	9.7
	25	1850	19.7	20	8,870	10.6
	50	1915	24.1	46	4,165	12.6
	75	1975	29.8	80	2,147	15.1
B	0	1770	20.5	0	9,800	11.6
	25	1887	26.5	30	6,890	14.0
	50	1920	33.7	64	3,346	17.5
	75	1960	39.4	95	1,784	20.1

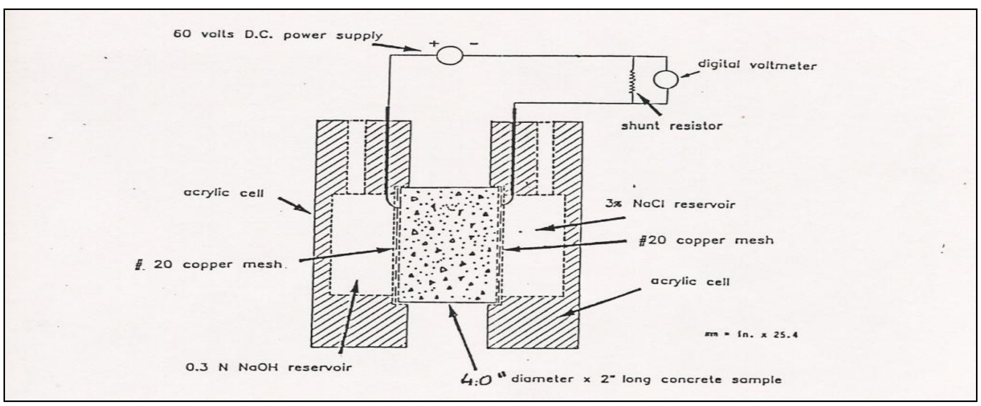

Fig. 1 : Schematic of rapid chloride permeability test apparatus.

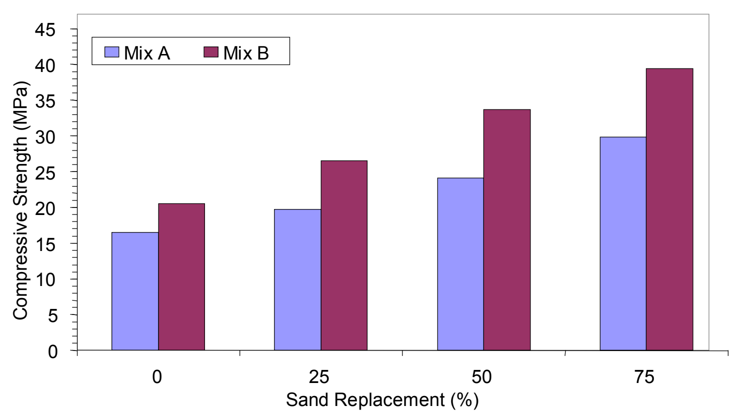

Fig. 2 Effect of Sand Content on the Compressive Strength of lightweight concrete.

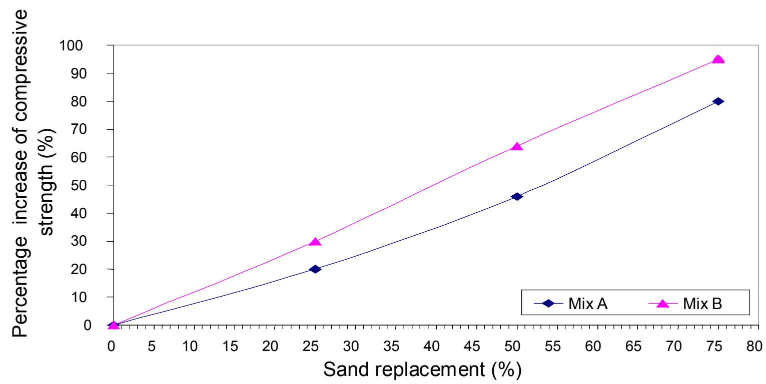

Fig. 3 Effect of Sand Content on the percentage increase of compressive strength of light concrete.

