*Journal of Ceramic Processing Research. Vol. 16, Special. 1, pp. s138~s143 (2015)*

J O U R N A L O F
Ceramic Processing Research

# Effect of incorporation of self healing admixture (SHA) on physical and mechanical properties of mortars

**Byung Wan Jo[a], M.Ali Sikandar[b]*, Zafar Baloch[b], R.M.Asad Khan[b]**
[a]*Professor ,Department of Civil & Environmental Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu 133-791, Seoul, Korea*
[b]*Department of Civil & Environmental Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu, 133-791 Seoul, Korea*

**This paper presents the results of experimental investigation carried out to assess the effect of crystalline admixture-a self healing admixture (SHA) on the physical and mechanical properties of mortars. Crystalline admixture (CA) totaling 3% by weight of cement was added into cements and lime mortars. The porosity and water absorption capacity was significantly reduced for mortars with SHA. An overall improvement in compressive and flexural strength was observed with the inclusion of SHA. An increase in modulus of elasticity and reduction in brittleness factor was observed for mortars with SHA. Effect of sand gradation was also found prominent on physical and mechanical properties of mortars.**

**Key words: Self healing, admixture, cement, ductility, lime, compressive strength.**

## Introduction

The role of self healing materials in construction materials is well established in construction materials. Over the last decade, the concept of autogenous repair by construction materials has surfaced as the promising approach to overcome its damage with time [1]. Though, the self healing potential of concrete is limited, the self healing materials have the property to repair concrete in relatively less time.

Various methodologies have been adopted with time to enable construction materials to self heal during their service life. Mineral admixtures have been incorporated to increase self healing properties of concrete by reducing its permeability [2]. The pores and micro cracks are formed due to dissolution of hydrated products [3] within the concrete. Usually, pozzolonic admixtures are added in cement to initiate the secondary hydration reaction, to help reduce the porosity of concrete [4]. The concept of inclusion of SHA in construction materials to improve their physical and mechanical characteristics maintains its novelty among researchers. However, the idea of incorporating SHA in construction materials would be generally accepted, if their physical and mechanical properties are thoroughly investigated and studied. The role of self healing material is well known in construction materials, but a little work so far has been done to assess the impact of these materials on physical, mechanical and stress strain properties of construction materials.

The role of CA as SHA has been successfully proved in previous studies [5-7]. ACI classifies CA as hydrophilic materials that reacts actively with water to form more dense and compact hydrated products, which reduce porosity and water absorption by producing pre-blocking deposits [8].Therefore, this study aims at studying the effect of crystalline admixture a type of SHA on mechanical and physical properties of mortars. In one previous study [9], the dosage of CA in concrete has been optimized as 3% by weight of cement to get the best results for compressive strength, whilst, in another study [5] the dosage of 3% has been recommended. Therefore, in this study the CA has been added 3% by weight of cement to study the physical, mechanical and stress strain characteristics in detail.

## Experimental

### Materials

Ordinary Portland Type-1 cement conforming to ASTM C-150 specification was used throughout the experimental work to produce mortars. The density and specific surface of cement used throughout experimental program was and 3200 kg/m$^3$ and 350 m$^2$/kg respectively. Locally available two types of natural conforming to ASTM C-144 gradation requirements were used in entire experimental program and were referred as coarse and fine sands. Coarse sand has fineness modulus of 2.74 and fine sand has the fineness modulus of 1.9. Figure-1 shows the sand gradation curve for coarse and fine sands used in this study. Hydrated lime type-N conforming to ASTM C-207 standard was used in the

*Corresponding author:
Tel : +
Fax: +
E-mail: muhammadalisikandar@yahoo.com

**Table 1.** Chemical composition of OPC and SHA.

| Sample | MgO | $Al_2O3$ | $SiO_2$ | $SO_3$ | $K_2O$ | CaO | $Fe_2O_3$ | Total |
|---|---|---|---|---|---|---|---|---|
| Cement | 2.1 | 5.4 | 20.7 | 3.5 | 0 | 63.9 | 3.2 | 98.8 |
| SHA (CA) | 12.8 | 3.9 | 17.1 | 2.7 | 0.3 | 59.9 | 3.0 | 99.7 |

