An Experimental Study on Properties of Concrete by Partial Replacement of Cement with Cement Kiln Dust and Fine Aggregate with Dune Sand

Chiranjeevi Rahul Rollakanti, Kiran Kumar Poloju, Dr Ram Kishore Manchiryal, Ali Maher Abdul Sattar Abo Khomrah

Abstract— **Million tons of solid waste is being produced every year from various domestic and industrial activities in the Sultanate of Oman. Consequently, solid waste management has become one of the major challenges and environmental concern. Moreover, recent advancements and industrialization promoted the generation of various wastes such as municipal solid waste, e-wastes, industry waste etc. Scientific and sustainable recycling of industry byproducts as ingredients of concrete may protect environment and reduces the cost of construction. Cement Kiln Dust (CKD) is one of the byproducts of cement manufacturing process. In this study, an attempt was made to study the effect of CKD and Dune Sand (DS) on mechanical properties of M25 (1:1:2) grade of concrete. Experimental investigation was carried out to determine density, workability and compressive strength when Ordinary Portland Cement (OPC) is partially replaced with CKD varying from 0% to 50% with interval of 10%. In addition to this, Fine Aggregate (FA) was replaced with 20% of DS as constant. A standard water-cement ratio of 0.55 is maintained among all concrete mixes and tested at the age of 7 and 28 days. From the experimental results, it was noticed that replacement of CKD with OPC up to 30% and 20% of dune sand with fine aggregate has attained reasonable target strength of OPC concrete**

Index Terms— **Industry Waste, Alternative Materials, Cement Kiln Dust, Ordinary Portland Cement, Dune Sand, Workability, Compressive Strength**

I. INTRODUCTION

The conventional waste disposal method in the sultanate of Oman is landfilling. The process of dumping wastes at various authorised and unauthorized yards creates environmental concerns and health hazards [1]. During this decade, the amount of waste generating from private sectors such as commercial centers and Industries has been rapidly increasing [2]. The study states that 40% of the solid wastes are comprised of recyclable materials and recommended the utilization of recyclable wastes which in turn reduces the disposal of solid wastes in existing landfills. Therefore, recent investigations related to construction industry are majorly focused on usage of industry by products as fully or partially replacing any of the constituents of the concrete such as cement, fine aggregate and coarse aggregate [3]. This practice may save energy, environment as well as conserves economical and natural resources of Oman. The Ordinary Portland Cement (OPC) is among the most important construction material throughout the world due to its usage in construction of many structures especially with concrete. Cement is a type of material consists of calcium, silicon, Aluminum, iron and other ingredients which binds other constituents of concrete [4]. The Cement is the major ingredient of concrete and the manufacturing process of cements has several environmental and social impacts. Cement Industry emits huge amount such as 900kg of carbon dioxide is emitted during the production of every ton of cement [5]. In addition to this there is another by product of cement manufacturing process, Cement Kiln Dust (CKD). It looks like a fine powder similar to Portland Cement. It consists of very small micron particles which are residue of electrostatic precipitators collected at the production area of cement clinker [6]. Kiln dust can be from dust collection system which can be recycled or else discarded. The particles exist in CKD consists high amount of limestone as main component and lesser portion of quartz with calcium sulfate, sodium chloride, potassium Sulphate etc. [7]. The chemical composition of CKD is similar to OPC and contains notable amount of alkalies, therefore CKD is potential for recycling or reusing in several ways [8]. However, the significant and common ways of reusing CKD are waste treatment plants, to stabilize weak or poor soil, asphalt pavement and especially as replacement of cement. From a study it was noticed that a medium scale cement manufacturing plant produces CKD up to 30,000 tons annually and most of that is disposed off without any further action [9]. Another study investigated the effect of CKD on compressive strength and corrosion resistance of concrete have reported a noticeable positive effect when 5% of CKD was replaced by weight of cement [10] [11]. Fine aggregate (sand) is the another major component of concrete mixes. Sand formed from natural deposits of gravel or crushed rocks can be considered as a suitable material in the production of concrete. Sand is generally used along with coarse aggregate in the production of concrete and only sand can be used with cement to prepare mortar which is used in masonry and plastering works [12]. A comparative study was done on strength properties of conventional sand mortar mix and dune sand mortar mix at various water cement ratios of 0.40, 0.45 and 0.50. The results of the study notified lower strength upon addition of dune sand. However, positive effect on strength was observed by the adding 1% of additive plasticizer [13]. Various other studies were focused on the comparison of beach sand, dune sand, wadi sand etc. at respective combinations resulted in stating that replacement of dune sand under 60% with actual fine aggregate may be used as an alternative material in concrete [14] [15].

