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Optimizing Cement Kiln Dust Density to Improve Landfill Air Space Utilization

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Original scientific paper

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Abstract

Optimizing the density of waste materials in landfills by proper compaction prolongs the facility life due to the efficient use of landfill airspace. Cement kiln dust (CKD) is a waste by-product produced in huge amounts which exceeds the used quantities in the cement recycling industry and beneficial CKD applications. The vast amount of CKD is almost landfilled in its loose state in Egypt which causes a big loss in landfill airspace due to the low density of CKD. The hydraulic binder effect and dusty behavior of reactive CKD complicates its compaction process. Accordingly, this research was performed to investigate CKD compaction properties with three types of lubricants, which are potable water, salt water and waste oil. Maximum dry density (MDD) and optimum moisture content (OMC) for these lubricant types and different wetting methods were investigated in order to improve the landfill air space utilization and to reduce the dusty effect of CKD during compaction. The effect of immediate compaction after wetting and the effect of compaction delay by allowing CKD to hydrate initially for a certain period were studied. Compaction energy and methods of the wetting of CKD either by full submergence in water or prewetting were tested. The maximum weights of a disposed CKD and durations required to fill an intended landfill air space for different CKD conditions, lubricant types and compaction methods were presented for a case study in Ain Sokhna, Egypt.

Keywords:

landfills; compaction; waste management; disposal; environment; solid waste

1. Introduction

Landfill airspace is considered as the volume permitted for the disposal of waste materials. Efficient use of landfill airspace depends on the biggest amount of waste which could be placed in this volume. A landfill's performance can be monitored in regard to airspace utilization by periodically quantifying how much airspace is being consumed related to the inbound waste tonnage. Airspace utilization factor (AUF) means the effective density of waste material in the landfill. The AUF is recorded as the total tons of waste received divided by the total volume of landfill airspace consumed during the same time (**Cline et al., 2020; Hanson et al., 2021; Kieckhäfer et al., 2017**). Cement kiln dust (CKD) is a fine cementitious powder produced in massive amounts as a by-product during cement manufacturing. Unsafe disposal of CKD in Egypt causes it to spread on land and in the atmosphere causing pollution problems and health hazards due to its tiny particle size, alkalinity and other environmental hazards (**Wang et al., 2022**). Many studies were performed to find economical and efficient ways for using CKD in various beneficial applications such as: soil stabilization, concrete mixes, roads, pavements, bricks, and others (**Abdel-Gawwad et al., 2021; Hanein et al., 2020; Lake et al., 2019**). However, there are still large amounts of this waste product that aren't consumed yet in these applications or recycled in industry. This could be attributed to transportation costs, high alkaline ratio in CKD and negative impacts on the environment, hence the need for safe and economic landfill disposal of CKD is still highly required till the whole of CKD is consumed in beneficial uses (**Beltagui et al., 2018a**).

CKD is a loose dusty material of a density equal to 4.8 kN/m^3. It is transferred from factory to disposal areas in closed tanks like water tanks, and this type of waste transport is considered expensive and hazardous (**Alzahrani, 2022**). CKD is classified by the U.S. Environmental Protection Agency (**US EPA, 1997**) as a "special waste". Its dry density was tested for landfills, and it reached a range between 35-65 lbs/ft^3 (i.e. 5.5-10.2 kN/

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m^3). When CKD is discharged and accumulated in its loose density, it results in a big loss of landfill air space (**Lanzerstorfer, 2016**). The price of landfill areas in Egypt is very expensive, so it is necessary to find the best way to use the landfill airspace. Recently, Al-Arabia for Cement (AAC) a cement factory in the Ain Sokhna zone in Egypt intends to use a series of landfills to bury this powder and to minimize its environmental hazards. The proposed landfills are a deep excavated land behind the AAC factory, and they consist of continuous impermeable limestone rock layers. Economic burial of CKD requires compaction in special procedures and optimum moisture content to save landfill airspace as much as possible. High density of compacted landfill will enhance the bearing properties of the compacted materials and will increase its California Bearing Ratio (CBR) and shear strength values (**Sarmah et al., 2021**). The compaction process should take into consideration the reactive behavior of CKD with water. There is a lack of studies concerning the compaction behavior of CKD with different lubricants, and the values of maximum dry densities and required optimum moisture content which could be used (**Beltagui et al., 2018b; Jo and Jang, 2021; Qarahasanlou et al., 2022**).