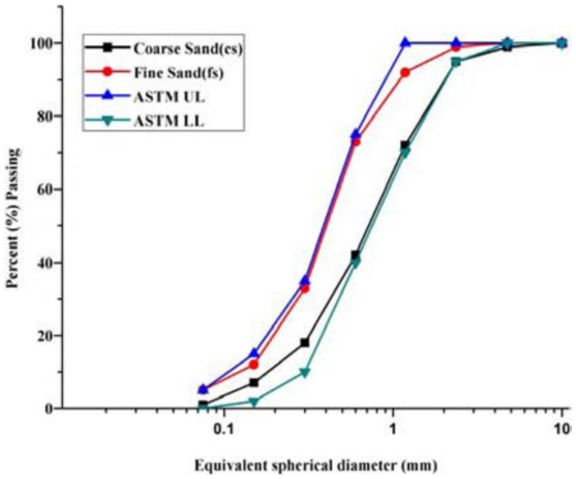



**Fig. 1.** Sand gradation curves of sands used.

**Table 2.** Mix proportions for mortars.

| Mix Designation | Sand Type | w/c Ratio |
|---|---|---|
| CMS (1:2.75+ 3 % CA) | Coarse sand (cs) and fine sand (fs) | 0.5,0.8,1 |
| CMC (1:2.75) | Coarse sand (cs) and fine sand (fs) | 0.5,0.8,1 |
| CLMS (1:0.5:4.5+ 3 %CA) | Coarse sand (cs) and fine sand (fs) | 1.0,1.2,1.4 |
| CLMC (1:0.5:4.5) | Coarse sand (cs) and fine sand (fs) | 1.0,1.2,1.4 |

experimental program. Lime was ground and was chemically treated with water before use and lime putty was allowed to hydrate for 24 hours. The density and specific surface of lime used were 591 $m^2$/kg and 1988 kg/$m^2$.Water for producing mortars was clean and free of acids, alkalis, and organic materials. Crystalline admixture was used as a self healing admixture in this study. The composition of OPC and CA are given in table 1.

## Mix proportions and testing methods

Extensive testing on cement sand and cement lime sand mortars both in fresh and hardened states was performed. In order to analyze the effectiveness of crystalline admixture-self healing admixture on physical and mechanical properties of mortars, the specimens were prepared using crystalline admixture in cement and cement lime mortars using coarse and fine sands. In total four mixes of mortars with and without crystalline admixture were produced. The cement to sand ratio was kept as 1 : 2.75 for cement mortars with self healing admixture (CMS) and cement mortar control (CMC); in the former composition the self healing admixture was added in about 3% of cement by weight. In cement lime mortars (CLMS = cement lime mortar with SHA and CLMC = cement lime mortar control) the aggregate to binder ratio was kept as 1 : 0.5 : 4.5 (Portland cement: lime: sand), except in cement lime mortar with self healing admixture (CLMS), the crystalline admixture was added in about 3% by weight of cement. The water to cement ratios were selected as 0.5, 0.8 and 1 and 1.0, 1.2, 1.4 for cement sand and cement lime mortars respectively. Table 2 presents all mix proportions produced in this experimental program.

All mortars used in the experimental scheme were prepared using standard mortar mixer in accordance with ASTM C305-12.The water was first introduced in a mixer then the dry material was added to water and was mixed for 30 seconds, the mixing was done in 3 steps in a sequential order. The mortars were cast into moulds and were kept in plastic sheeting for 24 hrs to avoid evaporation of water. After 24 hours specimens were removed from the moulds and were placed in water tank for 7, 14 and 28 days at 23 ± 2 ºC.

The physical properties of mortars were characterized by determining porosity; water absorption and dry density of mortars in accordance with ASTM C-642.Three samples for each composition were used to get average value. The flow table index for mortars was evaluated by performing flow table test for workability of mortars in accordance ASTM 1437-13. Average flow table value for each composition was obtained by testing three specimens of mortars

The compressive strength test was performed on 50 mm side cubes cured for 7, 14 and 28 days cured in accordance with ASTM C-109 using universal testing machine CCM 200-A,Schimadzu inc., Japan. Compressive strength being an important property was determined at various ages of hardened mortar. Flexure strength of mortars was estimated by performing flexure test on prismatic beam specimens of dimensions 40 mm × 40 mm × 160 mm in accordance with ASTM C-1072 on 28 day cured samples using universal testing machine AG-1 Schimadzu,Inc.Japan . For the sake of precision, three specimens each were used to determine average strength in compression and flexure.