II. RESEARCH SIGNIFICANCE

Research on CKD and DS was very limited and minimal research works were published on the usage of these in

concrete and mortar mixtures. The demand and interest has been increasing towards the usage of industry waste [16] as alternative materials in construction in order to protect environment and concerns related to disposal at landfills [17]. The rapid growth of construction and industrialization in Oman led to manufacturing huge amount of cement and as a result million tons of CKD is also produced and unused [18]. Additionally, sand from river basins, wadis or any other natural deposits is majorly considered ideal to be used in construction works, but very natural fine sand is abundantly available throughout many desert regions. Almost one fourth of the Oman is covered by naturally formed fine dune sand, but as it doesn't meet standard requirements of being used in construction activities [19]. Research on the usage of dune sand as a constituent of concrete is limited and these is no provision of standard guidelines towards the usage of dune sand in concrete or mortar [20]. In this study, attempt was to make to study the effect of using CKD and DS on workability and compressive strength characteristics of concrete.

III. MATERIALS USED

Various materials used for this study and collection process was discussed in this section.

A. Ordinary Portland Cement

OPC manufactured by Oman Cement Company SAOG (OCC) of 53 grade was used for the experimental study. Cement properties such as initial and final setting time, fineness and specific gravity are determined through respective tests.

TABLE 1.
PROPERTIES OF ORDINARY PORTLAND CEMENT

Property	Test result
Initial Setting Time	42 minutes
Final Setting Time	390 minutes
Fineness of Cement	4.3%
Specific Gravity	3.12

B. Cement Kiln Fust

This material was collected from OCC manufacturing plant located at Al Misfah, Muscat. The left over residue of CKD, which was disposed on site and not returned back to then kiln, was gathered and used for this study.

Figure 1. CKD powder collected from OCC manufacturing plant

TABLE 2.
PROPERTIES OF CEMENT KILN DUST

Property	Test result
Specific Gravity	2.72
Fineness of CKD	5.6%

C. Dune Sand

The dune sand used in the preparation of concrete was collected from the Wahiba Sands, a desert region near to Al Mintirib and alter transported to MEC labs for further experimentation process.

TABLE 3.
PROPERTIES OF DUNE SAND (WAHIBA SANDS)

Property	Test result
Specific Gravity	2.61
Fineness Modulus	0.72

D. Fine Aggregate

Normal sand used in this experimental study was from Zone 2. The sand is naturally formed gravel that is locally available in the area around Al Khoud. The sample was collected and sieved using mechanical sieve shaker available in MEC lab. Sand passed through 4.75mm was collected and utilized for concrete mixing.

TABLE 4.
PROPERTIES OF FINE AGGREGATE (AL KHOUD REGION)

Property	Test result
Specific Gravity	2.66
Bulking of Sand	13.8%
Fineness modulus	3.12
Bulk Density	1584.6 Kg/m^3
Percentage Voids	28.45%

E. Coarse Aggregate

Coarse aggregate size ranging from 12 mm to 20 mm was considered for this study. The sample used in this extermination process was collected from MEC lab and sieved appropriately.

F. Water

Water collected from MEC lab itself and water was found to be pure through visual inspection and does not have any colour or organic manner present in it.

F. Additive Super Plasticizer

Conplast SP430, 0.5% of cement weight was used in this study to enhance the workability of concrete mixes.

