IOP Conference Series: Materials
Science and Engineering

PAPER • **OPEN ACCESS**

Using SF and CKD as cement replacement materials for producing cement mortar

To cite this article: M Abdulredha *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1058** 012007

Using SF and CKD as cement replacement materials for producing cement mortar

M Abdulredha[1], Adnan A. Muhsin[2], Abduljaleel Al-Janabi[3], Bader N. Alajmi[4,*], M. Gkantou[5], Joseph Amoako-Attah[5], Dhiya Al-Jumeily[5], Jamila Mustafina[6], Ahmed AlKhayyat[7]
[1] Department of Civil Engineering, College of Engineering, University of Kerbala, Kerbala, Iraq.
[2] Al-Furat Al-Awsat Technical University, Al-Mussaib Technical Institute, Iraq.
[3] BS.c Engineering, Faculty of Engineering, University of Babylon, Iraq.
[4] B.Sc. Student, Civil Engineering Department, Liverpool John Moores University, UK.
[5] Liverpool John Moores University, Liverpool, UK.
[6] Kazan Federal University, Russia.
[7]Department of Building and Construction Technical Engineering, College of Technical Engineering, the Islamic University, 54001 Najaf, Iraq.

Email: B.N.Alajmi@2017.ljmu.ac.uk

Abstract. When considering binding materials, cement mortar is thought to be one of the most conventional and effective materials. The cement mortar is mainly containing cement, sand (fine and rough), and water. In fact, there are many environmental and economical limitations to the usage of raw materials in mortar blends. For considering these limitations, many researchers studied the ability to incorporate waste-materials to fully or partially replace conventional raw materials. In this research, compressive strength and ultrasonic pulse velocity (UPV) will be studied by incorporating (SF) and (CKD) of mortar specimens and study the effect after 7,14, and 28 days. The obtained results from the collected samples (M1, M2, and M3) were compared with the reference mortar samples that contain ordinary Portland cement (OPC) only. The collected results showed that samples with CKD and SF have less compressive strength than ones with OPC with 28 days of curing. In addition, with higher CKD content, lower compressive strength was obtained. Samples (M1, M2) have the highest (UPV) values at different curing periods.

1. Introduction

Cement mortar could be simply defined as a paste composed of cement, sand, and water. The cement mortar has a wide range of uses in construction using its advantages of high workability and followability. This mortar can be used for masonry construction and also as a binder to fill up the gaps in masonry construction mostly in small buildings and houses. Moreover, cement mortar was also used in bridge construction as epoxy materials [1, 2]. In Ordinary Portland Cement (OPC) manufacturing, raw materials such as river sand and cement which is produced by processing limestone. Recently, many regulations were found regarding the use of raw materials and their negative impacts from an economic and environmental perspective [3, 4]. The environmental effects can be summed up in the fact that a higher average of pollution is produced in addition to landslide issues that may arise with higher use of raw materials. In addition, the chemical composition of cement allows CO_2 releasing and hence, higher energy consumption and then environmental negative impact and contributing in the global warming [5, 6]. The latter is responsible for many environmental problems, such as the shortage of freshwater [7-11], and uneven distribution of water on a global-scale [12-15]. Moreover, the generated wastewater from the cement-based industries are very alkaline and contains high concentrations of organic matter and solid particles [16-18], which heavily pollutes the receiving water bodies and, therefore; efficient treatment methods are needed to control this pollution [19-22]. For example, adsorption [23-26], coagulants [27-29], electrocoagulation [30-39], natural coagulants [40, 41], biological units [42, 43], and hybrid methods [44] were used for this goal. On the other hand, the negative economic impact can be attributed to higher costs of production and maintenance with a higher need for raw materials [45, 46]. On the top of these effects, demolition of concrete structures represent another challenge as these wastes must be managed and disposed in controlled landfills that requires effect high costs [47, 48]. All the mentioned problems with using raw materials are going against the principles of green technology [49]. Another point is that with the increasing world population, more houses need to be built which means more raw materials will be required unless eco-friendly alternatives are developed [50, 51]. Due to this high demand, raw materials are replaced with new materials that ensure low cost and acceptable load-bearing capacity. To contribute to enhancing the environment and reducing the costs to the minimum, the alternative materials used are commonly wastes including agricultural wastes and industrial wastes. Agriculture is producing millions of tons of wastes annually such as harvest residues (including grains, herbs, and root tubers), palm oil fuel, corn cops, and tobacco [47, 52]. These quantities of wastes with a lack of proper management and planning led to numerous problems concerning the human population and environment. In most cases, a large area is allocated to dump these wastes leading to bigger issues such as continuously reducing the land suitable for agriculture and housing and other environmental issues. The collected wastes are generally processed by burning in the dump area resulting in excessive smoke and CO_2 emission. As a result, it is essential to study the ability to utilize these wastes to be useful in different industries [1].

