DEVELOPMENT OF CEMENT REPLACEMENT MATERIAL / POZZOLAN FROM WASTE PAPER SLUDGE

Abdullah Saand[1], MantharAli Keerio[2], Sadam Hussain Jakhrani[3], Daddan Khan Bangwar[4]

[1] Abdullah Saand, Professor, Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah.

[2]Manthar Ali Keerio, Assistant Professor, Department of Civil Engineering, Quaid-e-Awam University College of Engineering, Science and Technology, Larkano.

[3]M.E student, Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Pakistan

[4]Daddan Khan Bangwar, Assistant Professor, Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah.

Correspondent Email: abdullah@quest.edu.pk

ABSTRACT: *This research study instigate the consequence of heat and heating duration on the pozzolanic activity of waste paper sludge (WPS) .Waste paper sludge is calcined by heating in a furnace at 600, 700, & 800 °C temperatures for 1h, 2h and 3 hours period. The Energy Dispersive Spectrometry (EDS) and X-ray Diffraction (XRD) are carried out to confirm the presence amorphous silica in produced waste paper sludge. The strength activity index (SAI) is conducted with 20% substitution of cement with calcined waste paper sludge as per ASTM. The percentage increase of chemical compounds in developed waste paper sludge (DWPS) samples were SiO_2 21%, Al_2O_3 66% and CaO 100% than the WPS samples. The extent of quartz (raw impurities) in DWPS was decreased by 82%. The acquired outcomes of SAI conclude that the optimal thermal activation temperature of waste paper sludge is 600 °C with 3 hours duration. The X-ray Diffraction Analysis authenticated the pozzolanic reactivity of produced waste paper sludge and confirmed the outcome of Strength Activity Index. Furthermore, it is observed that the calcined waste paper sludge has a significant improvement in compressive strength of the mortars.*

Keywords: Waste paper sludge, XRD, SAI, Compressive Strength, Pozzolanic material

1. INTRODUCTION

The most widely used construction material in the world is concrete. Twelve billion tones of concrete are being produced by the concrete industry each year, for this amount approximately 1.6 billion tones of Portland cement is being used [1]. In the atmosphere 0.8 Tones of Carbon die oxide (CO_2) is emitted for the manufacture of 1 tons of cement, which is about 5–8% of worldwide CO_2 emission [2]. Not only CO_2 releases from manufacture of cement, but other harmful gases are also released into atmosphere. The production of cement consumes considerable amounts of limestone, its energy demand is about 1700-1800 MJ/tone clinker [3]. To decrease the environmental impact of cement, cementitious materials are used to replace part of cement and to improve workability, mechanical and durability properties of concrete [4]. During manufacturing of 1 tone of Ordinary Portland Cement (OPC) about 1 to 1⅓ tone limestone, etc. is required. The CO_2 emissions act as a silent killer of the environment under several practices. In these conditions, search for for inexpensive substitute to OPC is needful [5]. Pozzolans are used in combination with binding materials to improve the workability, mechanical and durability properties of concrete and decrease its cost. [6]. Carbon reducing cements, if could be developed for commercial-scale application, probably offer the safest, most reasonable and neat Carbon capture and storage technology [7]. Pozzolans are of rising attention for the reason that of their use in concrete/mortar to reduce environmental effect of OPC and overall construction cost [8-10]. Highly reactive metakaolin produced by calcination of the paper sludge exhibited good pozzolanic properties and recognized its incorporation in cement systems [11]. It was exposed from results that the calcined waste paper sludge can be used as active trappings for the manufacture of Portland cements, according to the current standard [12]. The efficient mixing of a pozzolanic material in OPC is a consequence of the calcination of an industrial waste [13].

As the production of one tone of ordinary Portland cement releases approx. 0.8 tones of CO_2 in the environment, it accounts approx 5–8% of total global of CO_2 emission [2]. To decrease the manufacturing of cement to obtain decrease in CO_2 release, decrease of energy consumption and decrease in construction cost, environmental friendly cement replacement material is required. The aim of this research is to develop the cement replacement material from waste paper sludge collected from paper pulp industries Kotri, Hyderabad, Sindh, Pakistan.