Therefore, in this study an experimental program was performed to investigate the maximum density of compacted CKD which could be reached using compaction tests. The compaction process is done using different percentages of different lubricants already available in the factory, such as potable water or saltwater (**Ying et al., 2021**) or by using waste oil from machines and trucks in the factory service station. Saltwater is pumped out from deep wells already drilled in the factory and, accordingly, it is not as costly as potable water which is transmitted to the factory through governmental pipes. These lubricants are highly important in the compaction process, not only to increase the density when acting as a lubricant, but to decrease the dusty behavior of CKD when subjected to compaction energy, as CKD flies everywhere with any motion, much like coal dust (**Moradi et al., 2020; Shah et al., 2020**). Since CKD reacts with water and undergoes a continuous chemical reaction during hydration, much like cement, another procedure was studied in the research to specify whether it is more favorable to compact CKD before or after it hydrates (**Czapik et al., 2020**). So, it was suggested in the research to delay the compaction process (**Nazari et al., 2021**) with a certain period and allow CKD to be hydrated by two methods:

- First, by soaking it in a big quantity of water and leaving it for a certain period, and then compacting it after hydration and drying. This process is named the full submerged process.
- Second, by wetting it partially as is done with cement and leaving it till the hydration reaction reaches its initial set and then it's crushed by compaction force and compacted.

Waste oil doesn't react with CKD and it only acts as a lubricant in the compaction process. Hence, the values of the compaction process using potable water and salt water was compared with waste oil. Waste oil is used in this research for comparison purposes to define the hydration effect of potable and salt water, but it also could be used in a landfill as a lubricant to have the benefit of the disposal of two waste materials with the same sustainable landfill air space. Whenever using waste oil in CKD, landfill compaction will require a special technique for CKD spreading and applying. Also, necessary environmental and safety studies according to governmental authority regulations will be required before its use in a landfill.

2. Material properties

The materials used in this study are CKD, potable water, saltwater and waste oil. Cement kiln dust was obtained from the "Al-Arabia for Cement" factory (in the Ain Sokhna zone, Egypt) in a fresh condition from a single production batch to have constant properties and was isolated in a sealed vessel throughout the research period to prevent a reaction to moisture. Materials were stored at a room temperature of about 23ºC to 28ºC. The potable water used was ordinary tap water. Saltwater salinity is 35 parts per thousand of normal table salt composed primarily of sodium chloride (NaCl). Waste oil was collected from used cars' engine oil and used lubricant fluids.

3. Experimental program

The experimental program consists of chemical/physical analyses of CKD and the influence of different variables on MDD of CKD. **Table 1** summarises the variables studied in the experimental program. Four testing groups were performed to study the effect of different factors on CKD compaction. The studied factors are the lubricant fluid type used in mixing with CKD, the compaction energy used in two methods of compaction, the duration of the full submergence of CKD samples in potable water before compaction (soaking duration) and partial prewetting duration of CKD at a definite water content before compaction.

The last two groups study the impact of CKD hydration before compaction to determine the effect of compaction delay on this reactive material. It was observed that a 10% increment of water content was the suitable increment for operating the compaction test on CKD samples. A standard proctor test (SP) was performed according to AASHTO T-99 and a modified proctor test (MP) was performed according to AASHTO T-180 standard. According to AASHTO standards, the energy used in the MP method is higher than that used in the SP method. For the SP test, the compaction energy is set to be 593.7 kJ/m^3, while in the MP test, the compaction energy is set to be 2693.3 kJ/m^3 as the compaction

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Table 1: Experimental testing program

Group No.	Test No.	Study Factor	Lubricant Type	Test Type	Test Duration	Sample Condition
G-1	1-1	Lubricant fluid	Potable water	Standard Proctor	Following the standards requirements	Dry CKD mixed with potable water
	1-2		Saltwater			Dry CKD mixed with saltwater
	1-3		Waste Oil			Dry CKD mixed with used oil
G-2	2-1	Compaction method	Potable water	Standard Proctor	Following the standards requirements	Dry CKD mixed with potable water
	2-2			Modified Proctor		
	2-3		Saltwater	Standard Proctor		Dry CKD mixed with saltwater
	2-4			Modified Proctor		
	2-5		Waste Oil	Standard Proctor		Dry CKD mixed with used oil
	2-6			Modified Proctor		
G-3	3-1	CKD Soaking duration in water for hydration	Potable water	Standard Proctor	Soaking for 1day	Fully submerged CKD in potable water
	3-2				Soaking for 7 days	
	3-3				Soaking for 30 days	
G-4	4-1	CKD Partial pre-wetting duration for hydration	Potable water	Standard Proctor	Pre-wetting and 1 hr. for hydration	Dry CKD mixed with 10% potable water
	4-2				Pre-wetting and 12 hrs. for hydration	
	4-3				Pre-wetting and 24 hrs. for hydration	

Table 2: Chemical composition of CKD

Chemical composition	Silicon Dioxide, SiO_2	Aluminum Oxide, Al_2O_3	Iron Oxide, Fe_2O_3	Calcium Oxide, CaO	Magnesium Oxide, MgO	Sodium Oxide, Na_2O	Potassium Oxide, K_2O	Sulfur Trioxide, SO_3	Loss on Ignition
Percentage	13.857	4.528	2.986	56.909	2.966	1.488	5.515	2.18	2.112