Different types of wastes, such as fly ash, bottom ash, lime, fuel ash… etc., were studied as a replacement for cement and they resulted in acceptable properties and good strength value. Mortar with pozzolanic or mineral materials as cement replacement is called modified mortar. Adding pozzolanic material as a partial replacement of cement could enhance the compressive strength and the durability properties of mortar. Silica Fume (SF) which is generated as waste material in the thermal power plant. A wide range of plants is now using SF as a cement replacement to improve the quality of mortar relating to compressive strength and durability.

One of the main wastes produced by the cement production plants is the Cement Kiln Dust (CKD). It is comparable to the (OPC) in terms of appearance (fine powdery material) and chemical composition. One of the negative properties of CKD is its lack of self-cementitious, this could be solved by combining its other pozzolanic material to use it as a partial OPC alternative in mortar blend with keeping the durability and strength properties. This research investigates the cement mortar engineering properties when using CF mixed with CKD as a cement replacement.

2. Materials and methods

Four mortar specimens were prepared with water and sand ratios to the binder of 0.4 and 2.5 respectively. The first sample was prepared to be as a reference for the collected results as it was made from OPC only, the other specimens (M1, M2, and M3) were made with different ratios of (OPC, SF, and CKD) as illustrated in the table below.

Table 1. The measured concentrations of the studied heavy metals in the collected soil samples.

Description	**OPC**	**SF**	**CKD**
Reference mortar made of OPC only	100 %	0%	0%

Mortar made of (OPC, SF, and CKD) (M1)	90 %	5 %	5 %
Mortar made of (OPC, SF, and CKD) (M2)	80 %	10 %	10 %
Mortar made of (OPC, SF, and CKD) (M3)	70%	15 %	15 %

To find the effect of different mixture ratios, both compressive strength and UPV were studied for all collected samples and compared with the reference sample.

2.1. Compressive strength test

All prepared samples with different proportions were tested for compressive strength following BS EN 196-1 (British Standards) for the sample preparation and testing. In the beginning, dry materials were mixed properly to guarantee homogeny using an electrical mixer. The dry blend is then mixed with the proper percentage of water. A prism with dimensions of (40 x 40 x 160 mm). Before placing the mortar, the prism was oiled in order to make it easier when extraction after hardening. To minimize the moisture loss in the time of curing, the samples were wrapped in polyethylene bags. To ensure the reliability of the results, three samples of each mixing proportion were prepared and tested.

2.2. The ultrasonic pulse velocity test

The Ultrasonic pulse velocity test is essential as it contributes to making important decisions about conditions of concrete structure such as deterioration control and structure quality [53]. This test was carried out following the British Standard BS EN 12504-4 (2004). In the same way with a compressive strength test, the samples were prepared using a cubic mold with dimensions of 100 mm x 100 mm x 100 mm. For each mixing proportion, three samples were prepared in order to meet the standard requirements. After casting the samples, they left in the laboratory with (20±2 ºC) and 100% relative humidity for different curing periods (7,14, and 28) days.

