Civil Engineering

HYDROTHERMAL REACTIONS BETWEEN LIME AND AGGREGATE FINES II. EXPERIMENTAL CONDITIONS FOR STRENGTH IMPROVEMENT USING SATURATED STEAM AT ELEVATED PRESSURE

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SUMMARY: Compressive strengths have been determined for various mixtures of lime and aggregate fines such as silica sand, slate and rice husk ash, autoclaved at a steam pressure of 1.17 MPa (180°C) for 4.5 hours. It has been observed that the maximum compressive strength of 59.8 MPa was recorded after 4.5 hours reaction between 80.0% silica sand, 15.0% lime and 5.0% slate, 47.6 MPa was recorded after reacting 85.0% silica sand and 15.0% lime and 43.4 MPa compressive strength when the reactants are 80.0% silica sand, 15.0% lime and 5.0% rice husk ash. On the other hand if the reaction is between slate (85.0%) and lime (15.0%), it leads to a lower compressive strength (34.7 MPa).

Key Words: Hydrothermal reaction, mineral admixtures.

INTRODUCTION

Silica sand and limestone are abundantly available in Pakistan. These indigenous natural raw materials are interesting sources to manufacture high strength building materials if treated hydrothermally.

In a preceding paper (1), a comprehensive study on the reactions of the locally available silica sand and lime at a steam pressure of 0.1 MPa (100°C) was presented. Various other indigenous aggregates, e.g. china-clay, Na_2CO_3, $CaSO_4.2H_2O$, slate, fire-clay and Na_2SiO_3 had also been incorporated in order to improve the strength of the product. Hydrated calcium silicate (CSH: For the sake of clarity we shall adopt the symbols used by cement experts: C=CaO; S=SiO_2; H=H_2O) was the main product in all cases, which is a strong and durable cementing agent.

The present study deals with the hydrothermal reactivities of silica sand, lime, slate and rice husk ash under a steam pressure of 1.17 MPa (180°C) for a time period of 4.5 hours. Compressive strengths of the various hardened products have been determined.

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MATERIALS AND METHODS

Starting materials: CaO was prepared by heating $CaCO_3$ at 1000-1100°C and then hydrolyzed to $Ca(OH)_2$. Two silica sand samples were used of particle sizes below 100 μm (47%) and 200-300 μm (53%) respectively; both contained 99.0% SiO_2. Similarly two slate samples were used, of particle sizes below 100 μm (47%) and 200-300 μm (53%) respectively and contained 63.0% SiO_2 and 19.0% Al_2O_3 while rice husk ash was of the composition containing 88.0% SiO_2 and 2.0% Al_2O_3. All these materials are locally available. $Ca(OH)_2$ and rice husk ash both were of particle sizes below 100 μm.

Preparations: Different dry mixes of silica sand, slate, rice husk ash and hydrated lime were prepared, in different proportions by weight as shown in Tables 1 and 4.

Cylindrical specimens of 3.8 cm diameter by 5.1 cm in height were mounded at a pressure of 30.7 MPa after the requisite amount of water (8 weight % of total solids) had been added. These were then autoclaved at a steam pressure of 1.17 MPa (180°C) for 4.5 hours.

Table 1 : Compressive strengths of autoclaved silica sand-$Ca(OH)_2$ Moulds.

Silica sand (200-300 µm) %	Silica sand (-100 µm) %	Ca $(Oh)_2$ (-100 µm) %	Compressive strength at 4.5 hours (MPa)
50.35	44.65	5.0	8.58
49.00	43.50	7.5	20.00
47.70	42.30	10.0	28.47
46.38	41.12	12.5	36.46
45.05	39.95	15.0	47.57
42.40	37.60	20.0	34.32
39.75	35.25	25.0	28.08