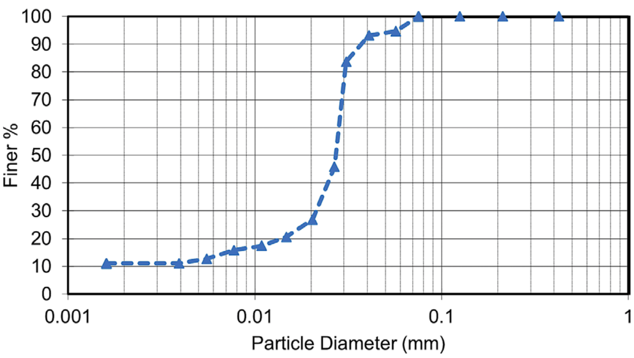

Figure 1: Particle size distribution curve for the CKD sample

weight is heavier and is falling from a higher height than in the SP test.

4. Test results and discussion

Chemical analysis was performed using an XRF test as per ASTM C114. The chemical composition **of a CKD sample in percentage by weight** is presented in **Table 2.** The particle size distribution curve for CKD represents a generally fine material with almost 90% in silt size (0.002 mm > D > 0.06 mm) as shown in **Figure 1**. The specific gravity of CKD is 2.738 based on ASTM D-854-92.

Results of compaction were obtained based on an experimental test program.

4.1 The effect of fluid type (Group 1)

The density of CKD is 4.8 kN/m^3 and when it was compacted initially without any lubricant, it gave MDD

= 9.7 kN/m^3 in the case of the SP test and 12 kN/m^3 in the case of the MP test. The compaction of CKD without lubricant is very difficult as it acts as dust and flies everywhere. Precautions and sealing were done during the test to continue compaction in a better way. So, it's not recommended to compact CKD in site without a lubricant which acts as a sticky material for CKD. Accordingly, the value of zero lubricant percentage wasn't included in **Figures 2** and **3**. **Figure 2** shows the relation between dry density and water content (compaction curve) of a tested CKD sample blended with potable water and a CKD sample blended with saltwater. The obtained MDD and corresponding optimum moisture content (OMC) resulting from the SP test using potable water are 13.19 kN/m^3 and 28.979% respectively and 13.42 kN/m^3 and 30.323% respectively in the SP test using saltwater.

The results show that mixing CKD with saltwater gives a slightly higher value of MDD than mixing with potable water for about the same OMC (~29-30%). This means that the use of salt water available from deep wells or seawater at a lower cost will be more economic in CKD landfills than the use of potable water. **Figure 3** shows the compaction curve of dry density as a function of waste oil content. The achieved MDD and corresponding optimum oil content were 14.91 kN/m^3 and 0.205% respectively. Therefore, using waste oil provided the highest value of MDD and by far the lowest value of optimum fluid content with respect to potable water and seawater. This MDD value exceeds the MDD value obtained in test with potable water by about 13% and exceeds the value obtained in test with saltwater by about 11%.

Applying waste oil in compacting CKD showed very promising results, as it required a very low oil content (0.205%) to obtain an MDD value higher than those obtained using potable water and saltwater respectively. This means that using the waste oil in compacting CKD will yield two benefits:

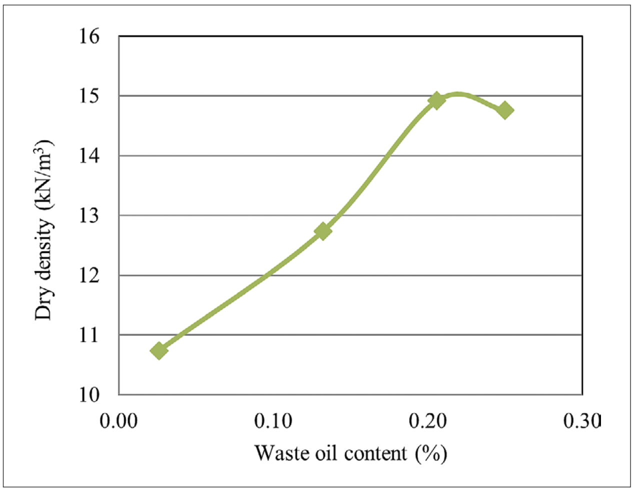

Figure 3: Compaction curve of CKD mixed with waste oil using SP test

1) disposing of two waste materials in one operation which is considered as an environmental benefit,

2) compacting the CKD to a higher density which means less storing volume compared to the volume required in case of using potable water and saltwater. However, the environmental hazards of using waste oil in this process should be considered, namely the using of waste oil will require an impermeable lining for the landfill.