The principle of calculating UPV is by projecting sound waves inside the material and measure the time it needs to transfer through it. As the distance is known, it would be possible to calculate the UPV [53].

3. Results and discussion

The compressive strength test results showed that using OPC only showed the highest compressive strength among all with 28 curing days. On the other hand, both M2 provided higher resistance than OPC mortar with a value of 10.875 MPa at 7 days. At 14 days, the compressive strength of the mixed mortar M3 was on the top reaching 11.78 MPa compared with 11.37 MPa for M2 and 11.35 for the OPC only mortar. It is worth mentioning that using mix design (M1) which contains 5% SF and 5 % CKD resulted in a drop for the compressive strength at all curing ages. In fact, the compressive strength top value was fluctuating between (OPC, M1, M2) with the three studied curing ages as shown in Figure 1. All the tested specimens followed the same pattern where it reached the peak of compressive strength at 14 days to face a noticeable decrement at age of 28 days.

The obtained results were coinciding with what was found by Shoaib and Balaha [54] when he studied the impact of adding blast furnace sludge cement (BFSC) with (CKD) as cement replacement on the compressive strength. In the same way, two concrete mixes were used with two cement kinds (OPC and BFSC) with mixing proportion of (1Cement: 1.9 sand: 3.52 Gravel: and 0.5 W/C) and the CKD replacement proportions were 0, 10, 20, 30 and 40 %. Different curing ages were considered (1,3, and 6) months, and the compressive strength test was carried out at each age. The results obtained showed that compressive strength was inversely proportional to CKD addition percent. The OPC mixture achieved a compressive strength of 27, 28.5, and 32 MPa at (1,3, and 6) months respectively. With concrete containing (40% CKD), the compressive strength was reduced by about 44% of the OPC concrete only. This decrement is caused by replacing cement clinker which is responsible for the compressive strength development.