2. EXPERIMENTAL PROGRAM

2.1. Materials Used

OPC, Lucky brand is used. Hill sand as fine aggregate passed on sieve #30 and retained from sieve #60 was used.

Water used in the mixture was clean and free from dirt and other salty compounds.

The waste paper sludge (WPS) samples were collected from a Pulp and Paper Industries located in Kotri, near Hyderabad, Sindh, Pakistan. The material was grinded into powder form and was passed from sieve #325 before used in mix. The powdered form of waste paper sludge, which was passed from sieve #325, was calcined in muffle furnace at different temperatures and heating durations to remove impurities present in the samples. The samples were calcined at 600°C, 700°C and 800°C with the heating durations of 1hr, 2hrs and 3hours.

2.2. Mix Proportion of Mortar

A control mortar mixture and nine modified mixture of mortar containing calcined paper sludge treated at 600°C, 700°C and 800°C with 1hr, 2hrs & 3hrs duration were considered. Ten cubes for each sample with a size of (50 x 50 x 50) mm were caste. The cubical specimens were caste with 80% of cement and 20% of calcined waste paper sludge to examine SAI at 7 and 28 days as per ASTM C-150. The mixtures were prepared using cement to sand ratio as 1:2.75 and water to binder ratio as 0.49 as per ASTM C-150. All the specimens were allowed for curing in a water tank under room temperature for 7 and 28 days.

2.3. Test Methods

To examine chemical and mineralogical composition of waste paper sludge and developed waste paper sludge EDS and XRD test was carried out. Specific gravity, dry density and Loss on ignition were conducted by density bottle method according to IS-2720, density bottle method as per BS-1377:1975 and ASTM C-114 respectively, of waste paper sludge (WPS) and developed waste paper sludge (DWPS). Testing of mortar specimen for compressive strength at 7 and 28 was conducted as per ASTM C 109.

Table1. Details of mixture ratio of mortar

Mixture	Calcination Temperature (°C)	Heating Duration (Hrs)	Cement (%)	Replacement of cement with calcined WPS (%)	Water/binder	Binder/ Sand
A	--	--	100	---	0.49	1:2.75
B	600	1	80	20	0.49	1:2.75
C	600	2	80	20	0.49	1:2.75
D	600	3	80	20	0.49	1:2.75
E	700	1	80	20	0.49	1:2.75
F	700	2	80	20	0.49	1:2.75
G	700	3	80	20	0.49	1:2.75
H	800	1	80	20	0.49	1:2.75
I	800	2	80	20	0.49	1:2.75
J	800	3	80	20	0.49	1:2.75

3. RESULTS AND DISCUSSION

3.1. Physiochemical properties of waste paper sludge and developed waste paper sludge

The outcomes of Physiochemical properties of waste paper sludge and developed waste paper sludge are presented in Table 2.

The pozzolans are a broad class of siliceous or siliceous and aluminous materials. It is oblivious from the data presented in Table 2 that the siliceous and aluminous materials of developed calcined waste paper sludge i.e. SiO_2, Al_2O_3 and CaO increases in DWPS was 21%, 66%, and 100% increased as compared to the composition of WPS samples

3.2. Mineralogical composition of waste paper sludge and developed waste paper sludge

The outcomes of XRD for mineralogical composition of waste paper sludge and produced waste paper sludge are presented in Table 3. From the Table 3 it is clear that after calcinations the quantity of quartz (raw impurities) was 82.19% decreased in DWPS than the WPS samples, and upon decreasing of quartz as a raw impurity, pozzolanic reactivity

Table: 2 Physiochemical details of cement, WPS and DWPS

Description	%age by weight of Cement	%age by weight of WPS	%age by weight of DWPS
SiO_2	20.78	33.54	40.45
Al_2O_3	5.11	5.54	9.20
CaO	60.89	12.82	25.69
MgO	3	2.14	2.57
Fe_2O	3.17	2.74	2.69
K_2O	--	0.75	0.98
Na_2O	--	1.40	1.39
SO_3	--	1.47	1.45
LOI (%)	1.71	10.66	0.78
Specific gravity	3.15	2.14	2.54
Moisture content	--	3.46	1.15
Dry density Kg/m^3	--	690	807