4.2 The impact of the compaction method (Group 2)

The compaction method impact on MDD and OMC is studied in this group. **Figure 4** to **6** presents the compaction behaviour of CKD mixed with different contents of potable water, saltwater and waste oil samples using SP and MP tests respectively.

The results of tests with potable water and saltwater show that MDD is higher and the OMC is lower in the MP test than in the SP test. The optimum oil content in the MP method is higher than optimum oil content in the SP method, as the sample is compacted on five equal layers in the MP method, and in the SP method the sample is compacted on three equal layers, so the required amount of waste oil in the MP method is higher than that in the SP method.

In the MP test using potable water, the MDD increased by about 8.4% compared with the MDD value in the SP test (13.19 kN/m^3 versus 14.30 kN/m^3) and the OMC decreased by about 28.3% compared with the OMC value in the SP test (28.98% versus 20.77%). In the MP test using saltwater, the MDD increased by about 6.9% (13.42 kN/m^3 versus 14.34 kN/m^3) and the OMC decreased by about 9.9% (30.32% versus 27.31%). In the MP test using waste oil, MDD increased by about 6.0% (14.91 kN/m^3 versus 15.80 kN/m^3) and the optimum oil content increased by about 44.9% (0.21% versus 0.30%). The MDD values of CKD obtained using

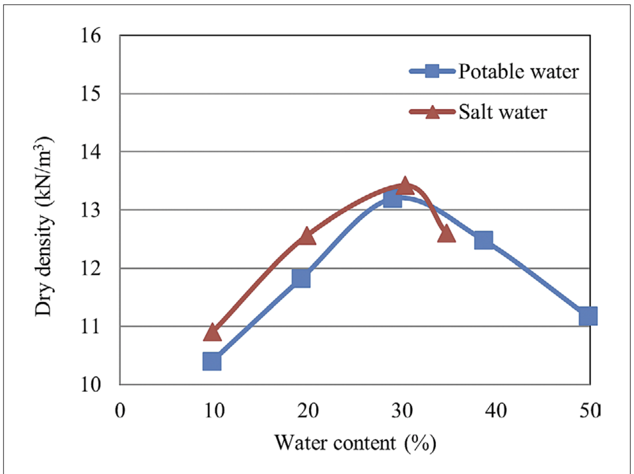

Figure 2: Compaction curve of CKD mixed with potable water and CKD mixed with saltwater using SP test

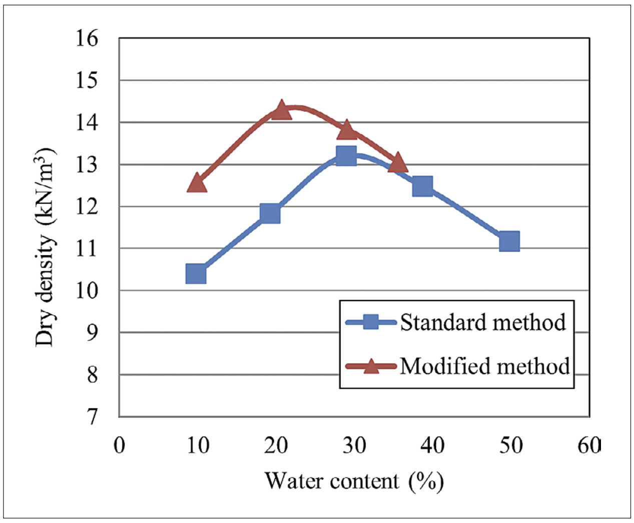

Figure 4: Compaction curves of CKD mixed with potable water using SP and MP tests