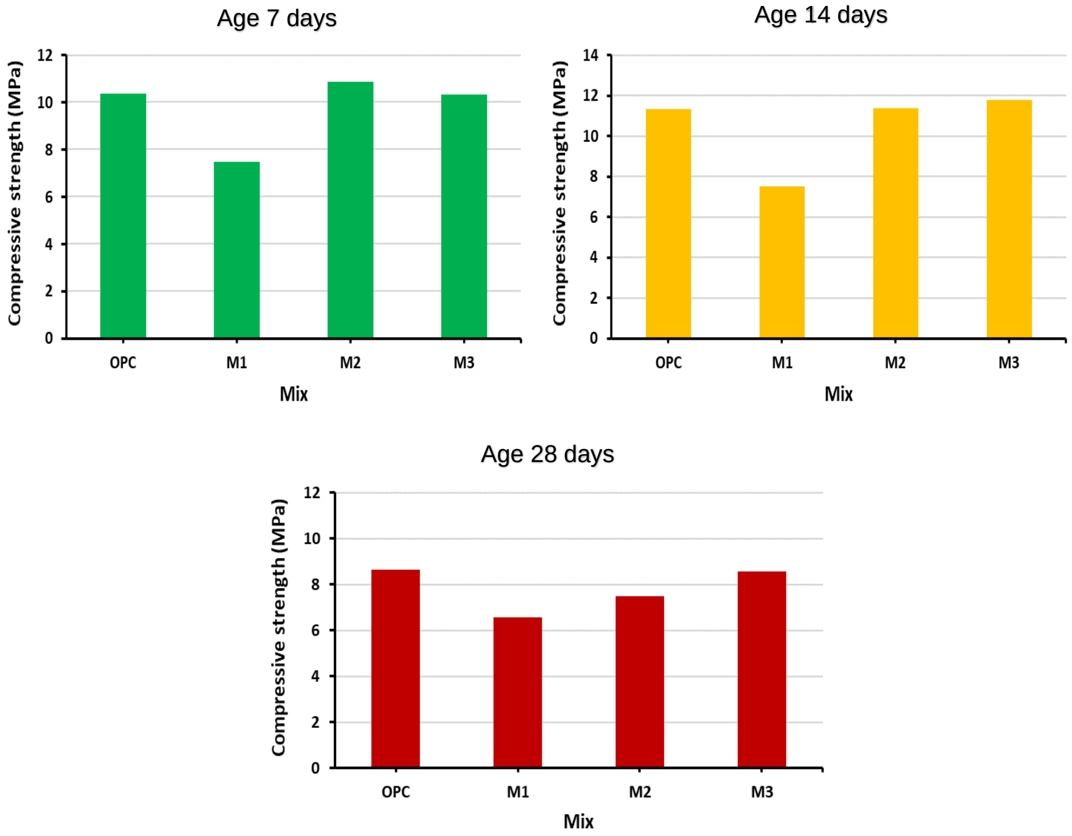

Figure 1. Compressive strength values with different ages.

On the other hand, the UPV test was carried out in the same conditions (mixtures and curing time). In general, it was clear that the UPV average develops with longer curing time. In the M1 mortar mixture, UPV achieved the optimum value at all curing periods, see Figure 2.

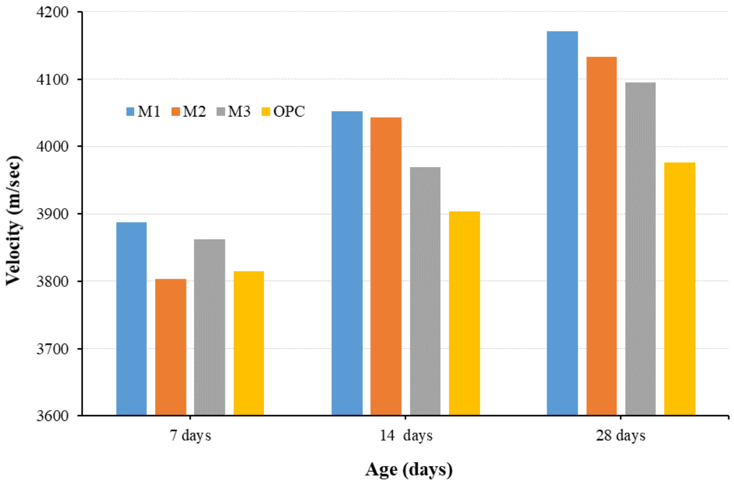

Figure 2. UPV test results.

Additionally, the UPV value was developing with more curing time from 3887 m/s at 7 days to 4171 at 28 days. Incorporating pozzolanic materials (SF and CKD) will result in pore structure tightens and highly reduce the mortar porosity which in turn will enhance the UPV [1, 53]. Though the UPV is a world-wide recognised test and it provides dependable results, real-time data is still needed to have a better understanding of structural behaviour under different conditions, therefore embedding sensors in the concrete could be a very efficient monitoring tool as reported by many relevant studies [55-58].

4. Conclusions

Based on the obtained results and analysis, the study could be concluded in the following points:

- The compressive strength was negatively impacted when replacing cement with pozzolanic materials (CKD&SF) at all ages.
- Between the other mortar mixes, M3 with (15% SF and 15% CKD) was higher than M1 and M2 and it was slightly less than OPC mortar.
- The optimum UPV was obtained using the M1 mortar mix at all curing ages.
- In general, incorporating pozzolanic materials (SF & CKD) in mortar is directly proportional to the UPV value.
- Increasing the curing age generally resulted in higher UPV at all mortar mixes.

In terms of recommendations, it has been mentioned in the main text that although the UPV is a world-wide recognised test and it provides dependable results, real-time data is still needed to have a better understanding of structural behaviour under different conditions, therefore embedding sensors in the concrete could be a very efficient monitoring tool. A number of studies could be focused on this goal.

References

[1] Shubbar A A, Sadique M, Shanbara H K and Hashim K 2020 *The Development of a New Low Carbon Binder for Construction as an Alternative to Cement. In Advances in Sustainable Construction Materials and Geotechnical Engineering* (Berlin: Springer).