Table: 3 Mineralogical Compositions of WPS and DWPS

Minerals	Composition of WPS by mass (%)	Composition DWPS by mass (%)
Kaolinite	19.50	-
Calcite	36.70	55.40
Quartz	43.80	7.80
Talc	-	27.80
Chlorite	-	9.00

3.3. Thermal Activation (XRD Analysis)

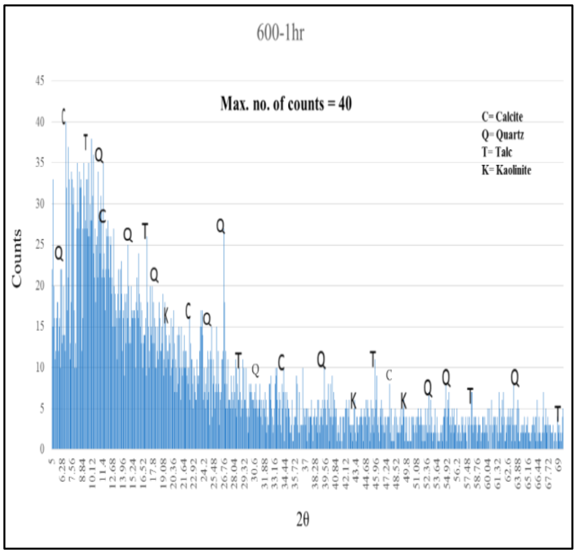

Figure.1 XRD analysis of calcined WPS samples at 600 ^{o}C for 1 hour duration

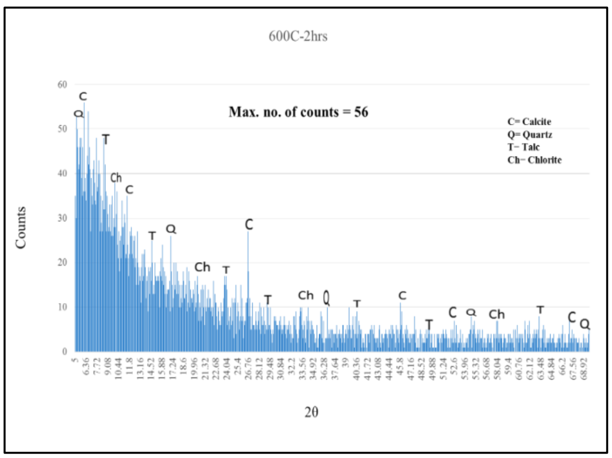

Figure. 2 XRD analysis of calcined WPS sample at 600°C for 2 hour duration

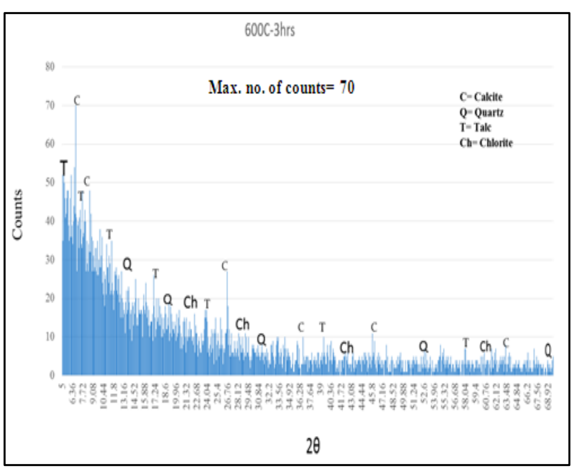

Figure. 3 XRD analysis of calcined WPS samples at 600°C for 3 hour duration

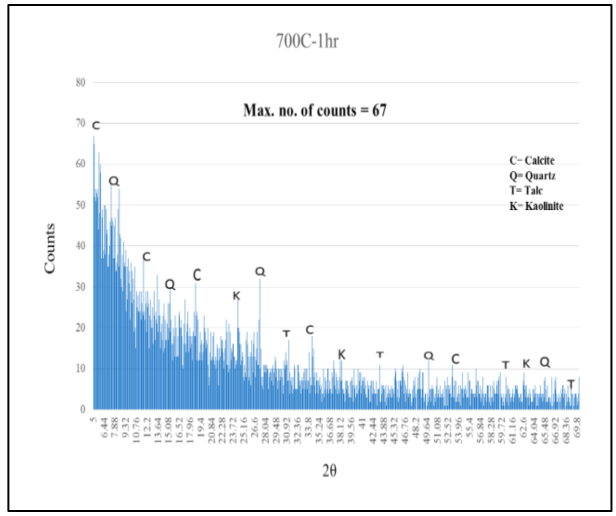

Figure. 4 XRD Analysis of Calcined WPS Samples at 700°C for 1 Hours Duration

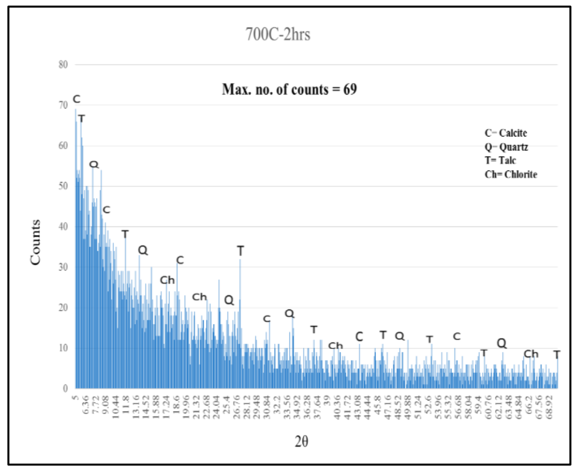

Figure. 5 XRD analysis of calcined WPS at 700 ^{0}C for 2 hours duration

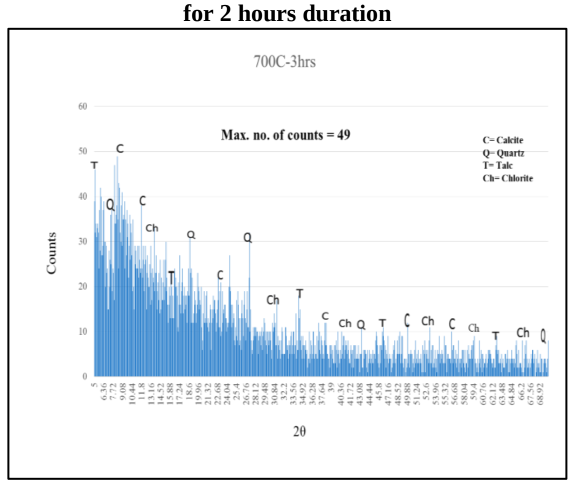

Figure.6 XRD analysis of calcined WPS at 700 ^{0}C for 2 hours duration

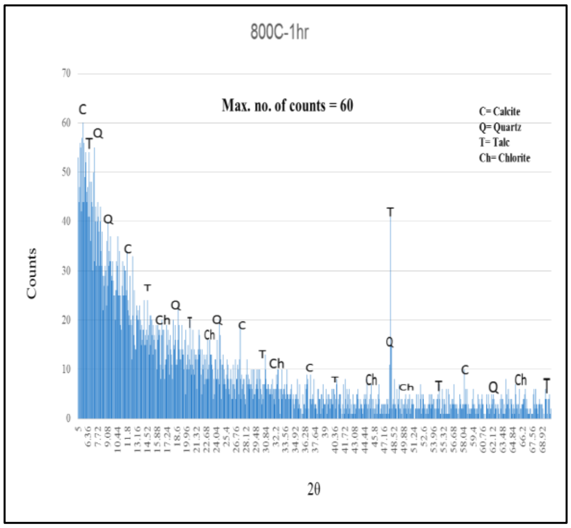

Figure. 7 XRD analysis of calcined WPS at 800°C for 2 hour duration

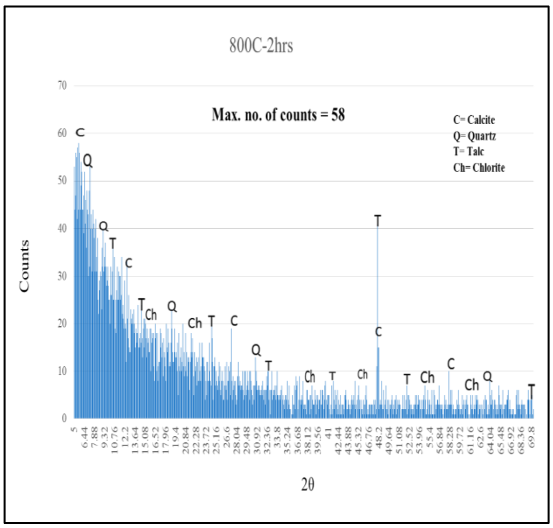

Figure. 8 XRD analysis of calcined WPS at 800°C for 2 hour duration

