Recycling of industrial by-products in concrete: Experimental study

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Abstract. The construction industry consumes enormous amounts of ordinary Portland cement (OPC) to bond the fine and coarse aggregates that give the concrete strength. However, the OPC causes many environmental severe impacts, such as the huge generation of CO₂ gas and alkaline wastewater, which triggered concerns about the health consequences of OPC manufacturing. Therefore, the search for eco-friendly alternatives for OPC has increased rapidly during the last decades, such as the recycling of agricultural and industrial by-products. In this research, residuals of cement furnaces (the dust of cement furnace) and silica fume were mixed and the latter was used as a partial replacement for the OPC. Initially, the chemical structure of the cement dust, silica fume and the OPC were tested. Then, three different (0-45%) percentages of the cement dust and silica fume were added to the concrete mix. The mechanical properties of the produced concrete were investigated using a non-destructive method (ultrasonic pulse velocity) and compared with the properties of the traditional OPC concrete. The results showed the cement dust and silica fume contain the favourable oxides, and the best mixing ratio was 12.5% of silica fume, 12.5% of cement dust and 75% of OPC that achieved pulse velocity of 4102 m/s (the best compressive strength).

Keywords: ultrasonic pulse velocity, cement kiln dust, silica fume.

1. Introduction
It is well-known huge quantities of Ordinary Portland Cement (OPC) are consumed in the construction of the infrastructure of cities, such as the construction bridges, houses, high rise buildings, pavements, and sewers [1, 2]. Although is a proved fact that OPC plays a major role in the development of civilisation and the global financial system, its role in environmental deterioration is also proved [3-5]. OPC factories are estimated to emit about 10% of total CO₂ in the air, leading to catastrophic environmental effects such as weather change [6, 7]. Therefore, the pollution and consumption of water have risen substantially [8, 9]. The released effluents from concrete plants and casting activities are highly particular due to the chemical composition of Conventional concrete [10, 11]. Also, the production of solid waste from cement industry was has resin remarkably [12, 13], especially from the demolition of old concrete structures in the cities (municipal areas) [14, 15]. As a result, devastating impacts on the overall quality of water and the degradation of living beings have occurred [16, 17]. Different treatments techniques have been developed to remove many pollutants found in cement plant effluent and other industrial wastewaters [18-20], including filtrations [21-24], coagulation [25-29], electrocoagulation [30-32], sonication-assisted [33, 34], electro-chemical [35-37], electro-physical [38-41], and hybridised methods [42-45]. However, recent studies show an increase in water pollution [39-41] and freshwater consumption [46-48]. Additionally, these techniques are inadequate to control all anticipated pollutants from cement factories. Because of the huge volumes of Carbon dioxide released into the air from the operations related to conventional cement, as well as contaminants discharged into...
water bodies, cement manufacture has become a growing subject of attention [49-51]. As a consequence, reviews show that the development of replacements for cement components, such as silica fume (SF) and cement kiln dust (CKD), is the most viable solution to minimise cement production [52, 53]. Although the utilisation of SF and CKD can improve the properties of concrete, previous studies have proven that the use of these materials has also detrimental effects on the characteristics of concrete. As the percentage of CKD to cement increased, the workability of fresh mixes dropped. Furthermore, as the percentage of CKD increases, the strength of concrete lowers. SCMS materials like SF and CKD are extremely effective and widely employed as cementitious materials because they have large surface areas and contain a considerable quantity of silica oxides. Earlier research has shown that replacing Cement with SF at a proportion of (0.22–30) is an effective way to maintain the strength of concrete. The ultrasonic pulse velocity (UPV) is a non-destructive testing method that is used to assess the quality of concrete buildings. This technique, which involves measuring the velocity of the ultrasonic pulse velocity travelling through concrete members, is used to analyse several attributes of concrete, such as quality and strength [17, 54]. The present investigation evaluates the effectiveness of SF and CKD as cement substitutes. The main goal of this study is to investigate if these chemicals impact cement characteristics like strength at different curing periods using an ultrasonic pulse velocity test (one and 4) weeks. The ultrasonic pulse technology was used in this study because it cheap and accurate [55-57], and also it could be used on the surface of the concrete sample or by embedding it in the body of the concrete and connect it to the receiver using wireless technologies [56, 58-60].