[2] Shubbar A A, Jafer H, Dulaimi A, Hashim K, Atherton W and Sadique M 2018 The development of a low carbon binder produced from the ternary blending of cement, ground granulated blast furnace slag and high calcium fly ash: An experimental and statistical approach *Construction and Building Materials* **187** 1051-60.

[3] Naqi A and Jang J G 2019 Recent progress in green cement technology utilizing low-carbon emission fuels and raw materials: A review *Sustainability* **11** 537.

[4] Shubbar A A, Al-Shaer A, AlKizwini R S, Hashim K, Hawesah H A and Sadique M 2019 Investigating the influence of cement replacement by high volume of GGBS and PFA on the mechanical performance of cement mortar *First International Conference on Civil and Environmental Engineering Technologies (ICCEET)* 584.

[5] Zubaidi S L, Al-Bugharbee H, Muhsen Y R, Hashim K, Alkhaddar R M, Al-Jumeily D and Aljaaf A J 2019 The Prediction of Municipal Water Demand in Iraq: A Case Study of Baghdad Governorate *12th International Conference on Developments in eSystems Engineering (DeSE)*

[6] Zubaidi S L, Kot P, Hashim K, Alkhaddar R, Abdellatif M and Muhsin Y R 2019 Using LARS–WG model for prediction of temperature in Columbia City, USA *IOP Conference Series: Materials Science and Engineering* 584.

[7] Zubaidi S, Al-Bugharbee H, Ortega Martorell S, Gharghan S, Olier I, Hashim K, Al-Bdairi N and Kot P 2020 A Novel Methodology for Prediction Urban Water Demand by Wavelet Denoising and Adaptive Neuro-Fuzzy Inference System Approach *Water* **12** 1-17.

[8] Zubaidi S L, Abdulkareem I H, Hashim K S, Al-Bugharbee H, Ridha H M, Gharghan S K, Al-Qaim F F, Muradov M, Kot P and Alkhaddar R 2020 Hybridised Artificial Neural Network model with Slime Mould Algorithm: A novel methodology for prediction urban stochastic water demand *Water* **12** 1-18.

[9] Zubaidi S L, Al-Bugharbee H, Muhsin Y R, Hashim K and Alkhaddar R 2020 Forecasting of monthly stochastic signal of urban water demand: Baghdad as a case study *IOP Conference Series: Materials Science and Engineering* 888.

[10] Zubaidi S L, Kot P, Alkhaddar R M, Abdellatif M and Al-Bugharbee H 2018 Short-Term Water Demand Prediction in Residential Complexes: Case Study in Columbia City, USA. In: *11th International Conference on Developments in eSystems Engineering (DeSE),* (University of Cambridge, UK: IEEE)

[11] Grmasha R A, Al-sareji O J, Salman J M, Hashim K S and Jasim I A 2020 Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Street Dust WithinThree Land-Uses of Babylon Governorate, Iraq: Distribution, Sources, andHealth Risk Assessment *Journal of King Saud University - Engineering Sciences* **33**, 1-15

[12] Zubaidi S L, Hashim K, Ethaib S, Al-Bdairi N S S, Al-Bugharbee H and Gharghan S K 2020 A novel methodology to predict monthly municipal water demand based on weather variables scenario *Journal of King Saud University-Engineering Sciences* **32** 1-18.

[13] Zubaidi S L, Ortega-Martorell S, Al-Bugharbee H, Olier I, Hashim K S, Gharghan S K, Kot P and Al-Khaddar R 2020 Urban Water Demand Prediction for a City that Suffers from Climate Change and Population Growth: Gauteng Province case study *Water* **12** 1-18.

[14] Zubaidi S L, Ortega-Martorell S, Kot P, Alkhaddar R M, Abdellatif M, Gharghan S K, Ahmed M S and Hashim K 2020 A Method for Predicting Long-Term Municipal Water Demands Under Climate Change *Water Resources Management* **34** 1265-79.