The stress strain behavior of hardened mortars was evaluated by obtaining stress strain curves and determining elastic modulus by testing 50 mm × 100 mm mortar cylinders under compressive loads using extensometers and strain gauges. The average stress strain diagrams were obtained by averaging strains corresponding to average stress for three specimens. The brittleness factor was obtained by dividing compressive strength by its flexural strength. The modulus of elasticity in compression ($E_c$) was obtained by dividing the stress and its corresponding strain in elastic region of ascending curve.

## Results and Discussions

### Physical performances

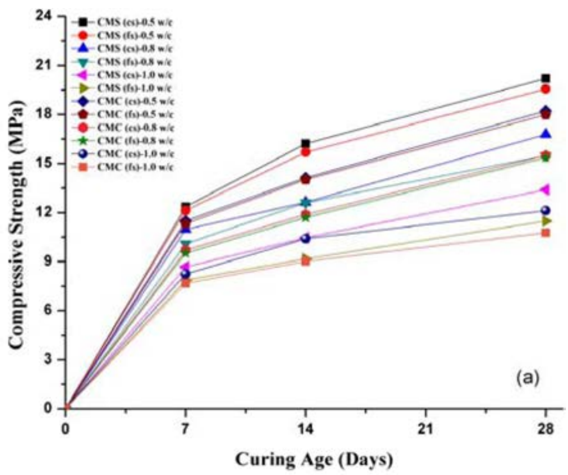
The dry density, porosity, water absorption and flow table test results of all mortar compositions are shown in the table 3 at distinct water cement ratios. The flow table values for all mortars are found in direct correlation with water cement ratio. It is found that for a particular water cement ratio fine sand mortars display less flow table value as compared to coarse sand mortars, this phenomenon may be attributed to high specific surface of fine sand mortars, same findings were reported in early research [10].The inclusion of SHA in cement and lime mortars at every water cement ratio reduces the flow table value as compared to respective control mortars. An improvement in dry density is noticed for mortars with SHA, it is believed that SHA is capable of filling in pores in cement sand matrix resulting in denser hydrated products. Similarly, the porosity and water absorption is reduced for mortars with SHA; it is presumed that SHA are capable of filling the pores efficiently in cement sand matrix, consequently, reducing porosity and water absorption of mortars. Usually, low water absorption and porosity values help in attaining high compressive strength in mortars.

