Hydrothermal Reactions between Lime and Aggregate Fines II. Experimental conditions for Strength Improvement using Saturated Steam at Elevated Pressure

SHAH ALAM KHAN
PCSIR Laboratories, P.O. PeshawarUnivesity,
Peshawar-25120, Pakistan

(Received 19th March, 1995, revised 17th July, 1995)

Summary: Investigation into the compressive strengths of various mixtures of indigenous materials consisting of lime and aggregate fines such as silica sand, slate and rice husk ash, autoclaved at a temperature of 180°C under a steam pressure of 1.17 MPa for 4.5 hours was undertaken. It was found that the maximum compressive strength of 59.8 MPa could be achieved after 4.5 hours reaction between a mixture of 80.0% silica sand, 15.0% lime and 5.0% slate under the above conditions of temperature and pressure. However, under the same conditions of temperature and steam pressure, lower strengths were obtained for other mixtures of these materials. Thus, for example, when, a mixture of 80.0% silica sand, 15.0% lime and 5.0% rice husk ash and a mixture of 85.0% slate and 15.0% lime were tried, then the respective strengths of 47.6 and 34.7 MPa were achieved.

Introduction

Silica sand and limestone are abundantly available in Pakistan. These indigenous raw materials can be used for the manufacture of high strength building materials after hydrothermal treatment.

In a previous report [1] a comprehensive study on the reactions of the locally available silica sand and lime at a steam pressure of 0.1 MPa and a temperature of 100°C was presented. Various other indigenous aggregates such as china clay, slate and fire clay, along with Na_2CO_3, $CaSO_4.2H_2O$ and Na_2SiO_3 were also incorporated in order to improve the strength of the product. It was found that hydrated calcium silicate, a strong and durable cementing agent, was the main product in all cases.

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 at a temperature of 180°C for a period of 4.5 hours to determine the compressive strengths of the various hardened products.

Results and Discussion

The results of the compressive strengths of silica-sand and lime as well as that of slate and lime mixtures are shown in Tables 1 and 2 respectively whereas Figure 1 presents the results graphically.

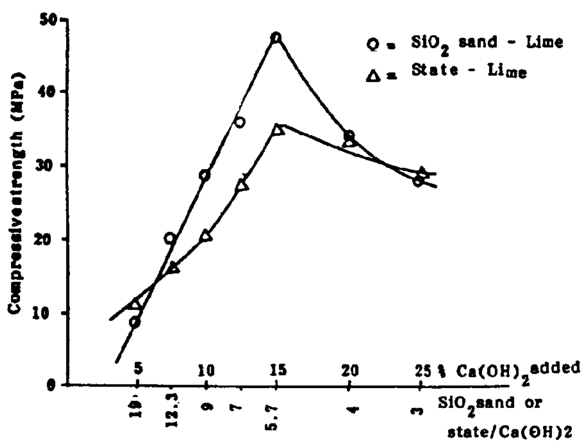

Fig.1: Variation of compressive stengths at 4.5 hours of $Ca(OH)_2$ - activated hydrothermal products versus SiO_2 sand or slate/$Ca(OH)_2$ ratio.

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 (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

As indicated in Table-1, the mixtures of sand and lime contain almost 99% SiO_2 which reacts with lime to produce cementitious materials of different compressive strengths. The curves of Figure 1 indicate that the strength of the moulds made from the sand-lime as well as slate-lime mixtures increases with the increase of the amount of lime up till 15% and it decreases with the further addition of lime. A maximum strength of 47.6 MPa is indicated in the moulds of sand-lime mixtures as compared with the maximum strength of 25.8 MPa reported to have been achieved in our earlier study [1] using 30% lime in the sand-lime mixture which was autoclaved at 100°C with a steam pressure of 0.1 MPa for 48 hours.

The curve of Figure 1 for the slate-lime mixture shows a maximum strength of 34.7 MPa with 15% lime. A comparable strength of 34.3 MPa is indicated in the sand-lime mixture with 20% lime content.

The strength of these materials seems to be related to a reaction between SiO_2 and $Ca(OH)_2$ solution resulting in the formation of hydrated calcium silicate, a strong material, as indicated in the following reaction which has been proposed by different workers [2-5].

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

The result of Figure 1 indicates that at a critical ratio of 5.7 between SiO_2 present in sand or slate and lime gives maximum strength to the moulds made from mixtures containing sand or slate. For the higher or lower ratios, the strengths of both the moulds of sand and slate decrease.

The reaction is most likely to take place in the mixtures used in the present study. The results of the present study expressed in Tables 1-2 and Figure 1 indicate that stronger moulds are obtained using sand-lime mixtures than those of slate-lime mixtures because the amount of SiO_2 is more in the former than in the latter mixtures.

It is known [6] that finely divided siliceous materials (including clays, zeolites and diatomite) can react with free lime of cement leading to the formation of hydrated products having good binding properties. Small additions of basic materials like NaOH [7] are found to be good accelerators.

