Utilization of Industrial Waste as a Composite Cementing Materials

M. I. Khan
King Saud University, Riyadh, Saudi Arabia, miqbal@ksu.edu.sa

ABSTRACT

The deterioration in concrete structures exposed to harsh environments has become a matter of global concern. The requirement for high durability in concrete structures cannot be easily achieved using ordinary portland cement. Therefore, new materials and composites are being investigated and improved cements are produced to enhance the concrete durability.

The present state of the art in concrete research has demonstrated the benefits of by-product mineral admixtures as partial cement replacements. The by-product mineral admixtures (industrial waste) such as fly ash, slag and silica fume are used as partial cement replacement to enhance the performance of concrete. In addition, the use of by-product materials conserves energy and has environmental benefits as a result of the reduced use of cement (the production of which is associated with high carbon dioxide emission).

This research was aimed at investigating the performance of concrete utilizing locally available industrial waste. The industrial waste was incorporated in concrete as partial cement replacement to study the effect of replacement level on the fresh and hardened properties of concrete at various ages. Results of chemical analysis of industrial waste, fresh properties and hardened properties including strength and chloride permeability of concrete prepared with this material are reported.

Keywords: industrial waste, concrete, composites

1 INTRODUCTION

Utilization of industrial waste in concrete reduces the production of cement which results in conserving energy and has environmental benefits as a result of the reduction carbon dioxide emission of associated with the production of cement. In the Kingdom of Saudi Arabia the consumption of cement is about 25 million tons per year which is among the highest per capita cement consumption countries in the world. There is an urgent need of using waste materials or new materials and composites to produce economical and environmental friendly concrete which may enhance the concrete durability as well.

Concrete incorporating supplementary cementitious materials (SCMs) demonstrate improved performance than that of ordinary Portland cement with respect to modified microstructure and durability of concrete [1-4]. The incorporation of SCMs in concrete enhances bleeding, segregation, and cohesiveness of concrete. Additionally, reduces heat hydration and thus leads to reduction in crack formation during hardening. The inclusion of fly ash or slag or silica fume results in concrete with reduced or similar permeability to that of plain concrete. These materials increases the resistance of concrete against chloride attack and performs satisfactorily against sulfate attack [1,5].

Industrial wastes such as fly ash, silca fume and slag are well documented and being used in concrete production for attaining specific pereformance. Locally available industrial waste has not been used in the production of concrete. Therefore, there is no information of its behaviour in concrete. There is a need to investigate and explore the potential of this material for the use in concrete production. A full investigation was carried out for potentail use of this local industrial waste (LIW) for the producton of concerte. In this paper chemical and physical analysis of LIW, fresh concrete properties and engineering properties incorporating LIW as partial cement replacement are reported.

2 EXPERIMENATAL PROGRAM

2.1 Materials and Methods

Local industrial waste (LIW) is available in the form of thick slurry. It was dried and grounded to achieve fineness approximately equivalent to the cement. There average fineness was recorded as 4170 cm^2/g.

Cement Type I complies with the requirements of the ASTM C 150, fly ash (FA) complying with ASTM C 618 Class F, and silica fume (SF) complying with ASTM C 1240 were used throughout the investigation.

Two types of fine aggregates were used in this study. The natural red sand was supplied in the form of rounded grains of quartz uncontaminated by clay or other foreign substances, as shown in Figure RS. It does not meet the grading requirements of ASTM C33. Therefore, another type of fine aggregate i.e. crushed sand was used in combination with RS. The crushed sand has angular grains with sizes lower than 4.75mm. Coarse aggregate of a nominal size of 10 mm was used throghout.

The conceret mix was designed with water to binder (w/b) ratio of 0.50 and the ratio was constant throughout the experimental program. Mixing was done in revolving drum mixer in accordance with ASTM C 192. LIW replacements were selected at 10%, 15%, 20% and 25% as a partial cement replacement by weight of cement content. For the sake of comparison, some mixes were prepared using FA and SF. All specimens were cast and compacted in two layers by external vibration in accordance to the ASTM specifications. After casting, the samples were covered with damp hessain and polyethylene sheets for 24 hours. The samples were demoulded the following day and then kept in the curing environment prior to testing. Compressive strength and chloride permeability measurements were conducted in accordance to the ASTM standards.

2.2 Properties of LIW

The physical properties such as fineness and specific gravity of LIW powder were measured and are reported in Table 1. The fineness of LIW powder was determined using the Blaine's air permeability apparatus, as per ASTM C 204, in terms of the specific surface expressed as total surface area in square centimeters per gram of powder.