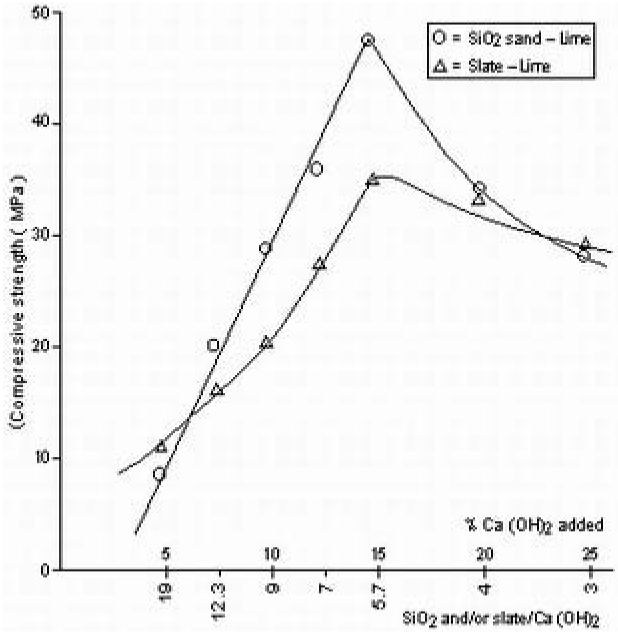
After autoclaving the specimens were removed and placed in a desiccator to cool and were retained under dry CO_2-free conditions until they were needed for further examinations. The specimens were tested for compressive strength.

RESULTS AND DISCUSSION

Strength development

a. Sand-Lime mixture: As shown Figure 1 (Table 1), it appears that sand which contains almost 99.0% SiO_2 reacts with $Ca(OH)_2$ leading to a cementation material of variable compressive strength. The strength shows a gradual increase with the quantity of lime. It first increases with addition of lime up to 15.0% followed by a decrease with higher lime contents.

Figure 1: Variation of compressive strengths at 4-5 hours of $Ca(OH)_2$ activated hydrothermal products versus SiO_2 sand or slate/$Ca(OH)_2$ ratio.



A maximum strength of 47.6 MPa is obtained after 4.5 hours autoclaving and 15% $Ca(OH)_2$ content (silica sand/$Ca(OH)_2$=5.67) while in our earlier investigation (1) the maximum strength of 25.8 MPa was recorded after 48 hours autoclaving at a steam pressure of 0.1 MPa (100°C) and 30.0% lime content.

b. Slate-Lime mixture: The hydrothermal reaction

Table 2 : Compressive strengths of autoclaved slate-$Ca(OH)_2$ Moulds.

Slate (200-300 µm) %	Slate (-100 µm) %	Ca $(Oh)_2$ (-100 µm) %	Compressive strength at 4.5 hours (MPa)
50.35	44.65	5.0	11.31
49.00	43.50	7.5	16.00
47.70	42.30	10.0	20.28
46.38	41.12	12.5	27.28
45.05	39.95	15.0	34.71
42.40	37.60	20.0	32.96
39.75	35.25	25.0	28.46
37.10	32.90	30.0	27.69

Table 3: Compressive Strengths of Autoclaved Silica Sand-Slate-$Ca(OH)_2$ Moulds.

Silica sand (200-300 µm) %	Silica sand (-100 µm) %	Silate (-100 µm) %	Ca $(Oh)_2$ (-100 µm) %	Compressive strength at 4.5 hours (MPa)
45.05	37.45	2.5	15.0	59.28
“	34.95	5.0	“	59.76
“	32.45	7.5	“	55.11
“	29.95	10.0	“	54.79
“	24.95	15.0	“	54.30
“	19.95	20.0	“	48.95
“	14.95	25.0	“	28.85
“	9.95	30.0	“	27.81
“	-	39.95	“	27.30

Table 4 : Compressive strengths of autoclaved silica sand-rice husk ash-$Ca(OH)_2$ moulds.