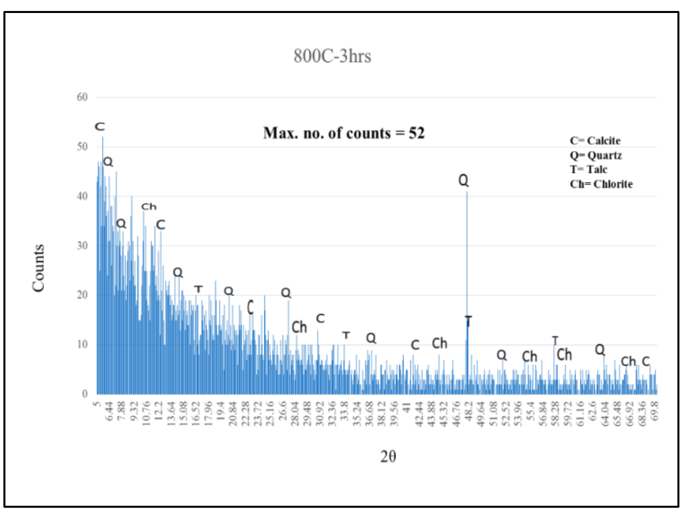

Figure. 9 XRD Analysis of Calcined WPS Samples at 800°C for 3 Hour Duration

he thermal activation of waste paper sludge was carried out in a electric oven at (600, 700 and 800 °C) for1, 2 and 3 hours. The X-Ray diffraction analysis results given in figures 1 to 9 shows the strongest peaks present in calcined waste paper sludge heated at different temperatures and durations. Figure 1, 2 and 3 represents the peak for maximum counts for waste paper sludge heated at 600 ºC for 1, 2 and 3 hours duration. Figure 4, 5 and 6 represents the peak for maximum counts for waste paper sludge heated at 700 ºC for 1, 2 and 3 hours duration. While, figure 7, 8 and 9 represents the peak for maximum counts for waste paper sludge heated at 800 ºC for 1, 2 and 3 hours duration. The presence of considerable silica as major ingredient to contribute pozzolanic activity in treated waste paper sludge is obvious in figure 3. The calcinations of waste paper sludge with 600 ˚C temperature with 3 hours duration demonstrated the peak with maximum number of counts of silica content as illustrated in figure 3.

3.4. Compressive Strength

To examine the pozzolanic activity of calcined waste paper sludge, the compressive strength tests were carried out on mortar specimen prepared with 20% replacement of cement with calcined waste paper sludge. The mortar specimens were tested at 7 and 28 days age as per ASTM C109.

3.4.1. Compressive strength of mortar at 7 days

The relationship of compressive strength at 7 days prepared with 20% substitution of cement by inclusion of different prepared calcined waste paper sludge is apparent in figure 10. Results captured in Figure 10 shows that, mix E has maximum compressive strength of mortar, mix E has been prepared with 20% replacement of cement with calcined waste paper sludge treated at 6000 C for 3 hour duration.

3.4.2. Compressive strength of mortar at 28 days

Figure 11 depict the relationship compressive strength at 28days prepared with 20% substitution of cement by inclusion of different prepared calcined waste paper sludge. It is clear from Figure 11 that, mix E has maximum compressive strength of mortar and mix E has been prepared with the 20% replacement of cement with treated waste paper sludge heated at 600 0C for 3 hour duration.