**Table 3.** Porosity, absorption, density and flow table index of each mortar composition.

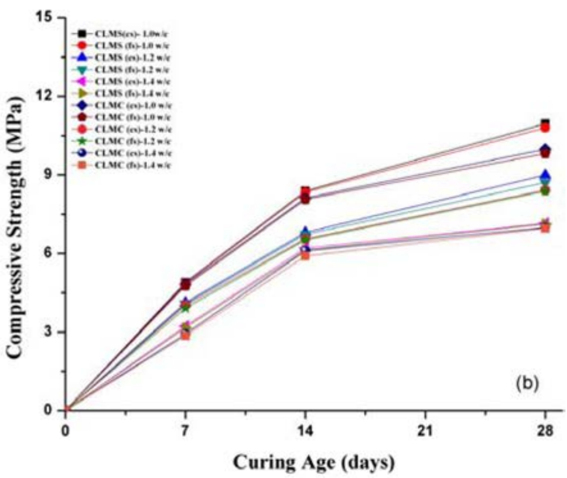
| | Sand type | w/c | Porosity (%) | Absorption (%) | Density (g/cm$^3$) | Flow index (mm) |
|---|---|---|---|---|---|---|
| CMS | Coarse sand | 0.5 | 15.90 | 9.23 | 2.12 | 110 |
| | | 0.8 | 17.10 | 9.53 | 2.07 | 184 |
| | | 1.0 | 18.10 | 10.10 | 2.02 | 218 |
| | Fine sand | 0.5 | 16.90 | 10.05 | 2.06 | 95 |
| | | 0.8 | 17.50 | 10.06 | 1.99 | 142 |
| | | 1.0 | 18.4 | 10.14 | 1.96 | 186 |
| CMC | Coarse sand | 0.5 | 16.01 | 9.50 | 2.07 | 115 |
| | | 0.8 | 17.50 | 9.70 | 2.02 | 194 |
| | | 1.0 | 18.20 | 10.23 | 1.98 | 230 |
| | Fine sand | 0.5 | 17.10 | 10.20 | 2.04 | 95 |
| | | 0.8 | 18.00 | 10.18 | 1.95 | 155 |
| | | 1.0 | 18.8 | 10.4 | 1.92 | 200 |
| CLMS | Coarse sand | 1.0 | 18.50 | 11.05 | 2.33 | 92 |
| | | 1.2 | 18.49 | 11.45 | 2.32 | 135 |
| | | 1.4 | 18.58 | 11.68 | 2.26 | 172 |
| | Fine sand | 1.0 | 18.45 | 11.02 | 2.29 | 87 |
| | | 1.2 | 18.45 | 11.52 | 2.22 | 132 |
| | | 1.4 | 18.72 | 11.65 | 2.20 | 165 |
| CLMC | Coarse sand | 1.0 | 18.70 | 11.16 | 2.30 | 100 |
| | | 1.2 | 18.82 | 11.65 | 2.25 | 145 |
| | | 1.4 | 19.01 | 11.76 | 2.19 | 190 |
| | Fine sand | 1.0 | 18.90 | 11.24 | 2.28 | 95 |
| | | 1.2 | 18.92 | 11.72 | 2.18 | 142 |
| | | 1.4 | 19.06 | 11.80 | 2.19 | 185 |

### Compressive strength

The variation in compression strength with respect to curing age of all mortars at distinct water-cement ratios are shown in figure 2(a) and 2(b).As expected, it is found that an increase in water cement ratio results in decrease in compression strength of all mortar compositions. It may be concluded that the extra water at high water cement ratios contributes in high flow value of mortars which in turns causes to weaken the bond between mortar components leading to lower strengths. An overall improvement is noticed in the compression strength of mortars with SHA, this could




(a)




(b)

**Fig. 2** (a). Variation in compressive strength with age for mortars with SHA (cured for 7,14 and 28 days) (b). Variation in compressive strength with ag for mortar samples without SHA (cured for 7,14 and 28 days.

**Table 4.** Flexural strength of mortar samples (cured for 28 days).

| Mix Proportion | Sand type | w/c | 28-day flexural strength (MPa) |
|---|---|---|---|
| CMS | Coarse sand | 0.5 | 3.03 |
| | | 0.8 | 2.40 |
| | | 1.0 | 1.876 |
| | Fine sand | 0.5 | 2.91 |
| | | 0.8 | 2.26 |
| | | 1.0 | 1.62 |
| CMC | Coarse sand | 0.5 | 2.36 |
| | | 0.8 | 2.17 |
| | | 1.0 | 1.45 |
| | Fine sand | 0.5 | 2.51 |
| | | 0.8 | 2.00 |
| | | 1.0 | 1.18 |
| CLMS | Coarse sand | 1.0 | 1.65 |
| | | 1.2 | 1.30 |
| | | 1.4 | 1.04 |
| | Fine sand | 1.0 | 1.62 |
| | | 1.2 | 1.28 |
| | | 1.4 | 1.01 |
| CLMC | Coarse sand | 1.0 | 1.49 |
| | | 1.2 | 1.16 |
| | | 1.4 | 0.94 |
| | Fine sand | 1.0 | 1.17 |
| | | 1.2 | 1.17 |
| | | 1.4 | 0.84 |