Silica sand (200-300 μm) %	Silica sand (-100 μm) %	Rice husk ash (-100 μm) %	Ca $(Oh)_2$ (-100 μm) %	Compressive strength at 4.5 hours (MPa)
45.05	37.95	2.0	15.0	31.01
"	36.95	3.0	"	34.71
"	35.95	4.0	"	37.44
"	34.95	5.0	"	43.38
"	33.95	6.0	"	39.19
"	32.95	7.0	"	30.61
"	31.954	8.0	"	28.41

data of the mixture are presented in Figure 1 (Table 2). A strength of 34.7 MPa is recorded after 4.5 hours autoclaving reaction of 15.0% $Ca(OH)_2$ and 85.0% slate (slate/$Ca(OH)_2$=5.67) which is comparable to the strength (34.3 MPa) obtained in the preceding sand-lime reaction with 20% lime content (Table 1). Again there is a decrease in the strengths with 20.0%, 25.0% and 30.0% lime contents in the mixtures respectively.

The above results are consistent with earlier findings (2) that with the contact of siliceous particles with cement solution, OH^-, Ca^{++}, Na^+, K^+ are adsorbed on the silica surface. The adsorption of OH^- provokes the dissolution of silicium atom on silica surface while Ca^{++} is adsorbed more strongly so first it reacts with dissolv-

Figure 2: Variation of compressive strengths at 4-5 hours of $Ca(OH)_2$ and slate activated hydrothermal products versus SiO_2 sand /(15% $Ca(OH)_2$+ slate) ratio.

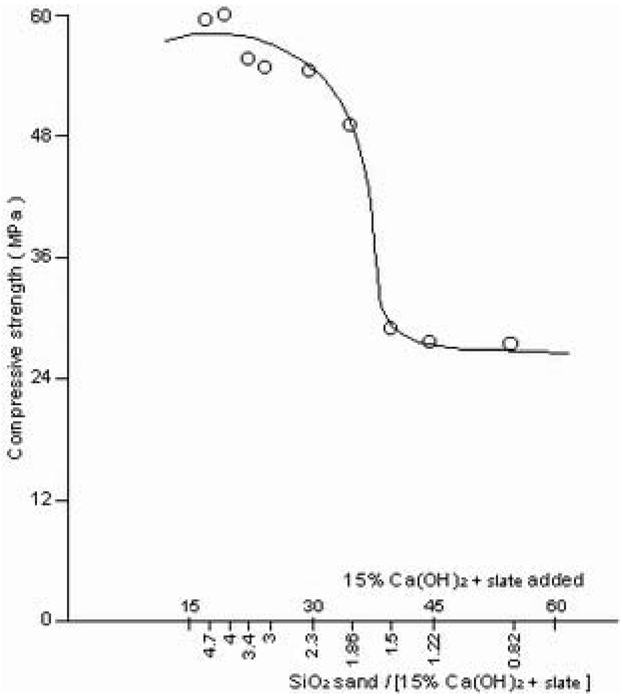
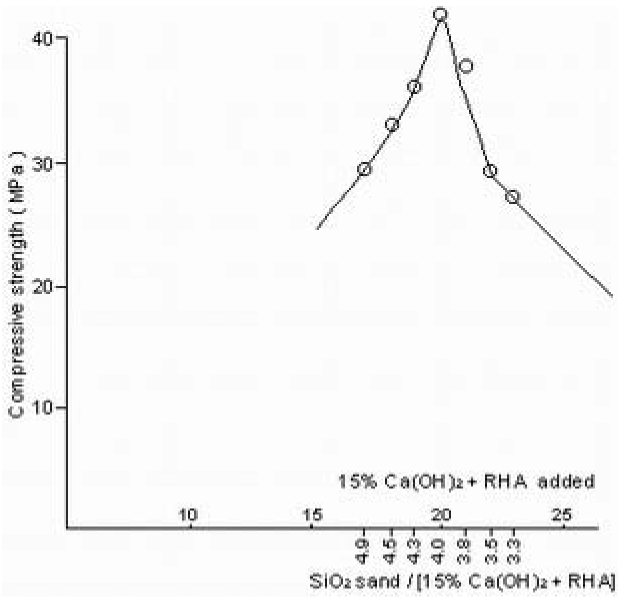


Figure 3: Variation of compressive strengths at 4-5 hours of $Ca(OH)_2$ and rice husk ash-activated hydrothermal products versus SiO_2 sand/(15% $Ca(OH)_2$* RHA) ratio.



ing silica to form CSH (C=CaO, S=SiO_2, H=H_2O).