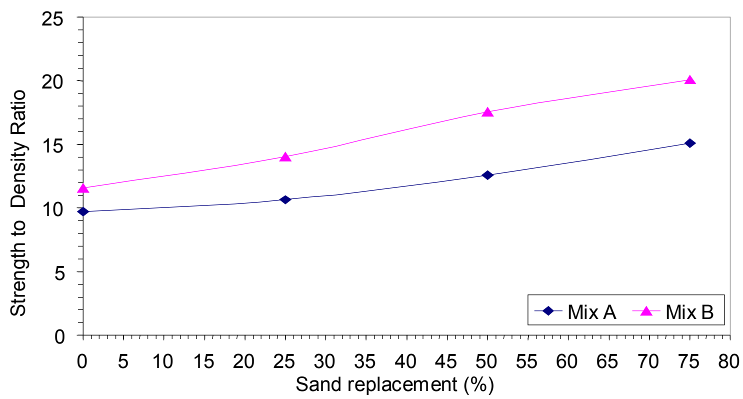

Fig. 4 Effect of Sand Content on the strength to density ratio of lightweight concrete.

8. Effect of sand content

The density, compressive strength, chloride ion permeability and strength-to-density at 28 days are given in Table 3. It can be observed from this table it was generally observed that the chloride ion permeability decreases and compressive strength increases gradually when the sand content increased up to 75%. Both compressive strength and the resistance of LWAC to chloride ion penetration were enhanced by using silica fume as an addition of 10% by weight of the cement content.

The effect of sand replacement on compressive strength is shown in Figures 1 and 2. The compressive strength increased by increasing the sand content by about 80% and 95% for mix A and mix B respectively at a level of sand replacement equal to 75% as shown in Fig.2. From the above figures, it can be observed in Figure 3 that there is a linear relationship between the percentage increase in compressive strength and the sand content percentage for all mixes. By increasing the percentage of sand from 0% to 75%, the density of concrete increased gradually in the range between 1700 and 2000 Kg/m^3. Moreover, as shown in Fig.4, the strength-to-density ratio was found to increase when increasing the sand content. These results may be attributed to the fact that concrete density was increasing when the sand content increased.

The resistance to chloride ion penetration is an important aspect that needs a better definition in relation to structural materials, which fill the pores between coarse aggregate and consequently increasing the compressive strength of concrete. It is generally accepted that mineral admixtures significantly improve this through the chloride binding and pore filling effects. The pore filling effect is expected to be the factor that helps in the case of silica fume. The charge passing through these concretes ranged from 1500 to 2000Coulombs, which is considered to be very low chloride permeability as shown in Table4. Also, the concrete made with sand showed lower chloride permeability for all types of mixes as reported in Table3. The results are similar to those observed for high-strength concrete made with expanded clay aggregates [4]. It was observed that the Coulombs charge passing through high-strength concretes containing silica fume varied from 1000 to 2000

Coulombs, which compares well with the present investigation at the corresponding w/(c + s) ratios.

Table 4: Chloride permeability classifications

Charged Passed (Coulombs)	Chloride Permeability	Typical of
> 4,000	High	High water-cement ratio (> 0.6), conventional PCC.
2,000-4,000	Moderate	Moderate water-cement ratio (0.4-0.5), conventional PCC.-
1,000-2,000	Low	
100-1,000	Very Low	Low water-cement ratio « 0.4), conventional PCC.
< 100	Negligible	Latex-modified concrete, internally sealed concrete. Polymer impregnated concrete, polymer concrete.

9. Effect of silica fumes addition

The effect of adding silica fume for different percentages of sand replacement is shown in Fig. 5. The effect of silica fume as a modification for aggregate structure or as a cementitous material was significant at 28 days. It was found that there is an interaction of both effects (physical and chemical), especially at 28 days, where silica fume had enough time to react and hydrate. It was reported that the penetration of silica fume particles into the open pores of the lightweight aggregate is deeper than that of cement, which is due to lower viscosity and the smaller particles of silica fume. Thus, silica fume will penetrate into the aggregate and result in a low dosage of cementation when compared to the mixture of Portland cement. For LWA without dense outer shells, the effect may be shown clearly, resulting in an increase in compressive strength and a decrease in chloride ion permeability.