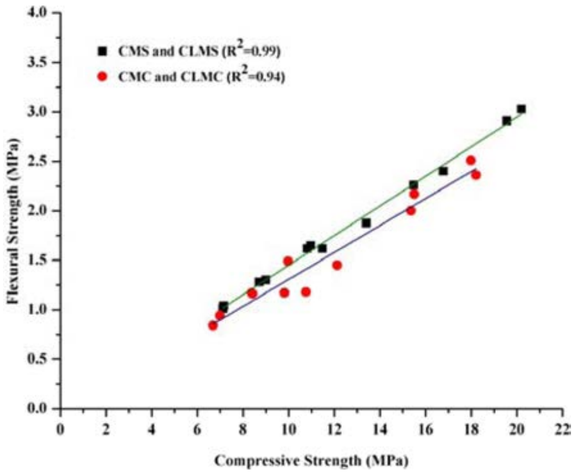



**Fig. 3.** Relation between compressive and flexural strength of mortar samples with and without SHA (cured for 28 days).

be due to the fact that SHA fills the micro cracks in cement sand matrix, which in turns reduces the porosity and water absorption, and consequently higher compressive strength of mortars is achieved. The 28-day compressive strengths of cement mortars with SHA having coarse sand are found to be 20.2, 16.78 and 13.4 MPa compared to 18.21, 15.5 and 12.12 MPa for cement mortars without SHA having coarse sand at water cement ratios 0.5, 0.8 and 1 respectively. Similarly,28-day compressive strength for cement lime

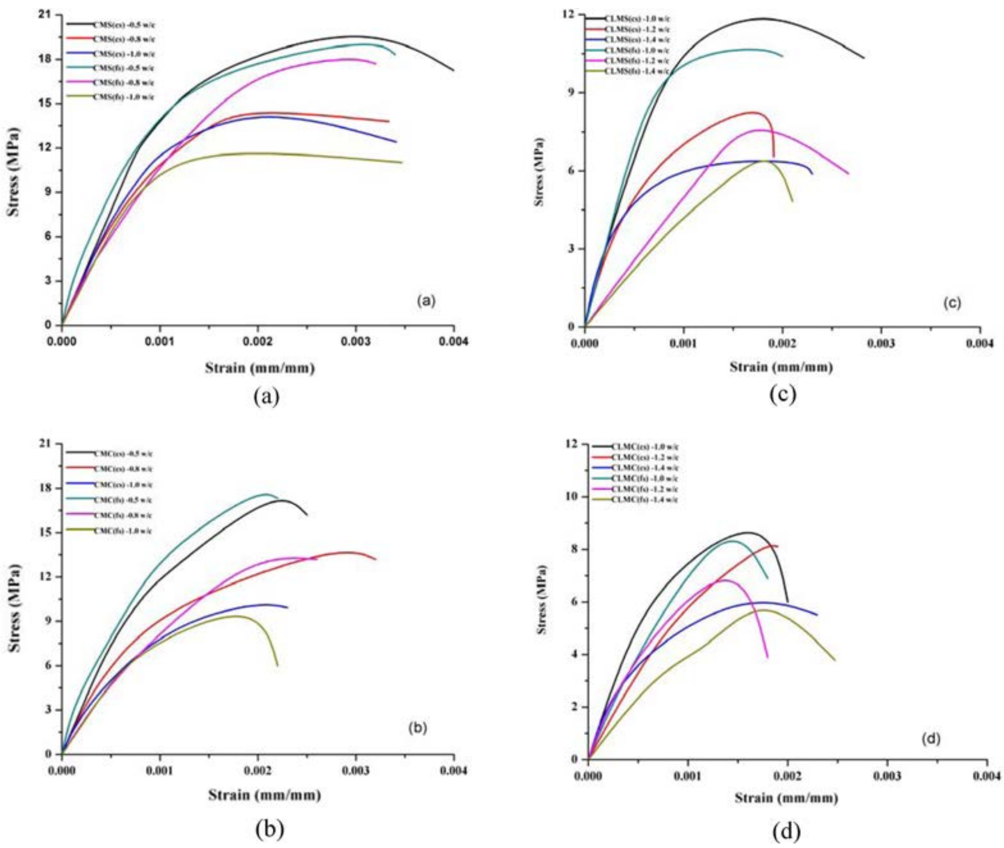



**Fig. 4** (a) Stress-strain curve for CMS samples cured for 28 days, (b) Stress-strain curve for CMC samples cured for 28 days, (c) Stress-strain curve for CLMS samples cured for 28 days and (d) Stress-strain curve for CLMC samples cured for 28 days.