IV. METHODOLOGY

This investigation study was to determine the possible effect of CKD and DS on concrete properties. Six types of M25 grade concrete mixes with replacement of 0%, 10%, 20%, 30%, 40% and 50% of CKD with OPC being 20% of Dune Sand as constant, which is replaced with Fine Aggregate. Six cubes of each proportion were casted using moulds of size 150mmx150mmx150mm and cured. Three cubes were tested on seventh and another three were tasted on 28th day

respectively. Respective experiments were conducted to determine workability, Density and Compressive Strength and compared against results of conventional concrete.

TABLE 5.
CONCRETE MIX DETAILS WITH CKD AND DS

MIX	Cement (%)	CKD (%)	Normal Sand (%)	Dune Sand (%)
CKD_0	100%	0%	100%	0%
CKD_1	90%	10%	80%	20%
CKD_2	80%	20%	80%	20%
CKD_3	70%	30%	80%	20%
CKD_4	60%	40%	80%	20%
CKD_5	50%	50%	80%	20%

V. RESULTS AND DISCUSSION

A. Slump and Unit Weight

Figure 2 displays the variation of slump height in mm and unit weight at 7 days and 28 days for fresh concrete mixes CKD_0 to CKD_5. Results obtained were summarized in the Table 6 with a constant water cement ratio of 0.55. It is noticeable that slump was gradually increased with increase in the percentage of CKD; however, the presence of sand dune content due to its spherical shape increased the slump value when compared to conventional concrete. Figure 3 exhibits the average unit weights of concrete mixes and it is observed that at the age of 28 days, the unit weight is gradually decreased with increase in the percentage of CKD and dune sand being constant.

TABLE 6.
VALUES OF SLUMP HEIGHT AND UNIT WEIGHT

Mix	Slump (mm)	Average Unit Weight (Kg/m^3)	
		7 days	28 days
CKD_0	135	2463.20	2522.16
CKD_1	120	2477.66	2482.60
CKD_2	105	2465.83	2494.33
CKD_3	96	2460.26	2483.96
CKD_4	85	2490.26	2492.63
CKD_5	82	2451.46	2447.30

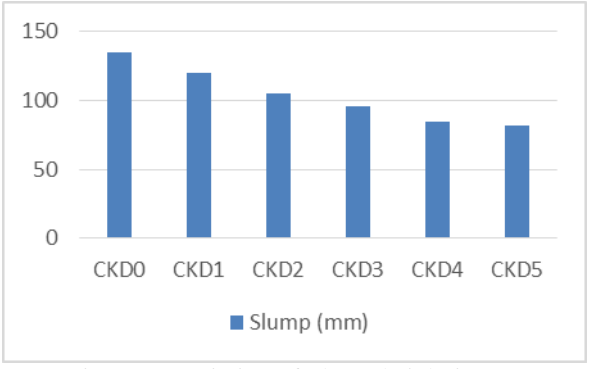

Figure 2. Variation of Slump height in mm

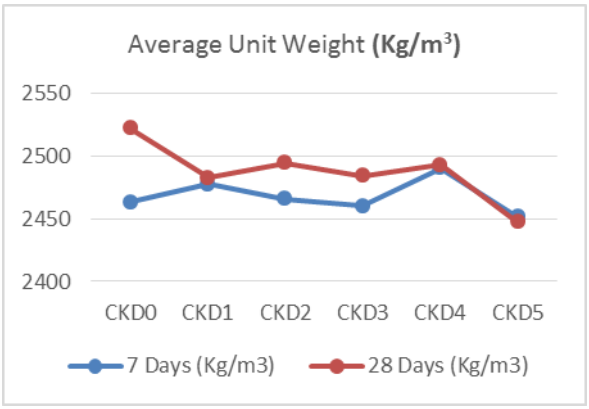

Figure 3. Average Unit Weight of all mixes at 7 and 28 days

B. Compressive Strength

The six concrete specimens were tested for each mix proportion and maximum load; compressive strength and average compression strength at 7 days and 28 days were represented through tabular forms and discussed below.