The following reaction has been proposed (3) for the chemisorption of $Ca(OH)_2$ on the surface of silanol groups which has been confirmed by different workers (4-6).

$SiO_{2(s)}+Ca^{++}(ag)+2OH^{-}_{(ag)}\rightarrow n_1CaO.SiO_2.n_2H_2O(s)$

Furthermore, slate is giving lower compressive strength which can be attributed to the fact that slate is containing 19.0% Al_2O_3 and it has been reported (7) that the solubility of Al_2O_3 in aluminosilicates is 30 times lower than that of SiO_2.

c. Sand-Lime with different mineral admixtures: It is known (8) that finely divided siliceous materials (including clays, zeolites and diatomite) can react with free lime of cement leading to formation of hydrated products having binding properties. Small additions of basic materials like NaOH (9) are found to be good accelerators.

Figures 2 and 3 (Tables 3 and 4) depict a comprehensive profile of the compressive strengths obtained with different admixtures of the sand-lime reaction. Slate and rice husk ash have been incorporated in variable proportion in order to know their effect on the strength. 15.0% (w/w) lime has been used throughout and a maximum strength of 59.8 MPa with 5.0% slate (-100 mm) was recorded while a strength of 43.4 MPa was obtained with 5.0% rice husk ash (-100 mm).

It is evident that if silica sand is partially replaced by slate, a noticeable high strength is obtained which is contrary to our previous findings (1). The 47.8 MPa strength obtained with sand-lime reaction

(Figure 1, Table 1) has decreased to 43.4 MPa with addition of rice husk ash (5.0%), a source of 88.0% SiO_2. The rationale for this is unknown.

CONCLUSION

High strength cementations products can be obtained from the reaction between silica sand and $Ca(OH)_2$ when autoclaved at higher steam pressure (1.17 MPa). The strength can further be increased by adding small amount of finely divided siliceous materials such as slate while rice husk ash has an adverse effect on the strength. These materials are abundantly available in Pakistan. Slate-lime reaction can also give better strength materials.

REFERENCES

1. Khan SA and Talib YA : Hydrothermal reactions between lime and aggregate fines I. Experimental conditions for strength improvement using saturated steam at atmospheric pressure. Jour Isl Acad Sci, 6:140-144, 1993.

2. Urhan S : Alkali silica and pozzolanic reactions in concrete I. Interpretation of published results and an hypothesis concerning the mechanism. Cem Concr Res, 17:141-152, 1987.

3. Greenberg SA : Reaction between silica and calcium hydroxide solutions I. Kinetics in the temperature range 30-85. J Phys Chem, 65:12-16, 1961.

4. Barret P, Menetrier D and Cottin B : Study of silica-lime solution reactions. Cem Concr Res, 7:61-68, 1977.

5. Grutzeck MW, Atkinson S and Roy DM : Mechanism of hydration of condensed silica fume in calcium hydroxide solution. In Fly Ash, Silica Fume, Slag Other Miner By-Prod Concr Am Concr Inst Sp, Pub 79, Vol 2, pp 643-664, 1983.

6. Cheng-yi H and Feldman RF : Hydration reactions in Portland cement-silica fume blends. Cem Concr Res, 15:585-592, 1985.

7. Hill RD : The long-term expansion of perlite plaster and concrete. Australian J Appl Sci, 9:141-162, 1958.

8. Stanton TE : Expansion of concrete through reaction between cement and aggregate. Proc Am Soc Civil Engrs, 66:1781-1811, 1940.

9. Metso J, Kajaus E : Activation of blast furnace slag by some inorganic materials. In Fly Ash, Silica Fume, Slag Other Miner By-Prod Concr Am Concr Inst Sp, Pub 79, Vol 2, pp 1059-1073, 1983.

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