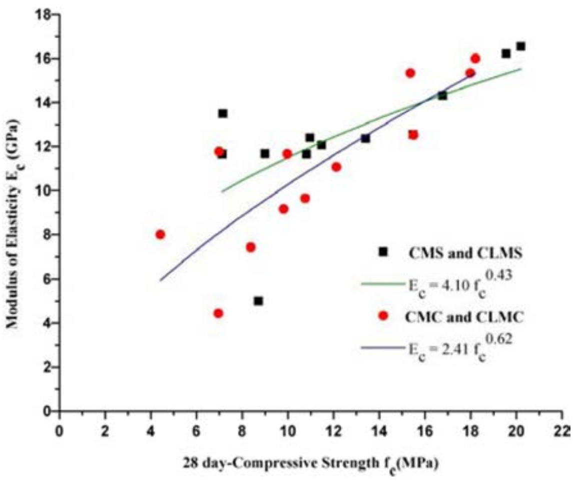



**Fig. 5.** Relation between Elastic modulus ($E_c$) and compressive strength of samples cured for 28 days.

mortars with SHA having coarse sand, are found to be 10.96, 8.99 and 7.15 MPa, whilst for cement lime mortars without SHA having coarse sands 9.98, 8.42 and 6.99 MPa at water cement ratios 1, 1.2 and 1.4 respectively. Negligible effect on compressive strength is observed with regard to sand gradation. Therefore, it is deduced that the compressive strength of mortars increase with SHA inclusion.

## Flexure strength

It is revealed that flexure strength follows the same trend as compressive strength of mortars. Table 4 shows 28 day flexural strength of all mortars at distinct water cement ratios. With the increase in water cement ratio, the flexure strength decreases for all mortar compositions having coarse and fine sand. The addition of SHA in the mortars results in increase in the flexure strength of mortars; it could be due to the reason that SHA compacts the mortar components compared to control mortars, which consequently enhance their capability to offer more resistance to bending. Strong relationship between flexure and compression strength for mortars with SHA is obtained having regression coefficient of 0.99 comparing to 0.94 of mortars without SHA, therefore, it is deduced that compression strength can be used as the estimator of flexure strength for mortars with SHA at higher confidence level than mortars without SHA. This phenomenon may be attributed to the fact that coarse sands are more compact in cement matrix as compared to fine sands, and are capable of offering more resistance to bending.Figure-3 shows the plot between 28-days flexure and compression strength of all mortar compositions.

## Stress strain Behavior

The 28-day cured cylindrical specimens of all mortar compositions were strained to fail in compression to evaluate stress strain behavior of mortars. Stress strain curve exhibited by each mortar composition at distinct water cement ratios is shown in figures-4(a), 4(b), 4(c) and 4(d). From the figures, it is observed that the incorporation of SHA in mortars results in increased strain capacity of mortars, owing to their ductile behavior. It is therefore, deduced that SHM inclusion results in formation of hydrated products at large scale. These hydrated products heal the shrinkage cracks and pores in cement matrix. The hydrated products also enhance the load carrying and strain capacity of mortars. The brittleness factor for CMS and CLMS is found to be in range of 6.69 to 7.14 and 6.64 to 7.04 respectively compared to their control counterparts for whom it is lying in range of 7.14 to 9.11 and 6.69 to 8.39 respectively. This proves the increased ductility of mortars with inclusion of SHA. In addition, fine sand mortars for all mortar compositions show low peak strain values in comparison to their corresponding coarse sand mortars, due to the fact that increased local compressive stresses under loading point results in overall low compressive strength compared to coarse sand mortars, as indicated in early findings [11].The peak strain and brittleness factor are tabulated in table 5.