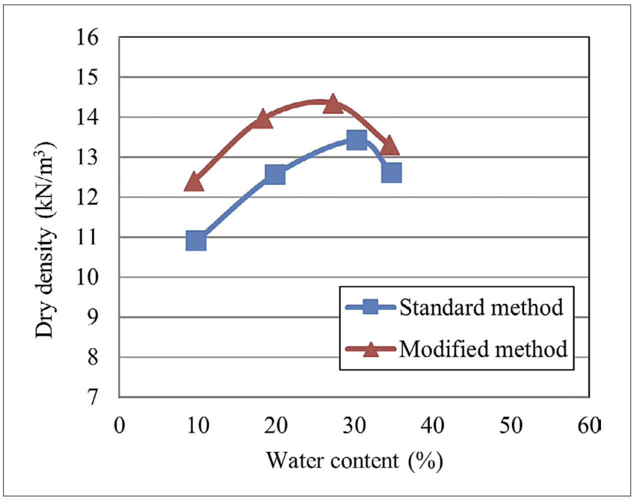

Figure 5: Compaction curves of CKD mixed with saltwater using SP and MP tests

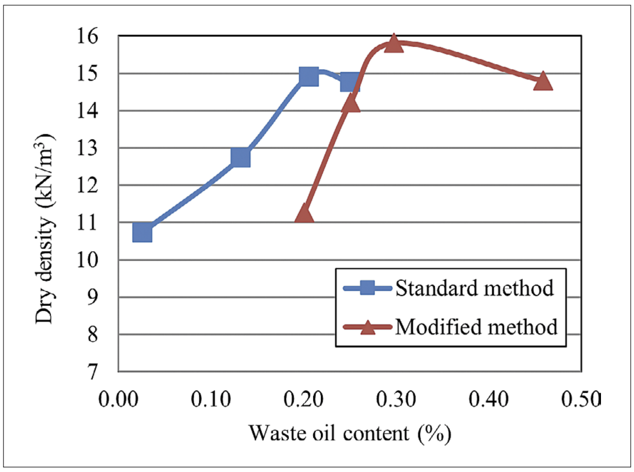

Figure 6: Compaction curves of CKD mixed with waste oil using SP and MP tests

either SP or MP tests are significantly higher than the dry density values of CKD (5.5-10.2 kN/m^3) reported in **US EPA (1997)**.

4.3 The effect of submergence duration on a CKD sample before the compaction process (Group 3)

Potable water was used in this group of tests, while the submergence duration was changed, and the compaction process was delayed. CKD samples were submerged in potable water for 1 day, 7 days and 30 days. After being soaked, samples were oven-dried for 24 hours at 10ºC as shown in **Figure 7**. After drying, samples were crushed and tested in an SP apparatus to get the compaction curves for the three durations with the same procedures adopted previously. The compaction curves are shown in **Figure 8**. The recorded maximum dry densities and corresponding OMC are: 9.88 kN/m^3 and 51.51% in the case of the CKD sample submerged for 1 day; 9.3 kN/m^3 and 49.28% in the case of the CKD sample submerged for 7 days, and 8.76 kN/m^3 and 48.66% in the case of the CKD sample submerged for 30 days.

Figures 9 and **10** show the effect of soaking duration on MDD and OMC respectively. It was noticed that increasing the soaking time results in a decrease in both the MDD and corresponding OMC. However, when comparing the compaction results in the case of CKD compacted using potable water without soaking with the results in the case of soaking, it was observed that soaking the samples for one day resulted in a decrease in the reached MDD by 25.09% and increasing the OMC by about 77.7%. In the case of soaking for seven days, the MDD decreased by 29.49% while the OMC increased by 70.06%. Soaking for thirty days resulted in an MDD decrease by 33.59% and an increase of OMC by 67.91%. This decrease in MDD could be attributed to the hydration effect of CKD. Accordingly, it is not recommended to submerge CKD in water before compaction as the

Figure 7: Sample of CKD after soaking prepared for the drying process in an oven

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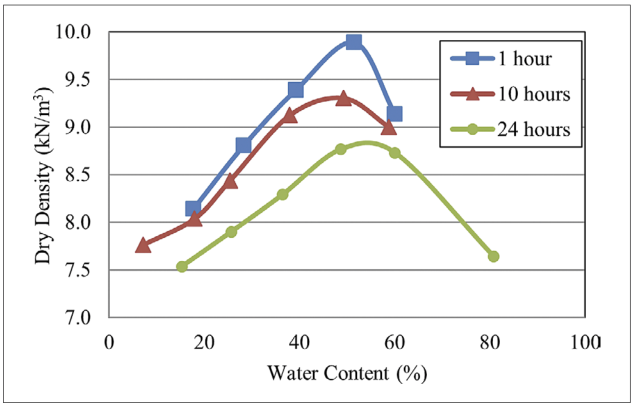

Figure 8: Compaction curves of CKD samples after submergence in potable water for 1 day, 7 days and 30 days