The above-mentioned reasons may explain the behavior of lightweight concrete presented in Fig. 5 and Fig. 6. The resistance to chloride ion penetration was observed higher in lightweight concrete samples containing silica fume in mix B compared with mix A. The chloride ion permeability was nearly the same and the effect of silica fume can be negligible at higher values of sand replacement (75% sand replacement) as shown in Fig.5.

The effect of compressive strength of lightweight concrete, with and without silica fume, on the chloride permeability was plotted in Fig.6. It was found that the resistance to chloride ion penetration increased by increasing the compressive strength of lightweight concrete for all types of mixes. This may be attributed to the fact that the increase of compressive strength depends mainly on the enhancement of the matrix performance due the physical and chemical effect of silica fume and the increase of overall density of lightweight concrete by increasing the sand content.

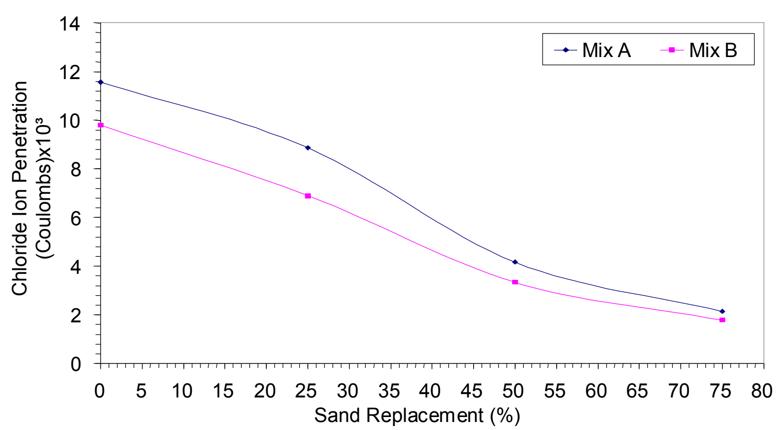

Fig. 5 Effect of silica fume content for different ratios of sand replacement on the Chloride Ion Permeability of Lightweight concrete.

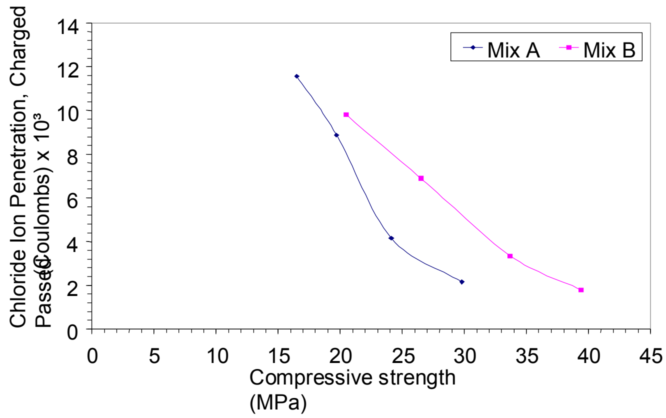

Fig. 6: Effect of Compressive strength on the Chloride Ion Permeability of Lightweight concrete.

10. Conclusions

The effect of sand replacement (0, 25, 50, and 75%) was studied in terms of density, compressive strength, strength to density ratio and chloride permeability of natural scoria lightweight aggregate concrete with and without silica fume.

The analysis of the experimental test results leads to the following conclusions:

- Socria lightweight aggregate can be used with silica fume to produce a lightweight concrete with cube compressive strength of about 33 MPa.
- The compressive strength of lightweight aggregate concretes increases when adding silica fume.
- The chloride ion permeability of concrete samples decreases when using silica fume in the mix.
- The effect of replacement LWA by natural sand gives acceptable results in terms of strength-to-density ratio, densities and chloride ion permeability of concrete.
- With the increase of sand content in the mixes, both density and compressive strength of concrete increases by 30 % and 27 % respectively.
- As per the assessment criteria, all the lightweight concrete containing silica fume showed a low chloride permeability of < 2000 C. Consequently these concretes also exhibited much lower corrosion rates compared to the normal concrete.

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