TABLE 7.
RESULTS OF COMPRESSIVE STRENGTH TEST AT 0% CKD AND 0% DS (CKD_0)

Sample	Age (days)	Maximum Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
1	7	602.100	26.76	26.68
2		625.500	27.8	
3		573.300	25.48	
4	28	802.575	35.67	35.70
5		813.600	36.16	
6		793.800	35.28	

The compressive strength properties of conventional concrete mix were analysed and presented in the Table 7. From the results, it is observed that compressive strength of three samples tested after 7 days are curing are 26.76, 27.8 and 25.48 Mpa and the average strength is found to be 26.68 Mpa. The same mix of concrete cubes tested after 28 days have resulted in compressive strength of 35.67, 36.16 and 35.28 Mpa respectively and the average compressive strength was 35.70 Mpa. The maximum load at 7 days was 625.500 KN and 813.600 KN was observed at 14 days.

TABLE 8.
RESULTS OF COMPRESSIVE STRENGTH TEST AT 10% CKD AND 20% DS (CKD_1)

Sample	Age (days)	Maximum Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
1	7	587.700	26.12	26.48
2		615.825	27.37	
3		583.650	25.94	
4	28	791.550	35.18	35.17
5		803.025	35.69	

6		779.625	34.65	

Compressive test results of concrete mix with 10% of CKD and constant value of 20% DS are presented in the Table 8. Compressive strength at 7 days were observed as 26.12, 27.37 and 25.94 Mpa with an average value of 26.48 Mpa and at 28 days the strength of three samples of the respective mix are 35.18, 35.69 and 34.65 Mpa and average compressive strength being 35.17 which is almost near to the concrete mix without CKD and DS. No much significant decrease in the compressive strength was observed between CKD_0 and CKD_1. The performance of concrete mixes consisting of 10% CKD and 20% DS were almost near.

TABLE 9.
RESULTS OF COMPRESSIVE STRENGTH TEST AT 20% CKD AND 20% DS (CKD_2)

Sample	Age (days)	Maximum Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
1	7	559.575	24.87	24.96
2		571.050	25.38	
3		554.400	24.64	
4	28	763.875	33.95	33.35
5		752.850	33.46	
6		734.625	32.65	

Compressive strength results from Table 9 exhibits a slight decrease in the values when compared to conventional strength but not less than the characteristic strength of the M25 grade. At 7 days the maximum load resisted by the specimen was 571.050 KN, followed by strength values of 24.87, 25.38 and 24.64 with an average strength of 24.96 Mpa. The maximum load at 28 days was observed to be 763.875 KN and compressive strength values were 33.95, 33.46 and 32.65 Mpa respectively and the average compressive strength was 33.35 Mpa.

TABLE 10.
RESULTS OF COMPRESSIVE STRENGTH TEST AT 30% CKD AND 20% DS (CKD_3)

Sample	Age (days)	Maximum Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
1	7	498.150	22.14	22.58
2		536.175	23.83	
3		489.600	21.76	
4	28	708.525	31.49	31.40
5		695.025	30.89	
6		715.950	31.82	

Table 10 represents values of 30% CKD and 20% DS with further more decrease in the compressive strength value with the increase of CKD percentage. The maximum compressive strength was observed to be 23. 83 Mpa and the average strength ay 7 days was 22.58 Mpa which was 12% less than the strength of conventional concrete. The maximum compressive strength at 28 days was 31.82 Mpa and the average strength was 31.40 Mpa which is 15.4% less than conventional strength. The maximum load taken by the specimen at 7 days was 536.175 KN and at 14 days was 715.950 KN. Hence, from this discussion it is notified that the acceptable replacement of CKD can be considered until 30% along with 20% of DS.

TABLE 11.
RESULTS OF COMPRESSIVE STRENGTH TEST AT 40% CKD AND 20% DS (CKD_4)

Sample	Age (days)	Maximum Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
1	7	451.125	20.05	20.61
2		483.525	21.49	
3		456.300	20.28	
4	28	668.700	29.72	29.04
5		638.100	28.36	
6		653.625	29.05	

Compressive strength values at 40% CKD and 20% DS were observed to be drastically decreased and it is observed that increase in percentage of CKD leading to reduction in the compressive strength and also the capacity of the specimen to withstand again the maximum load by the machine. From Table 11, compressive strength values at 7 days were observed as 20.05, 21.49 and 20.28 Mpa and 29.72, 28.36 and 29.05 Mpa at 14 days. Compressive strength at 7 days was reduced by 22.75% and at 14 days was 18.65%. The maximum load values have also been decreased to minimum of 451.125 KN at 7 days and 638.1 KN at 14 days.