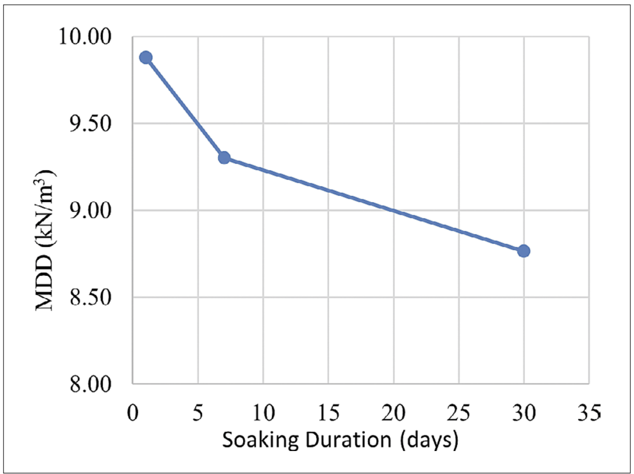

Figure 9: Effect of soaking duration on MDD

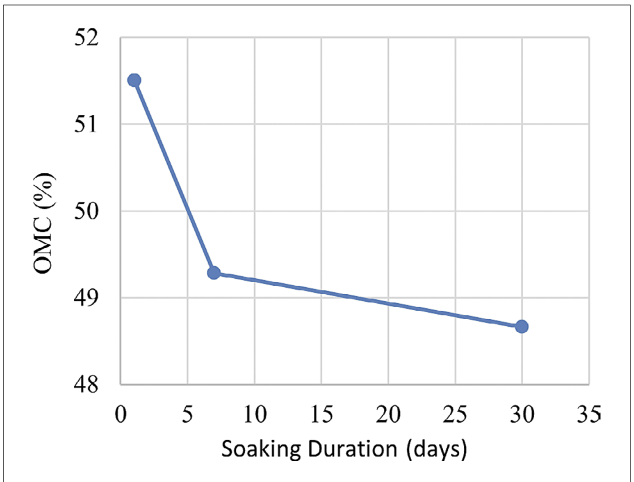

Figure 10: Effect of soaking duration on OMC

achieved density after compaction will be lower causing larger storage volume required to dispose of CKD in a landfill. Furthermore, the large amount of water required for the soaking process will add an extra cost to the total disposal expenses. However, the hydrated CKD is easier for compacting than the loose reactive CKD as the hydration decreases its dusty behaviour during compaction.

4.4 The effect of partial pre-wetting duration on a CKD sample before compaction (Group 4)

The effect of delaying compaction is studied in this group. The samples are wetted with potable water to a certain water content, then it is left for a definite duration to allow a chemical reaction. This chemical reaction causes the initial setting of CKD, then compaction process starts using the SP test procedure. This group is important to study the effect of the prewetting duration of CKD before compaction. Samples were mixed with potable water, at a water content amounting to 10 wt% of the CKD sample, and left for hydration for 1 hour, 10 hours and 24 hours. **Figure 11** represents the results i.e. values of MDD and OMC obtained for the three hydration durations. MDD and corresponding OMC for 1 hour of hydration were 12.56 kN/m³ and 35.089% respectively. For 10 hours of hydration, MDD and OMC were 11.36 kN/m³ and 42.415% respectively, and for 24 hours of hydration, they were 11.12 kN/m³ and 44.616% respectively.

Figures 12 and **13** show the effect of prewetting duration on MDD and OMC respectively. It is observed that increasing the prewetting time results in a decrease in both MDD and the corresponding OMC. However, when comparing the compaction results in the case of CKD compacted using potable water without prewetting with the results in the case of prewetted CKD and allowed to hydrate, it was observed that the hydration of samples for 1 hr resulted in a decrease in the achieved MDD by about 4.78% and an increase in the OMC by about 21.08%. In the case of a hydration period of 10 hours, the observed MDD decreased by 13.87% while the OMC increased by 46.36%. Prewetting for 24 hours resulted in an MDD decrease by 15.69% and an increase of OMC by 53.96%. According to the observed results, it is not recommended to prewet CKD and delay compaction more than 1 hour as a decrease in MDD for eve-

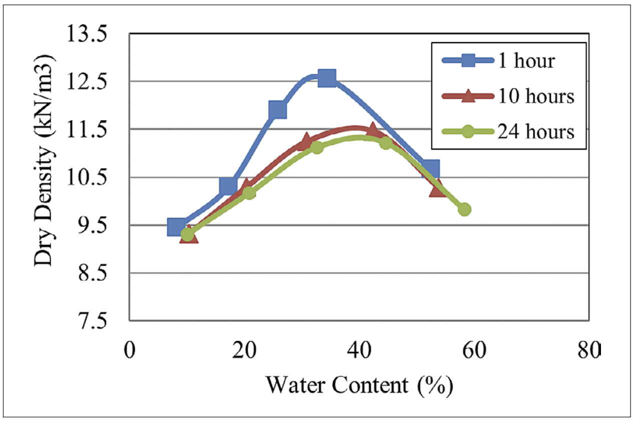

Figure 11: Compaction curves of prewetted CKD after different hydration periods

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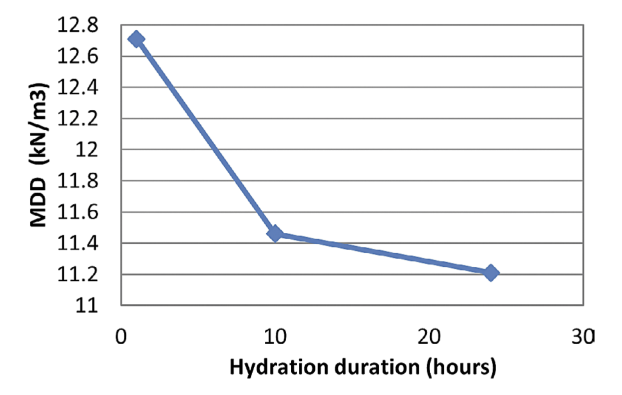