2. Experimentation curriculum

The experimental studies focused on the measurement of the ultrasonic pulse velocity of the concrete mix produced by partially substituting cement with SF and CKD to evaluate its mechanical properties

2.1. Materials

Cement Kiln Dust (CKD) is a by-product of the cement industry. It's a finely powdered substance that looks like Portland cement. usually, CKD is made up of micron-sized grains recovered by combustion processes during the cement clinker manufacturing process [4, 52]. Cement kiln dust CKD is a fine powdery substance that ranges in hue from grey to brown and is relatively homogeneous in dimension. The manufacturing process, dust collecting technique, chemical properties of CKD, and alkali concentration all influence the gradation of CKD. With fly ash and GGBS, in various percentages up to 16%, this product could be used as a cementitious substance. If CKD is utilised separately, the resultant combination may have decreased workability, weight, and setting time due to the high alkali concentration [52, 54].

Silica fume is regarded as a by-product of the silicon and ferrosilicon alloy manufacturing industries, and it is produced at extreme temps from quartz reduction. Because of its properties that promote the cementitious reaction, silica fume is widely utilised as a cementitious material in concrete. It is an ultrafine powder consist of 84-96 non-crystalline silica and about 76 percent silicon [4]. The quantity of Silicon dioxide in silica fume is proportional to the kind of alloy generated in the manufacturing facility.

SF partials are extremely tiny and round, roughly 100 times finer than ordinary cement particles. Previous researches show that the SF concrete have reduced bleeding, porosity, and permeability. Because SF oxides react with and consume Calcium hydroxide, which is CH generated during cement hydration.

The main binding ingredient in this experiment was Portland Cement, which has strong mechanical characteristics that help the combination to remain coherent. The cement properties used in this study were measured according to BS EN 196-2:2013. Diagrams 1, 2, and 3 show the chemical composition of SF, CKD, and Portland cement. These features meet the requirements of the BS-EN-197-1(2011) and BS-EN-450-1 standards (2012). The particle size of the grains, and even the chloride and sulfate concentrations, were checked using the BS EN 12620:2002+A1 standard (2008).

Concrete was prepared and treated using impure and organic-free portable water.
Figure 1: The chemical structure of silica fume.

Figure 2: The chemical structure of CKD.

Figure 3: The chemical structure of OPC.
2.2. Testing Techniques
For every mix, three prisms (160x40x40 mm) were cast to see how substituting cement with CKD and SF affected the quality of the mortar mixture. These tests are limited to examining items poured from cement mortar. The investigated specimens are then built up of cement in three different concentrations of CKD and SF. Upon completion of the initial setting time of the mixtures, all samples were maintained in good condition, molded, and placed in water for the cure. BS EN 12504-4:2004 was used to conduct ultrasonic tests on hardening specimens at one week and 4 weeks.

2.3. Design of Mixture
In this study, part of the design process includes determining the proportions of fine aggregate, water, cement, and materials additive ingredients for the control concrete mixes. To match conventional rating curves, fine aggregates have been utilised in the mixture design. The water to binder ratio was 0.4 in all of the mixes. The ratio of sand to a binder that used in this study was 2.4 in all of the mixes. The percentage of each component of the mix is shown in figure (4).

![Figure 4: The mix design.](image)

The ultrasonic pulses are sent through the sample to be examined, and the time required for the pulse to permeate the specimen is measured. A high speed implies that the examined structure is of top condition, whereas a low velocity suggests that the examined structure is of bad condition. Pulse producers, a transducer for converting electronic pulses into mechanical pulses with vibrations of 40 to 50 kHz, and a pulse detector are all used in UPV assessment. The velocities of pulses are determined as follows:

\[
\text{Pulse velocity} = \frac{\text{The specimen's thickness}}{\text{The required time for the pulse to penetrate the sample}}
\]  

(1)
3. Results

The results of examining a control concrete mix with substitute material of cement with varying quantities of SF and CKD at different curing periods are explained in Table 1 and Figure 5.