XRF analysis revealed that the main elemental oxides are composed of CaO, Fe_2O_3, SiO_2 and SO_3. This powder was also found to contain low amount of Al_2O_3 and a significant content of Cl (6.8%). This powder was then investigated using XRD analysis. The following minerals are expected to be found in this powder, such as hastingsite (potassium sodium calcium magnesium aluminum iron titanium), gypsum (calcium sulfate), quartz (silicon dioxide), hydrotalcite (magnesium aluminum carbonate hydroxide Hydrate) and anthophyllite (iron magnesium silicate hydroxide), as shown in Figure 1.

3 RESULTS

3.1 Benchmarking against ASTM Standard

The strength activity index LIW powder was conducted at 7 and 28 days in accordance to ASTM requirements. The ASTM requirement for strength index of cementitious material is that mortar prepared in accordance with ASTM procedure must have 75% (0.75) compressive strength of its companion control mix at 7 and 28 days. In this investigation, mortar mixes of control mix (100% cement) and LIW powder mortar mix (80% cement : 20% LIW powder) were prepared in accordance to the ASTM C 311 specifications. The compressive strength results obtained at 7 and 28 days are presented in Table 2. From this table, the 7 and 28 days compressive strength of LIW powder mix is about 75% and 72% of the control mix, respectively. These results demonstrate that the 7-day strength comply with the specification of ASTM C 618 whereas 28-day strength value is slightly (3%) lower as required by ASTM. However, this slight reduction is not significant. Therefore, the above mentioned recommendation that the mixes containing LIW powder up to 20% are suitable for normal strength (35 MPa) concrete elements is further strengthened.

3.2 Properties of Fresh Concrete

The results demonstrated that the concrete mixes containing 10 and 15% LIW and control mix showed similar slump of 90 mm. Whilst concrete containing 20 and 25% LIW concrete showed slump of 80 and 70, respectively. It can be concluded that the incorporation of LIW concrete upto 15% has no effect on the slump whilst concrete containing 20% and above reduces the slump as compared to control mix.

The initial and final setting times were performed in accordance to the ASTM C 1202. During the standing time, the mortar specimens were covered to minimize water loss through evaporation. The results demonstrate that the initial setting time of control mix and mix containing 10% LIW powder are almost similar. Mixes containing 15% LIW powder and above showed slightly lower setting time values. The concrete containing LIW powder reduces final setting time almost linearly with the increase in the incorporation of LIW powder. Concrete mixes containing 20 and 25% did not show significant variation. However, these results are promising and are not significantly detrimental to the cocncrete.

Properties	LIW powder
Fineness - Blaine (cm^2/g)	4170
Specific gravity	2.25
Color	Dark grey
Form	Slurry form

Table 1: Physical properties of LIW powder.

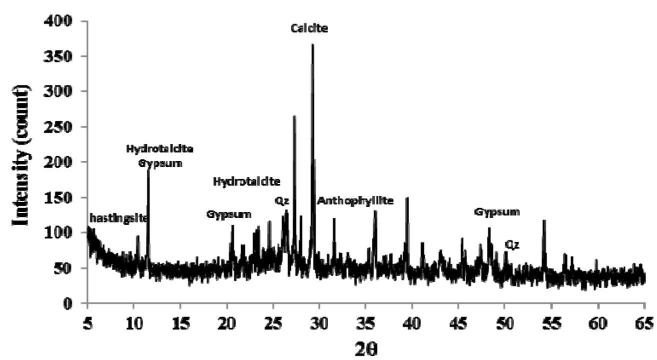

Figure 1: XRD pattern.

Mix	Compressive Strength (MPa)	
	7-days	28-days
Control mix (100% cement)	38.9	48.7
LIW powder mix (80% cement + 20% LIW powder)	29.0	34.8

Table 2: Strength Activity Index results in accordance to ASTM specifications.

3.3 Compressive Strength Development

Compressive strength development of concrete prepared with 0, 10, 15, 20 and 25% LIW powder as partial cement replacement is shown in Figure 2. Compressive strength of concrete decreased with an increase in LIW powder replacement level. The decrease in the mix containing 10% is not significant as compared to its companion control mix, however, the mix containing 15% and above decreases the strength development. It is worth to note here that the reduction in the strength of concrete mixes containing 15 and 20% is not significant. At 28 and 90 days, the strength pattern remained similar to that at 7 days, however, the rate of gain is increased. The strength development of mixes containing 15 to 25% LIW powder did not reduce drastically. This figure clearly depicts the influence of LIW powder on the strength development at various ages.