[15] Hashim K S, AlKhaddar R, Shaw A, Kot P, Al-Jumeily D, Alwash R and Aljefery M H 2020 *Electrocoagulation as an eco-friendly River water treatment method. In Advances in Water Resources Engineering and Management* (Berline: Springer).

[16] Alyafei A, AlKizwini R S, Hashim K S, Yeboah D, Gkantou M, Al Khaddar R, Al-Faluji D and Zubaidi S L 2020 Treatment of effluents of construction industry using a combined filtration-electrocoagulation method *IOP Conference Series: Materials Science and Engineering* 888.

[17] Hassan Alnaimi I J I, Abuduljaleel Al-Janabi, Khalid Hashim, Michaela Gkantou, Salah L. Zubaidi, Patryk Kot, Magomed Muradov 2020 Ultrasonic-electrochemical treatment for effluents of concrete plants Ultrasonic-electrochemical treatment for effluents of concrete plants *IOP Conference Series Materials Science and Engineering* 888.

[18] Zanki A K, Mohammad F H, Hashim K S, Muradov M, Kot P, Kareem M M and Abdulhadi B 2020 Removal of organic matter from water using ultrasonic-assisted electrocoagulation method *IOP Conference Series: Materials Science and Engineering* 888.

[19] Hashim K S, Al-Saati N H, Alquzweeni S S, Zubaidi S L, Kot P, Kraidi L, Hussein A H, Alkhaddar R, Shaw A and Alwash R 2019 Decolourization of dye solutions by electrocoagulation: an investigation of the effect of operational parameters *First International Conference on Civil and Environmental Engineering Technologies (ICCEET)* 584.

[20] Hashim K S, Hussein A H, Zubaidi S L, Kot P, Kraidi L, Alkhaddar R, Shaw A and Alwash R 2019 Effect of initial pH value on the removal of reactive black dye from water by electrocoagulation (EC) method *2nd International Scientific Conference*

[21] Omran I I, Al-Saati N H, Hashim K S, Al-Saati Z N, Patryk K, Khaddar R A, Al-Jumeily D, Shaw A, Ruddock F and Aljefery M 2019 Assessment of heavy metal pollution in the Great Al-Mussaib irrigation channel *Desalination and Water Treatment* **168** 165-74.

[22] Hashim K S, Al-Saati N H, Hussein A H and Al-Saati Z N 2018 An investigation into the level of heavy metals leaching from canal-dreged sediment: a case study metals leaching from dreged sediment *First International Conference on Materials Engineering & Science*

[23] Abdulla G, Kareem M M, Hashim K S, Muradov M, Kot P, Mubarak H A, Abdellatif M and Abdulhadi B 2020 Removal of iron from wastewater using a hybrid filter *IOP Conference Series: Materials Science and Engineering* 888.

[24] Abdulraheem F S, Al-Khafaji Z S, Hashim K S, Muradov M, Kot P and Shubbar A A 2020 Natural filtration unit for removal of heavy metals from water *IOP Conference Series: Materials Science and Engineering* 888.

[25] Alenezi A K, Hasan H A, Hashim K S, Amoako-Attah J, Gkantou M, Muradov M, Kot P and Abdulhadi B 2020 Zeolite-assisted electrocoagulation for remediation of phosphate from calcium-phosphate solution *IOP Conference Series: Materials Science and Engineering* 888.

[26] Hashim K S, Ewadh H M, Muhsin A A, Zubaidi S L, Kot P, Muradov M, Aljefery M and Al-Khaddar R 2020 Phosphate removal from water using bottom ash: Adsorption performance, coexisting anions and modelling studies *Water Science and Technology* **83** 1-17.

[27] Alenazi M, Hashim K S, Hassan A A, Muradov M, Kot P and Abdulhadi B 2020 Turbidity removal using natural coagulants derived from the seeds of strychnos potatorum: statistical and experimental approach *IOP Conference Series: Materials Science and Engineering* 888.