TABLE 12.
RESULTS OF COMPRESSIVE STRENGTH TEST AT 50% CKD AND 20% DS (CKD_5)

Sample	Age (days)	Maximum Load (KN)	Compressive Strength (Mpa)	Average Compressive Strength (Mpa)
1	7	419.625	18.65	18.61
2		433.800	19.28	
3		402.525	17.89	
4	28	594.000	26.4	25.93
5		583.200	25.92	
6		573.300	25.48	

This is the final trail mix of this investigation process where as percentage of CKD reached to 50% and replacing OPC and 20% of DS was maintained constant throughout the study. At the age of 7 days, compressive strength was decreased 30.24% and at 14 days it was 27.36% when compared with conventional M25 grade concrete with the available materials. Therefore, the current percentage of replacing CKD was not suggestable.

Over all comparison of compressive strengths varying from 0% of CKD and 0% of DS to 50% CKD and 20% DS has been discussed through the Figure 4.

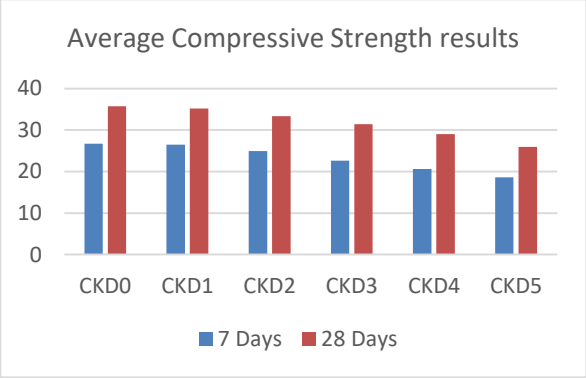

Figure 4. Comparison Of Average Compressive Strength Results Of All Concrete Mixes At 7 And 28 Days

CONCLUSION

The investigation process was majorly focused towards replacement of Cement Kiln Dust with Ordinary Portland Cement at various percentages ranging from 0-50% and Fine Aggregate was replaced by 20% of Dune Sand as constant. According to these percentages of replacements, concrete cubes have been casted at a constant water cement ratio of 0.55 respectively and cured for 7 and 28 days. Later, all these samples of 6 each per trail mix were tested for workability, density and compressive strength. In line with the obtained results of this investigations conclusion were drawn as below:

1. Considering the concrete mixing process of the whole investigation with CKD and Dune Sand, it is noticed that addition of these alternatives consumed more amount of water when compared with mixing process of conventional concrete.
2. The results of the compressive strength at 0% and 10% CKD doesn't have much significant difference. Hence, it is recommended to restrict the percentage of CKD to 10% as replacement of Ordinary Portland Cement and not more than 20% of Dune Sand from all workability, unit weight and compressive strength perspectives.
3. The compressive strength was observed to be decreasing with the increase in percentage of Cement Kiln Dust. The percentage of reduction of compressive strength was from the range between 0.15% to 30.24%.
4. The slump values also decreased with the percentage increase of CKD and a constant 20% of Dune Sand. The range of reduction of slump value is in the range of 11% to 39.25%.
5. The unit weight of the concrete at 7 days and 28 days was also gradually decreasing with the increase in percentage of CKD and this might be due to the presence of Dune Sand material which is very fine and light in nature compared to naturally available fine aggregate.
6. From this experimental study, it can be concluded and recommended that the materials such as Cement Kiln Dust and Dune Sand as alternative materials.

REFERENCES

[1] S. Zafar, "Solid Waste Management in Oman" EcoMENA, 2020 [Online]. Available: https://www.ecomena.org/solid-waste-oman [Accessed: 02- Jul- 2020].

[2] Alaa El-Zawahry, Abulbasher M. Shahalam, Ramzi Taha and Turki Al-Busaidi "An Assessment of Solid Waste and Landfilis in Muscat Area, Oman". Science and Technology, 6 (2001) 1-11.