Figure 12: Effect of hydration duration on MDD

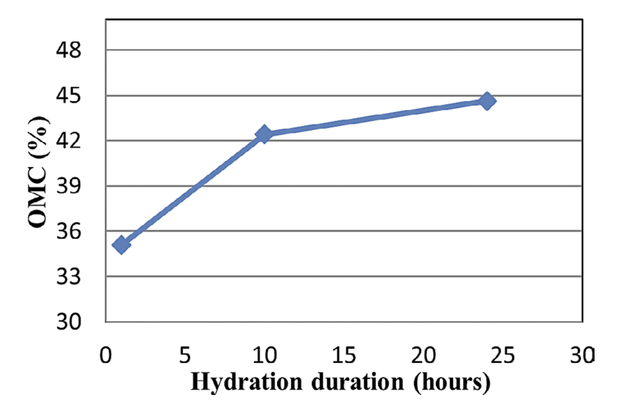

Figure 13: Effect of hydration duration on OMC

ry hour is noticeable and this results in losing storage volumes in landfills.

5. Case Study

Al-Arabia for Cement (ACC), a cement factory in the Ain Sokhna zone in Egypt, intends to prepare a series of landfills to bury CKD and to minimize its environmental hazards and to save on the high expenses of transporting and disposing of CKD in far governmental landfills. The proposed landfills are of dimensions 120 m × 50 m × 10 m and are prepared in already excavated zones behind the factory. The landfills are excavated and surrounded with hard impermeable limestone rocks. This area is proposed to be an extension for the factory, so it is required to be compacted in a proper and effective way. The depth is limited to 10 m as the rock strata could be cut without the need of a supporting system for deep excavation. The volume of each landfill is 60,000 cubic meter, while the total number of landfills could reach 14. If fresh CKD is disposed in its loose state with a density of 4.8 kN/m^3, a big loss in volume will be produced.

ACC produces about 4.5 million tons of cement. This production results in CKD which amounts to about 2.22% of cement production (i.e. ca 100,000 tons/year) according to their bypass furnace technology. The research results were applied on the case of a single landfill with 60,000 cubic meter air space. The weights of disposed CKD and durations required to fill a landfill space for different CKD conditions, lubricant types and compaction methods are presented in **Table 3**. The results are arranged in the table in ascending order according to the compaction type which produces the maximum disposed weight for the same landfill air space.

6. Conclusions

This research studies the compaction density of reactive fresh CKD mixed with the available lubricant fluids in cement factories (potable water, saltwater and waste oil from factory machines) and the corresponding optimum fluid content. The research could be concluded in the following:

Table 3: Proposed Weight of disposed CKD and Landfill capacity duration

Items no. *	Condition of CKD before Compaction	Type of Lubricant used in compaction	Proctor test	Maximum Dry density (kN/m^3)	Weight of disposed dry CKD (tons per 60,000 m^3)	Duration of disposal to fill the capacity of a landfill (days)
1	Fresh Dry	Waste oil	Modified	15.8	94800.0	341.3
2	Fresh Dry	Waste oil	Standard	14.91	89460.0	322.
3	Fresh Dry	saltwater	Modified	14.34	86040.0	309.74
4	Fresh Dry	saltwater	Standard	13.42	80520.0	289.9
5	Fresh Dry	Potable water	Modified	14.3	85800.0	308.9
6	Fresh Dry	Potable water	Standard	13.19	79140.0	284.9
7	Soaked for 1 day	Potable water	Standard	9.88	59280.0	213.4
8	Soaked for 7 days	Potable water	Standard	9.30	55800.0	200.9
9	Soaked for 30 days	Potable water	Standard	8.76	52560.0	189.2
10	hydrated for 1 hr. with 10% potable water	Potable water	Standard	12.56	75360.0	271.2
11	hydrated for 12 hrs. with 10% potable water	Potable water	Standard	11.36	68160.0	245.3
12	hydrated for 24 hrs. with 10% potable water	Potable water	Standard	11.12	66720.0	240.1