[28] Alhendal M, Nasir M J, Hashim K S, Amoako-Attah J, Al-Faluji D, Muradov M, Kot P and Abdulhadi B 2020 Cost-effective hybrid filter for remediation of water from fluoride *IOP Conference Series: Materials Science and Engineering* 888.

[29] Abdulhadi B, Kot P, Hashim K, Shaw A, Muradov M and Al-Khaddar R 2021 Continuous-flow electrocoagulation (EC) process for iron removal from water: Experimental, statistical and economic study *Science of The Total Environment* **756** 1-16.

[30] Aqeel K, Mubarak H A, Amoako-Attah J, Abdul-Rahaim L A, Al Khaddar R, Abdellatif M, Al-Janabi A and Hashim K S 2020 Electrochemical removal of brilliant green dye from wastewater *IOP Conference Series: Materials Science and Engineering* 888.

[31] Hashim K, Kot P, Zubaid S, Alwash R, Al Khaddar R, Shaw A, Al-Jumeily D and Aljefery M 2020 Energy efficient electrocoagulation using baffle-plates electrodes for efficient Escherichia Coli removal from Wastewater *Journal of Water Process Engineering* **33** 101079-86.

[32] Hashim K S, Ali S S M, AlRifaie J K, Kot P, Shaw A, Al Khaddar R, Idowu I and Gkantou M 2020 Escherichia coli inactivation using a hybrid ultrasonic–electrocoagulation reactor *Chemosphere* **247** 125868-75.

[33] Mohammed A-H, Hussein A H, Yeboah D, Al Khaddar R, Abdulhadi B, Shubbar A A and Hashim K S 2020 Electrochemical removal of nitrate from wastewater *IOP Conference Series: Materials Science and Engineering* 888.

[34] Hashim K S, Shaw A, AlKhaddar R, Kot P and Al-Shamma'a A 2021 Water purification from metal ions in the presence of organic matter using electromagnetic radiation-assisted treatment *Journal of Cleaner Production* **280**

[35] Hashim K S, Shaw A, Al Khaddar R, Ortoneda Pedrola M and Phipps D 2017 Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach *Journal of Environmental Management* **197** 80-8.

[36] Hashim K S, Shaw A, Al Khaddar R, Pedrola M O and Phipps D 2017 Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor *Journal of Environmental Management* **189** 98-108.

[37] Hashim K S, Shaw A, Al Khaddar R, Pedrola M O and Phipps D 2017 Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water - Experimental, statistical, and economic approach *Journal of Environmental Management* **196** 224-33.

[38] Abdulhadi B A, Kot P, Hashim K S, Shaw A and Khaddar R A 2019 Influence of current density and electrodes spacing on reactive red 120 dye removal from dyed water using electrocoagulation/electroflotation (EC/EF) process *First International Conference on Civil and Environmental Engineering Technologies (ICCEET)* 584.

[39] Hashim K S, Khaddar R A, Jasim N, Shaw A, Phipps D, Kot P, Pedrola M O, Alattabi A W, Abdulredha M and Alawsh R 2019 Electrocoagulation as a green technology for phosphate removal from River water *Separation and Purification Technology* **210** 135-44.

[40] Al-Jumeily D, Hashim K, Alkaddar R, Al-Tufaily M and Lunn J 2019 Sustainable and Environmental Friendly Ancient Reed Houses (Inspired by the Past to Motivate the Future) *11th International Conference on Developments in eSystems Engineering (DeSE)*

[41] Al-Saati N H, Hussein T K, Abbas M H, Hashim K, Al-Saati Z N, Kot P, Sadique M, Aljefery M H and Carnacina I 2019 Statistical modelling of turbidity removal applied to non-toxic natural coagulants in water treatment: a case study *Desalination and Water Treatment* **150** 406-12.

[42] Alattabi A W, Harris C, Alkhaddar R, Alzeyadi A and Hashim K 2017 Treatment of Residential Complexes' Wastewater using Environmentally Friendly Technology *Procedia Engineering* **196** 792-9.