[3] V, Mahesh, Hemalatha C, Vani A, & Sreenivasulu Dandagala "Evaluation of admixture effect on strength and durability properties of concrete - a critical review." International Journal of Engineering & Technology [Online], 7.2.1 (2018):28-31.

[4] V. Ramachandran and R. Feldman "Concrete Admixtures Handbook", Concrete Science 1996, pp. 1-66,

[5] Natesan Mahasenan, Steve Smith and Kenneth Humphreys "The Cement Industry and Global Climate Change: Current and Potential Future Cement Industry CO2 Emissions". Greenhouse Gas Control Technologies – 6th International Conference, ISBN 978-0-08-044276-1 - Volume II, 2003, Pages 995-1000.

[6] Siddique R "Cement Kiln Dust". Waste Materials and By-Products in Concrete, 2008. pp 351-380. Springer, Berlin, Heidelberg.

[7] Batis G, Rakanta E, Sideri E, Chaniotakis E, Papageorgiou A "Advantages of simultaneous use of cement kiln dust and blast furnace slag". Challenges of Concrete Construction: Volume 5, Sustainable Concrete Construction, July 07, 2015.

[8] Shoaib MM, Balaha MM, Abdel-Rahman AG "Influence of cement kiln dust substitution on the mechanical properties of concrete". Cement and Concrete Research - 2000, Volume 30 (3): 371–337.

[9] Bhatty JI. "Alternative uses of cement kiln dust". Skokie, Illinois, USA: RP327 Portland Cement Association, 1995.

[10] El Sayed, H.A., Gabr, N.A., Hanafi, S., Mohran, M.A "Reutilization of by-pass kiln dust in cement manufacture". International Conference on Blended Cement in Construction, Sheffield, UK, September 1991.

[11] Batis, G., Rakanta, E., Sideri, E., Chaniotakis, E., Papageorgiou, A "Advantages of simultaneous use of cement kiln dust and blast furnace slag". International Conference on Challenges of Concrete Construction, University of Dundee, Dundee, UK, September 2002.

[12] Banfill P, Carr M "The properties of concrete made with very fine sand". Concrete 1987(3):11–6.

[13] Guettala A, Melkmi S, Tibermacine N. "A study of mechanical characteristics for sand concrete", 7th Arab structural engineering conference, Nov 1997, Kuwait, 24–26.

[14] Kay A, Frearson J. "An investigation into the use of dune sand in concrete." Engineering characteristics of arid soils. Rotterdam: Ballkema; 1994.

[15] Laquerbe M, Cisse I, Ahouansou G. Pour "Utilization rationelle des gravelleux lateriques et des sables de dunes comme ganulats abeton application au cas du Senegal". Mater Structures 1995; 28:604–10.

[16] Chiranjeevi Rahul Rollakanti, Dr. C.Venkata Siva Rama Prasad, Satyanarayana.P.V.V and M. Pavan Kumar "Experimental Investigations and Cost Effectiveness of Preformed Foam Cellular Concrete Blocks in Construction Industry". Journal of Xi'an University of Architecture & Technology, Volume XII, Issue IV, 2020, ISSN No: 1006-7930.

[17] Kiran Kumar Poloju, Dr. Ram Kishore Manchiryal and Chiranjeevi Rahul R "Development of sustainable concrete by using paper industry waste". Elixir Civil Engg. 102 44152 (2017) 44152-44154.
[18] Al-Barami, B.S. "Solid Waste Management in Muscat Area", Final year Project - 1999, Department of Civil Engineering, Sultan Qaboos University, Oman.
[19] Al-Harthy, A. S., Halim, M. A., Taha, R., & Al-Jabri, K. S. "The properties of concrete made with fine dune sand". Construction and Building Materials, 2007. 21(8), 1803-1808.
[20] Al-Harthy, A. S., Taha, R., & Al-Maamary, F. "Effect of cement kiln dust (CKD) on mortar and concrete mixtures". Construction and Building Materials 2003, 17(5), 353-360