**Table 1.** One week and 4 weeks ultrasonic pulse velocity testing.

| Number of tests | Cement (%) | SF (%) | CKD (%) | UPV test (m/s) |
|-----------------|------------|--------|---------|----------------|
| MIX1            | 100        | 0      | 0       | 3828           |
| MIX2            | 75         | 12.5   | 12.5    | 3850           |
| MIX3            | 65         | 17.5   | 17.5    | 3785           |
| MIX4            | 55         | 22.5   | 22.5    | 3578           |

The main conclusions that may be drawn from the findings of this study are listed below:

The use of a partial replacement of SF and CKD in mixes has been demonstrated to lower concrete pulse velocity values by a tiny portion. In comparison to the control mixture, the pulse velocity of mixtures two and three have been enhanced by 2.3% and 11% after 4 weeks of curing, respectively. Whereas, mixture number four decrease the velocity by 3.6%. This would be based on the view that just a little amount of cementitious materials is required to fill empty fields in the mortar, therefore improving its mechanical properties. Previous studies showed that CKD and SF are ineffectual substances at first and require time to connect with cement components. Therefore, it can be noted that after one week of curing, using 45 percent of a partial substitute decreases the pulse velocity measurements of the mix by around 6.5 percent. while this value fell to 3.6 after curing for 4 weeks. This is because extra cementitious ingredients reduce concrete compressive strength, which is a key component of the manufacture gel (C-S-H) in concrete. After sitting time, they interact and utilise the moisture components, Ca (OH)2, to allow and initiate hydration of silica fume and cement kiln dust.

According to the observations, specimens that were treated for 4 weeks had greater pulse velocity readings. That was based on the fact that the curing time improves C-S-H, which leads to a decline in the number of interior gaps or porosity in the conventional concrete, which impacts the properties of concrete and enhances its capacity to withstand compressive stresses. The Ultrasonic Pulse Velocity method, a non-destructive test methodology, was used in this investigation. As a result, more sophisticated procedures for verifying concrete properties are now
accessible. Sensors were used to monitor for microcracks, concrete humidity, and other applications in the past. Additional research might utilise the same approach.

4. Conclusions

The outcomes of the current investigation confirmed the partial replacement of the OPC by silica fume and CKD in concrete increases, the pulse velocity values decrease. The material quality, on the other hand, shows a little improvement with a restricted replacement rate. Whenever the cement in a combination is replaced with extra material, a longer curing period results in a higher-quality specimen. The use of 25 ~ 35 percent additional cementitious material as a cement substitution for cement could be appropriate proportions, with an increment in this ratio resulting in a slight improvement in quality assessment. Moreover, the used strategy in this research was UPV, which is a traditional instrument; consequently, more current technologies, such as high frequency radars and laser, are recommended to evaluate the mechanical properties of concrete.

References

[1] 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
[2] Farhan S L, Jasim I A and Al-Mamoori S K 2019 The transformation of the city of Najaf, Iraq: Analysis, reality and future prospects Journal of Urban Regeneration & Renewal 13 160-71
[3] 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
[4] 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)
[5] Farhan S L, Antón D, Akef V S, Zabuadi S L and Hashim K S 2021 Factors influencing the transformation of Iraqi holy cities: the case of Al-Najaf Scientific Review Engineering and Environmental Sciences 30 365-75
[6] 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 Within Three Land-Uses of Babylon Governorate, Iraq: Distribution, Sources, and Health Risk Assessment Journal of King Saud University - Engineering Sciences 33 1-18
[7] Al-Sareji O J, Grmasha R A, Salman J M, Idowu I and Hashim K S 2021 Street dust contamination by heavy metals in Babylon governorate, Iraq Journal of Engineering Science and Technology 16 3528 - 46
[8] Obaid M K, Nasr M S, Ali I M, Shubbar A A and Hashim K S 2021 Performance of green mortar made from locally available waste tiles and silica fume Journal of Engineering Science and Technology 16 136-51
[9] Al-Jumeily D, Hashim K, Alkaddar R, Al-Tufailey M and Lunn J 2019 Sustainable and Environmental Friendly Ancient Reed Houses (Inspired by the Past to Motivate the Future). In: 11th International Conference on Developments in eSystems Engineering (DeSe), (Cambridge, UK pp 214-9
[10] Farhan S L and Nasar A Z 2021 Urban Identity in the Pilgrimage Cities of Iraq: Analysis Trends of Architectural Designers in the City of Karbala J. Urban Regen. Renew 14 2-14
[11] Jasim I A, Farhan S L, Al-Maliki L A and Al-Mamoori S K 2021 Climatic Treatments for Housing in the Traditional Holy Cities: A Comparison between Najaf and Yazd Cities. In: IOP Conference Series: Earth and Environmental Science: IOP Publishing) p 012017
[12] Alyafei A, AlKizwini R S, Hashim K S, Yeboah D, Gkantou M, Al Khaddar R, Al-Faluji D and Zabuadi S L 2020 Treatment of effluents of construction industry using a combined filtration-electrocoagulation method. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012032
[13] Alnaimi H, Idan J J, Al-Janabi A, Hashim K, Gkantou M, Zubaidi S L, Kot P and Muradov M 2020 Ultrasonic-electrochemical treatment for effluents of concrete plants. In: IOP Conference Series Materials Science and Engineering (University of Kufa, Najaf, Iraq pp 1-9