[43] Alattabi A W, Harris C B, Alkhaddar R M, Hashim K S, Ortoneda-Pedrola M and Phipps D 2017 Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor *Journal of Water Process Engineering* **20** 207-16.

[44] Al-Marri S, AlQuzweeni S S, Hashim K S, AlKhaddar R, Kot P, AlKizwini R S, Zubaidi S L and Al-Khafaji Z S 2020 Ultrasonic-Electrocoagulation method for nitrate removal from water *IOP Conference Series: Materials Science and Engineering* 888.

[45] Shubbar A A, Sadique M, Nasr M S, Al-Khafaji Z S and Hashim K S 2020 The impact of grinding time on properties of cement mortar incorporated high volume waste paper sludge ash *Karbala International Journal of Modern Science* **6** 1-23.

[46] Kadhim A, Sadique M, Al-Mufti R and Hashim K 2020 Long-term performance of novel high-calcium one-part alkali-activated cement developed from thermally activated lime kiln dust *Journal of Building Engineering* **32** 1-17.

[47] Abdulredha M, Rafid A, Jordan D and Hashim K 2017 The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition *Procedia Engineering* **196** 779-84.

[48] Idowu I A, Atherton W, Hashim K, Kot P, Alkhaddar R, Alo B I and Shaw A 2019 An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences *Waste Management* **87** 761-71.

[49] Kadhim A, Sadique M, Al-Mufti R and Hashim K 2020 Developing One-Part Alkali-Activated metakaolin/natural pozzolan Binders using Lime Waste as activation Agent *Advances in Cement Research* **32** 1-38.

[50] Shubbar A A, Sadique M, Kot P and Atherton W 2019 Future of clay-based construction materials–A review *Construction and Building Materials* **210** 172-87.

[51] Majdi H S, Shubbar A, Nasr M S, Al-Khafaji Z S, Jafer H, Abdulredha M, Masoodi Z A, Sadique M and Hashim K 2020 Experimental data on compressive strength and ultrasonic pulse velocity properties of sustainable mortar made with high content of GGBFS and CKD combinations *Data in Brief* **31** 105961-72.

[52] Abdulredha M, Al Khaddar R, Jordan D, Kot P, Abdulridha A and Hashim K 2018 Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression *Waste Management* **77** 388-400.

[53] Shubbar A A, Jafer H, Abdulredha M, Al-Khafaji Z S, Nasr M S, Al Masoodi Z and Sadique M 2020 Properties of cement mortar incorporated high volume fraction of GGBFS and CKD from 1 day to 550 days *Journal of Building Engineering* 101327.

[54] Shoaib M and Balaha M 2004 THERMO-CHEMICAL STABILITY AND MECHANICAL PROPERTIES OF MORTAR MADE WITH CEMENT KILN DUST-BLENDED CEMENT *ERJ. Engineering Research Journal* **27** 49-58.

[55] Gkantou M, Muradov M, Kamaris G S, Hashim K, Atherton W and Kot P 2019 Novel Electromagnetic Sensors Embedded in Reinforced Concrete Beams for Crack Detection *Sensors* **19** 5175-89.

[56] Ryecroft S, Shaw A, Fergus P, Kot P, Hashim K, Moody A and Conway L 2019 A First Implementation of Underwater Communications in Raw Water Using the 433 MHz Frequency Combined with a Bowtie Antenna *Sensors* **19** 1813-23.

[57] Ryecroft S P, shaw A, Fergus P, Kot P, Hashim K and Conway L 2019 A Novel Gesomin Detection Method Based on Microwave Spectroscopy *12th International Conference on Developments in eSystems Engineering (DeSE)*
[58] Teng K H, Kot P, Muradov M, Shaw A, Hashim K, Gkantou M and Al-Shamma'a A 2019 Embedded Smart Antenna for Non-Destructive Testing and Evaluation (NDT&E) of Moisture Content and Deterioration in Concrete *Sensors* **19** 547-59.