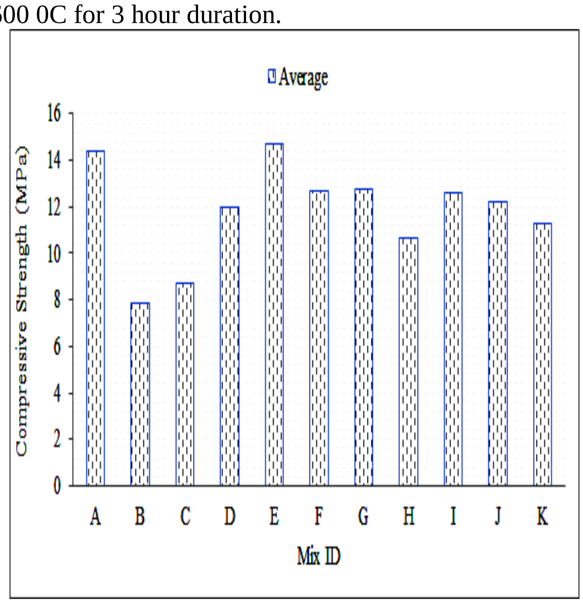

Fig.10 Compressive strength of mortar specimen at 7days curing

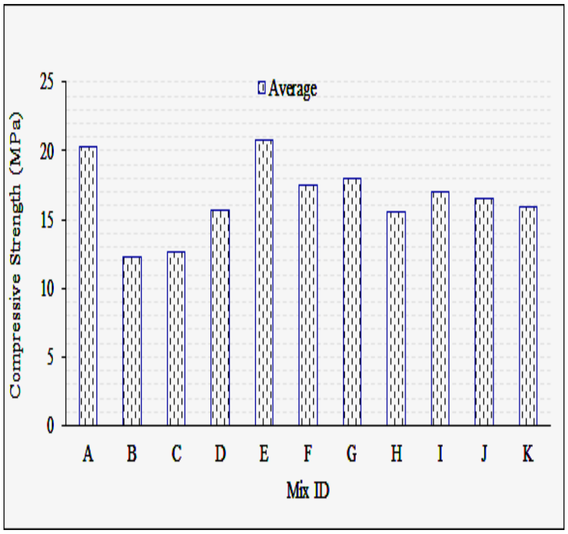

Fig. 11 Compressive Strength of mortar at 28 days curing

3.5. Strength Activity Index (SAI)

SAI is the accurate and effective test to evaluate reactivity of any pozzolanic material and strength activity index test classify the actual contribution of pozzolanic outcome [14]. The relationship of SAI at 7 and 28 prepared with 20% substitution of cement by inclusion of different prepared calcined waste paper sludge is presented in figure12.

The maximum SAI observed as 102 % in E-mixture and E-mixture is produced with 20% substitution of cement by treated waste paper sludge at 600 0C for 3 hour duration. The attained maximum SAI (%) at substitution of cement by treated waste paper sludge at 600 0C for 3 hour duration is 102%, which is above the requirement of SAI (i.e 75%), as per ASTM C 618 to be utilized as pozzolanic/partial cement substitution material in concrete.

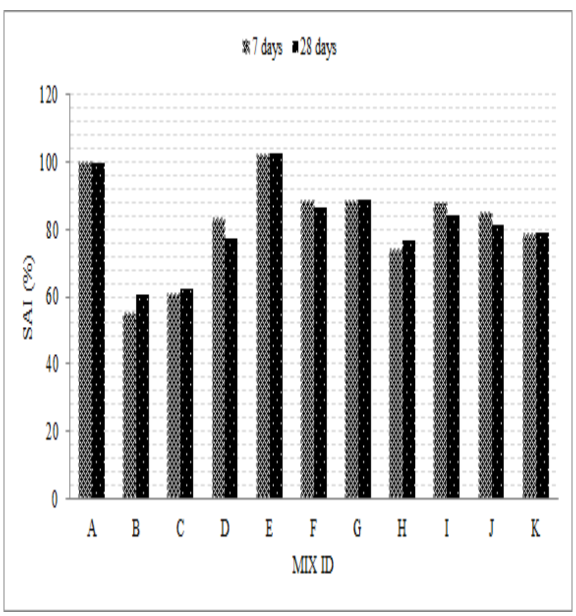

Fig. 12 SAI at 7 and 28 days curing

4. CONCLUSION

On the basis of conducted research study the conclusions can be drawn as:

- The major chemical compounds present in waste paper sludge (WPS) and developed waste paper sludge (DWPS) samples were SiO_2, Al_2O_3, CaO and Fe_2O_3. The composition of SiO_2, Al_2O_3 and CaO in DWPS was 21%, 66%, and 100% increased as compared to the composition of WPS samples except Fe_2O_3, which was slightly reduced.
- The quantity of quartz in DWPS was decreased by 82%, which is positive sign for the pozzolanic materials.
- The XRD investigation of produced waste paper sludge at 600 ˚C for 3 hours duration demonstrated the peak with maximum number of counts of silica and observed satisfactory as pozzolanic material.
- The strength activity index of the MIX ID E, which was calcined at 600°C for 3 hours heating duration showed 102.22% and 102.71% higher value than control mix at 7 days and 28 days curing period respectively.
- It can be concluded that the produced waste paper sludge (calcined at temperature 600 °C with heating duration 3 hours) collected from a Pulp and Paper Industries located in Kotri, near district Hyderabad, Sindh, may be utilized as pozzalans in mortar/concrete.

5. ACKNOWLEDGEMENT

The authors express their thanks to Paper Industries @ Kotri and Civil Engineering Department QUEST, Nawabshah, for necessary support.

REFERENCES

1 V.Sivasundaram , V. M. Malhotra, *High- performance high-volume fly ash concrete*, Indian concrete journal, 78 (2004), 13-21.

2 I.Janotka, F. Puertas, M. Palacios, M. Kuliffayová, C. Varga, *Metakaolin sand–blended-cement pastes: Rheology, hydration process and mechanical properties*. Construction and BuildingMaterials, 24(5) (2010), 791-802.

3 A. O. Ajayi, A. Y. Atta, B. O. Aderemi, S. S. Adefila, *Novel Method of Metakaolin Dealumination-Preliminary investigation*. Journal of Applied Sciences Research, 6(10), (2010), 1539-1546.

4 V. Ferrándiz-Mas, T. Bond, E. García-Alcocel, C. R. Cheeseman, *Lightweight mortars containing expanded polystyrene and paper sludge ash*. Construction and Building Materials, 61(2014), 285-292.

5 R.Sirinivasan, K. Sathiya, M. Palanisamy, *Experimental investigation in developing low cost concrete from paper industry waste.* Buletin ulIn stitutului Politehnic din lasi. SectiaConstructii, Arhitectura, 56(1) (2010), 43.

6 S. D Nagrale, H.Hajare, P. R. Modak,*Utilization of rice husk ash*. Carbon, 2(2012), 6-42.

7 M.S. Imbabi, C. Carrigan, S. McKenna, *Trends and developments in green cement and concrete technology*. International Journal of Sustainable Built Environment, 1 (2012), 194-216.

8 S. Donatello, M.Tyrer, C.R. Cheeseman, *Comparison of test methods to assess pozzolanic activity*. Cement and Concrete Composites, 32(2) (2010), 121-127.

9 A. Saand, M.A. Keerio, D.K. Bangwar, M.K. Samo, *Development of Metakaolin as a Pozzolanic material from Local Natural Material, Soorh,* accepted in Arabian journal of science and engineering DOI:10.1007/s13369-016-2216-1.

10 A. Saand, D.K. Bangwar, M.A. Keerio, *Devlopment of rice husk ash polymer modified concrete*, Advance research material, 1129 (2015), 500-505.

11 R. Fernández, B. Nebreda, R.V. De la Villa, R. García, M. Frías *Mineralogical and chemical evolution of hydrated phases in the pozzolanic reaction of calcined paper sludge*. Cement and Concrete Composites, 32(10) (2010), 775-782.

12 M. Frías *et al*, *Thermal activation of a paper waste as pozzolan for the manufacture of cements*., 1st Spanish National Conference on Advances in Materials Recycling and Eco – Energy, Madrid, (2009), 209-212.

13 R.García, R.V. de la Villa, I.Vegas, M.Frías, M.S. de Rojas, *The pozzolanic properties of paper sludge waste*. Construction and Building Materials, 22(7) (2008), 1484-1490.

14 A .Tironi, M.A .Trezza, A.N. Scian, E.F Irassar, *Assessment of pozzolanic activity of different calcined clays*. Cement & Concrete Composites, Vol.37, pp 319–327(2013).