[14] Abdulredha M, Abdulridha A, Shubbar A, Alkhadder R, Kot P and Jordan D 2020 Estimating municipal solid waste generation from service processions during the Ashura religious event. In: IOP Conference Series: Materials Science and Engineering (IOP Publishing) p 012075

[15] Abdulredha M, Kot P, Al Khaddar R, Jordan D and Abdulridha A 2020 Investigating municipal solid waste management system performance during the Arba'een event in the city of Kerbala, Iraq Environment. Development and Sustainability 22 1431-54

[16] Abdulredha M, Rafid A, Jordan D and Alattabi A 2017 Facing up to waste: how can hotel managers in Kerbala, Iraq, help the city deal with its waste problem? Procedia engineering 196 771-8

[17] Khamenees S S, Kadhum M M and Alwash N A 2020 Experimental and numerical investigation on the axial behavior of solid and hollow SIFCON columns SN Applied Sciences 2 1-15

[18] 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-dredged sediment: a case study metals leaching from dredged sediment. In: First International Conference on Materials Engineering & Science, (Istanbul Aydin University (IAU), Turkey pp 12-22

[19] Hashim K S, Al-Saati N H, Alquzweeni S S, Zubaidi S L, Kot P, Kraidy L, Hussein A H, Alkhadder R, Shaw A and Alwash R 2019 Decolourisation of dye solutions by electrocoagulation: an investigation of the effect of operational parameters. In: First International Conference on Civil and Environmental Engineering Technologies (ICCEET), (University of Kufa, Iraq pp 25-32

[20] Alattabi A W, Harris C, Alkheddar R, Alzyayed A and Abdulredha M 2017 Online Monitoring of a sequencing batch reactor treating domestic wastewater Procedia engineering 196 800-7

[21] 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. In: IOP Conference Series: Materials Science and Engineering (IOP Publishing) p 012034

[22] 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. In: IOP Conference Series: Materials Science and Engineering (IOP Publishing) p 012064

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

[24] Al-Saati N H, Hussein T K, Abbas M H, Hashim K S, Al-Saati Z N, Kot P, Sadique M, Aljeferiy 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

[25] Omran I I, Al-Saati N H, Al-Saati H H, Hashim K S and Al-Saati Z N 2021 Sustainability assessment of wastewater treatment techniques in urban areas of Iraq using multi-criteria decision analysis (MCDA) Water Practice and Technology 16 649-60

[26] 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 Aljeferiy M 2019 Assessment of heavy metal pollution in the Great Al-Mussaib irrigation channel Desalination and Water Treatment 168 165-74

[27] Ryecroft S P, shaw A, Fergus P, Kot P, Hashim K and Conway L 2019 A Novel Gosemin Detection Method Based on Microwave Spectroscopy. In: 12th International Conference on Developments in eSystems Engineering (DeSE), (Kazan, Russia pp 429-33

[28] Zubaidi S L, Al-Bugharbee H, Muhsen Y R, Hashim K, Alkhadder R M, Al-Jumeily D and Aliaaf A J 2019 The Prediction of Municipal Water Demand in Iraq: A Case Study of Baghdad Governorate. In: 12th International Conference on Developments in eSystems Engineering (DeSE), (Kazan, Russia pp 274-7

[29] Mousazadeh M, Paiial B, Naghdali Z, Mortezaan Z, Hashemi M, Karamati Niargoh E, Aghababaei M, Ghobankhani M, Lichtfouse E, Sillanpää M, Hashim K S and Enamjomeh M
M 2021 Positive environmental effects of the coronavirus 2020 episode: a review Environment, Development and Sustainability 21 1-23

[30] Hashim K S, Hussein A H, Zubaide S L, Kot P, Krali D, 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. In: 2nd International Scientific Conference, (Al-Qadisiyah University, Iraq) pp 12-22

[31] Hashim K, Kot P, Zubaide S, Alwash R, Al Khaddar R, Shaw A, Al-Jumeily D and Aljeferiy M 2020 Energy efficient electrocoagulation using baffle-plates electrodes for efficient Escherichia coli removal from Wastewater Journal of Water Process Engineering 33 101795-86