It is worth to mention here that the maximum reduction in the strength in LIW powder concrete (up to 25% LIW powder) is limited to 25% as compared to the control mix. No mix containing LIW powder is attaining strength equal to control mix, however, the maximum reductions in the strength is limited to 26% which is acceptable as per ASTM specifications. The decrease in the strength development of concrete containing admixtures like LIW powder is expected. For the concrete containing admixture, it is quite normal that strength development is delayed at early ages due to its delay in the hydration process. The hydration reaction is responsible for the development of strength. Due to the delayed hydration reaction, the strength development of concrete containing admixture is expected to emerge at later ages.

In construction practice strength of normal concrete needed is 30-35 MPa at 28 days. This value of strength is accepted and the concrete is used for the construction. It can be seen that the strength of concrete containing 10, 15 and 20% LIW powder are achieving more than 35 MPa at 28 days. Whilst mixes containing 25 LIW powder showed slightly lower strength than 35 MPa. Therefore, mixes containing LIW powder up to 20% are recommended for normal strength concrete elements (up to 35MPa). The mixes containing above 20% can also be useful for the concrete where strength is not paramount.

3.4 Influence of SF on LIW

The investigation on the beneficial use of SF in combination with fly ash is already established [1]. Figure 3 shows the influence of SF incorporation on the compressive strength development of LIW concrete. It can be seen that incorporation of 10% SF to LIW concrete (20% LIW mix) increased the compressive strength and is almost similar to that of plain concrete mix. The increase in the strength is due to highly natural pozzolanicity and extreme fineness of SF. The use the LIW in combination with SF has proven to be beneficial in gaining the strength at all ages. However, due high cost of SF the production of the concrete will be costlier. The optimization of use of SF in LIW material is still under investigation and results are expected to be published later.

3.5 Comparison of LIW with fly ash

The use of fly ash is well established in the literature and its application has gained tremendous impetus. In normal concrete mixes the use of fly ash is about 20%. Keeping in view the understanding, utilization and adoptability of fly ash, LIW mixes are compared with fly ash as shown in Figure 4. It is evident that mix cintaining 15% LIW is slightly lower that of that the mix containing 20% fly ash. The drop in the strength is not very significant comparable to fly ash mix. Therefore, it is clear that the incorporation of LIW can be use up to 15% instead to 20% fly ash.

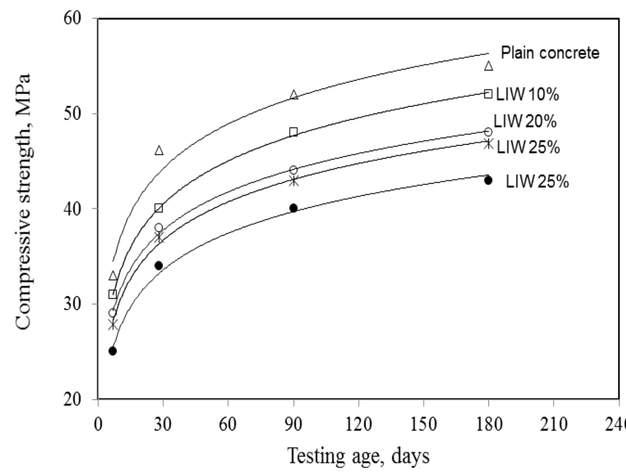

Figure 2: Compressive strength development.

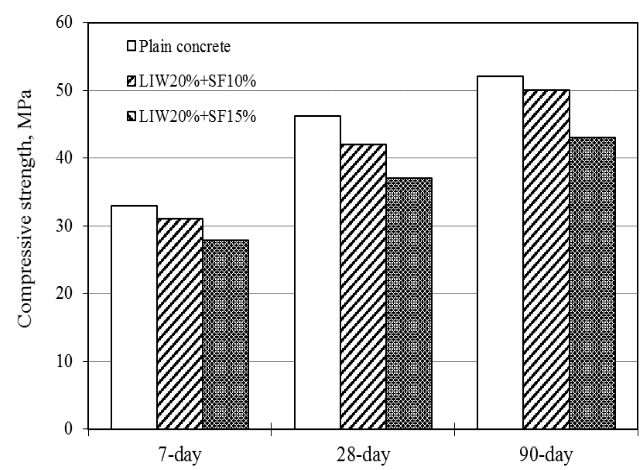

Figure 3: Influence of SF.