* Items no. of compaction arranged ascendingly acc. to MDD

- The reached MDD values of CKD will save a lot of landfill airspace, which will have a direct impact on health, environmental and financial issues. These values are significantly improved compared to the values reported in **US EPA (1997)**;
- Compaction of CKD in dry conditions is too difficult due to its dusty behaviour, which increases the health and environmental hazards. The use of lubricants in compaction decreases its dusty effect as powder particles stick to a fluid lubricant. Accordingly, air pollution during compaction is decreased;
- Potable water and salt water undergoes a hydration process with CKD, while waste oil does not react with it. Therefore, care should be taken with regard to compaction duration when water is used to achieve the required MDD values before hydration and initial setting to decrease the voids ratio in CKD and to increase its density. Waste oil was introduced in this research as a new lubricant in CKD compaction and it gave the highest MDD which is 14.91 kN/m^3 and the lowest optimum fluid content of 0.205%. However, the application of waste oil requires some environmental and safety precautions. The second-best fluid in CKD compaction was saltwater as it achieves an MDD of 13.42 kN/m^3 and an OMC of 30.32%. Using saltwater is cheaper than using potable water in many zones in Egypt, and is also a preferable option due to the limitations of using potable water in the current days and its shortage;
- The effect of compaction energy on CKD samples mixed with different lubricants is not the same. In the MP test using potable water, the OMC decreased by about 28.3% compared with the OMC value in the SP test (28.98% versus 20.77%). In the MP test using saltwater, the OMC decreased by about 9.9% (30.32% versus 27.31%), and in the MP test using waste oil, the optimum oil content increased by about 44.9% (0.205% versus 0.297%). The addition of water and allowing CKD samples to hydrate prior to compaction (i.e. compaction is delayed) either by soaking (full submergence) in water for certain periods or by prewetting and leaving the samples to hydrate for certain durations, didn't result in an increase of CKD dry density. However, the compaction process was easier as the dusty effect of CKD decreased a lot by hydration, but it needs a lot of water to reach the OMC, in addition to the required water for soaking or prewetting. This increase of water quantities will impact the compaction expenses.
- According to the observed prewetting results, it is not recommended to prewet CKD and delay compaction more than 1 hour as a decrease in MDD for every hour is noticeable and results in the loss of storage volumes in landfills;
- The maximum weights of a disposed CKD and durations required to fill an intended landfill air space for different CKD conditions, lubricant types and compaction methods were presented for a case study. The results (see **Table 3**) are arranged in ascending order according to the maximum disposed weight to advise similar factories for the best solutions and landfill capacities to gain the maximum benefit with landfill air space.

Conflict of interest

The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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SAŽETAK

Optimiziranje gustoće prašine iz peći za dobivanje cementa s ciljem poboljšanja iskorištenja prostora na odlagalištu

Optimiziranje gustoće otpadnih materijala na odlagalištima pravilnim zbijanjem produljuje vijek trajanja objekta zahvaljujući učinkovitom korištenju odlagališnog prostora. Prašina iz peći za dobivanje cementa (PDC) je otpadni nusproizvod koji nastaje u velikim količinama koje znatno premašuju količine materijala koji se može reciklirati u cementnoj industriji i korisno upotrijebiti na druge načine. Velika količina PDC-a u Egiptu se odlaže na odlagališta u rastresitom stanju, što uzrokuje veliki gubitak odlagališnog prostora zbog niske gustoće PDC-a. Učinak hidrauličkog veziva i ponašanje reaktivnog PDC-a kao prašinastog materijala komplicira proces njegovog zbijanja. U skladu s tim, ovo je istraživanje provedeno kako bi se ispitala svojstva zbijanja PDC-a s tri vrste ovlaživača/lubrikanata pitka voda, slana voda i otpadno ulje. Maksimalna suha gustoća i optimalni sadržaj vlage ispitani su za te vrste ovlaživača/lubrikanata i za različite metode vlaženja kako bi se poboljšala iskorištenost odlagališnog prostora i smanjio negativni učinak PDC-a tijekom zbijanja. Proučavani su učinak neposrednog zbijanja nakon vlaženja i učinak odgode zbijanja dopuštanjem PDC-u da se inicijalno hidratizira tijekom određenog razdoblja, a zatim odradi zbijanje. Ispitana je energija zbijanja i metode vlaženja PDC-a potpunim uranjanjem u fluid ili prethodnim vlaženjem. Prezentirane su maksimalne težine odloženog PDC-a i vrijeme potrebno za ispunjavanje predviđenog odlagališnog prostora za različite PDC uvjete, vrste ovlaživača/lubrikanata i metode zbijanja za studiju slučaja Ain Sokhna u Egiptu.

Ključne riječi:
odlagališta; zbijanje; gospodarenje otpadom; zbrinjavanje; okoliš; kruti otpad

Author's contribution

Mahmoud E. Hassan (MSc. Eng, assistant researcher) performed the data collection and field work, and analyzed the results. **Ayman L. Fayed** (Full Professor): methodology and final revision. **Mohamed Y. Abd El-Latief** (Assistant Professor) managed the whole process from the beginning to the end, including writing.