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

[33] Zaniki 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. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012033

[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 1-17

[35] 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. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012036

[36] 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. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012037

[37] 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 760 1-16

[38] Emamjomeh M M, Kakavand S, Jamali H A, Alizadeh S M, Safdari M, Mousavi S E S, Hashim K S and Mousazade M 2020 The treatment of printing and packaging wastewater by electrocoagulation–Flocculation: the simultaneous efficacy of critical parameters and economics Desalination and water treatment 205 161-74

[39] Emamjomeh M M, Mousazadeh M, Mokhtari N, Jamali H A, Makkabiabi M, Naghdali Z, Hashim K S and Ghanbari R 2020 Simultaneous removal of phenol and linear alkylbenzene sulfonate from automotive service station wastewater: Optimization of coupled electrochemical and physical processes Separation Science and Technology 55 3184-94

[40] Hashim K S, Ali S S M, AlRiFai 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

[41] 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/electroflootation (EC/EF) process. In: First International Conference on Civil and Environmental Engineering Technologies (ICCEET), (University of Kufa, Iraq) pp 12-22

[42] 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. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012035

[43] 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. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012031

[44] Alhendal M, Nasir M J, Hashim K S, Amoako-Attah J, Al-Faliji D, Muradov M, Kot P and Abdulhadi B 2020 Cost-effective hybrid filter for remediation of water from fluoride. In: IOP Conference Series: Materials Science and Engineering: IOP Publishing) p 012038
[45] Al-Marri S, AlQuzweeni S S, Hashim K S, AlKhaddar R, Kot P, AlKizwini R S, Zubaidei S L and Al-Khafaji Z S 2020 Ultrasonic-Electrocoagulation method for nitrate removal from water. In: IOP Conference Series: Materials Science and Engineering (IOP Publishing) p 012073

[46] Salah Z, 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

[47] Salah Z, Hashim K, Ethaiib 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

[48] Salah Z, 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

[49] 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. In: First International Conference on Civil and Environmental Engineering Technologies (ICCEET), (University of Kufa, Iraq pp 31-8

[50] Hashim A M and Kadhum M M 2021 Numerical and Experimental Study of Postfire Behavior of Concentrically Loaded SIFCON Columns ACI Structural Journal 118 73-86

[51] Kadhum M 2015 Prediction of Meehanical Properties of Reactive Powder Concrete by Using Artificial Neural Network and Regression Technique after the Exposure to Fire Flame Jordan Journal of Civil Engineering 159 1-19

[52] 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

[53] Kadhum M M, Alwash N A, Tuama W K and Abdulraheem M S 2019 Experimental and numerical study of influence of crude oil products on the behavior of reactive powder and normal strength concrete slabs Journal of King Saud University-Engineering Sciences 32 293-302

[54] 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

[55] Omer G, Kot P, Atherton W, Muradov M, Gkantou M, Shaw A, Riley M, Hashim K and Al-Shamma’a A 2020 A Non-Destructive Electromagnetic Sensing Technique to Determine Chloride Level in Maritime Concrete Karbala International Journal of Modern Science 6 1-14

[56] Kot P, Muradov M, Gkantou M, Kamaris G S, Hashim K and Yeboah D 2021 Recent Advancements in Non-Destructive Testing Techniques for Structural Health Monitoring Applied Sciences 11 1-28

[57] Omer G, Kot P, Atherton W, Muradov M, Gkantou M, Shaw A, Riley M, Hashim K and Al-Shamma’a A 2021 A Non-Destructive Electromagnetic Sensing Technique to Determine Chloride Level in Maritime Concrete Karbala International Journal of Modern Science 7 61-71

[58] Ryecroft S, Shaw A, Fergus P, Kot P, Hashim K, Tang A, Moody A and Conway L 2021 An Implementation of a Multi-Hop Underwater Wireless Sensor Network using Bowtie Antenna Karbala International Journal of Modern Science 7 113-29

[59] Ghazali R, Hussain A J, Al-Jumeily D and Merabti M 2007 Dynamic ridge polynomial neural networks in exchange rates time series forecasting. In: International Conference on Adaptive and Natural Computing Algorithms: Springer) pp 123-32

[60] Fergus P, Hussain A, Al-Jumeily D, Huang D-S and Bouguila N 2017 Classification of caesarean section and normal vaginal deliveries using foetal heart rate signals and advanced machine learning algorithms Biomedical engineering online 16 1-26