3.6 Chloride Permeability

The values of chloride permeability of LIW concrete at the various ages are presented in Figure 5. At 28 days, the chloride permeability increased gradually with an increase in LIW. However, as age increased, the chloride permeability dropped significantly. At 90 days, all mixes containing LIW demonstrated much lower chloride permeability as compared to the plain concrete mix. The rate of the decrease in the permeability is related the incorporation of the LIW content. Similar trends were obtained at the age of 180 days. The decrease in the permeability is related to the late pozzolanic activity of LIW. However, this late pozzolanic activity was not significant in case of compressive strength. The reason may be due the sensitivity of the chloride permeability due to the pozolanicity of the LIW material.

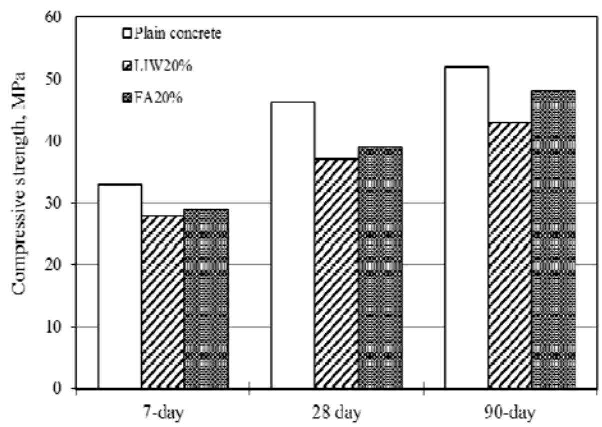

Figure 4: Comparison of LIW with fly ash.

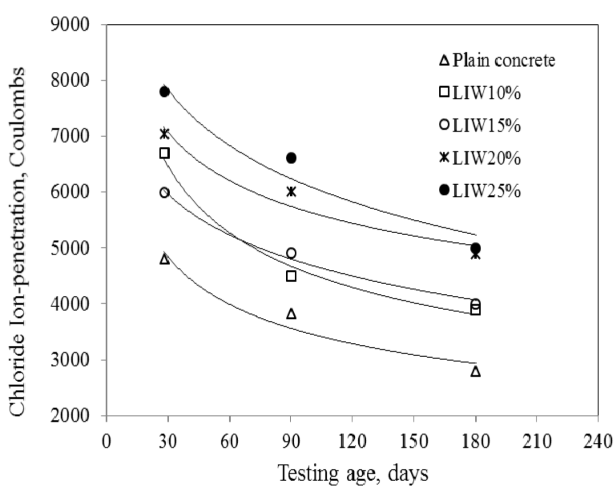

Figure 5: Chloride permeability results.

4 CONCLUSIONS

Following conclusion have been drawn from the results of present study:

The initial slump and setting times of concrete containing LIW are not significantly detrimental to the concrete. Therefore, the incorporation of LIW in the concrete (as far as workability and setting times are concerned) is highly promising.

Both mortar and concrete mixes containing Ti by-product LIW up to 20% as partial cement replacement showed 28-day strength higher than 35 MPa which is accepted for the normal strength concrete elements in construction practice.

Based on the results obtained in this study, it is concluded that the mixes containing LIW up to 20% as partial cement replacement are recommended for normal strength concrete elements (35 MPa @ 28 days). The mixes containing 25 and 30% LIW can also be useful for the concrete where strength is not paramount. However, the durability aspect of these mixes needs to be investigated thoroughly before its practical usage.

REFERENCES

[1] R. Sissiqui and M.I. Khan, “Supplementary Cementing Materails,” Springer, p. 350, 2011.

[2] V.M. Malhotra and P.K. Mehta, “Pozzolanic and Cementitious materials – Advances in Concrete Technology,” Vol. I, Gordon and Breach Publishers, Amsterdam, Netherlands, 1996

[3] M.I. Khan and C.J. Lynsdale, “Strength, permeability and carbonation of high-performance concrete,” Cement and Concrete Research, USA, 32(1), pp 123-131, 2002

[4] M.I. Khan, “Permeation of concrete,” ASCE Material Journal, USA, August 2003.

[5] R.D. Hooton, “Permeability and pore structure of cement pastes containing fly ash, slag, and silica fume,” Blended Cements, ASTM STP 897, G. Frohnsdorff, Ed., ASCE, Philadelphia, pp. 128-143, 1986.