**Table 5.** Modulus of elasticity ($E_c$), brittleness factor and peak strains of mortar samples (cured for 28 days).

| Mix Proportion | Sand type | w/c | Brittleness Factor (fc/ff) | Modulus of Elasticity (GPa) | Peak strain (%) |
|---|---|---|---|---|---|
| CMS | Coarse sand | *0.5* | 6.84 | 16.54 | 0.311 |
| | | *0.8* | 6.99 | 14.31 | 0.200 |
| | | *1.0* | 7.14 | 12.36 | 0.200 |
| | Fine sand | *0.5* | 6.72 | 16.22 | 0.317 |
| | | *0.8* | 6.84 | 12.55 | 0.294 |
| | | *1.0* | 7.08 | 12.06 | 0.160 |
| CMC | Coarse sand | *0.5* | 7.71 | 16.00 | 0.222 |
| | | *0.8* | 7.14 | 12.52 | 0.282 |
| | | *1.0* | 8.35 | 11.07 | 0.200 |
| | Fine sand | *0.5* | 7.16 | 15.34 | 0.210 |
| | | *0.8* | 7.68 | 9.95 | 0.200 |
| | | *1.0* | 9.11 | 9.65 | 0.176 |
| CLMS | Coarse sand | *1.0* | 6.64 | 12.40 | 0.210 |
| | | *1.2* | 6.91 | 11.68 | 0.209 |
| | | *1.4* | 6.87 | 13.50 | 0.207 |
| | Fine sand | *1.0* | 6.67 | 14.50 | 0.180 |
| | | *1.2* | 6.80 | 5.01 | 0.176 |
| | | *1.4* | 7.04 | 4.57 | 0.174 |
| CLMC | Coarse sand | *1.0* | 6.69 | 11.66 | 0.180 |
| | | *1.2* | 7.25 | 8.00 | 0.175 |
| | | *1.4* | 7.43 | 11.77 | 0.153 |
| | Fine sand | *1.0* | 8.39 | 9.16 | 0.177 |
| | | *1.2* | 7.16 | 7.43 | 0.150 |
| | | *1.4* | 8.28 | 4.44 | 0.176 |

## Modulus of elasticity

At lower water to cement ratios the modulus of elasticity for mortars with SHA are found to be comparable with their control counterparts; however as water content increases the mortars with SHA have shown high modulus of elasticity than mortars without SHA. This ability to take loads at higher strains may be attributed to formation of hydrated products at larger scale. Modulus of elasticity is dependent upon compressive strength; the modulus of elasticity has been plotted as the function of compressive strength to obtain power equations for elastic modulus for mortars with and without SHA. Figure-7 shows relationship between modulus of elasticity and compression strength of all mortars. The modulus of elasticity for each mortar composition is given in table 5. The results are supported by earlier research [12] in which it was demonstrated that the modulus of elasticity and compressive strength are hydration criteria of mortars, and they are in linear relationship.

## Conclusions

An experimental investigation work dealing inclusion of SHA in mortars (lime and without lime) was carried out. The SHA successfully reduced the water absorption and porosity of mortar systems. Overall improvement in mechanical properties of mortars is found with inclusion of SHA in mortar system, due to its ability to form more hydrated product. Thus inclusion of SHA in mortar system enhances the mechanical and physical properties of mortars. The capability of SHA to produce more hydrated products and healing the pores during the hydration makes it suitable for improving mechanical and physical performances.

## References

1. C. Victor Li and Emily Herbert, J. Adv.concr. Tech. Vol 10,207-218, June 2012.
2. T. Kishi, T.H. Ahn, M. Morita and T. Koide, in the Proceedings of the3rd Int'l Conf.on Self Healing Materials,YK 2011.
3. B. Lothenbach, F. Winnefield, C. Alder, E. Wieland, P. Lunk, Cem. Concr. Res. (2007) 37:483.
4. F.A. Kronlo Mater Struct (1994) 27:185.
5. M. Roig-Flores, S. Moscato, P.Serna, L. Ferrara, Constr. Build. Mater. (2015) 86:1-11
6. L. Ferraea,V. Krelani, M.A. Carsana, Constr Build Mater. 68: (2014) 535-51.
7. D. Jaroenratanapirom, R. Sahamitmongkol, J. Metals, Materials and Minerals Vol. 21 No. 1 pp.9-17, 2011.
8. Report on Chemical Admixtures for concrete ACI 212.3R-10
9. T. Lung and A. Cheng, Montash Chem. (2014) 145:195-200.
10. 0S.Harsh, Z.Shen, and D.Darwin ACI mater. J technical paper 1987; 84(4):278-85.
11. K.K. Sideris , P. Manita, K. Sideris, Cem. Concr. Comp. 26 (2004) 623-631.