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 (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

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 find their effect on the strength. A mixture of 15% (w/w) lime has been used throughout and a maximum strength of 59.8 MPa with 5% slate (-100 μm) was recorded while a strength of 43.4 MPa was obtained with 5% rice husk ash (-100 μm).

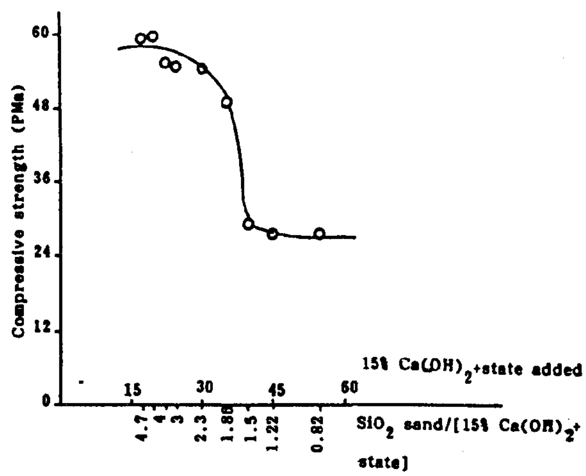

Fig.2: Variation of compressive strengths at 4.5 hours of $Ca(OH)_2$ and slate - activated hydrothermal products versus SiO_2 sand/(15% $Ca(OH)_2$ + slate) ratio.

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%), a source of 88% SiO_2. The rationale of which is unknown.

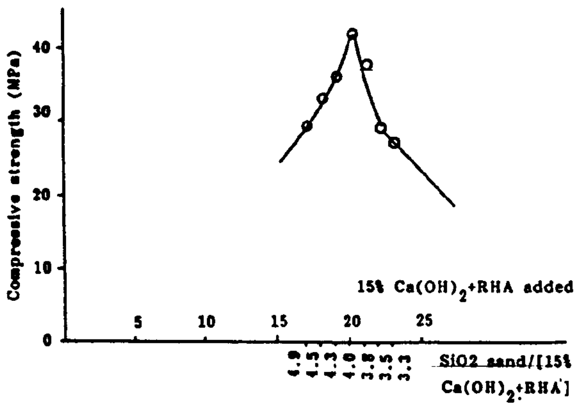

Fig.3: Varation of compressive strengths at 4.5 hours of $Ca(OH)_2$ and rice husk ash-activated hydrothermal products versus SiO_2 sand/ (15% Ca $(OH)^{+}_{2}$ RHA) ratio.

Table-3: Compressive strengths of autoclaved silica sand -Slate-$Ca(OH)_2$ moulds.

Silica sand (200-300 µm) %	Silica sand (-100 µm) %	$Ca(OH)_2$ (-100 µm) %	$Ca(OH)_2$ (-100 µm) %	Compressive strength (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 (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
""	31.95	8.0	""	28.41

Experimental

Materials

Calcium hydroxide of particle size < 100 µm was prepared by heating $CaCO_3$ at a temperature range of 1000-1100°C to CaO which was hydrolysed with water to produce $Ca(OH)_2$. Two silica sand samples containing 99% SiO_2 one with particle sizes < 100 µm (47%) and the other in the range of 200-300 µm (53%) as well as two slate samples of the same particle sizes as the above silica samples but with composition of 63% SiO_2 and 19% Al_2O_3 in the ratio of 47% of the first and 53% of the second particle size respectively were used. The composition of the rice husk ash was 88% SiO_2 and 2% Al_2O_3 and their particle size was < 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 Table 1-4.

Cylindrical specimens of 3.8 cm diameter by 5.1 cm in height were moulded 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 for 4.5 hours at a steam pressure of 1.17 MPa and a temperature of 180°C.

After autoclaving, the specimens were removed and cooled in a desiccator under dry CO_2-free atmosphere until they were needed for further examination. The specimens were tested for compressive strength. Compressive strength tests were done in accordance with ASTM test methods [8].

Conclusion

High strength cementitious 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. S.A. Khan and Y.A. Talib, *Jour. Isl. Acad. Sci.*, **6**, 140 (1993)
2. S.A. Greenberg, *Jour. Phys. Chem.*, **65**, 12 (1961).
3. par P. Barret, D. Menetrier and B. Cottin, *Cem. Concr. Res.*, **7**, 61 (1977).
4. M.W. Grutzeck, S. Atkinson and D.M. Roy, in "Fly Ash, Silica Fume, Slag and Other Miner By-Product Concrete", *Am. Concr. Inst. Sp. Pub. 79*, Vol. **2**, p 643 (1983).

5. H. Cheng-yi and R.F. Feldman, *Cem. Concr. Res.*, **15**, 585 (1985).
6. T.E. Stanton, *Proc. Am. Soc. Civil Engrs.*, **66**, 1781 (1940).
7. J. Metso and E. Kajaus, in "Fly Ash, Silica Fume, Slag and other Miner By-Product Concrete", Am. Concr. Inst. Sp. Pub. 79, Vol. 2, p. 1059 (1983).
8. Annual Book of ASTM Standards (Concrete and Aggregatges) Vol. 04.02 (1987).